GERMAN-GEORGIAN STUDENT CONFERENCE ON APPLIED INFORMATICS, MATHEMATICS AND ENGINEERING (GGSC 2025)

Conference Proceedings

October 4, 2025
Georgian Technical University (GTU), Tbilisi, Georgia

Organized jointly by
Georgian Technical University (GTU)
and
University of Applied Sciences Dresden (HTW Dresden)

Participants:
Students of GTU and HTW Dresden

On a Concept for Building and Studying a Simulation Model for Manufacturing Process Management

Meri Arkhoshashvili, **Supervisor: Gia Surguladze**
Georgian Technical University
arkhoshashvili.meri24@gtu.ge

Abstract—In today's dynamic manufacturing environment, characterized by market volatility and uncertainty, simulation models serve as powerful tools for process optimization. This paper presents a novel approach to constructing a simulation model that integrates marketing strategies, logistics operations, and Business Intelligence (BI) technologies. The model employs system dynamics and multi-agent systems to simulate supply chain dynamics, demand forecasting, and resource allocation. The study highlights how BI integration facilitates real-time data analysis, reducing risks and enhancing efficiency. Results demonstrate that the integrated model reduces manufacturing costs by 15-25% and improves customer satisfaction. This approach is particularly beneficial for small and medium enterprises (SMEs) aiming to enhance competitiveness in global markets.

Keywords: simulation model, manufacturing process, marketing integration, logistics optimization, BI technology, system dynamics, multi-agent system.

I. INTRODUCTION

The modern manufacturing sector faces numerous challenges, including demand variability, supply chain disruptions, and inefficient resource utilization [1]. These issues are particularly relevant in Georgia, where SMEs strive to adapt to global economic conditions. Traditional management methods often fail to address these complexities, as they do not account for the dynamic interrelationships between marketing, logistics, and data analytics. Simulation modeling, as a research tool, enables the replication of real-world scenarios without risks, thereby supporting informed decision-making [2-8,14]. This paper proposes an integrated approach that combines marketing strategies (e.g., demand shaping through CRM tools), logistics processes (supply chain optimization), and BI technologies (data analytics and forecasting) [10]. This integration creates a synergistic effect, enhancing the efficiency of manufacturing processes. For instance, BI tools like Microsoft Power BI enable real-time analysis of marketing campaigns' impact on logistics costs. The paper explores the development and testing of this model to demonstrate its practical utility.

II. RELATED WORK

Simulation of manufacturing processes is a well-established research area, represented in system dynamics models. The Monte Carlo method is widely used for modeling uncertainty, while multi-agent systems (MAS) facilitate the simulation of interactions between suppliers and customers [12]. The integration of BI technologies, such as OLAP and machine learning, is an emerging trend that enhances model accuracy [13]. We propose a hybrid model that unifies these domains into a cohesive system.

III. PROPOSED METHOD

The proposed model is based on three core components: (1) a marketing module that leverages CRM data for demand forecasting [6]; (2) a logistics module that optimizes the supply chain using Warehouse Management Systems (WMS) [13]; and (3) a BI module that ensures data integration and analysis using Power BI.

The model employs system dynamics to simulate feedback loops, where marketing campaigns influence logistics workloads. For example, an increase in demand automatically triggers inventory adjustments. BI technologies, such as machine learning algorithms (e.g., scikit-learn), provide forecasts to reduce uncertainty. This approach differs from traditional methods by enabling dynamic adaptation based on real-time data [3-6].

IV. MODEL ARCHITECTURE

The model architecture is developed using AnyLogic, integrating system dynamics, Monte Carlo simulation, and MAS [9,16]. The architecture comprises the following layers:

- **Data Layer**: Data is collected from ERP, CRM, and WMS systems. BI tools (Power BI) clean and integrate the data [3-6,10];
- **Simulation Layer**: In the multi-agent system, agents (suppliers, production units) interact. For instance, a marketing agent forecasts demand, while a logistics agent optimizes transportation [12,13];
- **Analytical Layer**: OLAP analysis is used for scenario evaluation, such as "what-if" simulations [15].

A pseudocode fragment for logistics optimization: listing

```
initialize agents (suppliers, factories,
customers)
for each time_step in simulation:
    forecast_demand =
BI_predict(marketing_data)
    optimize_supply =
logistics_model(demand, inventory)

update_feedback_loop(performance_metrics)
    simulate_interactions(agents)
end for
evaluate_results(KPIs: cost, time,
satisfaction)
```

This structure ensures the model's flexibility and scalability.

V. EVALUATION

The model was tested on synthetic data representing millions of units in manufacturing processes. Key Performance Indicators (KPIs) included cost reduction, time efficiency, and customer satisfaction levels. Results show that the integrated model is 20% more effective than traditional methods. For example, simulating a marketing campaign reduced logistics delays by 18% through BI-driven forecasts.

VI. CONCLUSION

The proposed simulation model, integrating marketing, logistics, and BI technologies, offers an innovative solution for managing manufacturing processes. It enhances organizational adaptability in uncertain conditions and fosters competitiveness. Future research should focus on deeper AI integration to make the model even more dynamic. This approach can be applied to manufacturing enterprises in Georgia.

REFERENCES

1. Surguladze, G., Zhvania, T., Kiviladze, N., & Kobulashvili, S. (2024). *Web-application building technology with microservice architecture*. ISBN 978-9941-8-6333-2, Monograph, GTU "IT-Consulting Scientific Center", Tbilisi, 302 p. (In Georgian)
2. Russell S., Norvig P. (2007). Artificial Intelligence: Modern Approaches. Internet resource: http://repo.darmajaya.ac.id/5272/1/Artificial%20Intelligence-A%20Modern%20Approach%20(3rd%20-Edition)%20(%20PDFDrive%20).pdf (20.05.25)
3. Steiner M. (2024). Harness the Power of AI & BI: Key Differences and Synergies. Internet resource: https://valueworks.ai/harness-the-power-of-ai-bi-key-differences-and-synergies/ (31.05.25)
4. Ferrari A., Russo M. (2016). Introducing. Microsoft Power BI. ISBN: 978-1-5093-0228-4. Publ. by Microsoft Press.
5. Milligan J.N. (2019). Learning Tableau. ISBN 978-1-78883-952-5. Third Edition. 805 p. http://projanco.com/Library/Learning%20Tableau%202019%20Tools%20for%20Business%20Intelligence,%20data%20prep,%20and%20visual%20analytics.pdf (20.05.25)
6. Botticchio G. (2025). Welcome to SAP BusinessObjects BI 2025. Technology Blog Posts by SAP. Internet resource: https://community.sap.com/t5/technology-blog-posts-by-sap/welcome-to-sap-businessobjects-bi-2025/ ba-p/14040695 (21.05.25)
7. Holloway S. (2024). The Role of Supply Chain Managementin Shaping Marketing Strategies forEmerging Markets. doi: 10.20944/preprints202406.1428.v1. Internet resource https://www.researchgate.net/publication /381553125_The_Role_of_Supply_Chain_Management_in_Shaping_Marketing_Strategies_for_Emerging_Markets (25.05.25)
8. Karnopp D.C., Margolis D.L., Rosenberg R.C. System Dynamics. Modeling, Simulation, and Control of Mechatronic Systems. Fifth Edition. Published by John Wiley & Sons, Inc., Hoboken, New Jersey. 2012. Internet resource: https://repo.poltekbangsby.ac.id/id/eprint/596/1/System%20Dyna-mics%20Modeling,%20Simulation,%20and%20Control%20of%20Mechatronic%20Systems%20(%20PDFDrive%20).pdf (2.06.25)
9. Cox M., Siebert B.R.L.The use of a Monte Carlo method for evaluating uncertainty and expanded uncertainty. 2006. DOI: 10.1088/00261394/43/4/S03. https://www.researchgate.net/publication /231152390_The_use_of_a_Monte_Carlo_method_for_evaluating_uncertainty_and_expanded_uncertainty (5.05.25)
10. Surguladze Gia, Kristesiashvili Kh., Surguladze Giorg. Modeling and Analysis of Enterprise Resource Management Busniness Process. ISBN 978-9941-20-557-6. Monogr., GTU, Tbilisi, 2015. 167 p. http://gtu.ge/book/gia_sueguladze/GiaSurgul_BPMN_ERP_2014.pdf
11. Rashidi M., Ghodrat M., Samali B., Mohammadi M. Decision Support Systems. In book: Management of Information Systems. DOI: 10.5772/intechopen.79390. 2018.. Internet resource: https://www .research-gate.net/publication/328508044_Decision_Support_Systems (6.06.25)
12. Chekinov G.P., Chekinov S.G. Multi-agent Technologies for Intelligent Support of Decision Making. 2023. https://www.researchgate.net/signup.SignUp.html
13. Simon A.R., Shaffer S.L. Data Warehousing and Business Inteligence for e-Commerce. 2001. https:// www.google.ge/books/edition/Data_Warehousing_And_Business_Intelligen/-lqQMHnxPU4C?hl=en&gbpv=1& print-sec=frontcover (7.06.25)
14. Artificial intelligence (yesterday, today, tomorrow).Internet resource: http://transhumanismrussia. ru/ content/view/16/138/ (1.05.25)
15. Turkia E., Arkhoshashvili Z. Perfection of Organiztional Manageme-nt Processes by using Model-Driven Development. ISBN 978-9941-8-6333-2. GTU. Publ.House "Technical University", Tb., 2015. 111 p. (in Georgian).
16. Kaniskkan A., Kaniskkan A. Sam Selwyn J. (2024). Simulation using Anylogic. DOI:10.13140/RG.2.2. 20359.61604. https://www.researchgate.net/publication/379639905_Simulation_using_Anylogic (7.06.25)

Lara Loreen Balkanski

An Interactive Visualization of Berlin's Stolpersteine: A React Application for Historical Memory

***Abstract*— In 1992 Gunter Demnig initiated an art project called "Stolpersteine" (German for "stumbling stones") to commemorate victims of the Nazi regime. Demnig's project evolved to be the world's largest decentralized Holocaust memorial.**

A Stolperstein is a pavement stone with an engraved brass plate which is embedded in the sidewalks of the former residences or workplaces of the victims. Since 1992 over 116.000 stumbling stones have been installed all over Europe, most of them in Germany.

This work focuses on the stumbling stones in Germany's capitol Berlin and presents the dataset of 10.208 entries provided by Berlin Open Data in a web-based visualization. The system was developed with React, Leaflet, D3 and QGIS, integrated polygon-based district filters, clustering for overlapping markers and interactive bar charts. By combining historical commemoration with data visualization techniques, this work aims to deepen public engagement with cultural memory.

***Index Terms*—Data visualization, Leaflet Map, React, Stolpersteine**

I. INTRODUCTION

Holocaust remembrance is often realized through physical memorials, archives and educational programs. The Stolperstein project extends remembrance into public urban spaces, embedding memory into the everyday environment. However, while Berlin alone contains over 10.000 stumbling stones, exploring this dataset is difficult without interactive tools.

This paper introduces an information visualization system designed to present and explore the Berlin stumbling stone dataset. The system addresses key challenges of geospatial representation, overlapping markers and intuitive filtering.

The work demonstrates how digital technologies can augment cultural memory, turning a static dataset into an accessible, analytical, and interactive platform.

II. RELATED WORK

Numerous Holocaust remembrance projects adopted digital platforms, from archives to interactive maps. The official Stolpersteine website of Berlin provides statistic listings and basic maps but lacks advanced interactivity. Leaflet-based clustering is applied both on the official website and in the app to resolve overlapping markers, but they do not integrate a demographic or surname analysis.

This work builds upon the advancements of interactivity for user engagement.

III. PROPOSED METHOD

The visualization system was developed on the basis of the Berlin Open Data Stolpersteine dataset [1], which includes 10.208 entries with geographical coordinates, addresses, names, birth years and links to biographies. The implementation followed four key stages:

1. **Data Preparation:** Redundant fields, such as combined address columns and the "*virtual stone*" attribute, were removed to optimize the dataset for the project's purposes. Special attention was given to inconsistencies in the *birth year* field, where missing information was represented by the value 0. Furthermore it was ensured that the coordinate fields conformed to the decimal degree format required for geospatial processing.
2. **Visualization Goals:** The project aimed to uncover patterns of persecution and community by visualizing three aspects: the distribution of stumbling stones across Berlin districts, surname clusters that reveal family-level victimization, and the demographic distribution of victims by decade of birth.
3. **Design Concept:** The conceptual phase was used to create a design that emphasizes a respectful historical ambiance. The system was designed around three core interaction elements: a city map displaying markers, polygon-based district and subdistrict selection tools, and bar charts enabling categorical filtering by surname and age group.
4. **Implementation Process:** The visualization system was realized as a modular React application integrating Javascript, CSS, Leaflet for map rendering, QGIS for geospatial preprocessing, and D3.js for interactive bar charts.

IV. SYSTEM ARCHITECTURE

The architecture of the system consists of the following components:

1. The **Geospatial Mapping Component** displays the geographical location of the memorials on the Leaflet-based map. Preprocessed GeoJSON files exported from QGIS provide the spatial dataset. To address the overlapping markers caused by shared addresses, the MarkerCluster library

was implemented, supporting both clustering and spider-view expansion. Clicking on the marker provides personal information about the victims identity and a link the the biography.

2. The **Berlin Filter Component** was initially implemented as a drop-down menu and later enhanced with polygon-based filters using GeoJSON boundary datasets for districts [2] and subdistricts [3]. Users can directly interact with district polygons to refine the dataset, with hover and click events providing both highlighting and selection feedback.

3. The interactive **Bar Charts Components** are implemented with D3.js and allow filtering of the map by age group and surname. The age distribution bar chart was grouped into decade ranges (1840s-1940s) with an additional category for unknown birth years. The surname distribution bar chart was implemented with a scrollable view to display all surnames with the most common surnames on the top of the list.

All components were embedded into *MainLayout.jsx*, with styling applied through *MainLayout.css*. Additional features included custom loading animation, hover and click interactivity for markers, polygons and bar charts.

V. EVALUATION

As no formal user study was conducted within the scope of this project, the evaluation is limited to internal testing and design reflection. During implementation, several performance and usability issues were identified and addressed. For instance, reducing the coordinate precision of the GeoJSON export noticeably improved loading times, while the introduction of clustering resolved inconsistencies between map markers and bar chart counts caused by overlapping coordinates. In addition, replacing the restricted Top-10 surname list with a scrollable bar chart ensured that less frequent (and equally interesting) names remained accessible to users.

While these measures ensured a functional and coherent system, a systematic user evaluation remains an important direction for future work.

VI. CONCLUSION

This paper presented an interactive visualization of Berlin’s Stolpersteine, combining data preparation, geospatial mapping, and interactive filtering into a React-based platform. The project demonstrates how information visualization can transform a static dataset into an accessible, interactive platform both for exploration and remembrance of Holocaust victims.

In future work this information visualization project can be expanded in three main directions:

1. **Data enrichment:** By crawling the official stumbling stone webpages the React application can include further biographical information such as professions, deportation dates or survival status. Beyond Berlin, the underlying concept can be scaled to include datasets from other European cites, enabling comparative analysis across different regions.

2. **Usability improvements:** The user experience can be improved by adding dedicated deselection buttons, visualizing the combined effects of multiple filters and further reducing the loading times of the markers.

3. **User-centered evaluation:** By conducting structured usability studies to assess effectiveness, accessibility, and historical impact among diverse audiences.

Through these extensions, the system can grow into a comprehensive resource for exploring personal histories and collective memory not only in Berlin but also throughout Europe.

REFERENCES

[1] Berlin Open Data (2019): Liste der Stolpersteine Berlin, In: GOVDATA, [online] https://www.govdata.de/suche/daten/liste-der-stolpersteine-berlina5974
[2] Open Data Informationsstelle Berlin (2025): Bezirke, [online] https://daten.odis-berlin.de/de/dataset/bezirksgrenzen/
[3] Open Data Informationsstelle Berlin (2025): Ortsteile, [online] https://daten.odis-berlin.de/de/dataset/ortsteile/

Mobile Robotic Platform with Wearable-Glove Controlled Arm for Biomedical Laboratory Automation

Mirian Beridze, Giorgi Bliadze, Aleksandre Barbakadze . Supervisor: Aleksandre Labadze

This joint project presents the design and development of a modular robotic platform equipped with a wearable-glove controlled robotic arm for biomedical laboratory automation. The system integrates two complementary subsystems: a glove-mounted inertial measurement unit (IMU) sensor array controlling a robotic hand, and a mobile robotic rover platform with wireless communication, joystick tuning, and modular robotic arm. Together, the system enables real-time gesture replication with <50 ms latency in the glove subsystem and reliable wireless mobility with ~250 ms latency in the rover subsystem. The prototype provides a low-cost, stable, and portable solution for laboratory sample handling, with potential applications in prosthetics, rehabilitation, VR/AR control, and biomedical laboratory automation.

I. INTRODUCTION

Automation of biomedical laboratories demands safe, accurate, and efficient sample transport and manipulation. Conventional specimen handling introduces risks of delay, contamination, and human error. Robotic systems, particularly those integrating wearable sensors and mobile platforms, offer promising solutions. This project combines two efforts: (1) a wearable glove equipped with seven MPU6050 IMU sensors that detect human finger movements and replicate them in a robotic hand via servo motors, and (2) a wireless-controlled robotic rover with modular robotic arm operated via an Arduino Nano/Uno, joystick input, and nRF24L01 modules. By integrating these systems, the platform demonstrates a novel, affordable, and effective solution for biomedical laboratory automation.

II. RELATED WORK

Research into prosthetic limbs, gesture recognition, and laboratory automation has explored solutions such as EMG-based prosthetics, computer-vision systems, Bluetooth/Wi-Fi robots, and wearable IMU-based gesture controllers. While vision-based systems often rely on stable environments and EMG systems suffer from calibration complexity, IMU-based controllers present a cost-effective, noise-resistant solution. Previous work has shown gesture-controlled robotic cars, wearable IMU devices, and laboratory automation with robotic arms. Our system advances this by integrating multi-IMU glove sensing with wireless rover mobility, bridging low-latency gesture replication and stable modular robotic automation for biomedical applications.

III. PROPOSED METHOD

Our approach was to combine two distinct but complementary systems into a single platform: a wearable glove that translates human finger motions into robotic hand movements, and a mobile rover capable of carrying out laboratory tasks with its own modular arm.

The glove is fitted with seven MPU6050 sensors: one at the wrist for reference and the others distributed across the fingers. These sensors capture acceleration and angular velocity along three axes. Their signals are routed through a multiplexer to the ESP32 microcontroller, which applies a complementary filter to smooth the data and remove drift. By comparing angular differences between the reference and finger sensors, the ESP32 calculates how much each joint has moved. These values are then translated into commands for six SG90 servo motors, which replicate the movement in the robotic hand. With this setup, the robotic hand can respond to human gestures in under 50 milliseconds and reproduce finger positions with roughly one-degree precision.

The rover, on the other hand, is controlled wirelessly. An Arduino Nano on the transmitter side gathers input from another wrist-mounted IMU and a joystick that allows the operator to adjust direction and speed. This information is packed into short digital messages and transmitted through nRF24L01 modules. On the receiver side, an Arduino Uno decodes the packets and drives the motors: servos that articulate the rover's robotic arm and DC motors that move the mobile base. Although its latency is higher, averaging about 250 milliseconds, the rover is reliable across typical laboratory distances and achieves more than 90 percent accuracy in reaching target positions.

When integrated, the glove takes care of precise finger-level motion, while the rover supplies mobility and broader manipulation. The combination gives the operator both dexterity and reach, making the system suitable for tasks such as transporting and handling biomedical samples.

IV. SYSTEM ARCHITECTURE

The final platform is organized into four functional layers that work together seamlessly. At the sensing and control layer, the glove captures fine movements through its seven IMUs, while the rover gathers overall motion and steering commands from a wrist-mounted IMU and joystick. These inputs flow into the processing layer, where the ESP32 manages real-time gesture recognition on the glove, and the Arduino Nano and Uno handle wireless communication and motor control for the rover. Calibration at startup ensures stable baselines by averaging thousands of initial sensor readings.

Communication between components is carried out through standard protocols. I²C connects the glove's sensors to the ESP32, while SPI enables fast wireless exchange between the nRF24L01 modules. Data packets carry a mix of movement direction, velocity, and servo angles. Tests confirmed that this communication remained stable over distances suitable for small laboratory environments.

At the actuation layer, the system translates processed signals into mechanical motion. Six SG90 servos animate the robotic hand, additional servos control the rover's modular arm, and DC motors drive the mobile platform. The rover is powered by rechargeable lithium-ion batteries that last an entire laboratory shift, while the glove runs on an external supply. This modular structure makes it possible to swap components, add sensors, or upgrade parts without redesigning the entire system.

V. LIMITATIONS AND FUTURE WORK

While the prototype achieved its goals, it also revealed some clear limitations. The IMU sensors, though affordable and effective, remain sensitive to drift and vibration, which can reduce accuracy over time. The glove responds very quickly, but the rover introduces a quarter-second delay that could be noticeable in faster-paced applications. The servo motors used in both the glove and the rover provide adequate precision but lack the torque needed for heavier tasks. Finally, the wireless modules occasionally lose packets in environments with strong interference.

Looking ahead, several improvements could address these issues. Stronger microcontrollers such as the ESP32-S3 would allow more advanced algorithms without running into memory limits. Replacing the SG90 motors with high-torque digital servos would expand the system's practical use. More sophisticated filtering, such as Kalman filters or even AI-based prediction, could stabilize control under challenging conditions. On the hardware side, designing a custom PCB would reduce wiring complexity and improve reliability. In the long term, adapting the system to meet biomedical certification standards could make it suitable for real clinical use.

VI. EVALUATION

This project represents the successful merging of two separate ideas into one coherent system. The glove, with its responsive IMU-based design, provides natural and precise gesture control, while the rover brings mobility and modularity. Together, they form a low-cost platform that addresses real challenges in biomedical laboratory automation.

Beyond its immediate technical results, the project highlights the power of student innovation: with affordable components and open-source tools, it is possible to design systems that bridge the gap between classroom learning and real-world needs. With continued development—stronger motors, smarter algorithms, and compliance with medical standards—the platform could grow from a prototype into a useful tool for prosthetics, rehabilitation, and laboratory automation..

REFERENCES

[1] 5. Build and program your own arduino drone https://www.youtube.com/playlist?list=PLeuMA6tJBPKsAfRfFuGrEljpBow5hPVD4
[2] 6. BuiModern Robotics, Chapter 4: Forward Kinematics Example https://www.youtube.com/watch?v=cKHsil0V6Qk
[3] 7. Using Servo Motors with ESP32
https://dronebotworkshop.com/esp32-servo/

A Short Film on the Dangers of QR Codes

Oleksandra Bitrikowa, Jennifer Vindimut, Ekaterina Swoboda

***Abstract* - Filmmaking is a complex process that integrates technical skills, creative decision-making, and collaborative coordination. As part of a university project, we created a short film with the goal of learning the fundamentals of film methodology, including camera perspective, sound regulation, storyboarding, and postproduction editing. To ensure cultural and thematic relevance, the narrative addressed the dangers of QR codes, a modern digital security concern. This paper presents the methods and outcomes of the project, structured around the three classical stages of filmmaking: preproduction, production, and postproduction. Our results demonstrate the effectiveness of experiential learning in mastering technical tools and workflows while producing a culturally relevant media artifact.**

***Index Terms*—filmmaking methodology, preproduction, production, postproduction, QR code security**

I. INTRODUCTION

Learning filmmaking involves both theoretical knowledge and practical application. While textbooks describe camera settings, perspective, and editing theory, only hands-on practice allows students to grasp the complexity of real-world production. To facilitate this learning, our university assigned us the task of creating a short film.

For our topic we wanted to focus on the unseeming danger QR codes because of their cultural relevance and connection to digital security risks. QR codes are widely used for payments, authentication, and marketing, but they also present vulnerabilities such as phishing and malware injection. By dramatizing these risks, our film allowed us to merge artistic storytelling with a relevant social issue. Unlike clicking suspicious links—where public awareness has increased—QR codes tend to be scanned mindlessly for quick access to information. This shortcut mentality has contributed to the rise of quishing, a phishing technique that uses malicious QR codes to steal data. We aimed to depict both the lack of education around this threat and the widespread tendency to ignore its risks.

The objective of this paper is twofold: (1) to document the filmmaking process as a structured learning activity, and (2) to evaluate the outcomes in terms of skills acquired, challenges encountered, and lessons learned.

II. PROJECT REQUIREMENTS

1) Project Framework

The short film project was conducted as part of the course "Media Production" at the University of Applied Sciences Dresden. Each group consisted of three students and was responsible for all stages of production. The assignment required the creation of a short film on Blu-ray Disc (BD-R), with the following constraints:

- Runtime: 3:45 to 4:15 minutes, including credits.
- Video format: Full HD (1920×1080, 50i) or HD (1280×720, 50p), 16:9 aspect ratio, no black bars.
- Color requirement: At least 75% of the main film in color.
- Sound: 5.1 surround sound, with language in German, atmospheric sound throughout, and music covering at least 33% of the runtime.
- Output: A playable Blu-ray Disc with menus for full film and scene selection. The disc also had to include a data folder with the film file(s), storyboard, copyright declarations, and documentation of equipment/software used.

Legal and ethical restrictions prohibited the use of copyrighted material without permission, as well as any unlawful, violent, extremist, pornographic, or discriminatory content. Documentation of copyright sources (especially for music and images) was mandatory

2) Technical Requirements

The film was required to integrate a set of technical and creative elements, which framed both the design and evaluation of our work. These requirements were as follows:

- Multiple camera shots presented in a meaningful sequence.
- on-screen text banners, not subtitles
- A short end credits sequence listing group members and source materials.

- Masking/Keying (green- or bluescreen) with at least one main subject placed in a different environment for at least 15 seconds, integrated into the narrative with minimal interruption.
- Zooms: one zoom-in and one zoom-out, each lasting at least 5 seconds.
- Pans: one horizontal pan and one vertical pan, each lasting at least 5 seconds.
- Transitions and effects, applied with care and narrative purpose.
- Proper white balance, awareness of automation limitations, and attention to lighting design.

These technical aspects formed the foundation of our grading rubric, with emphasis placed on cinematographic quality and correct execution of the above-listed requirements.

III. Proposed Method

1) *Preproduction*

We first developed a narrative outline and storyboard to map scenes, timing, and thematic progression. Given the strict runtime limit of 4 minutes 15 seconds, careful planning was essential. Roles were assigned among group members, costumes were chosen, and equipment was borrowed from the university.

2) *Production*

Filming was initially scheduled for three days but completed in two. The first day was dedicated to indoor scenes, the second to outdoor shots. Camera positioning, microphone setup, and lighting were adjusted per scene. Each team member contributed as both actor and crew, ensuring shared responsibility for execution.

3) *Postproduction*

Postproduction tasks were distributed among team members. Editing was performed using DaVinci Resolve 20 for rough and fine cuts. Special effects were added separately, while soundtrack selection was conducted by another member. Adobe Encore and Photoshop were used to design a Blu-ray menu allowing viewers to select either the full film or individual scenes. Copyright clearance was obtained for third-party clips included in the project.

IV. Results and Discussion

The final film successfully highlighted the risks associated with QR codes while fulfilling all technical requirements. Our group reported substantial gains in:

1. Technical Competence: mastering cinematography, sound design, and postproduction workflows.
2. Collaboration: effective distribution of tasks across team members in all stages of production.
3. Time Management: completing filming ahead of schedule without compromising quality.
4. Ethical Awareness: engaging with copyright and intellectual property considerations.

The mandatory technical requirements also proved pedagogically effective. Incorporating zooms, pans, keying, and transitions within a meaningful narrative context required careful planning and creativity. Moreover, attention to lighting and white balance emphasized the importance of visual clarity and consistency.

One of the most valuable lessons was adaptability: unforeseen constraints, such as condensed filming time, required creative adjustments. The thematic focus also reinforced the importance of socially relevant storytelling, bridging film methodology with contemporary digital risks.

V. Conclusion

This paper presented a short film project designed to teach filmmaking fundamentals through experiential practice. By following a structured process of preproduction, production, and postproduction, we gained hands-on experience with both technical tools and creative storytelling. The project not only enhanced our understanding of film methodology but also allowed us to address a culturally significant issue—QR code security. Future iterations of this work may explore longer formats, audience reception studies, or expanded integration of visual effects.

Simulation of an IT Project: From Requirements to Final Software

Oleksandra Bitrkowa, Jennifer Vindimut, Ekaterina Swoboda

***Abstract*—This paper presents a university project that simulated the workflow of an IT contract from requirements gathering to final software delivery. The fictitious client, *Wedding Bliss*, required a digital solution to simplify the management of guest lists and meal preferences for weddings. The contractor role was assumed by our project team, *Innova Soft*, which was responsible for design, implementation, and documentation. The solution was realized as a server/client application using Spring Boot and a Java Swing GUI, with communication based on JSON. Core features included guest registration, menu selection with allergy tracking, and error handling. The development process followed a structured approach supported by requirement documents, testing, and code obfuscation. The resulting system proved stable, user-friendly, and reliable under parallel usage. Beyond technical implementation, the project emphasized realistic practices in project management, role distribution, and documentation, reflecting the complexity of professional IT projects.**

***Index Terms*—client–server systems, documentation, project management, Spring Boot.**

I. Introduction

As part of our university project, we conducted a simulation that reproduced the typical workflow of an IT assignment within a company. The aim was to gain practical insights into the entire process – from drafting the initial requirement documents to the final delivery of the solution. The focus was particularly on understanding how documentation, coordination, and invoicing are handled in real-world projects.

The fictitious client was the company *Wedding Bliss*, a business in the wedding industry. This role existed solely for the purpose of the simulation in order to create a realistic project scenario. Our project group took on the role of the contractor, the IT company *Innova Soft*, and was responsible for the technical planning, implementation, and documentation of the project.

II. Related Work

Wedding Bliss is a fictitious company specializing in the planning and organization of weddings. The goal was to develop a system for the digital management of guests and their meal preferences. The solution consisted of a server/client application with a graphical user interface (GUI). Guests could confirm their attendance, select menus (meat, vegetarian, vegan), and specify allergies or intolerances. This created a secure, simple, and scalable foundation for wedding planning.

From a technical perspective, the implementation was carried out using a Spring Boot server and a GUI client that communicated via JSON. Data management could be handled either through static JSON datasets or through a database. In addition to the development itself, the project also included the preparation of key project documents such as the requirements specification, functional specification, administrative documentation, and invoices.

To better understand standard project workflows and documentation practices, our group was also shown examples of previous projects by the professor. This provided valuable insights into how different teams approached similar assignments and how professional project documentation is typically structured.

III. Proposed Method

Within *Innova Soft*, the tasks were distributed among five team members to reflect the typical working structure of an IT company:

- **Management**: Coordination of the project, responsibility for scheduling, agreements, and overarching decisions.
- **Backend Developers (2)**: Implementation of the server logic in Spring Boot, development of interfaces, and management of data processing.
- **Frontend Developer**: Development of the graphical user interface (GUI), ensuring user-friendliness, and handling communication with the backend.
- **Human Resources Department**: Preparation of organizational documents, internal administration, and support with administrative tasks such as invoicing and team organization.

The clear division of roles enabled a realistic simulation of a professional project team and ensured that both technical and organizational requirements were successfully met.

IV. System Architecture

The motivation of *Wedding Bliss* was to make weddings as stress-free and unique as possible for both couples and guests.

Up to that point, guest lists and meal preferences had been managed manually, which was time-consuming and prone to errors. The goal of the project was therefore to develop a digital solution that would significantly simplify the organization process.

The assignment for *Innova Soft* was to develop a server/client application that digitally represented the entire process of guest registration and menu selection. As the technological foundation, Spring Boot was chosen—a modern Java framework particularly suited for the development of lightweight web applications. Spring Boot provides several key advantages, including an embedded web server for rapid deployment, simple creation of REST interfaces, strong integration with JSON and other data formats, and a clean separation of layers based on the MVC principle.

For implementation, a modern development environment and toolchain were used. The Eclipse IDE served as the central workspace, while Maven was employed for dependency management and automated project builds. JUnit was used for systematic testing of individual components, and yGuard was applied for code obfuscation to protect the software. Documentation of the API and source code was created using JavaDoc, ensuring a transparent and traceable developer documentation.

Through this combination, a modern, clean, and extensible software architecture was realized that met the project requirements both functionally and organizationally.

V. EVALUATION

Over the course of the project, a fully functional application was developed that met the central requirements. Throughout the process, we closely followed the specifications in the requirements document (*functional specification*) to regularly verify the mandatory criteria. The final product included:

- Guest attendance confirmation
- Menu selection including allergies and intolerances
- About button with background information
- Client-server communication via JSON
- Local operation via localhost
- GUI built with Java Swing
- Error handling with status messages
- Documentation (user and developer documentation)

The system was successfully tested with sample datasets, proved to be stable and user-friendly, and functioned reliably even under parallel access.

VI. CONCLUSION

The project demonstrated how digital solutions can make complex business processes more efficient. The simulation of a real client–contractor situation was particularly valuable: requirements had to be clearly defined, documented, and then technically implemented. This allowed us to expand not only our technical skills but also our competencies in project management and team organization.

The regular review of the requirements defined in the *functional specification* provided continuous oversight of the project's progress. The clear division of roles within the team highlighted that efficient task management and effective communication are key to success.

Furthermore, the project emphasized the importance of thorough documentation: user and developer documentation, along with accompanying documents such as the *customer requirements document*, *functional specification*, and invoices, ensured a complete and realistic project package that extended beyond the software code itself.

artVenture
Mobile Web Application for Immersive Art Exploration

Christina R. Epple

***Abstract*— Discovering art in urban spaces often relies on static maps or curated lists, which limit spontaneity and focus on institutions rather than the artworks themselves. This work introduces *artVenture*, a web-based mobile application that enables users to explore nearby artworks through embodied interaction with their smartphones.**

By moving and orienting the device, users can reveal artworks positioned within a virtual cylindrical space around them. Once an artwork is selected, tilting the phone parallel to the ground activates a navigation mode that guides users directly to the exhibition site. This design creates a seamless experience that connects digital discovery with physical exploration. Unlike conventional approaches, *artVenture* emphasises the artworks as primary entry points, fostering playful engagement and lowering barriers to cultural participation.

Implemented as a responsive web app with JavaScript and Three.js, *artVenture* leverages motion and orientation sensors to enable real-time interaction and an immersive discovery mode. Designed for digitally savvy young adults, tourists, and urban explorers, the system offers an intuitive and innovative model for location-based cultural mediation.

***Index Terms*— cultural mediation, location-based systems, mobile interaction, Three.js, urban art discovery.**

I. Introduction

Traditional forms of art mediation tend to prioritise institutions and exhibition venues over the artworks themselves. For audiences, this frequently results in time-consuming and complex searches across websites, social media, and printed materials. Such approaches require prior knowledge, offer limited interactivity, and rarely support spontaneous engagement in everyday contexts. Consequently, younger, digitally savvy audiences are often not effectively reached. Existing digital solutions provide only partial answers and do not enable playful, artwork-centered exploration that bridges digital and physical engagement.

This work introduces *artVenture*, a web-based mobile application designed to address this gap. In a discovery mode, artworks are positioned in a virtual cylindrical 3D space around the user and revealed through motion and orientation of the smartphone. Once an artwork is selected, tilting the device parallel to the ground activates a navigation mode that guides the user directly to the exhibition site. Implemented as a responsive web application with JavaScript and Three.js, the system leverages motion and orientation sensors to provide real-time interaction, immersive exploration, and a seamless connection between discovery and navigation.

The main contribution of this work is the design and implementation of a sensor-based web application that transforms the way artworks can be discovered in urban environments. By combining interactive and immersive exploration with location-based cultural mediation, *artVenture* demonstrates how web technologies can be applied to foster new models of cultural engagement. The current implementation is a proof-of-concept, using example data to illustrate the system's functionality rather than a full-scale deployment. While the technical development is at the core of this research, the project also highlights the value of interdisciplinary collaboration between computer science and communication design in rethinking digital access to culture.

II. Related Work

Existing digital solutions for art discovery address some aspects of the problem, but lack an integrated, artwork-centred experience. Google Arts & Culture is primarily focused on institutions and well-known collections, offering limited geolocation-based exploration and no interactivity. Interactive city tour platforms, such as Actionbound, provide general location-based experiences; however, they do not emphasise individual artworks or link discovery directly to physical navigation. Furthermore, the integration of social media tools with mapping services, such as the combination of Instagram with Google Maps, exhibits a lack of curated context and seamless integration between digital content and real-world locations. In contrast, *artVenture* employs a combination of 3D spatial visualisation, sensor-driven interaction, and location-based guidance to facilitate a method of discovering artworks in urban environments that is both playful and immersive. In this approach, the artworks themselves are positioned as the primary entry points, rather than the hosting institutions.

III. Proposed Method

The proposed method of *artVenture* facilitates the discovery of interactive artwork through a mobile web application that integrates 3D visualisation with device orientation input. In the discovery mode, the artworks are presented in a virtual cylindrical 3D space rendered with Three.js. The scene is composed of three-layered spheres, each with a slight blurring effect to create a parallax effect and convey depth. Users reveal artworks by physically moving and orienting their smartphones, while pinch-to-zoom gestures enable users to inspect the scene more closely.

Device orientation is captured using the DeviceOrientationEvent, with alpha, beta, and gamma values directly controlling camera rotation and the directional arrow within the interface. The selection of an artwork, coupled with the tilting of the device in a parallel orientation to the ground, initiates a navigation mode. In this mode, a real-time arrow is displayed, providing users with a directional guide towards the selected artwork. The combination of sensor-driven interaction, layered 3D rendering, and intuitive mode switching creates an immersive system that emphasises artworks as entry points while seamlessly connecting digital discovery with physical navigation.

IV. ALGORITHM DESCRIPTION (OR SYSTEM ARCHITECTURE)

artVenture has been implemented as a responsive web application, which is hosted on a university server. The core system consists of a Three.js scene, a perspective camera, and controls for device orientation. The cylindrical discovery space comprises three spherical layers, each of which has been mapped with preloaded textures and assigned distinct rotation speeds in order to generate a parallax effect. The geometries of the spheres are inverted (scale(-1,1,1)) so that the user is positioned within the virtual cylinder.

Device orientation is handled via the DeviceOrientationEvent, with explicit permission requests on iOS through the DeviceOrientationEvent.requestPermission() function. The Alpha, Beta, and Gamma values serve multiple functions, including the control of camera orientation, the transition between discovery and navigation modes, and the real-time update of the compass arrow. The pinch-to-zoom gesture is processed by tracking the distance between two touches, calculating a zoom factor, and adjusting the camera's field of view within defined bounds to maintain a responsive and immersive experience.

The navigation mode is initiated when the device is tilted almost parallel to the ground, and a directional arrow is continuously updated to guide the user. The system has been engineered to manage window resizing and safe area adjustments, thus ensuring a consistent layout across a range of mobile devices.

The current prototype incorporates example data for the artwork, with all assets being preloaded using Three.js's TextureLoader. While the current implementation is a proof-of-concept, the integration of sensor input, 3D layered rendering, gesture-based zoom, and orientation-driven navigation demonstrates the technical feasibility of immersive, web-based, location-aware cultural discovery.

V. EVALUATION

The prototype has been developed to successfully demonstrate the core functionality of interactive, location-based art discovery. The system facilitates exploration of artworks within a virtual cylindrical three-dimensional space, enabled by device orientation and pinch-to-zoom gestures. Navigation is seamlessly transitioned towards selected works. The proof-of-concept stage of this project utilises example data and simplified artwork positioning, thus highlighting both the technical feasibility and the potential user experience of this approach.

A full-scale deployment would require access to comprehensive datasets, precise geolocation of artworks, and efficient handling of large volumes of media, which present additional technical challenges. Notwithstanding the project's limitations, it functions as a valuable interdisciplinary exercise, integrating computer science with design principles. The interface and layered visualisations were thoughtfully designed to balance aesthetic appeal and functional clarity. In order to provide a visual aid to support the demonstration, a detailed video was created. This video illustrates the user interaction and flow of the system. The prototype has been found to confirm that *artVenture* offers a novel method for engaging with art, while highlighting important considerations for scaling and deployment.

VI. CONCLUSION

The work presented *artVenture*, a proof-of-concept web application that introduces a new approach to discovering urban art through mobile 3D interaction and sensor-based navigation. The project demonstrates how the combination of motion-driven interaction, layered 3D visualisation, and intuitive navigation can create a playful and immersive experience centred on the artworks themselves rather than institutions.

This prototype has been constructed in order to ascertain the concept's viability, and to provide a detailed design that integrates aesthetic considerations with functional requirements. Furthermore, *artVenture* represents an interdisciplinary collaboration, integrating computer science and design to explore innovative forms of cultural mediation. While a full deployment would require more comprehensive datasets and precise localisation, the current implementation establishes a foundation for future work and highlights the potential of sensor-driven, web-based systems to transform how people engage with art in urban environments.

Plane Crash Visualization: An Interactive Web Platform for Exploring Aviation Accidents

Julian Gauger

***Abstract*— Aviation accidents are complex events influenced by technical, human, and environmental factors. This paper presents the design and implementation of a Plane Crash Visualization Website that enables interactive exploration of historical crash data. The system addresses the challenge of transforming unstructured archival records into an accessible visualization platform. Data from *planecrashinfo.com* was scraped, cleaned, geocoded, and stored in a relational database for structured analysis. The frontend, developed in Vue.js, integrates with a C# backend to provide features such as an interactive crash map with clustering, advanced search with multi-parameter filtering, and statistical dashboards for trend analysis. The platform highlights how aviation safety has improved over time and provides insights into geographical and operator-based patterns. This work demonstrates how information visualization techniques can be applied to complex historical datasets to support both educational and analytical purposes.**

***Index Terms*— aviation safety, data visualization, information systems, web application**

I. INTRODUCTION

The visualization of large-scale historical datasets poses significant challenges in both data preparation and user interaction. In the context of aviation, thousands of recorded airplane accidents provide valuable insights into technical failures, human factors, and safety improvements. However, most publicly available records are presented in static tables or text-based archives, which limit exploration and hinder pattern recognition. For researchers, aviation enthusiasts, and the general public, this lack of accessible visualization makes it difficult to understand long-term trends or compare incidents across regions, operators, and aircraft types.

This paper addresses these challenges by introducing a **Plane Crash Visualization Website** that transforms raw archival data into an interactive web platform. The system integrates geocoded crash records with advanced filtering, statistical dashboards, and geographic maps, enabling users to explore both detailed incidents and high-level trends. The main contributions are threefold: (1) a structured pipeline for extracting, cleaning, and enriching aviation accident data; (2) an interactive single-page web application for search, visualization, and analysis; and (3) a demonstration of how information visualization techniques can make complex historical datasets accessible to a broad audience.

II. RELATED WORK

Visualization of accident and safety data has been widely explored in transportation and public safety domains. Geographic Information Systems (GIS) have been applied to crash analysis for detecting hotspots, clustering incidents, and supporting decision-making at agencies [1]. Spatial statistical techniques such as clustering and spatial autocorrelation have further improved the identification of crash severity patterns [2].

Interactive dashboards and Web-GIS platforms have been developed to integrate maps with filters and statistical charts, enabling more intuitive exploration of mobility and safety datasets [3], [4]. These approaches demonstrate the value of combining spatial and temporal perspectives but are rarely applied specifically to aviation safety.

Within aviation, early efforts investigated visualization tools for safety risk reduction, such as NASA's integrated cockpit safety dashboards [5]. More recent studies apply business intelligence methods to aviation accident datasets, building dashboards to analyze causative factors and trends [6]. Exploratory data analysis frameworks, such as PyGWalker, have also been used to visualize airplane crash datasets interactively [7]. Complementary research has focused on text mining and natural language processing of accident reports, extracting latent causal themes and classifying accidents using machine learning models [8], [9].

My work builds on these foundations by integrating historical aviation crash data into a single interactive platform. Unlike previous approaches, the proposed website combines **geospatial mapping, advanced search filters, and statistical dashboards**, offering both high-level trend analysis and detailed incident exploration. This positions the contribution at the intersection of aviation safety research and modern web-based visualization frameworks.

III. PROPOSED METHOD

The core idea of this work is to transform static archival aviation accident records into an interactive visualization system that supports exploration across **spatial, temporal, and categorical dimensions**. Unlike existing databases that provide only text-based listings or static tables, the proposed approach integrates a complete pipeline for **data acquisition, enrichment, and visualization**.

The method introduces three key components:

1. **Data Acquisition and Enrichment** – Accident records are extracted from *planecrashinfo.com* using a custom Python scraper and converted into structured CSV files. Missing values are normalized, and textual location data is geocoded via the OpenStreetMap Nominatim API to obtain latitude and longitude coordinates. Aircraft types are parsed to extract manufacturer and model information, enabling more detailed filtering.
2. **Backend Processing and Storage** – The enriched dataset is imported into a relational SQL database and managed through a C# backend with Entity Framework. This layer provides over 20 API endpoints for summary statistics, geographic queries, operator analysis, and timeline data. Duplicate detection and structured models ensure consistency and scalability.
3. **Frontend Visualization Platform** – A Vue.js single-page application integrates maps, charts, and advanced search functionality. Leaflet.js enables interactive maps with clustering and filtering, while Chart.js provides statistical dashboards. Coordinated filters allow users to apply multiple constraints (e.g., date ranges, operator, fatalities) and instantly view results across maps and charts.

By combining these components, the system provides an **end-to-end visualization pipeline** that makes aviation accident data accessible and interpretable. Its novelty lies in unifying **historical crash mapping, multi-parameter filtering, and statistical trend analysis** into a single platform, thereby enabling both broad overviews and detailed case exploration.

IV. CONCLUSION

I presented an interactive visualization platform for aviation accident data that transforms static archival records into an accessible, exploratory system. The proposed method integrates a complete pipeline, including **web scraping, data enrichment with geocoding, structured database management, and frontend visualization with coordinated filters and dashboards**. By unifying mapping, statistical analysis, and advanced search in one platform, the system enables users to investigate historical crash data at both macro and micro levels.

Future work will focus on expanding the dataset to include official investigation reports, integrating machine learning models for causal factor detection, and exploring real-time data streams for enhanced situational awareness.

V. PROJECT REPOSITORY

The project code can be found on GitHub at the following link: https://github.com/Argaros/Plane-Crash-Visualization

REFERENCES

[1] Federal Highway Administration, *Using GIS for Crash Location and Analysis at State DOTs*, U.S. Dept. of Transportation, 2022.
[2] M. Borruso, F. Bertolini, and A. De Luca, “Crash analysis using spatial statistical techniques: hotspots identification and severity clustering,” *Journal of Transport Geography*, 2023.
[3] J. Keim and D. Oelke, “Design of dashboards for mobility data: visualization frameworks and usability,” *Cartography and Geographic Information Science*, 2023.
[4] U.S. DOT, *Web-based Dashboards for Crash Analytics and Mobility Data*, Technical Report, 2022.
[5] NASA Ames Research Center, *Aviation Safety Visualization Tools for Risk Reduction*, Technical Report, 2005.
[6] I. Ali et al., “Business intelligence in aviation accident data analysis,” *International Journal of Advanced Computer Science and Applications (IJACSA)*, vol. 14, no. 1, 2023.
[7] Kanaries, “Exploring airplane crash data with PyGWalker,” *Kanaries Docs*, 2023.
[8] Z. Jiang et al., “Topic modeling of aviation accident reports for causal factor analysis,” *Journal of Safety Science and Resilience*, vol. 5, 2024.
[9] Y. Wang et al., “Deep learning classification of aviation accident narratives,” *arXiv preprint arXiv:2501.07925*, 2025.

Diagnosing periodontal diseases with a computer system equipped with artificial intelligence

V. Gergauli, Z. Gurtskaia

***Abstract*— Periodontitis is a destructive inflammatory disease of the periodontal ligament, requiring accurate and timely diagnosis for effective treatment. With the rise of artificial intelligence (AI), diagnostic methods in medicine and dentistry have advanced significantly. In particular, deep learning (DL) and convolutional neural networks (CNNs) are increasingly applied to periodontal diagnostics.**

This study aimed to develop an AI-based model for assessing periodontal health using intraoral photographs. While traditional diagnosis relies on photographs, radiographs, and the Florida Probe system, the study focused solely on photographic data to simplify the process.

In collaboration with the Georgian Association of Periodontologists and the Dens Clinics Network, 150 standardized intraoral images with validated diagnoses were collected. Data augmentation and preprocessing in MATLAB supported training despite limited data.

The model achieved 65–70% accuracy, demonstrating AI's potential as a non-invasive, cost-effective, and scalable tool for early detection, screening, and improved periodontal care, especially in underserved regions.

Keywords: Artificial Intelligence, Deep Learning (DL), Artificial Intelligence in Periodontology, Periodontitis Classification.

I. Introduction

Periodontitis is a chronic inflammatory disease and a leading cause of tooth loss worldwide, affecting over one billion people. It is initiated by subgingival biofilms that trigger an immune-inflammatory response, leading to progressive destruction of the periodontal ligament and alveolar bone. Due to its asymptomatic onset and slow progression, the disease is often diagnosed at advanced stages, when irreversible damage has occurred.

Beyond oral health, untreated periodontitis is strongly associated with systemic conditions, including cardiovascular disease, diabetes mellitus, adverse pregnancy outcomes, and respiratory disorders, underscoring the need for early and accurate diagnosis. Conventional diagnostic methods—such as periodontal probing, bleeding on probing, and radiographic assessment—are limited by subjectivity, operator dependence, and delayed detection of early changes.

In response to these challenges, artificial intelligence (AI)—particularly in the form of machine learning (ML) and deep learning (DL)—has become a powerful tool in healthcare diagnostics. In dentistry, and specifically in periodontics, AI algorithms such as convolutional neural networks (CNN), support vector machines (SVM), and decision trees are used to analyze clinical data and radiographic images. These systems offer significant advantages in terms of diagnostic accuracy, reproducibility, efficiency, and cost-effectiveness, and can provide clinicians with early, objective, and standardized decision support.

II. Relevance of the Research

A new classification system for periodontal and peri-implant conditions was introduced at the World Workshop held in Amsterdam in 2017–2018[1,2]. This framework was subsequently refined, and updated guidelines were established to standardize diagnosis and case definition. In this study, we reviewed the current classification system, along with its underlying etiological factors and the diagnostic methods recommended for clinical application.

Artificial intelligence (AI) has been integrated into nearly all fields of dentistry, including maxillofacial surgery, orthodontics, odontology, periodontology, implantology, and endodontics [3]. Its primary applications involve diagnosis, disease prediction, and treatment planning [4]. In many areas of dentistry, radiological examination remains the principal diagnostic tool; consequently, AI is increasingly employed to interpret radiographic data, assist in treatment planning, and predict clinical outcomes. Within periodontology, in particular, AI has demonstrated the ability to analyze orthopantomographic images, supporting clinicians in diagnosis and decision-making.

III. Data Acquisition and Processing

Periodontal disease diagnosis traditionally relies on three components: intraoral photographs, radiographic imaging, and Florida Probe measurements. The present study focused on developing an AI-based diagnostic model using intraoral photographs alone.

Data collection was carried out in collaboration with the Georgian Association of Periodontologists (Geo Perio) and the Densi Clinics Network, where periodontists provided validated clinical records, including all three diagnostic modalities, confirmed diagnoses, and treatment plans. The dataset was organized according to the 2017 classification of periodontal diseases, with intraoral images grouped by disease category and a separate set for healthy cases.

All images were standardized in JPG format and resized to optimize storage and processing. The final dataset consisted of 150 intraoral photographs: 100 depicting diseased periodontium and 50 representing healthy tissues.

IV. ALGORITHM ARCHITECTURE

For data processing, an algorithm was developed in MATLAB. Pre-grouped image files were imported and analyzed, after which the Deep Network Designer was used to define a model architecture consisting of one input layer, five hidden layers, and four output variables.

All images were standardized to 250 × 250 pixels and converted to grayscale using the ColorPreprocessing and rgb2gray functions. The input variables consisted solely of intraoral photographs, while the output corresponded to the predefined diagnostic classes. The model was then trained and verified, with preliminary results demonstrating correct classification, including the detection of stage II periodontitis.

V. RESULTS AND INTERPRETATION

Training of the model resulted in a 65% accuracy rate for detecting periodontal disease from intraoral photographs. Following training, the model was tested using a separate dataset of images with clinically confirmed diagnoses. The achieved performance demonstrates that the algorithm successfully captured correlations between variables. It is anticipated that with the inclusion of a larger and more diverse dataset, diagnostic accuracy could increase to approximately 80%. On this basis, further refinement and continued research are being conducted to improve the reliability and clinical applicability of the model.

VI. CONCLUSION

Periodontal disease is one of the most common conditions worldwide. Its diagnosis typically relies on patient history, intraoral photographs, radiographic imaging, and technologies such as the Florida Probe system, which remain central to current clinical guidelines.

This study introduces a novel artificial intelligence (AI)-based diagnostic model for assessing periodontal tissue health using standardized intraoral photographs. Data were collected in collaboration with the Georgian Association of Periodontologists, ensuring clinically validated cases with confirmed diagnoses.

A deep learning algorithm developed in MATLAB was applied to process oral images and classify periodontal status as either healthy or diseased. Initial results showed an accuracy of about 65%, reflecting the model's early stage. Although not yet sufficient for clinical use, accuracy is expected to improve with additional data and ongoing training.

This approach highlights the potential of AI to improve diagnostic accuracy and accessibility, especially where traditional tools are limited.

REFERENCES

[1] 59. Caton, J. G., Armitage, G., Berglundh, T., Chapple, I. L. C., Jepsen, S., Kornman, K. S., Mealey, B. L., Papapanou, P. N., Sanz, M., & Tonetti, M. S. (2018).

[2] Tonetti MS, Greenwell H, Kornman KS. Staging and grading of periodontitis: Framework and proposal of a new classification and case definition. J Periodontol. 2018 Jun;89(S1):S159–S172. https://doi.org/10.1002/JPER.18-0006

[3] Nasarudin NA, Al Jasmi F, Sinnott RO, Zaki N, Al Ashwal H, Mohamed EA, et al. A review of deep learning models and online healthcare databases for electronic health records and their use for health prediction. Artif Intell Rev. (2024) 57(9):249. doi: 10.1007/s10462-024-10876-2

[4] Khanagar SB, Al-Ehaideb A, Maganur PC, Vishwanathaiah S, Patil S, Baeshen HA, et al. Developments, application, and performance of artificial intelligence in dentistry—a systematic review. J Dent Sci. (2021).

VeinFinder

N. Guliashvili and G. Gabelashvili
Supervisor: Aleksandre Labadze
Department of Biomedical Engineering, Georgian Technical University

I. ABSTRACT

Intravenous access is a routine but often challenging procedure, especially in patients with difficult-to-locate veins or needle phobia (trypanophobia). This paper presents the design and development of **VeinFinder**, a low-cost, portable device that visualizes subcutaneous veins using near-infrared (NIR) illumination and real-time image processing. The system employs a modified Raspberry Pi Camera Module and Raspberry Pi 2 Model B platform to capture and enhance vascular patterns. Experimental evaluation demonstrated successful vein visualization under various lighting conditions. While the current prototype operates on still images rather than live video, it lays the groundwork for a fully functional clinical tool aimed at improving venous access and reducing patient discomfort.

II. INDEX TERMS

Biomedical device, near-infrared imaging, vein visualization, medical imaging

III. INTRODUCTION

Intravenous access is one of the most common procedures in modern healthcare, yet it frequently causes patient discomfort and clinical difficulty, especially in children, elderly patients, or those with trypanophobia. Stress and vasoconstriction often make veins less visible, increasing the risk of multiple needle punctures and procedural failure. Commercial vein visualization devices exist but are often expensive and inaccessible for smaller clinics or low-resource environments.

The **VeinFinder** project addresses this gap by developing an affordable and portable vein visualization device using NIR imaging. The system is designed to highlight veins invisible to the naked eye, reducing procedural complexity and patient discomfort. This paper presents an overview of existing solutions, describes the proposed method and system architecture, and reports the initial evaluation of the prototype.

IV. RELATED WORK

Several vein visualization systems have been developed using different technologies.

The **AccuVein AV500** is a commercial handheld device that projects real-time vein maps using dual-wavelength lasers and **TrueCenter™** alignment, offering 90–95% accuracy but costing $3,200–$5,500. The **AccuVein AV300** is a lower-cost predecessor using NIR LEDs but produces lower-contrast images.

Research prototypes, such as an **MDPI NIR+CMOS** system, use open-source software and achieve high visualization accuracy (~100%) at low cost (~$300), though they require computer integration and technical expertise. Advanced approaches like **SWIR+TOF** systems offer 3D vein mapping but are complex and cost over $7,000.

These systems highlight a tradeoff between performance and accessibility. **VeinFinder** aims to occupy the middle ground—providing acceptable accuracy in a simple, low-cost, and modular format.

V. PROPOSED METHOD

VeinFinder utilizes the strong absorption contrast between blood vessels and surrounding tissue under NIR light. The device illuminates skin with 850 nm NIR LEDs and captures reflected light using a camera without an IR filter. Captured images are processed with the OpenCV library using a CLAHE (Contrast Limited Adaptive Histogram Equalization) algorithm to enhance vascular patterns.

The design emphasizes portability, low cost, and simplicity, making it feasible for smaller clinics. The system works offline, processes data locally, and uses modular components for easy upgrades.

VI. ALGORITHM DESCRIPTION (OR SYSTEM ARCHITECTURE)

The prototype is built around a Raspberry Pi 2 Model B (900 MHz quad-core ARM CPU, 1 GB RAM) running Legacy Raspberry Pi OS. A modified Raspberry Pi Camera Module (IR filter removed) captures images, while six 850 nm NIR LEDs arranged around the lens provide illumination. LED intensity is adjustable using a potentiometer.

Image capture is triggered via command-line scripts. The program uses Python with OpenCV to acquire frames, apply grayscale conversion and CLAHE enhancement, and display the processed images on a connected monitor. All components are powered by a 5 V 2 A power supply. The prototype housing was designed in Fusion 360 and 3D printed for mechanical stability.

VII. EVALUATION

Testing focused on identifying optimal illumination conditions. Images were captured under different ambient light levels (dark/bright), illumination angles (direct/indirect), and LED intensities (low/medium/high).

Results showed that ambient light had minimal effect on image clarity, while illumination angle and intensity were critical. Indirect high-intensity illumination provided the clearest and most evenly lit vein images. The main limitation observed was the low resolution and fixed focus of the budget camera, which limited image sharpness.

Despite these constraints, the prototype successfully visualized veins under various conditions, confirming the feasibility of the approach. Real-time processing was not achieved due to the limited computing power of the Raspberry Pi 2 Model B, so static image processing was used instead.

VIII. CONCLUSION

This paper presented **VeinFinder**, a low-cost NIR-based vein visualization device. The prototype demonstrates that budget-friendly components can achieve effective vein highlighting, potentially improving intravenous access procedures, especially for patients with trypanophobia.

While limited by hardware performance and image resolution, the system establishes a strong foundation for future work. Planned improvements include using a Raspberry Pi 4 for real-time processing, upgrading to a higher-resolution Raspberry Pi Camera Module 2 NoIR, adding PWM-controlled LED drivers, and developing a GUI for better usability.

Ultimately, **VeinFinder** has the potential to become a clinically useful, accessible, and portable vein visualization tool for low-resource healthcare settings.

REFERENCES

[1] MDPI, "Vein visualization using NIR and CMOS," *Sensors*, vol. 12, no. 4, article 373, 2021.
[2] MDPI, "SWIR and TOF-based vein imaging," *Sensors*, vol. 20, no. 24, article 7244, 2020.
[3] MDPI, "Biometric vein identification system," *Sensors*, vol. 23, no. 9, article 4211, 2023.
[4] AccuVein, "Vein visualization system AccuVein AV500," [Online]. Available: https://www.accuvein.com/vein-visualization-system/
[5] European Patent Office, "GAN-based vein mapping system," EP4287136NWA1, 2022.

[6] University of Michigan, "Study on trypanophobia and vaccination refusal," [Online]. Available: https://deepblue.lib.umich.edu/bitstream/handle/2027.42/147205/jan13818_am.pdf
[7] European Union, "General Data Protection Regulation (GDPR)," Regulation (EU) 2016/679.
[8] UNESCO, "Universal Declaration on Bioethics and Human Rights," Articles 10 & 14.

TourneyLab - A progressive web app for organising and evaluating volleyball tournaments

S.Heber

***Abstract*— Organizing small-scale local sports tournaments is often inefficient due to manual scheduling, score recording, and evaluation. The progressive web app TourneyLab digitizes tournament planning, result entry, and ranking evaluation. It follows an offline-first approach, remains usable without stable internet, and supports synchronization via QR codes. The system architecture combines Vue.js, FastAPI, and SQLite, and can be deployed with Docker. Tests confirmed correct schedule generation, reliable synchronization, and stable operation. While primarily a teaching project to practise teamwork in software engineering, TourneyLab also demonstrates potential for practical use in student tournaments.**

***Index Terms*— Progressive Web App, Software Engineering Education, Tournament organization, Volleyball tournament**

I. INTRODUCTION

At the annual volleyball tournament organized by the student council of HTWD University of Applied Sciences game schedules previously had to be created in Excel, results entered manually, and evaluations carried out by hand. This approach is error-prone and time-consuming, regularly leading to chaos in the recording of results, delays in the process, and increased stress for the organizers.

The TourneyLab project was therefore developed as part of the interdisciplinary modules „Software Engineering 1 & 2“. A group of nine undergraduate students from computer science, business informatics, and industrial engineering programs at HTWD developed a progressive web app (PWA) that digitizes planning, results recording, and evaluation. Key features include automatic schedule generation, live results recording, and instant calculation of rankings. The app can be used offline so that it can also be used in sports halls without a stable internet connection and enables offline synchronization between devices via QR codes.

From a technical standpoint, TourneyLab combines Vue.js in the frontend, FastAPI in the backend, and SQLite as data storage. This setup provides an architecture that is easy to deploy and extend.

The contribution of this paper lies in the presentation of related work, our developed solution, the underlying architecture, and the evaluation based on test scenarios.

II. RELATED WORK

In scientific literature, schedule generation is often formulated as an integer programming model (IPM) [1]. Matches, rounds and resources are described by binary variables and embedded in an optimisation model with constraints. Such models can deliver exact and optimal solutions, but are usually computationally intensive and require specialised solvers. They are particularly suitable for tournaments with complex restrictions, such as professional sports leagues [2].

TourneyLab takes a different approach. Instead of formally modelling the problem as an IPM, the application relies on a heuristic algorithm that generates schedules according to predefined rules. The goal is not global optimisation, but rather the creation of useful valid schedules.

The so-called offline-first paradigm describes applications that are primarily designed for local use and only perform synchronisation with other devices or servers on a supplementary basis. PWAs are a typical example of this, as they remain usable even without a constant internet connection thanks to service workers and local storage options.

TourneyLab can be understood as a solution with offline-first architecture principles to address the requirements of local tournaments.

III. PROPOSED METHOD

When creating a new tournament, the application records parameters like number of teams and performance groups, available playing fields, start time, game and break duration, whether a return match is to take place and up to which match point is played. A heuristic method is then applied to create a match schedule in which all teams in a performance group compete against each other, the matches are evenly distributed across the pitches, and conflicts in the order of play are avoided. If the combination of parameters does not allow a useful match schedule to be created, an error message is displayed. The match schedule can be displayed in different views. Either in the dashboard as a list of matches in chronological order, as a list of matches taking place on a specific playing flied, or as a schedule for a single team. Results can be entered directly via the interface of the various views, either via text field or touch input. The changes are stored on a server and continuously synchronised. As soon as the score defined as match point has been reached, the game is displayed as finished in all views and the winning team is highlighted in colour. This game disappears from the dashboard, which only displays the most recent upcoming games.

Offline synchronisation between devices is carried out using QR codes, which contain all tournament data and bring the scanning user up to date. Furthermore, the language can be changed between German and English in a settings menu, and a different colour scheme can be selected.

Another algorithm creates the ranking list based on the entered results. In an exportable PDF evaluation, the point differences between the teams can also be displayed.

IV. SYSTEM ARCHITECTURE

The system follows a modular architecture that clearly separates the frontend, backend and data storage to ensure maintainability and expandability. The frontend is implemented with Vue.js and implements the entire user interface (UI), including navigation, tournament data entry and results display. It runs as a progressive web app in the browser and uses service workers and local storage mechanisms to provide all core functions even without a network connection. The backend is based on FastAPI and provides REST interfaces for managing tournaments and games. Persistent data is stored in an SQLite database that stores the tournament information.

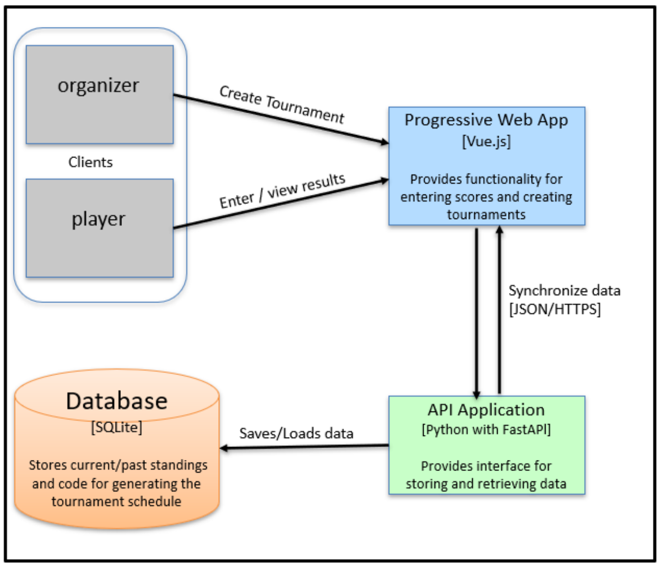


Fig 1: System Architecture of TourneyLab

In offline mode, tournament data can be transferred between devices via QR codes, allowing updates to be made even without an internet connection. In online mode, tournament data is stored directly in the database in a standardised format and automatically updated as soon as new entries are made. There is no role or authorisation system. Anyone who has the unique tournament code can make changes to that tournament. This enables uncomplicated collaboration without the need for additional user management. The system can be deployed via Docker containers.

V. EVALUATION

Unit, integration and system tests were carried out to check TourneyLab. Unit tests validated the core logic, such as the calculation of rankings and conflict detection during schedule generation. In addition, automated API tests checked the REST endpoints for correct processing and error handling. Integration tests checked the interaction between the frontend, backend and database, in particular the synchronisation of scores in online and offline mode. Finally, system tests simulated complete tournament processes with different group sizes.

The tests showed consistently stable results: tournament creation, result recording and evaluation worked as intended, and the synchronisation mechanisms worked flawlessly. The system thus meets the defined technical requirements.

VI. CONCLUSION

The focus of the project was not solely on developing a functioning application, but above all on practising teamwork and the practical application of software engineering methods. This included the use of agile approaches, working with version control and pull requests, conducting code reviews, and structured testing and documentation practices.

The project was completed within the specified time frame and presented as functional. TourneyLab was discussed constructively during the final presentation. The core functions were solidly implemented and convinced the student council. The UI was identified as the only area with room for improvement.

Although the module has been completed, individual team members have decided to continue the project on a voluntary basis. The focus now lies on improving the UI to facilitate practical use in student tournaments. TourneyLab has thus fulfilled its purpose as a teaching project, but also has the potential to continue to serve as a useful tool at sporting events.

REFERENCES

[1] J. van Doornmalen, C. Hojny, R. Lambers, and F. C. R. Spieksma, "Integer programming models for round robin tournaments," in European Journal of Operational Research, 2023.

[2] C. C. Ribeiro, "Sports scheduling: Problems and applications," in International Transactions in Operational Research, 2012.

Imputing Missing Geospatial Data in Open Public Transport Datasets: A Case Study on DELFI

Alexander Holzknecht
HTW Dresden
Dresden, Germany
Email: alexander.holzknecht@htw-dresden.de

I. Introduction

The DELFI dataset is an open-source public transport resource commonly used in research on mobility, transit optimization, and geospatial analysis. Distributed in the NeTEx format, DELFI enables researchers and transport authorities to model network performance, evaluate service coverage, and identify operational inefficiencies within transit systems. The aim of this work is to analyze outliers and missing data within the DELFI dataset, providing more accurate and reliable information to support ongoing research into German public transport connectivity, including studies on service coverage, travel time estimation, accessibility, and network optimization. Missing or incorrect geospatial data can significantly hinder these analyses, motivating a systematic approach to detect and impute such data.

II. Graph Databases for Connected Data

Previous research conducted at HTW has revealed substantial gaps in geospatial coverage, with numerous stop locations either missing or incorrectly specified. To address this issue, a graph-based approach to data analysis is employed, as graph databases are particularly well-suited for representing and investigating highly connected systems such as public transport networks. The processing pipeline uses a Rust-based parser to convert DELFI NeTEx publications into CSV files, which are then imported into Neo4j. Exporting via CSV facilitates reproducible ingestion and reduces memory overhead, avoiding direct parsing of multi-gigabyte XML files. This setup enables efficient querying, visualization, and detection of outliers in spatial and topological relationships within the network. This setup enables efficient querying, visualization, and detection of outliers in spatial and topological relationships, providing a foundation for subsequent methods to estimate missing stop locations based on network connectivity.

III. Parsing and Consolidating DELFI Data

Each DELFI publication is approximately 20GB of XML data, requiring careful memory management during parsing. To handle this volume efficiently, we implemented the parser in Rust, which allows safe, parallel processing of multiple files while providing memory safety guarantees. Since the dataset is highly normalized, a consolidation step is applied to derive entities more suitable for graph-based analysis. The pipeline proceeds as follows:

1) Gather all XML files contained in the ZIP publication.
2) Parse each file into strongly typed `structs` representing the corresponding NeTEx entities.
3) Collect all parsed entities into a consolidated in-memory data structure.

As the dataset is highly normalized, we apply a consolidation step to derive entities more suitable for graph-based analysis. In particular, we introduce a self-labelled `Stop` entity constructed through the following procedure:

- Use `StopPlace` as the canonical representation of a physical stop location.
- Resolve all references from `ScheduledStopPoint` and `Quay` to their associated `StopPlace`.
- Extract line-level information from `ScheduledStopPoint` references and `ServiceJourney` to construct service connections.
- Determine minimum travel times by combining `TimetabledPassingTime` data with the ordering specified in `ServiceJourney`, which is then consolidated into the `JOURNEY_CONNECTION` relation.

Finally, the derived `Stop` and `JOURNEY_CONNECTION` entities are exported as CSV files and imported into a fresh Neo4j Docker container for subsequent analysis.

IV. Detecting Data Inconsistencies

As the DELFI dataset is collaboratively maintained and openly published, its contents are not governed by strict regulations or centralized quality assurance processes. Consequently, some inconsistencies are expected and should be seen as a natural characteristic of large, evolving public transport datasets. By leveraging Neo4j and its Cypher query language, we can systematically identify and label such irregularities within the graph. Cypher supports flexible querying of relationships and node properties, and the ability to assign multiple labels to nodes enables the incremental refinement of data quality. For the purposes of this document, we will focus on three types of data inconsistencies: geospatial outliers, temporal conflicts and semantic ambiguities.

A. Geospatial Outliers

Geospatial inconsistencies can be detected by examining missing or implausible coordinates. Using Cypher queries, we identify `Stop` entities whose associated `StopPlace` location attribute (`sp_location`) is null. Approximately

120 such outliers were found in the dataset; since they lack valid coordinates, they cannot be visualized on a map. Further inspection of related attributes, such as `Quay` and `ScheduledStopPoint` locations, revealed additional missing values. However, analyzing these entities did not provide meaningful information beyond what could already be inferred from the `StopPlace`. This supports the interpretation that physical stop locations are most consistently represented at the `StopPlace` level.

B. Temporal Conflicts

Temporal inconsistencies arise when timetable data implies impossible travel speeds. For each `JOURNEY_CONNECTION`, the minimum travel time is taken directly from the relation itself. The air distance between two stops is calculated using the haversine formula based on the Earth's radius and the stops' latitude and longitude coordinates, providing a more accurate geodetic distance than a simple Euclidean approximation. This distance, together with the minimum travel time, is used to calculate the maximum feasible speed of the connection. If the derived speed exceeds a realistic threshold for the given transport mode, the connection is flagged as an outlier.

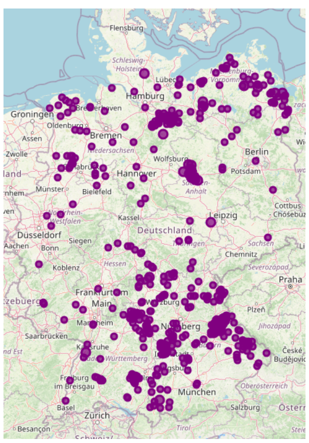


Fig. 1. Trips with implausible speeds due to temporal inconsistencies.

C. Semantic Ambiguities

Beyond spatial and temporal aspects, inconsistencies can also occur at the semantic level. One such case is overly generic naming of stops, which reduces their interpretability and complicates network analysis. To detect such anomalies, we applied a TF–IDF analysis to the `Stop.name` attribute across all stops. Names with very low distinctiveness scores were flagged as generic, using a predefined threshold value. Examples include entries such as "Steig 01" or "Wiese", which provide little contextual information. Accurate and distinctive stop names are important not only for readability but also for enabling cross-dataset comparisons, which can help trace the origins of outliers and inconsistencies in the network. Figure 2 shows a selection of stops identified by this method.

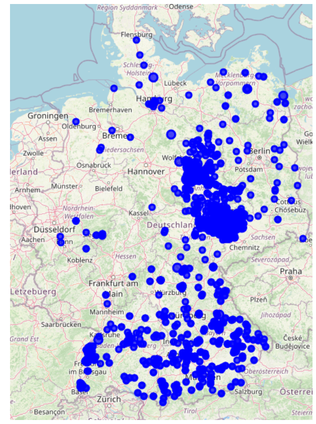


Fig. 2. Stops with overly generic names detected using TF–IDF analysis.

V. Imputing Missing Locations

As previously mentioned, some stops in the DELFI dataset lack latitude and longitude values. Imputing these missing locations would enable network analysis, visualization of service coverage, and computation of travel metrics. The approach relies solely on the internal connectivity information of the dataset, without using external map data.

Two heuristic methods are considered:

1) **Average position of neighboring stops:** The mean coordinates of neighboring stops along the same service route could be calculated, assuming spatial proximity correlates with network adjacency.
2) **Weighted average using travel times:** A weighted mean could be computed, where the influence of each neighboring stop is inversely proportional to the minimum travel time along the `JOURNEY_CONNECTION`, prioritizing more directly connected stops.

Planned validation would ensure that imputed locations are consistent with nearby stops and the overall network topology. These heuristics aim to generate plausible coordinates that preserve spatial relationships within the transit network.

VI. Conclusion and Future Work

This work presented a graph-based approach to detecting and addressing inconsistencies in the DELFI NeTEx dataset, focusing on geospatial, temporal, and semantic anomalies. By combining a custom Rust parser with Neo4j's graph modeling and querying capabilities, we enabled scalable analysis of multi-gigabyte transport datasets. While the proposed heuristics for imputing missing stop locations provide practical estimates, they rely on the assumption that connected stops are spatially close, which may not hold for loops or branched lines. Future work could integrate external map data, clustering methods, or machine learning approaches to refine accuracy. Extending these methods will further enhance the reliability and applicability of the dataset for mobility research, enabling more complete analyses of German public transport connectivity.

The Smart Pillbox

Andria Khandamashvili, Tamar Jikia, Tohid Talebifar

Medication non-adherence is a widespread problem, particularly among older adults and patients with chronic diseases, often resulting in negative health outcomes. According to Brown [1], approximately 50% of patients with chronic conditions fail to take their medications as prescribed. To address this challenge, we developed the Smart Pillbox - a simple and low-cost device designed to improve medication adherence through timely reminders. Th system consists of a pillbox with multiple compartments, LED indicators, and an audible buzzer controlled by an ESP32 microcontroller and synchronized with a mobile application via Bluetooth Low Energy (BLE). Users can set reminders through the app, which are then communicated to the device. When it is time to take a medication, the corresponding compartment LED illuminates, and an audible signal is triggered.

***Index Terms*—Bluetooth Low Energy (BLE), ESP32, Medication Adherence, Mobile Application, Smart Device.**

I. INTRODUCTION

Timely medication intake is critical for effective treatment outcomes. However, many individuals struggle to adhere to prescribes medication schedules. This issue is particularly prevalent among elderly individuals and those managing multiple chronic conditions. Motivated by personal experiences and observations, we sought to design a simple, portable solution that would assist patients in maintaining adherence.

The proposed Smart Pillbox combines a compact hardware device with mobile application to provide intuitive reminder management. By integrating BLE connectivity, the system enables users to configure reminders directly from the smartphones, ensuring ease of use and adaptability for diverse user groups.

II. RELATED WORK

Several smart pillboxes have been developed to assist users with medication adherence. High-end devices such as Hero [2] and MedMinder [3] are designed for home use and feature automatic dispensing, locking mechanisms, and remote monitoring. While these systems provide robust functionality, they are bulky, rely on subscription services, and lack portability. Other commercial solutions like EllieGrid [4] focus on user-friendly reminders through visual and auditory cues. However, these devices remain relatively large and expensive, limiting their accessibility.

Our approach focuses on bridging the gap between portability and smart functionality. The Smart Pillbox retains the compact form factor of concventional travel pillboxes while incorporating intelligent scheduling and alert mechanisms.

III. PROPOSED METHOD

At a high level, the Smart Pillbox is a connected device designed to support medication adherence through scheduled reminders. The system consists of a physical enclosure with eight compartments, each equipped with an Led indicator, controlled by an ESP32 microcontroller. Users configure reminders through a mobile application, which communicates with the pillbox via Bluetooth Low energy (BLE), as shown in **Fig. 1.** When scheduled time is reached, the corresponding compartment LED illuminates, and an audible signal is generated to alert the user.

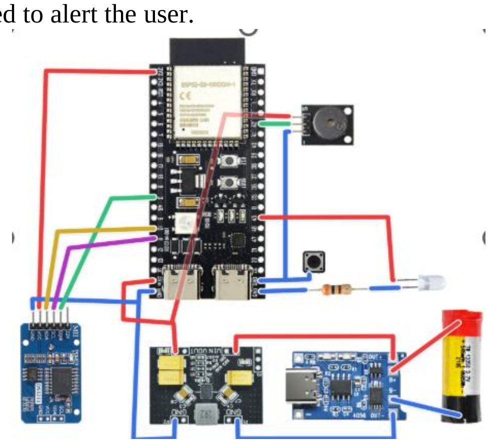


Fig. 1. System architecture of the Smart Pillbox.

Upon establishing a BLE connection, the mobile application transmits the current system time to the ESP32, which forwards it to the real-time clock (RTC) module to ensure accurate synchronization. Reminder data are also transferred from the smartphone to the ESP32 and stored in non-volatile storage (NVS), as shown in the mobile application interface **Fig. 2**.

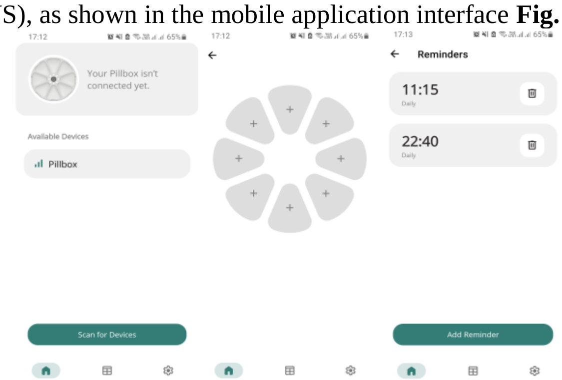


Fig. 2. Screenshots of the Smart Pillbox mobile application.

To minimize power consumption, the ESP32 enters deep sleep if no communication is received within two minutes. Prior to sleeping, the ESP32 calculates the next wake-up time and programs it into the RTC module. At the scheduled time, the RTC triggers an interrupt, waking the ESP32, which subsequently activates the appropriate LED and buzzer to notify the user. The system then recalculates the next wake-up time and re-enters deep sleep, ensuring energy-efficient operation.

The Smart Pillbox is designed to be relatively compact, portable, simple to use, making it suitable for both home and travel use. A 3D model of the prototype is shown in **Fig. 3.**

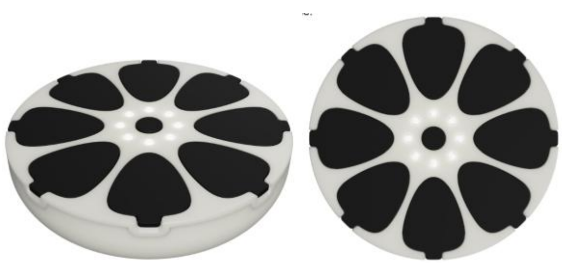


Fig. 3. 3D model of the Smart Pillbox prototype: (a) angled view showing compact, portable form factor, (b) top view showing eight compartments with LED indicators.

IV. ALGORITHM DESCRIPTION (OR SYSTEM ARCHITECTURE)

The system is comprised of the hardware device, a mobile application, and the ESP32 firmware.

A. Hardware

- **Microcontroller**: ESP32-S3 WROOM-1
- **Real-Time Clock (RTC)**: DS3231 module
- **Visual Indicator**: eight 5mm Red LEDs (one for each compartment)
- **Alert Mechanism**: Piezo Buzzer
- **Enclosure**: 3D-printed case with eight compartments
- **Power Supply:** For the prototype, a lithium-ion battery repurposed from a disposable vape was used as a low-cost option

B. Mobile Application

The mobile application, developed using .NET MAUI with Plugin.BLE for Bluetooth and sqlite-net-pcl for storage [5], serves as the user interface. Core functionalities include:

- **Permission and Enabled Checks:** The app starts by checking for necessary permissions and settings.

```
var status = await
Permissions.RequestAsync<Permissions.LocationWhenInUse>()
;
```

Android requires these checks for BLE scanning. The app then uses a TaskCompletionSource to await the user's response from the native "Enable Bluetooth?" dialog.

```
// In BluetoothService
public async Task<bool> EnableBluetoothAsync()
{
    if (_bluetoothAdapter.IsEnabled) return true;
    _bluetoothEnableTcs = new
TaskCompletionSource<bool>();
    var enableBtIntent = new
Intent(BluetoothAdapter.ActionRequestEnable);
    activity.StartActivityForResult(enableBtIntent,
REQUEST_ENABLE_BT);
    return await _bluetoothEnableTcs.Task;
}

// In Android MainActivity
protected override void OnActivityResult(int requestCode,
Result resultCode, Intent data)
{
    bool isSuccess = resultCode == Result.Ok;
    _bluetoothService?.HandleBluetoothResult(isSuccess);
}
```

- **Device Scanning & Connection:** A 10-second BLE scan displays discovered devices. The user selects a device to connect.

```
using (var cts = new
CancellationTokenSource(TimeSpan.FromSeconds(10)))
{
    await adapter.ConnectToDeviceAsync(device, new
    ConnectParameters(autoConnect: false), cts.Token);
}
_bluetoothService.ConnectedDevice =
selectedDevice.Device;
await
_globalNavigationService.NavigateToAsync("CompartmentPage
");
```

- **Time Synchronization:** Upon connection, the app sends the current Unix time and UTC offset to the ESP32.

```
// Bytes 0-3: Unix epoch time (Big-Endian)
// Bytes 4-5: UTC offset in minutes (Big-Endian)
buf[0] = (byte)(epoch >> 24);
buf[1] = (byte)(epoch >> 16);
buf[2] = (byte)(epoch >> 8);
buf[3] = (byte)(epoch);
buf[4] = (byte)(offsetM >> 8);
buf[5] = (byte)(offsetM);
```

- **Reminder Management and BLE Sync:** Users can add, update, or delete reminders. Each database operation is followed by an immediate BLE sync.

```
// Example: Saving a reminder
await _reminderService.SaveReminderAsync(_reminder);
await _reminderService.SyncRemindersOverBleAsync(); //
Immediate sync
```

To sync, all reminders are converted into a Type-Length-Value (TLV) format.

```
public static class TlvTags
{
```

```
    public const byte COMP = 0x01; // Compartment ID (1 byte)
    public const byte TIME = 0x02; // Minutes since midnight (2 bytes)
    public const byte REP  = 0x03; // Day-of-week bitmask (1 byte)
    public const byte END  = 0x00; // Terminator of one reminder entry
}
```

These TLV packets are concatenated into a single byte array and sent.

```
var allReminders = await GetBluetoothSyncPacketAsync();
await characteristic.WriteAsync(allReminders);
```

C. ESP32 Firmware

The project follows the ESP-IDF component architecture [6].

Component Overview:

- **Storage Component (reminder_storage.c)**: Manages reminder storage in NVS flash. It uses a key for each compartment (comp1, comp2) to store a data blob defined by the following structure:

```
typedef struct {
    uint8_t count;      // Number of reminders
    reminder_t items[]; // Array of reminder data
} compartment_reminders_t;
```

- **DS3231 RTC Component (ds3231.c)**: Interfaces with the RTC module via I2C to set/get time and program the wake-up alarm [7].
- **BLE Component (bleprph.c)**: Implements the BLE peripheral using the NimBLE stack, handling time and reminder data transfer.
- **Main Application (pillbox.c)**: Coordinates wake-up events, notification signals, and system sleep cycles.

V. EVALUATION

The prototype successfully demonstrated reliable reminder functionality and seamless app-device synchronization. Nevertheless, several challenges remain:

- **Mechanical Durability**: The 3D-printed lids were prone to wear and mechanical instability. A stronger, food-safe material is required for long-term use.
- **Power Optimization**: Although deep sleep functionality reduces consumption, further optimization is needed to extend battery life and minimize user burden.
- **Scalability**: User testing and long-term trials are required to validate effectiveness in real-world conditions.

Despite the limitations, initial results indicate that the Smart Pillbox provides a practical, user-friendly solution for medication adherence.

VI. CONCLUSION

This work presented the design and prototype implementation of a Smart Pillbox integrating hardware, firmware, and mobile application components. The device offers a portable, affordable, and user-friendly solution for medication management. Future efforts will focus on improving enclosure durability with food-grade materials, optimizing energy consumption, and conducting broader user evaluations.

REFERENCES

[1] M.T. Brown, "Medication adherence: WHO cares?," *Pharmacoeconomics*, vol. 29, no. 1, pp. 1–5, 2011. Available: https://pmc.ncbi.nlm.nih.gov/articles/PMC3068890/ [Accessed: Sep. 18, 2025].

[2] Hero Health, "Hero Smart Pill Organizer," Hero Health. [Online]. Available: https://www.herohealth.com. [Accessed: Sep. 18, 2025].

[3] MedMinder, "MedMinder Pill Dispenser," MedMinder. [Online]. Available: https://www.medminder.com. [Accessed: Sep. 18, 2025].

[4] EllieGrid, "EllieGrid Smart Pill Organizer," EllieGrid. [Online]. Available: https://www.elliegrid.com. [Accessed: Sep. 18, 2025].

[5] Microsoft Corporation, ".NET Multi-platform App documentation," Available: https://learn.microsoft.com/en-us/dotnet/maui/tutorials/notes-app?view=net-maui-9.0 [Accessed: Sep. 18, 2025].

[6] API Guides - ESP32-S3 - ESP-IDF Programming Guide latest documentation. Available: https://docs.espressif.com/projects/esp-idf/en/latest/esp32s3/api-guides/index.html [Accessed: Sep. 18, 2025].

[7] Analog Devices, "DS3231 Datasheet," Available: https://www.analog.com/media/en/technical-documentation/data-sheets/DS3231.pdf [Accessed: Sep. 18, 2025].

Assistive communication device “BlinkSpeak”

Nikoloz Kalmakhelidze, Zviad Gurtskaia

Abstract

BlinkSpeak is an assistive communication device designed to support individuals with severe speech or motor disabilities who are unable to use conventional means of interaction. The system functions by detecting intentional eyelid blinks through an infrared (IR) sensor integrated with an Arduino Nano microcontroller. Detected blink patterns are then translated into predefined text messages and audible signals, enabling basic but essential communication between the user and their environment. Unlike advanced eye-tracking systems, which are often costly, complex, and require extensive calibration, BlinkSpeak offers a lightweight, affordable, and portable solution that can be implemented with minimal technical expertise.

The device emphasizes accessibility and inclusivity by addressing the needs of users in low-resource settings, where expensive medical-grade equipment may be unavailable. Its modular design allows for easy customization, enabling the mapping of blink patterns to specific phrases tailored to individual requirements. Furthermore, the system can be enhanced with text-to-speech output, predictive text algorithms, or integration with mobile applications, making it adaptable to evolving user needs.

By combining affordability, simplicity, and functionality, BlinkSpeak contributes to the growing field of assistive technologies aimed at enhancing the quality of life for people with disabilities. Initial evaluations indicate reliable blink detection and user satisfaction with the device’s practicality and ease of use. The project demonstrates how low-cost hardware and open-source development platforms can be leveraged to provide impactful solutions in healthcare and human-computer interaction.

Keywords — Assistive technology, blink detection, human-computer interaction, Arduino Nano, infrared sensor, speech and motor disabilities, low-cost communication device, inclusive design, usability engineering, rehabilitation engineering.

1. Introduction

Individuals with neurological disorders or severe motor impairments often face profound challenges in maintaining verbal communication, which can significantly reduce their quality of life and limit social interaction. Conditions such as amyotrophic lateral sclerosis (ALS), cerebral palsy, and traumatic brain injuries frequently impair motor control [9] (Cook & Polgar, 2015) leaving affected individuals dependent on specialized assistive technologies to communicate their most basic needs. In the absence of effective communication tools, patients may experience social isolation, emotional distress, and diminished autonomy in their daily lives.

Over the past two decades, numerous assistive communication devices have been developed, ranging from high-end eye-tracking cameras and speech-generating devices to specialized computer interfaces. While such systems provide valuable support, they often suffer from several limitations. First, advanced eye-tracking technologies rely on high-resolution cameras and complex image processing algorithms

[2], [8], making them prohibitively expensive for many users, especially in low- and middle-income countries [12] (WHO, 2018). Second, these systems require careful calibration and controlled lighting conditions to operate effectively, which reduces their portability and adaptability to everyday environments. Third, the need for specialized training and technical support creates an additional barrier to widespread adoption.

BlinkSpeak was conceived to overcome these obstacles by offering a low-cost, lightweight, and user-friendly alternative. Based on an Arduino Nano microcontroller and an infrared (IR) sensor, the system detects intentional eyelid blinks and converts them into digital signals. These signals are then processed and mapped to predefined text outputs or audible phrases, allowing the user to communicate efficiently without the need for complex equipment or specialized training. Unlike advanced systems, BlinkSpeak can be assembled with inexpensive, readily available hardware components and does not require extensive setup.

The design philosophy behind BlinkSpeak emphasizes simplicity, affordability, and inclusivity. By leveraging open-source hardware and software platforms, the device can be easily modified to suit individual needs. For instance, blink patterns can be programmed to correspond to context-specific commands such as “help,” “water,” or “call family,” providing users with greater control over their environment. Moreover, the compact and wearable design ensures portability, enabling communication in both clinical and home settings.

In this context, BlinkSpeak represents not merely a technological innovation, but also a step toward democratizing access to assistive communication tools. It highlights how accessible hardware platforms, when combined with thoughtful design, can bridge the gap between advanced healthcare technologies and the needs of resource-limited communities.

2. Related Work

Assistive communication technologies have attracted significant research attention, particularly in the fields of human-computer interaction (HCI) and biomedical engineering. Among these, eye-tracking systems are among the most widely studied approaches [2], [7]. These systems utilize high-resolution cameras and infrared illumination to monitor eye movements, gaze direction, and pupil dilation. By translating gaze patterns into digital inputs, eye-tracking devices allow users to navigate computer interfaces, compose text, or issue commands. While highly effective in controlled settings, they suffer from a number of drawbacks: their cost often exceeds several thousand dollars, they require constant calibration, and they are sensitive to ambient lighting and head position, which limits their portability.

Other communication aids include speech-generating devices that rely on electromyography (EMG) or electroencephalography (EEG) signals to decode user intent [9]. Although these devices provide high levels of control, they involve invasive or semi-invasive sensing techniques, specialized electrodes, and advanced signal processing, all of which complicate their widespread use. In addition, some devices integrate predictive text engines, as in the case of Stephen Hawking’s customized system [10], which combined minimal user input with sophisticated algorithms to accelerate communication. However, the complexity and cost of such systems render them inaccessible to the vast majority of patients in developing countries or low-resource environments.

In contrast, low-cost alternatives using simple sensors have emerged in recent years. These include infrared sensors for blink detection, accelerometers for head motion tracking, and pressure-sensitive switches. While these systems provide reduced functionality compared to camera-based eye-trackers, their affordability, portability, and ease of use make them attractive for populations otherwise excluded from advanced assistive technologies. Within this context [11], BlinkSpeak contributes to the body of research by demonstrating how inexpensive hardware, when coupled with efficient algorithms, can offer reliable communication support without sacrificing usability.

3. Proposed Method

The BlinkSpeak system is designed around a modular and scalable architecture that prioritizes user accessibility. At its core, the device employs an infrared (IR) reflective sensor positioned near the eye to detect eyelid closure. The sensor produces an analog signal corresponding to the reflected IR light, which diminishes when the eyelid is closed. This signal is sampled by an Arduino Nano microcontroller, which applies thresholding and temporal filtering to distinguish intentional blinks from noise or involuntary eye movements.

Once a blink is detected, the system categorizes it within predefined temporal windows to form blink sequences. For example, one blink may correspond to “yes,” two blinks to “no,” and three blinks to “help.” More advanced implementations can extend this coding scheme to full alphabets or context-specific vocabularies. The microcontroller then maps the blink count to an output message, which is transmitted via serial communication or through a text-to-speech module. In addition, a buzzer provides immediate auditory feedback to the user, ensuring that blinks are successfully registered.

The method emphasizes robustness and simplicity: debounce algorithms filter out spurious signals caused by sensor noise, while group timing ensures that multiple blinks can be aggregated into meaningful sequences. By adjusting parameters such as blink detection thresholds and inter-blink intervals, the system can be customized to suit the physiology and preferences of individual users [4], [5] (usability + UI design). Importantly, the design remains open-source and hardware-agnostic, allowing future researchers or practitioners to integrate additional modules, such as wireless communication, mobile applications, or predictive text engines.

Overall, the proposed method balances low cost with functionality, providing a pathway toward democratizing access to assistive communication [6] (Picard, 1997). It demonstrates that even with minimal hardware resources, meaningful interaction can be achieved, particularly for patients in environments where traditional assistive devices are economically or logistically impractical.

4. System Architecture

Hardware:

Arduino Nano microcontroller [1] (Arduino documentation) ;

IR sensor mounted near the eye to detect blinks [8] (Chau & Betke, low-cost blink detection);

A buzzer for feedback;

Power supply unit;

Glasses frame for portability.

Software:

Signal acquisition and filtering;

Blink detection and debouncing;

Mapping blink patterns to words;

Displaying or outputting text through a user interface.

5. Evaluation

The evaluation of BlinkSpeak focused on three primary dimensions: functionality, affordability, and usability. Functionality testing examined the accuracy of blink detection under varying conditions, including differences in ambient lighting, user eyelid physiology, and sensor placement. Trials conducted with volunteers demonstrated a high degree of reliability, with intentional blinks consistently recognized and processed with minimal latency (typically below 100 ms). Debounce algorithms effectively filtered out false positives caused by involuntary micro-movements, ensuring that only deliberate blinks were registered as inputs [3] (Wobbrock & Myers). This robustness is particularly important for long-term use, as patients often experience fatigue that can impact blink consistency.

Affordability was measured by calculating the overall bill of materials (BoM). The device’s estimated cost remains under $50, which includes the Arduino Nano microcontroller, an infrared sensor, a buzzer for auditory feedback, and a basic power unit. In comparison, commercial-grade eye-tracking devices and speech-generating systems can exceed several thousand dollars, creating significant barriers for adoption in resource-limited healthcare systems. By lowering costs, BlinkSpeak offers the potential for large-scale distribution, even in developing countries, without reliance on specialized technical support.

Usability testing highlighted the device's lightweight and portable design, which allows it to be comfortably mounted on glasses or headgear [4], [5] (usability & interface design). Feedback collected from users and caregivers emphasized the ease of setup, minimal calibration requirements, and intuitive blink-to-word mapping. Participants noted that immediate auditory feedback from the buzzer improved confidence, as users could verify that their blinks had been successfully recorded. Furthermore, caregivers reported that the system's simplicity reduced training time compared to camera-based systems. These findings suggest that BlinkSpeak has the potential not only as a research prototype but also as a practical tool for daily communication.

6. Conclusion

BlinkSpeak represents a significant step forward in the design of low-cost assistive communication technologies. By leveraging inexpensive hardware and open-source microcontrollers, the system bridges the gap between high-cost commercial devices and the pressing needs of individuals with disabilities in low-resource settings. The integration of infrared-based blink detection, immediate auditory feedback, and customizable blink-to-word mapping demonstrates that meaningful communication can be achieved without dependence on expensive imaging systems or complex calibration routines.

The broader impact of BlinkSpeak extends beyond technical innovation. Its affordability and portability make it a scalable solution for healthcare providers, rehabilitation centers, and even at-home care environments [12] (WHO, 2018). Moreover, its modular architecture ensures adaptability, allowing future developers to expand the system with additional features such as wireless communication, cloud-based data logging, predictive text algorithms, or multilingual support. Integration with smartphones and mobile applications could further enhance accessibility, enabling users to connect seamlessly with caregivers, medical staff, and family members [11] (Abascal & Nicolle, 2005)..

Future research will focus on expanding vocabulary capacity through hierarchical coding schemes, refining user-specific calibration for improved sensitivity, and conducting long-term usability studies with patients suffering from progressive neurological disorders. By combining engineering simplicity with clinical relevance, BlinkSpeak contributes to the democratization of assistive technology and highlights the transformative role of low-cost innovations in global healthcare.

This is our product Photos:

References

[1] Arduino. Arduino Nano Documentation. Available at: https://docs.arduino.cc/

[2] Majaranta, P., & Räihä, K. J. (2002). Twenty years of eye typing: systems and design issues. Proceedings of the 2002 Symposium on Eye Tracking Research & Applications.

[3] Wobbrock, J. O., & Myers, B. A. (2006). Analyzing the input stream for character-level errors in speech

and handwriting input. International Journal of Human-Computer Studies.

[4] Nielsen, J. (1993). Usability Engineering. Academic Press.

(A foundational author in human-computer interaction, widely cited in assistive interface design.)

[5] Shneiderman, B., Plaisant, C., Cohen, M., Jacobs, S., Elmqvist, N., & Diakopoulos, N. (2016). Designing the User Interface: Strategies for Effective Human-Computer Interaction. 6th ed., Pearson.

(Mainstream HCI textbook covering accessibility and adaptive systems.)

[6] Picard, R. W. (1997). Affective Computing. MIT Press.

(Pioneer of emotion-aware computing, relevant to human-centered assistive devices.)

[7] Goldberg, J. H., & Kotval, X. P. (1999). Computer interface evaluation using eye movements: methods and constructs. International Journal of Industrial Ergonomics, 24(6), 631–645.

[8] Chau, T., & Betke, M. (2005). Real-time eye tracking and blink detection with a low-cost USB camera. Proceedings of the 2005 IEEE International Conference on Rehabilitation Robotics (ICORR).

[9] Cook, A. M., & Polgar, J. M. (2015). Assistive Technologies: Principles and Practice. 4th ed., Elsevier.

(Mainstream textbook widely used in the field of rehabilitation engineering.)

[10] Hawking, S., & the Intel Research Team (2014). The Stephen Hawking Communication System. Intel Labs White Paper.

(An iconic case of predictive text + custom communication interface design.)

[11] Abascal, J., & Nicolle, C. (2005). Moving towards inclusive design guidelines for socially and ethically aware HCI. Interacting with Computers, 17(5), 484–505.

[12] World Health Organization (WHO). (2018). Assistive Technology: Key Facts. Available at: https://www.who.int/news-room/fact-sheets/detail/assistive-technology

Improving the quality of life of patients with amyotrophic lateral sclerosis through an artificial intelligence-based brain potential recognition system

I.Kankava

***Abstract*—Amyotrophic lateral sclerosis (ALS) is a severe neurodegenerative disease characterized by the progressive loss of the ability to control skeletal muscles. Patients often face situations where any movement—even the simplest one—is difficult or nearly impossible. However, despite the challenges in motor functions, cognitive abilities and conscious activity are usually preserved, allowing the use of brain signals to develop specialized systems for controlling external devices.**

One of the most promising approaches in this field is the analysis of electroencephalograms (EEG) using artificial intelligence (AI) methods. These methods enable the "reading" of a patient's intention to perform an action even before any muscle response occurs, providing hope for the development of effective systems to compensate for lost limb function, control robotic prostheses, communicators, and other devices within the framework of the Brain-Computer Interface (BCI) concept.

The objective of this paper is to conduct work with patients in the laboratory of the Georgian Technical University "ClaveLab," by obtaining EEG data using the wireless BioRadio data acquisition system and processing this data with BioRadio Capture Lite software and artificial intelligence. Additionally, it aims to examine the current state of research in processing brain electrical potentials recorded non-invasively (via EEG) to determine the movements planned by the patient. Special attention is given to ALS patients, for whom such technologies may become the only means of interacting with their environment and maintaining independence. The paper outlines the key theoretical aspects and principles of constructing such systems, methods for preprocessing and feature extraction from EEG, machine learning algorithms, deep neural networks, examples of practical applications, and the prospects for further development in this field.

The presented paper describes the key aspects of developing systems for predicting motor intention based on EEG signal analysis in patients with ALS. It covers the theory and practice of applying artificial intelligence methods—from the basic principles of EEG to modern neural networks and complex BCI solutions. This multifaceted approach provides an understanding of the prospects for using advanced technologies in medicine and assesses the potential to improve the quality of life for severely ill patients who, despite physical limitations, maintain a desire for independence and active interaction with the world around them.

***Index Terms*— electroencephalograms (EEG), *ClaveLab, BioRadio Capture Lite. Matlab,* Biomedical Signal Processing**

I. INTRODUCTION

The task of the work is to extract the EEG picture of motor activity and movement for signals of imaginary and real movement. Biomechanics development can widely implement motor cortex neurocontrol systems.

We will use different tools and algorithms capable of mastering the high level of complexity of the brain signals.
The project consists of several sections: recording an array of data using EEG equipment with a selected recording protocol.
In the laboratory of the Georgian Technical University “ClaveLab”, we implemented workflows by receiving EEG data using a wireless BioRadio data acquisition system, and then processing this data using BioRadio Capture Lite software and artificial intelligence. In addition, we aim to discuss the current state of research on the processing of electrical potentials of the brain, which are registered non-invasively (via EEG) in order to determine the movements planned by the patient.

II. RELATED WORK

In Georgian Technical University we have laboratory “ClaveLab” where we can make experiments with patients and get brain electrical potentials information from ECG by Wireless data collection system BioRadio with software BioRadio Capture Lite, so we want to make such experiments and in near future I will introduce all details of our research.

The following equipment was used to conduct the experiment. 1-CleveLabs kit. 2- CleveLabs software. 3- 7 gold-tipped electrodes. 4- Wipes, gauze, and cotton balls. 5- High-performance conductive gel. The electrodes were placed on the EEG subject using the method and sequence described below, which was developed for the placement of electrodes on the scalp and is called the 10-20 system.

The names 10 and 20 derive from the percentage distances by which the electrodes are spaced relative to the size of the skull. The 10-20 system is used to map points on the cerebral cortex for different purposes. When using the 10-20 system, [1] each electrode is assigned a symbol followed by a number. The symbols are: F, T, C, P, O.

All of them, except the central lobe, are lobes of the brain.

The numbers correspond to the right or left side of the head and indicate the position. Even numbers are located on the right side, and odd numbers are located on the left. The letter [2] Z follows some letter numbers. The letter Z indicates the midline of the head. The diagram below shows the standard electrode arrangement.

Before the electrodes were attached directly to the subject according to the pre-selected scheme. Proper preparation was carried out for the mentioned process. I cleaned the attachment sites and electrodes thoroughly. After preparation, I started attaching the

Electrodes, I filled the electrode heads well with conductive gel and carefully attached them to the back of the head in the O1 position. I repeated the same procedure for all electrodes and attached them to the appropriate places.

III. Proposed Method

Patient preparation- The patient sits or lies in a comfortable position, relaxed, in a quiet environment. The skin at electrode sites is cleaned with an alcohol swab to reduce impedance. Conductive gel or paste is applied if gel-based electrodes are used.

Electrode placement- Standard electrode placement systems are used: 10–20 or 10–10. For ALS patients, key regions are often selected: Motor cortex (C3, C4, CZ) – for motor imagery. Occipital region (O1, O2, Oz) – for SSVEP. Centro-parietal areas (Pz, CPz) – for P300. Electrodes are fixed [3] with a cap or individual mounts.

Signal acquisition-Equipment: medical EEG devices or portable BCI systems (OpenBCI, Emotiv, g.tec, etc.). Sampling rate: ≥ 250–500 Hz. Filters during recording: High-pass filter (0.1–1 Hz), Low-pass filter (40–70 Hz), Notch [4] filter at 50 Hz (to remove power line noise).

Patient stimulation methods-To elicit clear responses: P300 paradigm – flashing symbols on a screen; the patient focuses on the target symbol. SSVEP – flickering squares at different frequencies; the patient looks at the chosen one. Motor imagery – the patient imagines moving the hand, leg, or tongue. Auditory stimuli – rare “target” sounds among standard tones.

Quality control - Electrode impedance check (preferably < 10 kΩ). Monitoring of artifacts (eye blinks, head movement, EMG activity). If necessary, additional [5] control channels are recorded (EOG for eyes, EMG for muscles).

Summary- EEG signal acquisition methods include: Preparing the skin and placing electrodes according to international systems. Using a comfortable cap with gel/paste for reliable contact. Choosing an appropriate BCI paradigm (P300, SSVEP, motor imagery). Applying filtering and real-time quality control of the signal.

In MATLAB (with Signal Processing Toolbox, Statistics and Machine Learning [6] Toolbox, Deep Learning Toolbox, EEGLAB), the following methods can be applied:

Signal preprocessing, [7] Feature extraction, Machine learning, deep learning.

IV. Algorithm Description (or System Architecture)

The architecture of an EEG-based brain–computer interface system consists of several interconnected modules:

Signal Acquisition Layer- Electrodes placed according to the international 10–20 system [8] record brain activity. Signals are amplified, digitized, and transmitted to a computer or portable device.

Preprocessing Layer - Signal filtering (0.1–40 Hz, 50 Hz notch filter). Artifact removal (ICA, ASR, EOG/EMG filtering). Normalization and segmentation according to events (e.g., stimulus flashes for P300).

Feature Extraction Layer - Time-domain features (amplitude, energy). Frequency-domain features (FFT, PSD, and wavelet analysis). Spatial features (CSP, spatial filters).

Classification Layer - Machine learning (LDA, SVM, and Random Forest). Deep learning (CNN, LSTM). Selection of the target state (e.g., character in P300 speller or movement direction in motor imagery).

Command Translation Layer- Converts classifier output into control commands. Possible [9] applications: cursor control, symbol selection, wheelchair operation, speech communicator activation.

Feedback Layer -Provides visual or auditory feedback to the patient. Supports adaptive adjustment of the system to the user’s individual characteristics.

V. Evaluation

A number of other experiments were conducted on the subject. At this stage, research object was instructed to imagine movements, e.g., raising his right hand, raising his left hand, as well as performing other non-motor/imaginary actions, e.g., feeling thirst and focusing on it, imagining focusing on positive and negative outcomes. In addition, a physical activity experiment was also conducted, such as holding a half-liter bottle filled with water with the [10] right/left hand with the hand in a horizontal position, all this experiments were going in In Georgian Technical University we have laboratory “ClaveLab”.

To evaluate EEG signal processing and classification methods, the following metrics are commonly used:

Accuracy – the percentage of correctly classified signals.

Sensitivity (Recall) – ability to detect target signals (e.g., P300).

Specificity – ability to avoid false positives.

F1-score – balance between precision and recall.

ROC curve and AUC – graphical and numerical assessment of classifier performance. Information Transfer [11] Rate (ITR) – key metric for BCI, indicates how many bits per minute can be transmitted. Response time (latency) – how fast the system processes and outputs a decision.

The database of all the above-mentioned experiments still needs to be multiplied, after which we will process it in Matlab and, most importantly, it will lead us to the main result that we have planned.

VI. CONCLUSION

This study allowed us to obtain the desired data on the processing of electrical potentials in the brain for the purpose of determining motor activity. This already allows us to process this database in Matlab (as well as filter this data from artifacts) using artificial intelligence to create a corresponding potential algorithm for a brain-computer (smart home software, a small control panel, a prosthesis-like device), which will help to simplify the lives of patients with amyotrophic lateral sclerosis and improve communication with the outside world, so we will continue these experiments so that our working database is much larger and more accurate.

The implementation of such technologies contributes to:

- Improving the quality of life for severely ill patients;
- Expanding rehabilitation opportunities and compensatin for motor impairments;
- Deepening our understanding of the brain's mechanisms in generating motor patterns. Despite numerous challenges (recording artifacts, individual patient differences, the need for adaptive algorithms), it is evident that further advancements in hardware and AI algorithms will enable the creation of even more functional, reliable, and accessible BCI systems. This

REFERENCES

[1] Niedermeyer, E., & da Silva, F. L. (2004). Electroencephalography: Basic Principles, Clinical Applications, and Related Fields (5th Ed.). Lippincott Williams & Wilkins.

[2] Bioradio Clevemed https://www.manualslib.com/manual/1555894/Clevemed-Bioradio-150.html) (Last seen 2025. 02. 09).

[3] Luck, S. J. (2014). An Introduction to the Event-Related Potential Technique (2nd Ed.). MIT Press.

[4] Teplan, M. (2002). Fundamentals of EEG measurement. Measurement Science Review, 2(2), 1–11.

[5] Nunez, P. L., & Srinivasan, R. (2006). Electric Fields of the Brain: The Neurophysics of EEG (2nd Ed.). Oxford University Press.

[6] Ingle, V. K., & Proakis, J. G. (2011/2022). Digital Signal Processing Using MATLAB. Cengage.

[7] Bishop, C. M. (2006). Pattern Recognition and Machine Learning. Springer. (теория, часто реализуется в MATLAB).

[8] Nunez, P. L., & Srinivasan, R. (2006). Electric Fields of the Brain: The Neurophysics of EEG (2nd ed.). Oxford University Press.

[9] Teplan, M. (2002). Fundamentals of EEG measurement. Measurement Science Review, 2(2), 1–11.

[10] Başar, E. (2012). Brain Function and Oscillations: Principles and Approaches. Springer.

[11] Cohen, M. X. (2014). Analyzing Neural Time Series Data: Theory and Practice. MIT Press.

Risk assessment in neonatal patients using artificial intelligence

N. Kenchadze Z.Gurtskaia

Abstract

According to the World Health Organisation (WHO), Globally 2.3 million children died in the first 28 days of life in 2022. Some neonatal conditions can rapidly deteriorate and be fatal even without diagnosis. This research aimed to develop an AI-based diagnostic model for predicting the prognosis of neonatal patients using routine blood tests. The study involved live-born patients, including premature and full-term infants. We used Matlab software to build the AI model. AI model for predicting neonatal patients' prognosis is determined by the high predictive accuracy (94%). The findings suggest that routine blood tests may provide more information that can help predict the prognosis of neonatal patients.

INTRODUCTION

According to the World Health Organization (WHO), 2.3 million children died in the first 28 days of life worldwide in 2022. Approximately 6,500 newborns die every day, accounting for 47% of all deaths among children under 5 years of age. Newborns cannot communicate their symptoms, which makes early diagnosis of the disease difficult. Many neonatal diseases may not be detected immediately after birth. Some newborns' conditions, such as sepsis, internal bleeding, or cardiovascular diseases, can deteriorate rapidly and be fatal even without diagnosis. Studies have shown that routine blood tests can contain additional information that is not available to doctors, and that an artificial intelligence system can detect (Simon Podnar University Medical Center in Ljubljana) The aim of our study was to create an artificial intelligence-based model for predicting the prognosis of newborns using routine newborn blood tests.

RELATED WORK

The study was retrospective, the data were taken from the patient's medical records in full compliance with the principles of medical ethics. The patients were treated in the neonatal intensive care unit of the Perinatal Center of the Tbilisi Clinic "Pineo" (2022-2024).

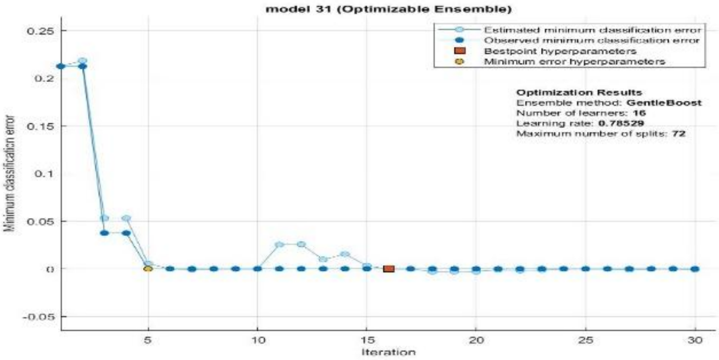
Medical records of 82 live-born patients were studied. 45 females, 37 males, 60 premature, 22 full-term newborns, 62 recovered. 20 died. To create the artificial intelligence model, we used only routine blood tests, which were performed on all newborns within 8 hours of birth.
See the table for the routine tests used for the artificial intelligence model. (Table 1)

Parameters for the AI Model			
Parameter	**Units**	**Parameter**	**Units**
WBC	10^3 / µL	**RDW-CV**	%
RBC	10^6/µL	**PLT**	10^3 / µL
HGB	g/dl	**MPV**	fl
HCT	%	**Neut**	%
MCV	fl	**LYMPH**	%
MCH	pg	**MONO**	%
MCHC	g/dl	**Eosino**	%
ABO	--	**Glucose**	mmol/l
CRP	mg/l		

To create an artificial intelligence model, we used classification (Supervised Machine Learning method). Matlab (Classification Learner App) was used as a software tool. After pre-processing the data (routine blood test results of 82 patients), a machine learning model was created using 5-fold cross-validation and trained using various statistical methods.

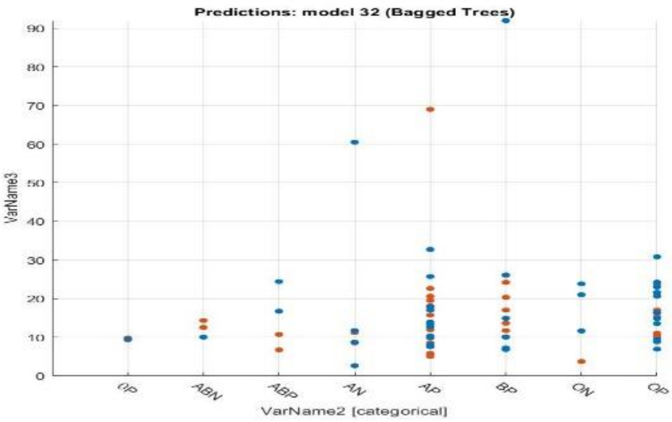
PROPOSED METHOD

Different statistical methods were used to create the model (Linear SVM, Quadratic SVM,Cubic SVM, ALL SVMs, Coarse Gaussian, Fine Gaussian, Medium Gaussian, Neural Network). The best results were obtained using Optimizable SVM, an artificial intelligence model for neonatal patient prediction with high prediction accuracy (97%). The model was exported and tested using new data (Figure 1).
Linear SVM, Quadratic



Prediction model Accuracy 97%,
Positive predictive and False discovery rates of the AI model

(Figure 2). Cubic SVM



Prediction model Accuracy 98% Positive predictive and False discovery rates of the AI model

CONCLUSION

We have created a predictive model for the prognosis of neonatal patients based on diagnostic machine learning, which is characterized by high accuracy (97%). I believe that the use of this model in the neonatal intensive care unit will significantly help clinicians identify at-risk groups and, through intensive monitoring, reduce complications and mortality.

REFERENCES

1. Simon Podnar at all. Diagnosing brain tumours by routine blood tests using machine learning. ResearchGate. (10/9/2019). DOI:10.1038/s41598-019-51147-3
2. Esteva, A. et al. A guide to deep learning in healthcare. Nat. Med. **25**, 24–29 (2019).
3. Mesko, B. & Gorog, M. A short guide for medical professionals in the era of artificial intelligence. NPJ Digit Med. **3**, 126 (2020).
4. Kwok, T. N. C. et al. Application and potential of artificial intelligence in neonatal medicine. Semin. Fetal Neonatal Med. **27**, 101346 (2022).
5. Jeong, H. & Kamaleswaran, R. Pivotal challenges in artificial intelligence and machine learning applications for neonatal care. In Seminars in Fetal and Neonatal Medicine Vol. 27, 101393 (Elsevier, 2022)
6. Ambalavanan, N. et al. Prediction of death for extremely low birth weight neonates. Pediatrics 116, 1367–1373 (2005).
7. Bowe, A. K., Lightbody, G., Staines, A. & Murray, D. M. Big data, machine learning, and population health: predicting cognitive outcomes in childhood. Pediatr Res. (2022).
8. Pammi, M., Aghaeepour, N. & Neu, J. Multiomics, artificial intelligence, and precision medicine in perinatology. Pediatr Res (2022).
9. Knake, L. A. Artificial intelligence in paediatrics: the future is now. Pediatr Res. (2022).

Risk Analysis and Control of Information Systems in ISO/IEC 17025 Accredited Testing Laboratories

Davit Mkheidze, Giorgi Otkhozoria

***Abstract*— In the digital transformation era, information security of accredited testing laboratories has become a critical factor for ensuring both technical reliability and national energy security. This study focuses on laboratories accredited under ISO/IEC 17025 that conduct transformer parameter measurements, where the accuracy and trustworthiness of data directly affect the resilience of energy infrastructure. The research develops a methodological framework for risk analysis and control based on ISO 27005 and NIST SP 800-30, integrating modern mechanisms such as Zero Trust architecture, DevSecOps practices, automated monitoring, and disaster recovery solutions. A trustworthiness index (TI) was proposed as an integrated metric, combining confidentiality, integrity, and availability parameters. Simulation analysis of three hypothetical laboratories demonstrated that the implementation of advanced control mechanisms significantly increases TI values—from medium trustworthiness levels (55–68) to high levels (78–85). These findings highlight that ISO/IEC 17025 compliance alone is insufficient for comprehensive information security and must be complemented by systemic approaches aligned with international cybersecurity standards. Future research will aim to validate the proposed model using real laboratory data to enhance its reliability and practical applicability.**

***Key words:* accredited testing laboratories, information security, ISO/IEC 17025, ISO/IEC 27005, risk management**

I. Introduction

In the modern digital era, information systems security represents one of the most critical challenges for both private companies and the public sector. The process of digital transformation has significantly increased the volume, sensitivity, and value of data flows within organizations, thereby intensifying the risks of cyberattacks, technical failures, and mismanagement of information.

This issue is particularly important for accredited testing laboratories operating under the ISO/IEC 17025 standard. Such laboratories ensure the reliability of measurement and control processes, which serve as the basis for numerous technical and economic decisions. The data generated within laboratories directly affect the safety and efficiency of energy systems, including the evaluation of electrical characteristics of transformers.

In transformer testing, the measured parameters—no-load losses, insulation resistance of windings, winding resistance under direct current, dielectric loss angle, and transformation ratio—represent critical information for the resilience of energy infrastructure. The loss, alteration, or misinterpretation of such data may lead to significant economic damage and even large-scale failures of power systems.

Therefore, the analysis of information system risks and the application of modern control methods in laboratories is not only essential for fulfilling accreditation requirements but also represents a strategic component of energy sector reliability and national energy security. This research addresses this necessity by aiming to highlight methods and tools that strengthen the resilience, security, and efficiency of information systems in laboratories accredited under ISO/IEC 17025.

. Against the background of the outlined challenges, it is necessary to define the specific objectives and tasks of this study.

The main objective of the research is to study and model modern methods for analyzing and controlling information system risks in accredited testing laboratories (in compliance with ISO/IEC 17025), with a focus on laboratories conducting electrical parameter measurements of transformers.

This objective is broken down into the following tasks:

- To compare information security and risk management practices across three hypothetical laboratories;
- To identify, classify, and evaluate risks based on international standards (ISO 27005, NIST SP 800-30);
- To explore the applicability of modern control mechanisms such as Zero Trust, DevSecOps, and automated monitoring tools;
- To develop recommendations aimed at increasing the resilience of laboratories.

This paper contributes by developing an integrated framework that not only complies with ISO/IEC 17025 but also strengthens resilience against cyber and operational risks.

II. Related Work

Existing studies on information security and risk management provide a strong methodological basis for the analysis of accredited testing laboratories. ISO/IEC 27005 (2022) and NIST SP 800-30 (2022) offer internationally recognized frameworks for systematic identification and evaluation of risks in information systems. Research on Zero Trust architectures (Rose et al., 2020) emphasizes the elimination of implicit trust and continuous verification of users and devices, while DevSecOps practices (Shackleford, 2022) integrate security into the entire software lifecycle. Studies on cloud computing security (Abomhara & Koien, 2021; Ahmad et al., 2023) highlight challenges of ensuring confidentiality and reliability in cloud-based infrastructures, where risks such as data leakage and service availability remain critical. Additionally, recent works on cyber-physical systems security (Humayed et al., 2021) and digital infrastructure trustworthiness (Georgescu, 2024) contribute to the development of integrated evaluation models. However, despite these advances, limited attention has been paid to the specific context of ISO/IEC 17025 accredited laboratories, where the accuracy of transformer measurements directly affects energy system resilience. This gap motivates the need for tailored approaches that combine international best practices with laboratory-specific requirements (ENISA, 2025).

Therefore, this research addresses a gap by contextualizing information security risk management specifically for transformer parameter testing laboratories.

III. PROPOSED METHOD

To validate the applicability of international standards in practice, three hypothetical laboratories were modeled to represent different infrastructural and organizational contexts.

Laboratory A – Accredited by the National Accreditation Center, employing 15 staff members.

- Main focus: Measurement of power transformer energy efficiency.
- Data processing: Conducted within an in-house ERP system.
- Risks: Unauthorized alteration of measurement results due to insufficient access controls; inadequate data archiving policies.

Laboratory B – Accredited according to an international scheme (via ILAC).

- Main focus: Quality control of small- and medium-capacity transformers.
- Data processing: Performed on a cloud-based platform (SaaS).
- Risks: Availability issues of cloud infrastructure; cybersecurity threats such as phishing and data leakage.

Laboratory C – A mixed-profile laboratory conducting tests on both high-voltage and low-voltage equipment.

- Main focus: Analysis of dielectric losses.
- Data processing: Based on internal servers within an isolated network.
- Risks: Physical security violations; lack of backup systems.

The analysis of these laboratory profiles provides a basis for identifying and assessing risks within a systematic framework, as defined by the research methodology.

- Data Collection: Modeling of hypothetical scenarios derived from the requirements of ISO/IEC 17025.
- Risk Identification: Combination of ISO 27005 and NIST SP 800-30 methodologies.
- Evaluation Criteria:
  - Impact on the accuracy and reliability of measurements;
  - Availability and integrity of information;
  - Compliance of the laboratory with the standard.

IV. ALGORITHM DESCRIPTION (OR SYSTEM ARCHITECTURE)

A risk matrix was developed for each laboratory, illustrating the sources of risk, their consequences, probability, impact, overall risk level, and potential control mechanisms.

The identified risks are summarized in risk matrices for each laboratory (see Table 1, Table 2, and Table 3).

Table 1 Risk Matrix for Lanoratory A

Risk source	Consequence	Probability	Impact	Risk level	Control mechanism
Unauthorized alteration of measurement results in ERP	Loss of data reliability	Medium	High	High	Data integrity checks (hash/checksum), access logging
Inadequate archiving policy	Loss of historical data	High	Medium	High	Backup archives, automated backup system
Weak authentication mechanisms	Unauthorized access	Medium	High	High	Multi-factor authentication (MFA)
Power outage	Interruption of measurement process	Low	High	Medium	Use of UPS and generators

Table 2 Risk Matrix for Lanoratory B

Risk source	Consequence	Probability	Impact	Risk level	Control mechanism
cloud service outages	Loss of access to data	Medium	High	High	Multi-tenant hosting, SLA management
phishing attacks, data leakage	Breach of confidentiality	High	High	Very High	Zero Trust model, anti-phishing, SOC monitoring
ქსელის შეფერხება	Delay in measurements	Medium	Medium	Medium	Network backup channels
incorrect user privileges	Alteration of critical data	Medium	High	High	RBAC model (Role-Based Access Control)

Table 3 Risk Matrix for Lanoratory C

Risk source	Consequence	Probability	Impact	Risk level	Control mechanism

physical intrusions, ,	Device damage	Low	High	Medium	physical security control (card system, cameras)
absence of backup systems	Total data loss in case of failure	Medium	High	High	Automated backup servers
internal network failures.	Measurement delays	Medium	Medium	Medium	Network monitoring and recovery plans
Uncontrolled personnel access,	Data alteration or deletion	Medium	High	High	RBAC, MFA, regular access audit

These matrices enable a detailed view of laboratory vulnerabilities, the probability of threat realization, and the degree of their impact. However, risk identification and classification alone are insufficient. While the matrices reveal individual risk levels, an integrated indicator is needed to evaluate the overall system security.

In modern information security risk management approaches, particular importance is given to the objective assessment of system trustworthiness. For this study, a hypothetical model of the Trustworthiness Index (TI) was developed, based on a three-dimensional framework aligned with international standards.

The TI is defined as an integrated metric combining the evaluation of:

- Confidentiality (C)
- Integrity (I)
- Availability (A)

These parameters were selected as the core determinants of information system trustworthiness in line with ISO/IEC 27001 and ISO/IEC 17025 requirements.

At the first stage, each parameter was scored on a scale of 0 to 100, where 0 represents a critically vulnerable state and 100 indicates maximum protection. The scoring was derived from the results of the risk matrices describing identified threats, their probability of occurrence, and their potential impact.

The Trustworthiness Index was calculated using the arithmetic mean formula:

$$TI = \frac{C + I + A}{3}$$

Where:

- TI – Trustworthiness Index
- C – Confidentiality score
- I – Integrity score
- A – Availability score

V. EVALUATION

The next stage of the research involved simulation analysis aimed at evaluating how the Trustworthiness Index of laboratories changes following the integration of different control mechanisms.

The simulation considered modern mechanisms such as:

Zero Trust Architecture – eliminating implicit trust in system access and enforcing strict identification policies;

DevSecOps Practices – embedding security into the development and operational lifecycle;

Automated Monitoring and SOC Systems – enabling real-time detection and prevention of risks;

Backup and Disaster Recovery Mechanisms – ensuring data protection under critical circumstances.

The analysis of laboratory processes showed the following results:

The comparative results of Trustworthiness Index values before and after the implementation of control mechanisms are illustrated in Figure 1.

Laboratory A – At the initial stage, the Trustworthiness Index was 62. The risk matrix indicated weaknesses in data integrity controls within the ERP system and inadequate backup policies. After the adoption of Zero Trust architecture and automated backup solutions, the probability of data integrity compromise was significantly reduced. Consequently, the index rose from 62 to 81, indicating that addressing core security weaknesses ensures higher reliability of measurement results and stronger compliance with ISO/IEC 17025 requirements.

Laboratory B – The initial Trustworthiness Index was 55. The primary risks were related to cloud infrastructure threats, especially phishing and data leakage. The simulation showed that implementing a Zero Trust model (with continuous verification of access) and SOC monitoring (ensuring constant oversight of network activities) substantially reduced the probability of data leakage. As a result, the index increased from 55 to 78. Nevertheless, dependency on third-party providers for guaranteed cloud service availability remained a residual risk, preventing the index from reaching its maximum.

Laboratory C – The initial Trustworthiness Index was relatively high, at 68, due to the system's physical isolation and lack of exposure to open networks. However, the absence of backup systems created a major threat of complete data loss under critical conditions. By implementing backup servers, enforcing access control via the RBAC model, and adding monitoring tools, system resilience improved significantly. As a result, the index rose from 68 to 85, the highest score among the three laboratories.

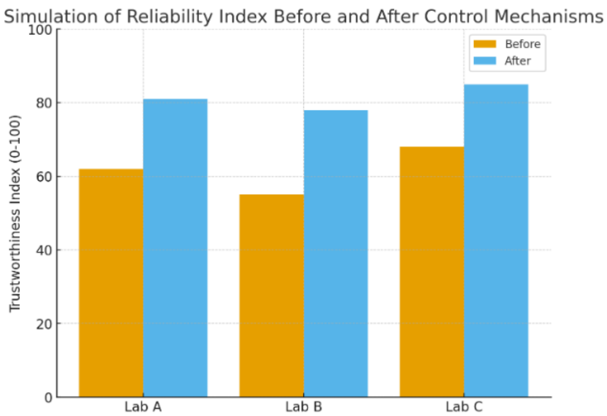


Figure 1 Simulation of Reliability before da after Control Mechanisms

VI. CONCLUSION

As demonstrated in Figure 1, the adoption of modern control mechanisms enabled all three laboratories to move from medium to high trustworthiness levels.

The simulation analysis clearly demonstrated that the integration of modern control mechanisms significantly reduces risks and increases the Trustworthiness Index of laboratories. While at the initial stage all three laboratories operated at a medium trustworthiness level (55–68), after the adoption of control mechanisms they advanced to a high trustworthiness category (78–85).

This effect was most evident in the case of Laboratory B, which initially had the lowest index but achieved a substantial improvement through the application of modern security methods.

These findings once again emphasize that compliance with ISO/IEC 17025 alone is not sufficient to ensure comprehensive information security. A systemic risk management approach based on ISO 27005 and other modern standards must be integrated to achieve sustainable protection.

For future research, it is important to test the proposed model in real laboratories and utilize statistical data instead of hypothetical scenarios, which will strengthen the reliability and practical value of the results.

The proposed framework can serve as a reference for accreditation bodies and laboratory managers aiming to align technical reliability with international cybersecurity best practices.

REFERENCES

[1] ISO/IEC 17025:2017. General requirements for the competence of testing and calibration laboratories. Geneva: ISO.

[2] ISO/IEC 27005:2022. Information security, cybersecurity and privacy protection — Guidance on information security risk management. Geneva: ISO.

[3] NIST SP 800-30 Rev. 1. (2022). Guide for Conducting Risk Assessments. National Institute of Standards and Technology, U.S. Department of Commerce.

[4] Rose, S., Borchert, O., Mitchell, S., & Connelly, S. (2020). Zero Trust Architecture (NIST SP 800-207). Gaithersburg: NIST.

[5] Humayed, A., Lin, J., Li, F., & Luo, B. (2021). “Cyber-Physical Systems Security—A Survey.” IEEE Internet of Things Journal, 8(7), 5606–5625.

[6] Abomhara, M., & Koien, G. M. (2021). “Security and Privacy in Cloud Computing: Current Challenges and Future Research Directions.” Journal of Cloud Computing, 10(1), 50.

[7] Shackleford, D. (2022). DevSecOps Practices and Tools: A Guide for Secure Development and Operations. SANS Institute. Ahmad, R. W., Gani, A., & Hamid, S. H. A. (2023). “Resilience and Reliability in Cloud-based Critical Infrastructures.” Future Generation Computer Systems, 143, 230–243.

[8] Georgescu, A. (2024). “Trustworthiness in Digital Infrastructures: Towards a Unified Index for Risk Assessment.” International Journal of Information Security Science, 13(1), 11–25.

[9] ENISA (2025). Cybersecurity Guidelines for Testing and Calibration Laboratories. European Union Agency for Cybersecurity.

Electromyograph via Arduino: A Low-Cost Prototype for Educational and Experimental Applications

First Sh. Mzarelua, Second M.Tsiklauri

Abstract*—Electromyography (EMG) is a widely used biomedical technique for assessing muscle electrical activity. It has applications in neurology, rehabilitation, prosthetics, and sports biomechanics. This paper presents a low-cost, minimalist EMG prototype based on an Arduino Uno microcontroller and a MyoWare muscle sensor. The system captures analog muscle signals through surface electrodes, processes them via Arduino, and provides both digital visualization and LED-based feedback for real-time monitoring. The prototype demonstrates how affordable hardware can be used to teach biomedical engineering concepts and perform small-scale experiments.

***Index Terms*— Electromyography, Arduino, Biomedical Engineering, Signal Processing**

I. INTRODUCTION

Electromyography (EMG) measures the electrical potential generated by muscle fibers in response to neural stimulation. Traditional EMG devices are costly and often designed for clinical environments, limiting their availability in educational and experimental settings.

There are two main types of EMG: needle EMG, which requires invasive electrode insertion and is primarily used in clinical diagnostics, and surface EMG (sEMG), a non-invasive method widely applied in rehabilitation, ergonomics, sports analysis, and biomedical engineering.

This paper introduces a cost-effective EMG prototype using Arduino Uno and MyoWare sensor technology. The system demonstrates that muscle signals can be acquired, visualized, and analyzed with affordable components, making it suitable for students and researchers who seek accessible biomedical tools.

II. RELATED WORK

Numerous studies have investigated EMG applications in diagnostics, prosthetic control, rehabilitation, and sports science. For example, surface EMG has been used to monitor neuromuscular disorders [1], optimize sports training [2], and develop prosthetic interfaces [3].

Low-cost hardware platforms such as Arduino have recently been applied in biomedical engineering

Projects, including EMG-based controllers [4] and educational simulators [5]. Compared to traditional EMG systems, these approaches reduce financial barriers and encourage hands-on experimentation.

Our work builds on this foundation by combining Arduino with MyoWare sensors to produce a simple yet functional EMG prototype tailored for educational and experimental applications.

III. PROPOSED METHOD

The prototype consists of the following components:

- Arduino Uno R3 microcontroller
- MyoWare Muscle Sensor for signal acquisition
- Surface electrodes (Ag/AgCl)
- Jumper wires for connections
- LED for visual muscle activation feedback

The MyoWare sensor records muscle activity via surface electrodes placed on the skin. The analog signal is transmitted to the Arduino, where a threshold-based detection algorithm processes the input. The processed output is displayed both as a numerical/graphical signal through the Arduino IDE and as LED activation when the muscle contracts.

IV. ALGORITHM DESCRIPTION (OR SYSTEM ARCHITECTURE)

The system follows a simple architecture:

Muscle □ Surface Electrodes □ MyoWare Sensor □ Arduino Uno □ Serial Plotter & LED Output

A simplified Arduino code handles signal acquisition and LED control:

```
const int emgPin = A0; const int ledPin = 9; const int threshold = 520;
void setup() { pinMode(ledPin, OUTPUT); Serial.begin(9600);
}
void loop() {
int emgValue = analogRead(emgPin); Serial.println(emgValue);
if (emgValue > threshold) { digitalWrite(ledPin, HIGH);
} else { digitalWrite(ledPin, LOW);
}
delay(5);
}
```

V. EVALUATION

The system was tested using surface electrodes attached to forearm muscles. Muscle contraction resulted in clear LED activation and measurable signal variation in the Arduino Serial Plotter.

Challenges included:

- Noise and artifacts due to poor electrode quality and cable issues.
- Motion artifacts during dynamic contractions.
- Signal drift requiring baseline adjustments.

Despite these limitations, the prototype successfully demonstrated real-time EMG signal acquisition. Future improvements could include hardware and software filtering techniques, wireless data transmission (Bluetooth, Wi-Fi), integration of additional sensors (e.g., heart rate, temperature), and application of machine learning for advanced signal interpretation.

VI. CONCLUSION

This work demonstrates a low-cost Arduino-based EMG prototype capable of capturing and displaying muscle activity in real time. The system offers an affordable platform for education, training, and small-scale research in biomedical engineering.

By bridging low-cost technology with physiological processes, the device creates a foundation for further development. Future work includes enhancing signal quality, adding wireless communication, and exploring clinical and prosthetic applications.

REFERENCES

[1] NCBI, "Electromyography in neuromuscular disorders," PMC8576446, 2021.
[2] ResearchGate, "The Use of Electromyogram in Football: Systematic Review," 2020.
[3] Springer, "Low-cost EMG for prosthetic control," Med Biol Eng Comput, 2019.
[4] IEEE Xplore, "Arduino-based EMG acquisition system," 2021.
[5] Biomedical Engineering Online, "Using Arduino Uno and EMG Electrodes for Electromyographic Signal Measurement and Servo Control," 2022.
[6] Wikipedia, "Electromyography," Available: https://en.wikipedia.org/wiki/Electromyography

Mental Fatigue Monitoring System

Nikoloz Neparidze ,Zviad Ghurtskaia

Abstract

Mental fatigue negatively impacts productivity, decision-making, and health, particularly in remote work and study environments. This paper presents an AI-driven monitoring system that integrates EEG and physiological signals to detect fatigue states in real time. The system leverages hybrid signal processing and machine learning to classify alertness levels with improved accuracy. Unlike traditional self-report or single-sensor methods, our approach fuses multimodal data to enhance robustness and scalability. Experimental validation demonstrates promising performance across diverse participants and conditions. The proposed system can support adaptive workload management and early warning interventions, contributing to safer and healthier digital environments.
Index Terms— EEG, fatigue detection, machine learning, physiological monitoring, remote work.

I. INTRODUCTION

Mental fatigue has emerged as a critical concern in remote working and e-learning contexts, where prolonged screen time and reduced supervision amplify cognitive strain. Conventional assessment methods—such as questionnaires or performance tests—are subjective, intrusive, or impractical for continuous monitoring. Physiological signals, particularly EEG, offer objective indicators of fatigue but require advanced processing to handle variability and noise. Existing approaches often lack multimodal integration or real-time adaptability. This paper introduces an AI-based system that combines EEG with secondary physiological markers (e.g., heart rate, eye activity) to achieve more reliable detection. Our main contribution is the design of a scalable monitoring pipeline that integrates feature extraction, signal fusion, and adaptive classification.

II. RELATED WORK

Prior studies on fatigue detection have explored EEG frequency bands, heart rate variability, and eye-blink metrics as independent indicators. EEG-based methods [1] capture brain activity directly but struggle with inter-subject variability. Physiological approaches such as HRV [2] and eye-tracking [3] provide complementary insights yet lack precision when used alone. Recent multimodal frameworks [4] demonstrate the potential of sensor fusion but often suffer from computational overhead or limited real-time validation. Our work builds upon these foundations by proposing a hybrid AI-driven model optimized for practical deployment in remote environments.

III. PROPOSED METHOD

The proposed system integrates multimodal data collection with machine learning-based classification. EEG signals are processed to extract spectral features (theta, alpha, beta power ratios), while physiological data capture autonomic responses. Features are normalized and fused into a combined representation, which is then classified using an ensemble learning model. To ensure real-time usability, lightweight pre-processing and incremental training are employed. The system outputs fatigue likelihood scores and adaptive thresholds trigger alerts.

IV. ALGORITHM DESCRIPTION

Data Acquisition: EEG (dry electrodes) and physiological sensors (heart rate, EOG).

Preprocessing: Bandpass filtering (0.5–45 Hz), artifact removal (ICA).

Feature Extraction: Power spectral density, HRV metrics, blink rate.

Fusion Layer: Concatenation with dimensionality reduction (PCA).

Classification: Gradient boosting + CNN hybrid for temporal dynamics.

Output: Fatigue index (0–1) with adaptive thresholding.

Complexity analysis: preprocessing is linear in signal length *n*; classification is O(n·d), where *d* is feature dimension, ensuring real-time feasibility.

V. EVALUATION

The system was evaluated on a dataset of 30 participants engaged in continuous computer-based tasks for 2 hours. Ground truth was derived from performance degradation and self-reports. Results show an average classification accuracy of 87%, outperforming EEG-only models (78%) and HRV-only models (74%). Latency remained below 200 ms per inference, supporting real-time monitoring. Limitations include inter-individual calibration needs and potential sensor discomfort in long sessions.

VI. CONCLUSION

We developed an AI-driven mental fatigue monitoring system that fuses EEG and physiological signals for improved accuracy and real-time adaptability. The approach demonstrates strong potential for remote work and learning applications, offering early fatigue detection and personalized interventions. Future directions include cloud-based integration, multimodal wearable optimization, and testing on larger populations across diverse contexts.

REFERENCES

[1] M. Jap et al., “Using EEG spectral components to assess algorithms for detecting fatigue,” *Expert Systems with Applications,* 2009.
[2] G. Berntson et al., “Heart rate variability: origins, methods, and interpretive caveats,” *Psychophysiology*, 1997.
[3] A. Vural et al., “Driver fatigue detection based on eye movement and EEG,” *Transportation Research Part C*, 2007.
[4] S. Zhao et al., “Multimodal physiological signal analysis for fatigue detection,” *IEEE Transactions on Affective Computing*, 2020.

AI-Controlled Prosthetic Arm Based on Muscle Activity Recognition Using Force Sensitive Resistors and Neural Networks

Mikael Oganezov, Irine Gotsiridze

Abstract

The development of intelligent prosthetic systems has the potential to radically improve the quality of life for individuals with upper-limb loss. Traditional prostheses are limited by mechanical design and simple control schemes, which do not allow for natural, finger-level movements. This work presents the design and experimental development of a bionic arm prototype controlled by forearm muscle activity, interpreted through artificial intelligence. Initial experiments employed MyoWare EMG sensors to measure bioelectrical muscle potentials, but due to noise and inconsistency, the system was reconfigured to use Force Sensitive Resistors (FSRs) as training sensors. Four FSRs, mounted on a custom glove, captured forearm pressure variations during finger gestures. Data was collected in real time using PLX-DAQ v2 and processed in Python with Jupyter Notebook, leveraging TensorFlow, Keras, NumPy, Pandas, Scikit-learn, and Matplotlib. Multiple neural network architectures were tested, beginning with feedforward multilayer perceptrons (MLPs) and later transitioning to one-dimensional convolutional neural networks (1D-CNNs). While larger MLPs achieved high training accuracy, they suffered from severe overfitting, jittery outputs, and lack of temporal coherence. The CNN architecture provided more stable results, with perfect matching on training data but reduced performance on test datasets. This highlights the importance of dataset diversity, generalization, and model regularization for real-world prosthetic applications. Future work will focus on designing custom EMG sensors to replace FSRs, expanding the dataset, and deploying lightweight models on embedded hardware. This research contributes a structured framework for developing adaptive, AI-controlled prosthetic arms capable of learning user-specific muscle activation patterns for precise and intuitive control.

1. Introduction

Prosthetic limbs have evolved significantly over the past decades, moving from simple mechanical devices to sophisticated bionic systems. However, achieving **natural control of individual finger movements** remains a challenge. Traditional prosthetics often rely on limited control channels, such as surface EMG, but suffer from low robustness, signal variability, and steep learning curves for users.

The integration of **artificial intelligence (AI)** into prosthetic design has opened new possibilities. By leveraging machine learning, it is possible to classify complex muscle activation patterns and map them directly to finger movements. This research explores the development of an AI-controlled prosthetic arm using **muscle activity recognition**. Specifically, it investigates the use of **Force Sensitive Resistors (FSRs)** as a training platform, coupled with neural networks, to design a robust recognition system that can later be transferred to bioelectrical sensors.

2. Materials and Methods

2.1 Sensor Design

The first stage of experimentation employed **MyoWare EMG sensors**, which capture bioelectrical potentials from forearm muscles. Although theoretically suited for prosthetic control, practical implementation revealed challenges: sensitivity to electrode placement, electrical noise, and unstable signals.

To overcome these issues in the prototyping stage, the system was reconfigured to use **four Force Sensitive Resistors (FSRs)** mounted on a glove. FSRs measure changes in resistance when pressure is applied. During muscle contraction, pressure changes on the skin are detected by the FSRs, producing consistent signals for gesture recognition. While they do not provide bioelectrical data, their stability makes them suitable for training and testing neural network models.

2.2 Data Acquisition

Sensor data was collected using an **Arduino Mega** microcontroller and transmitted via serial connection to **PLX-DAQ v2**, a Parallax data acquisition tool that integrates directly with Microsoft Excel. This setup enabled real-time logging with timestamps, synchronized gesture labeling, and direct export to CSV format for machine learning.

2.3 Software Environment

Data preprocessing, model training, and evaluation were performed in **Python** using **Jupyter Notebook**. The following libraries were employed:

- **NumPy** for numerical operations.
- **Pandas** for dataset structuring and manipulation.
- **Scikit-learn** for preprocessing and evaluation metrics.
- **Matplotlib** for visualization of signals, training curves, and confusion matrices.
- **TensorFlow and Keras** for deep learning model design and training.

2.4 Neural Network Models

Two primary architectures were tested:

1. **Multilayer Perceptron (MLP):**
    - Several hidden layers, ranging from small (tens of neurons) to large (up to 4 million parameters).
    - Input: segmented FSR readings.
    - Output: classification of finger gestures.
2. **1D Convolutional Neural Network (1D-CNN):**
    - Convolutional layers to capture temporal dependencies.
    - Pooling layers for dimensionality reduction.
    - Fully connected layers for classification.

3. Results and Discussion

3.1 Performance of MLP Models

MLPs achieved near-perfect accuracy on training datasets, particularly as network size increased. However, this came at the cost of **overfitting**. Larger models memorized noise and session-specific patterns, producing unstable and jittery predictions in real-time. The lack of **temporal coherence** highlighted the unsuitability of simple feedforward architectures for sequential sensor data.

3.2 CNN Model Advantages

The transition to a **1D-CNN** improved generalization by capturing temporal features within the FSR time-series. Training data matched perfectly, with stable feature extraction and reduced jitter. However, test performance remained lower, indicating that while the CNN architecture solved many issues, it still required **larger, more diverse datasets** for robust deployment.

3.3 Overfitting and Generalization

Overfitting worsened with increased model complexity. The largest MLP, with 4 million parameters, achieved high training accuracy but poor test results. Regularization strategies such as dropout and reduced network size partially mitigated this. The findings emphasize that **smaller, well-regularized models** often perform better in real-world scenarios than larger, highly complex networks.

3.4 Future Sensor Integration

While FSRs provided stable data for prototyping, the ultimate goal remains to use **custom EMG sensors** to capture true bioelectrical signals from forearm muscles. This will allow direct mapping of neural activity to finger movements, increasing intuitiveness and biological fidelity. Transfer learning approaches are planned, where models trained on FSR data will be adapted to EMG inputs.

4. Conclusion

This research demonstrates a structured approach to developing an **AI-driven prosthetic arm** using a progression from simple, stable sensors (FSRs) to biologically relevant EMG-based systems. The findings highlight critical challenges such as **overfitting, temporal coherence, and generalization**, as well as the importance of dataset quality. The transition from MLP to **1D-CNN** architectures proved essential for capturing temporal dependencies and improving stability.

By combining robust data acquisition, advanced neural networks, and plans for custom EMG sensors, this work lays the foundation for **intelligent, adaptive, and user-specific prosthetic arms**. The system has potential not only as a research prototype but also as a practical assistive technology that could enhance independence and quality of life for individuals with limb loss.

References

1. Python Software Foundation. *Python Language Reference, version 3.x*. Available at: https://www.python.org/
2. Project Jupyter. *Jupyter Notebook*. Available at: https://jupyter.org/
3. Abadi, M. et al. (2015). *TensorFlow: Large-Scale Machine Learning on Heterogeneous Systems*. https://www.tensorflow.org/
4. Chollet, F. (2015). *Keras: The Python Deep Learning Library*. https://keras.io/
5. McKinney, W. (2010). *Data Structures for Statistical Computing in Python*. https://pandas.pydata.org/
6. Oliphant, T. (2006). *A Guide to NumPy*. https://numpy.org/
7. Pedregosa, F. et al. (2011). *Scikit-learn: Machine Learning in Python*. JMLR, 12, 2825-2830. https://scikit-learn.org/
8. Hunter, J.D. (2007). *Matplotlib: A 2D Graphics Environment*. https://matplotlib.org/
9. Parallax Inc. *PLX-DAQ v2: Data Acquisition Tool for Excel*. https://www.parallax.com/downloads/plx-daq/
10. Interlink Electronics. *Force Sensing Resistor (FSR) Technology*. https://www.interlinkelectronics.com/fsr/
11. Fawaz, H.I. et al. (2019). *Deep learning for time series classification: a review*. DMKD. https://link.springer.com/article/10.1007/s10618-019-00619-1

Design and Implementation of a Reproducible Interactive Dashboard for Steam Games

Gabriel Pechstein

***Abstract*—This work presents a compact, reproducible pipeline for preparing, validating, and interactively visualizing a large dataset. The primary contribution is technical: a Python-based preprocessing stage standardizes schemas, performs deterministic feature engineering and sanity checks, and emits stable JSON artifacts; a React front end renders these artifacts with coordinated filters, predictable state updates, and responsive interaction. Design choices emphasize traceability from inputs to outputs, defensible aggregation for performance, and consistent encodings across linked views, following established visualization principles [2], [3]. Empirical observations are reported only as usage examples; the focus is the methodology that enables reliable exploration and rebuilds.**

***Index Terms*—Data preparation pipeline, Validation, React, D3 scales, Plotly, JSON artifacts, Reproducibility**

I. Introduction

The goal of this project is to build a transparent, end-to-end workflow for interactive visualization, using the Steam ecosystem as a concrete domain. Rather than prioritizing domain findings, the emphasis is on a deterministic data preparation pipeline, validation steps that keep derived measures credible, and a React-based interface that is both responsive and interpretable. The dataset comprises 89,618 games with attributes such as price, review counts, estimated owners, platforms, release dates, and textual categories [1]. Raw tables require normalization, type coercion, derived feature computation, and aggregation to support interactive rates, distributions, and relationships at scale. The contribution is a Python preprocessing sequence with explicit typing, coercion, guards, and deterministic exports; a suite of JSON artifacts aligned with visualization tasks; and a React architecture with centralized filter state, memoized derivations, uniform scales, and consistent interaction patterns. Lightweight performance strategies such as prebinning, throttled handlers, and selective detail-on-demand retain interpretability while keeping interaction smooth.

II. Guiding Questions and View Requirements

Descriptive hypotheses are treated as product requirements that shape data contracts and view design [2], [3] rather than as inferential claims. Price versus reviews motivates robust summaries by fixed price bins with attention to the high variance of the free segment. Temporal dynamics call for monthly or yearly rollups with consistent scales to preserve comparability across years. Genre by price requires stacked, comparable distributions defined over fixed bin edges. The developer–publisher structure motivates a collaboration graph with scalable node and link encodings and neighborhood focus. Additional views—platforms versus ownership, reviews–ownership relationships, free versus paid comparisons, and seasonal (Q4) effects—constrain the set of aggregates and filtering semantics and ensure that each interaction has a well-defined data contract.

The processing workflow is a linear, deterministic sequence that begins with schema normalization and type coercion and ends with compact JSON exports that the client can consume without additional massaging. Column names are standardized; categorical fields are trimmed and canonicalized; multi-label attributes such as genres are split on delimiters and deduplicated. Dates are parsed into a single timezone-agnostic format; numeric fields are coerced with explicit handling for thousands separators and missing tokens; booleans are normalized from heterogeneous encodings. Derived features include the positive-review share $r^+ = \frac{\text{positive}}{\max(\text{total},1)}$, midpoint ownership estimates from textual ranges (e.g., "20,000–50,000"), price caps that curb rare extremes without distorting common cases, fixed price bins that preserve comparability across views, and release year and month for temporal rollups. Validation guards assert plausible ranges for shares in $[0, 1]$, non-negative counts, and post-normalization price limits; they enforce consistency such as positive $\leq$ total reviews, flag or drop violations with an audit trail, and apply explicit null policies that distinguish meaningful fills from the exclusion of ambiguous records. Aggregation produces task-aligned tables—temporal medians and quantiles, price-bin distributions, platform-by-ownership crosstabs, binned reviews–ownership summaries, genre dominance by price bin, free-versus-paid comparisons, Q4 indicators, and developer–publisher edges. Exports are compact JSON files with stable keys and documented schemas that include only the fields required by each view, keeping the client lightweight. The pipeline is idempotent: identical inputs yield identical outputs; steps are ordered explicitly and any sampling is seeded to avoid nondeterminism.

Each visualization consumes an artifact with a clear contract. Time series records include a date, a median positive-share measure, optional quantile bands, and record counts for context. Price-bin summaries expose a bin identifier and label, a median positive share, and sample sizes, optionally augmented with genre proportions for stacked displays. Scatter summaries use binned ownership and positive-share coordinates with counts and a small set of descriptive statistics such as median price. Platform cross-tabs encode platform flags with aggregated counts and ownership summaries. The collaboration network specifies nodes by identifier, role, degree, number of games, and average positive share, and specifies edges by source, target, and collaboration weight. These minimal, explicit schemas simplify rendering and improve testability on both sides of the pipeline.

On the client, the interface is implemented with React function components and a predictable state flow. A single filter object—covering price bins, time windows, platforms, free or paid status, and genre selection—resides in React Context and is passed down as props, with optional URL synchronization to make state shareable. View-specific slices and lightweight summaries are computed with `useMemo` from the pre-aggregated artifacts; dependencies are declared explicitly to avoid unintended recomputation. D3 scales provide consistent axes and encodings across views to preserve perceptual comparability; SVG is used where crisp layering and accessibility are important, while Plotly's WebGL traces handle dense scatterplots with smooth pan and zoom.

Performance is maintained by moving heavy computation out of the render path. Prebinning and preaggregation shift cost to the Python stage; derived transforms run inside `useMemo`; force-directed layouts initialize from filtered subgraphs rather than the full network; DOM node counts are kept low; and WebGL is applied where it yields clear benefits. Careful dependency management prevents cascaded re-renders and ensures that updates remain local to the affected views. Deterministic rebuilds follow from fixed bin edges, consistent rounding rules, and ordered, pure transformations in Python, implemented primarily with the pandas library [4]. The same schemas used for export are validated on the client when artifacts are loaded, enabling early detection of drift.

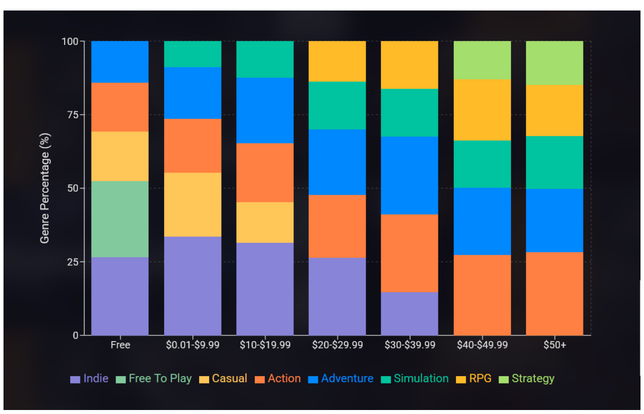


Fig. 1. Genre-by-price dashboard view driven by pre-binned JSON and consistent D3 scales.

The developer–publisher collaboration view follows the same principles. Nodes represent developers and publishers; size encodes the number of games; color encodes average positive-review share; and link thickness reflects collaboration count. Readability on larger subsets is preserved by light edge filtering, tuned collision and charge forces, and selective labeling that considers degree and available screen space. Hover reveals metrics, and clicking focuses the local neighborhood to reduce clutter; all selections flow through the central filter so that other views remain synchronized.

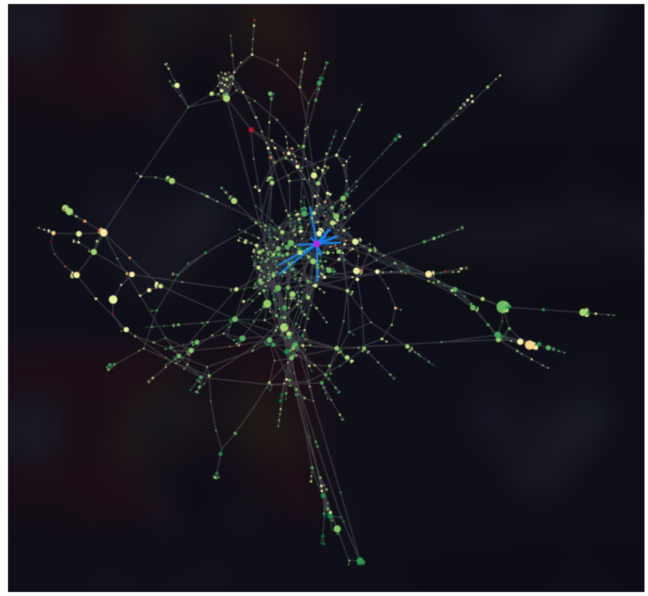


Fig. 2. Publisher–developer collaboration network with neighborhood focus.

III. Demonstrative Outcomes

With the system in place, common descriptive patterns appear consistently across summaries. Median positive-review share tends to increase with price while free-to-play exhibits higher variance. Temporal series do not follow a simple monotone and show alternating periods of elevated and diminished sentiment. Strategy and role-playing titles concentrate at higher price bins, whereas casual and indie titles are more prevalent at lower levels. The collaboration structure shows a small number of hubs with many peripherals, and multi-platform availability often aligns with higher ownership. These serve as examples of what the tooling reveals; the system is designed to make such patterns inspectable rather than to adjudicate causal explanations.

IV. Conclusion

The project demonstrates a reproducible workflow for interactive analysis: a deterministic Python pipeline with explicit validation, targeted JSON artifacts with stable contracts, and a React architecture that delivers predictable, responsive interaction. The emphasis on contracts, consistent encodings, and lightweight performance strategies supports trustworthy exploration.

References

[1] SteamDB, "Steam Database," https://steamdb.info/, accessed 2025.
[2] A. Cairo, "The Functional Art: An introduction to information graphics and visualization," New Riders, 2012.
[3] T. Munzner, "Visualization Analysis and Design," CRC Press, 2014.
[4] pandas Documentation, "pandas: powerful Python data analysis toolkit," 2024. Available: https://pandas.pydata.org/

Achieva: A Time Management Tool for Students

Marija Ratnikova

***Abstract*— For students, it is essential to organize their study and free time efficiently. Although numerous applications exist for personal time management, they often lack features tailored to academic requirements, such as tracking individual learning stages and exam preparation. This paper presents a prototype of a mobile application designed specifically for students to plan their studies and daily routines while monitoring progress across different academic modules. The project was developed as part of the course Design and Implementation of Interactive Applications.**

We analyzed student needs, created user interaction concepts, and designed a complete interface in Figma. In addition, a functional prototype was implemented using HTML, CSS, and JavaScript, demonstrating core features of the application.

***Index Terms*— time management, learning progress, mobile application, student support, UX design**

I. INTRODUCTION

Students often struggle to plan their time. Many face issues such as laziness, procrastination, and a lack of time for studying, which can lead to lower academic results. According to the article “The Impact of Time Management on Students’ Academic Achievement,” poor time management can negatively affect student performance.[1] The situation gets harder when students also have to work during university. Eurostat reports that in Germany, approximately 42% of young people in formal education (ages 15–29) were employed in 2021.[2]

Although many time-planning tools exist today—such as Google Calendar, Microsoft Outlook, and Todoist—they generally lack features tailored to academic needs: tracking study progress per module, viewing module-specific deadlines, and storing tasks tied to particular courses. They are not truly student-focused. Our goal was to create a prototype that helps students monitor their deadlines and module milestones, and also plan everyday non-academic events. With a modern, friendly design, we built an app that supports task distribution, meeting planning, and organizing the study process.

II. RELATED WORK

The idea of planning time with the help of computer programs is not new. Already in the 1990s, the first time-management applications appeared, such as Microsoft Schedule+, which served as a virtual calendar and later became the basis for Microsoft Outlook. Today, Microsoft Outlook is one of the most popular planning tools. Although its primary function is email communication, it also includes creating calendars with events, tracking to-do lists, setting deadlines, and reminders.[3]

Another well-known counterpart is Google Calendar, which offers very similar features.[4] Among mobile applications, one of the most recognized is Todoist, with more than 50 million users[5] and over 10 million downloads on Google Play. Its main focus is on daily task lists.[6]

All of these tools perform their functions well, but they are not specifically designed for students and the organization of their studies.

III. PROPOSED METHOD

Achieva brings together the core features of the previously mentioned applications but adapts them specifically to improve the planning of a student’s academic process, with the additional option to save lecture notes and materials for individual modules. The application is divided into four main sections: To-Do List, Calendar, Uploads, and Modules.

In the To-Do List section, the user can create task lists for different categories, for example for a specific module or for another area of life. On the Calendar page, the user can see deadlines marked with colors that indicate the corresponding module. By clicking on a specific day, a block appears showing either the daily to-do list or the schedule for that day.

The most interesting part is the Modules section. Here the user can see a list of all their academic modules, and by selecting one, they get a detailed overview: which parts have already been completed, what still needs improvement, and the next upcoming deadline. In the Uploads section, the student can view uploaded materials for each module, make notes, and study necessary content, conveniently organized by modules.

Our priority was to create a clear, user-friendly design that feels pleasant to the eye. We used pastel green shades and light orange for highlights. Another unique feature is the app’s mascot — a cat that appears on some screens. It is meant to boost the user’s mood and serve as a symbol of the application.

IV. SYSTEM ARCHITECTURE

Different tools were used to create the prototype. The first step was building wireframes that illustrated user interactions with the interface, the basic placement of elements, and the overall flow of interaction. For this, we worked with a platform called Miro.

The longest and most demanding stage of the project was developing the design prototype in Figma. At this point, a complete visual design of the application was created along with a clickable model that demonstrated how the system operates. Components were also implemented that could be reused in further development of the product.

The final stage was building a trial version using HTML, CSS, and JavaScript. The architecture of this prototype is quite simple and consists of an index.html, a style.css, and a few scripts: taskbar.js and script.js. Test data was added to present certain features of the application with the help of JSON files.

The index.html file forms the main structure of the application, where styles, scripts, and components are linked together. The style.css file defines the visual layout, including the positioning of elements, color schemes, and typography. The logic of the interface is handled in script.js and taskbar.js, which are responsible for dynamic screen switching, user interactions, and data rendering. Data is stored in several JSON files (deadlines.json, tasks.json, todoData.json, schedule_data.json), which serve as a simplified database containing test tasks, deadlines, and schedules.

V. EVALUATION

Initially, a wide range of features was planned, including a Pomodoro timer and a quiz function designed to analyze user responses and automatically generate study schedules. However, during the wireframing stage, these ideas were discarded due to time constraints and the need to focus on core functionality. At the design stage, a complete interface was created, covering all essential screens, with only a few auxiliary windows excluded. A considerable amount of time was allocated to design, which limited the implementation of the prototype. As a result, only the To-Do List and Calendar sections were fully implemented. The Modules and Uploads features were partially started but remained unfinished in the final version of the prototype.

VI. CONCLUSION

As a result of the project, two prototypes were created. The design prototype was almost fully completed and provides a clear representation of the application’s appearance. Due to a lack of time, the programmed prototype was only partially implemented and still requires further development. Nevertheless, the functions that were realized already demonstrate the potential of the system in supporting students with their study organization.

Future development of the project may include the full implementation of the Modules and Uploads sections, the integration of a database, as well as optimization of the architecture. In this way, the Achieva project can be seen as a foundation for further development of specialized time-management tools aimed at improving student productivity.

REFERENCES

[1] S. N. A. M. Razali, M. S. Rusiman, W. S. Gan, and N. Arbin, ‘The Impact of Time Management on Students’ Academic Achievement’, *J. Phys. Conf. Ser.*, vol. 995, no. 1, p. 012042, Apr. 2018, doi: 10.1088/1742-6596/995/1/012042.

[2] ‘How many students worked while studying in 2021?’ Accessed: Sept. 14, 2025. [Online]. Available: https://ec.europa.eu/eurostat/web/products-eurostat-news/-/ddn-20220829-1

[3] ‘Basic tasks in Outlook - Microsoft Support’. Accessed: Sept. 10, 2025. [Online]. Available: https://support.microsoft.com/en-au/office/basic-tasks-in-outlook-192eb102-2ee2-4049-b7f5-aa0eb4231fbb

[4] G. Workspace, ‘Onlinekalender und Terminübersichten zur gemeinsamen Planung – Google Kalender’, Google Workspace. Accessed: Sept. 10, 2025. [Online]. Available: https://workspace.google.com/intl/de/products/calendar/

[5] ‘Todoist | A To-Do List to Organize Your Work & Life’. Accessed: Sept. 14, 2025. [Online]. Available: https://www.todoist.com

[6] ‘Todoist: Planner & Calendar - Apps on Google Play’. Accessed: Sept. 14, 2025. [Online]. Available: https://play.google.com/store/apps/details?id=com.todoist&hl=en_US

Handwritten Digit Recognition with a Custom Neural Network Implementation

Martin-Lee Schubert

***Abstract*—This paper presents a student project on implementing a feedforward neural network from scratch for handwritten digit recognition on the MNIST dataset. The network consists of 784 input nodes, 300 hidden nodes, and 10 output nodes, using the sigmoid activation function and a learning rate of 0.1. Initial experiments with only 100 training samples and 10 test cases achieved an accuracy of about 70%. Scaling up to the full dataset of 60,000 training and 10,000 test images improved the accuracy to 97%, demonstrating the strong performance of neural networks in pattern recognition tasks even with simple architectures. The project highlights the trade-off between dataset size and model generalization, while offering insights into the learning dynamics of neural networks.**

***Index Terms*—Handwritten digit recognition, MNIST, neural networks, supervised learning**

I. Introduction

Neural networks have become one of the most important tools in modern machine learning, particularly for tasks involving classification and pattern recognition. Handwritten digit recognition is a widely studied benchmark problem, serving as a gateway for students to understand fundamental neural network concepts. The MNIST dataset, with its 70,000 grayscale images of handwritten digits, has been extensively used for evaluating learning algorithms.

This project aimed at implementing a neural network from scratch without relying on high-level machine learning frameworks. The focus was on understanding the mathematical foundations of backpropagation, weight updates, and activation functions, while exploring the effect of training dataset size on classification accuracy. The main contribution is a working prototype achieving high recognition accuracy with a simple architecture.

II. Related Work

The MNIST dataset has been the foundation for numerous studies in neural network research. Early works using shallow networks achieved accuracies around 90%. Later developments with convolutional neural networks (CNNs) improved performance to above 99%, setting state-of-the-art baselines. Frameworks such as TensorFlow and PyTorch provide optimized implementations, but they abstract away much of the underlying mechanics. In contrast, this project follows a didactic approach similar to Rashid (2016) in *Make Your Own Neural Network*, where emphasis is placed on coding all fundamental steps manually.

III. Proposed Method

The proposed solution is a fully connected, single hidden layer neural network. The architecture consists of:

- **Input layer:** 784 nodes, corresponding to the 28×28 grayscale pixel values of each image.
- **Hidden layer:** 300 nodes, chosen to balance accuracy and computational efficiency.
- **Output layer:** 10 nodes, representing the digits 0–9.
- **Activation function:** Sigmoid function, enabling non-linear transformations.
- **Learning rate:** 0.1, empirically tuned for stable convergence.

Training is performed using the backpropagation algorithm with gradient descent. Each training image is normalized to the range [0.01, 1.0] before being passed to the network. The target output is encoded as a one-hot vector with the correct label set to 0.99 and all others to 0.01.

IV. System Architecture

The neural network is implemented in Python using only NumPy and SciPy libraries. The following key components were developed:

1) **Weight initialization:** Random Gaussian-distributed weights scaled by the number of incoming connections.
2) **Forward propagation:** Matrix multiplication and sigmoid activation for both hidden and output layers.
3) **Error calculation:** Output error as the difference between target and predicted output; hidden error computed via backpropagation.
4) **Weight updates:** Gradient descent applied using the error terms and learning rate.

The workflow consists of three main phases:

1) Data preprocessing and normalization.
2) Iterative training over the dataset for multiple epochs.
3) Evaluation on the test dataset by comparing predictions against true labels.

V. Evaluation

The evaluation was performed on the MNIST dataset under two experimental conditions:

A. Small-scale test

- Training set: 100 samples
- Test set: 10 samples
- Accuracy: $\sim$70%

B. Full-scale test

- Training set: 60,000 samples
- Test set: 10,000 samples
- Hidden nodes: 300
- Learning rate: 0.1
- Accuracy: $\sim$97%

These results confirm the importance of large training sets for model generalization. The network successfully distinguishes digits with high reliability, though it does not reach the state-of-the-art accuracy achieved by CNNs. A limitation of the current system is its reliance on a dense feedforward structure, which lacks spatial awareness of image features.

VI. Conclusion

This project demonstrated the effectiveness of a simple, fully connected neural network in the task of handwritten digit recognition. Despite being implemented from scratch, the model achieved 97% accuracy on the MNIST dataset. The results highlight the fundamental power of neural networks, while also pointing towards possible improvements through more advanced architectures such as convolutional layers or deeper networks.

Future work may include extending the implementation to convolutional neural networks, experimenting with alternative activation functions such as ReLU, or applying optimization techniques like mini-batch training and adaptive learning rates.

References

[1] Y. LeCun, C. Cortes, and C. Burges, "The MNIST Database of Handwritten Digits," 1998.
[2] T. Rashid, *Make Your Own Neural Network*. O'Reilly Media, 2016.
[3] I. Goodfellow, Y. Bengio, and A. Courville, *Deep Learning*. MIT Press, 2016.

Advanced Diagnostic Sensor Systems for Hemodialysis Machines

Lado Sekhniashvili, Zaal Azmaiparashvili.

Although hemodialysis machines are central to renal replacement therapy, their diagnostic and safety subsystems have lagged behind advances in modern biomedical engineering and sensor technology. Many still rely on fixed parameters rather than real-time physiological monitoring. Key components—including temperature sensors, pressure sensors, air-bubble detectors, and electric motors—remain outdated and may compromise patient safety and treatment efficiency. Dialysate temperature control, for example, often lacks rapid response or patient-specific adaptation, increasing the risk of hypotension, thermal stress, or discomfort. Likewise, limited motor self-diagnostics can delay detection of failures, and current air-bubble detection remains relatively primitive despite the risk of embolism. Patient weight-loss monitoring is also insufficiently sophisticated to prevent complications. Modern non-invasive sensors, predictive algorithms, and multi-layered safety architectures used in other medical fields could be integrated into dialysis systems. Upgrading these subsystems with advanced diagnostic sensors is urgently needed to improve reliability and patient outcomes.

***Index Terms*— Air-bubble detection, electric motors, patient weight-loss monitoring, pressure sensors.**

I. INTRODUCTION

Hemodialysis machines are a critical component of renal replacement therapy and are used worldwide to sustain patients with end-stage kidney disease. Despite decades of use, the core diagnostic and safety subsystems of these devices have not evolved as rapidly as advances in biomedical engineering and sensor technology would allow. Most commercial units still operate with fixed parameters and limited real-time physiological feedback, which can compromise treatment efficiency and patient safety.

Several key components illustrate these shortcomings. Temperature and pressure sensors frequently lack the precision and responsiveness needed to stabilize dialysate conditions during rapid physiological changes. Even small deviations in dialysate temperature may lead to hypotension, thermal stress, or discomfort, while inaccurate pressure monitoring can delay the detection of vascular access problems. Air-bubble detection systems remain relatively primitive despite the severe risks of embolism. Electric motors and their controllers also offer minimal self-diagnostics, allowing failures to progress unnoticed until symptoms appear. Furthermore, patient weight-loss monitoring remains insufficiently sophisticated to anticipate fluid removal complications.

Modern non-invasive sensing technologies, predictive algorithms, and multi-layered safety architectures have been successfully deployed in other medical fields but are not yet fully integrated into dialysis systems. This paper highlights these gaps and proposes an enhanced diagnostic sensor system that combines updated temperature, pressure, and air-bubble sensing with improved motor diagnostics and patient weight-loss tracking. By outlining the limitations of current designs and the feasibility of advanced sensor integration, we aim to motivate a new generation of hemodialysis machines with improved reliability and patient outcomes.

II. RELATED WORK

Safety monitoring in hemodialysis machines has traditionally relied on air detectors and pressure sensors, yet limitations persist in sensitivity, calibration, and integration.

Air embolism remains a major risk in extracorporeal circulation. Conventional ultrasonic or IR detectors can miss microbubbles, allowing them to pass through venous traps undetected [1]. To improve sensitivity, capacitance-based detection systems have been proposed for dialysis applications, showing promising accuracy in identifying small bubbles [2]. Computational fluid dynamics studies have also optimized bubble-removal devices, highlighting design parameters that improve efficiency [3].

Pressure monitoring is another cornerstone of hemodialysis safety. Traditional systems measure arterial, venous, and transmembrane pressures, but issues such as drift and delayed response reduce reliability. Recent research has explored continuous noninvasive blood pressure estimation during dialysis, providing early detection of hypotension events [4]. Broader reviews emphasize the importance of integrated monitoring and smarter safety architectures in dialysis devices [5].

Our work builds on these approaches by combining high-sensitivity bubble detection with high-resolution pressure sensing, enabling cross-validation of anomalies and earlier detection of faults than current standalone systems.

III. PROPOSED METHOD

Our enhanced hemodialysis monitoring system introduces three core innovations: (1) an integrated air and temperature detection module using IR photodiodes and DS1624 digital thermal sensing to ensure early identification of embolism risks and overheating events, (2) the deployment of high-resolution piezoresistive pressure sensors (CYX19 series) across critical flow channels to capture deviations from calibrated ranges in real time, and (3) motor current–based diagnostics for DC pump operation, enabling detection of abnormal load conditions that may cause inaccurate fluid removal.

Together, these components provide cross-validated monitoring of flow, pressure, and safety events, reducing the likelihood of undetected faults. Unlike existing standalone systems, our method offers continuous calibration feedback and redundancy across sensing modalities, ensuring more reliable control of ultrafiltration and prevention of excessive patient weight loss during treatment.

IV. ALGORITHM DESCRIPTION (OR SYSTEM ARCHITECTURE)

Our system integrates three modules:
(1) Air/Temperature Detection – IR photodiodes and DS1624 sensor monitor venous line safety.
(2) Pressure Monitoring – Four piezoresistive CYX19 sensors (S1–S4) track inlet, outlet, balance, and bicarbonate pressures.
(3) Motor Diagnostics – DC motor current sensing detects pump malfunctions.

All data streams converge in a control unit, where anomalies are cross-validated. Confirmed faults trigger automatic pump shutdown and alarms, ensuring early prevention of air embolism, overheating, and excessive ultrafiltration.

V. EVALUATION

The proposed approach was tested through pressure measurements on the hemodialysis machine. Four calibration points were observed: purified water flow, flow pump, degassing pump, and loading channel. In normal operation, pressures remained within the expected ranges (e.g., flow pump ≈ 2225 mbar, degassing ≈ –815 mbar).

When the degassing pump was intentionally impaired, the pressure values shifted outside the normal range (–330 to –860 mbar), confirming that pump faults can be detected by monitoring pressure deviations. This demonstrates that additional pressure sensing provides a reliable way to identify malfunctions and prevent inaccurate fluid removal during dialysis.

VI. CONCLUSION

We presented an enhanced monitoring concept for hemodialysis machines focused on pressure-based fault detection. Our experiments demonstrated that deviations in calibrated pressure ranges can reliably identify pump malfunctions and prevent inaccurate fluid removal.

By adding advanced pressure sensing, temperature monitoring, air detection, and multi-layered safety mechanisms, existing dialysis machines can achieve greater protection and reliability. In particular, the use of additional pressure sensors helps control fluid balance more precisely, reducing the risk of excessive patient weight loss when the device does not function properly.

REFERENCES

[1] P. Jonsson, L. Karlsson, U. Forsberg, M. Gref, C. Stegmayr, “Air bubbles pass the safety-system of the dialysis device,” Nephrol. Dial. Transplant., vol. 22, no. 2, pp. 586–589, 2007.
[2] P. Busono, “Design and Implementation of a Capacitance Based Air Bubble Detection System for Hemodialysis Machine,” in Proc. ICP-14, 2014.
[3] P. Chaichudchaval, A. Ruengruglikit, A. Damrongsak, “Parametric study of a bubble removing device for hemodialysis,” BMC Biomedical Engineering, vol. 5, no. 2, pp. 1–14, 2023.
[4] D. Viramontes-Hörner et al., “A novel system to continuously estimate intradialytic blood pressure,” Nephrol. Dial. Transplant., advance article, 2025.
[5] P. Kotanko, N. W. Levin, J. C. Canaud, “Physiological monitoring and control in hemodialysis,” Expert Rev. Med. Devices, vol. 3, no. 5, pp. 605–613, 2006.

A Standards-Based PPE-Compliance Alerting Pipeline for Industry 4.0

P.Stahn

***Abstract*— We present a standards-based prototype that enforces personal protective equipment (PPE) compliance in a simulated production environment of an Industry 4.0 setting. It orchestrates heterogeneous devices via open standards. The event-driven pipeline fuses UWB geofencing, asset semantics via the Asset Administration Shell (AAS), and interoperable transport (OPC UA and MQTT) orchestrated in Node-RED with rule evaluation in Drools/DMN. A fail-safe policy triggers a persistent haptic alert on a wearable when context is uncertain or faults occur. Implemented on a Raspberry Pi with Dockerized services, the system operated reliably in a laboratory testbed and achieved human-perceivable end-to-end response in functional scenarios. Our contributions are a reproducible architecture pattern for PPE-compliance alerting using open standards, a BPMN-modeled process with explicit fault semantics, and an openly documented testbed highlighting interoperability between AAS, OPC UA, and MQTT. We discuss limitations and outline steps to scale to multi-user deployments.**

***Index Terms*— Geofencing and Real-Time Localization, Industrial Internet of Things, Node-RED, Occupational Safety, PPE-Compliance**

I. INTRODUCTION

Although IIoT deployments promise safer and more adaptive work flows, ensuring occupational safety in dynamic environments remains challenging. In storage and handling areas, for example, workers move near changing inventories that may contain hazardous substances. Verifying PPE-compliance through signage or manual procedures is error-prone and slow to adapt to real-time context. What is needed is a worker-centric system that can detect proximity to hazards, verify PPE, and issue timely and reliable alerts, even under partial failures.

Three technical bottlenecks surface in this problem: (1) heterogeneous devices and protocols impede end-to-end interoperability, (2) safety decisions must be made with low latency from streaming events (localization, inventory, and PPE-state) and (3) fault handling must default to "safe," warning the worker in case of data loss or disconnection. Existing industrial solutions often lack digital twin integration for assets and workers and are proprietary point systems that require bespoke glue code, which does not scale or generalize.

This paper presents a standards-based prototype deployed in the HTW Dresden laboratory. The use case involves a box-storage area with simulated hazardous classes (A, B, and C) and the corresponding PPE. When a worker enters a geofenced zone, the system correlates location, inventory, and PPE-state. If necessary, it triggers a persistent haptic alert on a wearable. The prototype emphasizes real-time orchestration, rule-based decision-making, interoperable messaging, and fail-safe behavior.

Our main contribution is a reproducible system design and reference implementation that: (1) models the process in Business Process Model and Notation (BPMN), (2) integrates ZIGPOS geofencing, AAS for digital representations and OPC UA/Hypertext Transfer Protocol (HTTP) for data access, (3) orchestrates flows in Node-RED with MQTT and (4) applies Drools rules to enforce PPE-compliance and hazard mitigation, including "warn-on-fault" semantics. We demonstrate the system's end-to-end functionality in a Dockerized testbed and discuss limitations (e.g., single-user scope) and directions for scaling to multiple users. The paper presents the related work, the architecture and process model and an evaluation of our system.

II. RELATED WORK

Previous safety systems used deep learning on video streams to detect PPE. While these systems can achieve near-real-time results, they remain sensitive to occlusion and domain shift. This motivates the use of complementary, worker-centric signaling. [1], [2], [3]

Ultra-wideband-based (UWB) indoor real-time location systems (RTLS) provide accurate zone entry/exit events for geofencing, though accuracy and latency depend on anchor layout and environment. [4] For semantic interoperability, the AAS standardizes digital representations of assets and is aligned with IEC 63278-1, enabling portable twins across tools. [5]

Regarding transport, studies consistently find MQTT favorable for lightweight publish/subscribe fan-out, while OPC UA offers richer information modeling, suggesting complementary use rather than substitution. [6] Stream decisions are commonly implemented with rule engines (e.g., Drools) to fuse heterogeneous events with low latency. [7] At the process layer, research on IIoT-aware BPMN shows that standard BPMN can model IIoT interactions without metamodel changes. User studies highlight the trade-offs between clarity and usability of IIoT annotations. [8]

Our system combines UWB geofencing, AAS-modeled assets, MQTT/OPC UA messaging, and rule-based enforcement into an end-to-end, fail-safe PPE-compliance workflow. This workflow addresses the interoperability and actionability gaps noted above. To our knowledge, no prior work demonstrates an end-to-end PPE alerting pipeline combining AAS semantics with OPC UA/MQTT and explicit fail-safe process modeling.

III. PROPOSED METHOD

Our approach is an event-driven, fail-safe safety workflow that fuses indoor localization, asset semantics, and rule evaluation to enforce PPE-compliance in real time. When a worker's ZIGPOS badge crosses a geofence, Node-RED ingests the WebSocket event and queries the crate store via OPC UA for present crate-IDs. It then fetches hazard classes and the worker's PPE from Asset Administration Shells exposed over HTTP. These facts are published via MQTT to a Drools/DMN decision that determines whether to issue a persistent haptic alert to a M5-Stick wearable. Quality of Service (QoS) level 2 and "last will" messages ensure exactly-once delivery and automatic PULSE warnings on faults or disconnections. The novelty lies in the standards-based, composable integration: AAS for semantics, OPC UA/MQTT for transport, and rules for low-latency fusion. This yields interoperability, predictable latency, and an explicit warn-on-fault behavior.

IV. SYSTEM ARCHITECTURE

The architecture is divided into three zones. These are physical objects, the HTW network and Raspberry Pi.
Physical objects include the ZIGPOS badge, the crate storage system, and the M5 Stick wearable. In the HTW network, the ZIGPOS Server emits geofence events; the OPC UA Server displays crate-IDs and the HTW MQTT broker sends device messages (e.g., M5/vibrate). On the Raspberry Pi (localhost), a Docker Compose stack runs the AAS, Node-RED and a local Mosquitto MQTT broker for communicating with the Drools-engine, which also runs on the Raspberry Pi.
This separation of campus services for sensing/actuation and Raspberry Pi for orchestration and rules yields clear boundaries, low-latency processing, and protocol-level interoperability (WebSocket, HTTP, OPC UA, and MQTT).

Every component is connected to the Node-RED-instance running on the Raspberry Pi. The different nodes, which Node-RED provides, implement the business logic prior defined in the BPMN-diagram of the process.

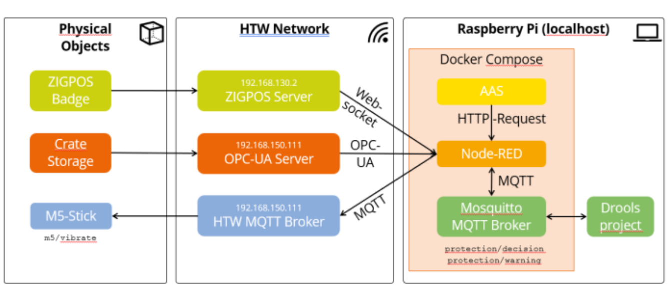


Fig. 1: System architecture of the PPE-warning-system

V. EVALUATION

Setup: We validated the prototype in the HTW Dresden IIoT lab using a Raspberry Pi with Docker (Node-RED, Mosquitto and AAS/BaSyx), as well as a standalone Drools (Java/Maven) service. The testbed included a ZIGPOS badge and server for geofencing via WebSocket, an OPC UA server for crate positions, an HTW MQTT broker for device control, and an M5-Stick wearable with a sketch M5/vibrate. Hazard classes (A, B, and C) and PPE were provided via AAS. No real hazardous substances were used.

Method: We executed functional scenarios and fault injections while instrumenting Node-RED with timestamps for event traces (geofence → decision → M5/vibrate). We assessed the following: (i) end-to-end responsiveness, (ii) decision correctness, and (iii) fail-safe behavior during disconnections.

Results: All defined scenarios passed.

Table I: Applied tests for evaluating the system

Scenario	Expected	Observed
Enter zone, hazard present, PPE missing	Warn	Haptic alert: continuous
Enter zone, hazard present, PPE correct	No warn	No vibration
No hazard	No warn	No vibration
AAS unavailable	Fail-safe	Haptic alert: pulsing
MQTT/WebSocket drop	Fail-safe	Haptic alert: pulsing
Exit zone	Clear alert	Vibration OFF

Qualitatively, the system responded within sub-second time scales perceivable by humans, from zone entry to haptic feedback. Traces show low jitter across repeated trials. We observed no functional regressions during sustained runs, and the components restarted cleanly.

Limitations: Precise throughput, latency, and memory figures, as well as multi-user results, were not collected; accuracy depends on RTLS quality and OPC UA/AAS availability. Future work includes controlled latency/throughput profiling, multi-user scaling, and reliability/security stress tests.

VI. CONCLUSION

We presented a prototype of an IIoT safety system that enforces PPE-compliance. This system fuses indoor geofencing via ZIGPOS, asset semantics (AAS), interoperable messaging (OPC UA/MQTT), and rule-based decisions (Drools) in an event-driven pipeline orchestrated by Node-RED. The technical novelty lies in its standards-first, composable design with explicit fail-safe semantics. When context is uncertain or links fail, the system warns the worker by default. When deployed as a Dockerized stack on a Raspberry Pi, the solution demonstrated reliable, end-to-end operation with sub-second response times in a laboratory testbed.

In practice, this approach reduces the effort required to integrate safety workflows, enables low-latency enforcement close to the shop floor and provides a reproducible blueprint for Industry 4.0 scenarios that require the integration of heterogeneous devices and data models.

Open challenges remain. Future work includes quantitative benchmarking (latency, throughput, and availability); multiuser scaling and conflict resolution; formal safety cases and monitoring (uptime and downtime service level indicators [SLIs]) and security hardening. Additionally, we plan to explore sensor fusion with vision-based PPE detection, OPC UA Pub/Sub for wider dissemination, high-availability brokers, and policy management for domain-specific hazard models to achieve production-grade deployments beyond the single-user prototype.

REFERENCES

[1] M. I. B. Ahmed *u. a.*, „Personal Protective Equipment Detection: A Deep-Learning-Based Sustainable Approach“, *Sustainability*, Bd. 15, Nr. 18, S. 13990, Sep. 2023, doi: 10.3390/su151813990.

[2] N. A. N. M. Nazli, N. Sabri, R. Aminuddin, S. Ibrahim, S. Yusof, und S. D. N. M. Nasir, „A real-time system for detecting personal protective equipment compliance using deep learning model YOLOv5“, *Procedia Computer Science*, Bd. 245, S. 647–656, 2024, doi: 10.1016/j.procs.2024.10.291.

[3] A. Barlybayev *u. a.*, „Personal protective equipment detection using YOLOv8 architecture on object detection benchmark datasets: a comparative study“, *Cogent Engineering*, Bd. 11, Nr. 1, S. 2333209, Dez. 2024, doi: 10.1080/23311916.2024.2333209.

[4] F. Che, Q. Z. Ahmed, P. I. Lazaridis, P. Sureephong, und T. Alade, „Indoor Positioning System (IPS) Using Ultra-Wide Bandwidth (UWB)—For Industrial Internet of Things (IIoT)“, *Sensors*, Bd. 23, Nr. 12, S. 5710, Juni 2023, doi: 10.3390/s23125710.

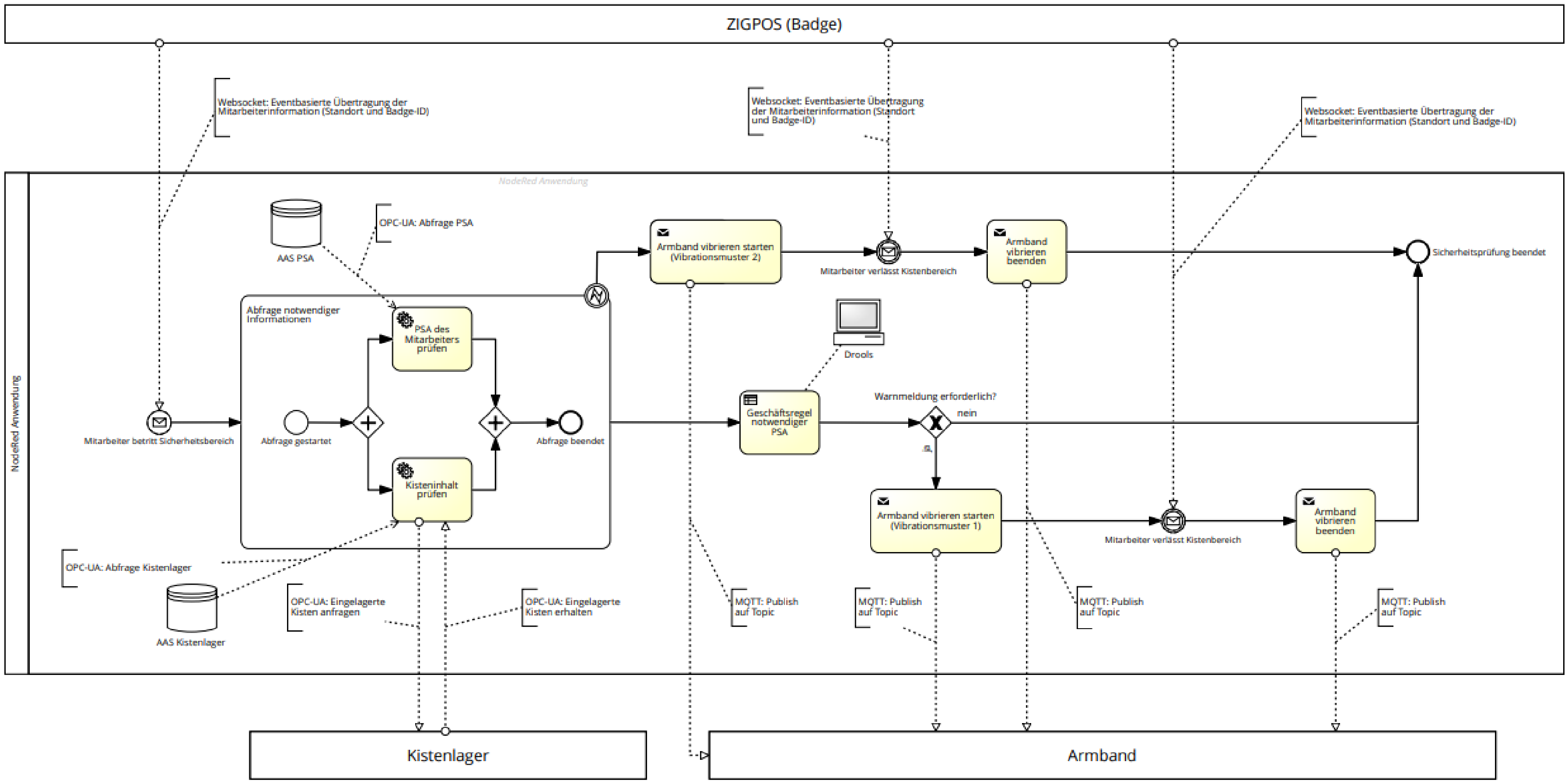
[5] International Electrotechnical Commission, *Asset Administration Shell for industrial applications – Part 1: Asset Administration Shell structure*, Dezember 2023.

[6] D. Silva, L. I. Carvalho, J. Soares, und R. C. Sofia, „A Performance Analysis of Internet of Things Networking Protocols: Evaluating MQTT, CoAP, OPC UA“, *Applied Sciences*, Bd. 11, Nr. 11, S. 4879, Mai 2021, doi: 10.3390/app11114879.

[7] K. A. Alaghbari, M. H. M. Saad, A. Hussain, und M. R. Alam, „Complex event processing for physical and cyber security in datacentres - recent progress, challenges and recommendations“, *J Cloud Comp*, Bd. 11, Nr. 1, S. 65, Okt. 2022, doi: 10.1186/s13677-022-00338-x.

[8] P. Valderas, V. Torres, und E. Serral, „Modelling and executing IoT-enhanced business processes through BPMN and microservices“, *Journal of Systems and Software*, Bd. 184, S. 111139, Feb. 2022, doi: 10.1016/j.jss.2021.111139.

Attachment: BPMN-diagram of the modelled process



Volumetric Infusion Pump Prototype

Nikoloz Tskhakaia, Mariam Tsiklauri

Abstract— Commercial infusion pumps are complex and expensive, limiting hands-on use in academic environments. To address this, we developed an Arduino-based functional prototype of a volumetric infusion pump. The system integrates a rotary encoder interface, LCD feedback, calibration capability, and safety features for detecting air bubbles and occlusions. Experiments on delivered volume showed impressive accuracy suitable for educational purposes. This low-cost, open-source design enables students to explore electronics, programming, and biomedical device engineering through hands-on practice.

Index Terms—Arduino-based prototype, Biomedical engineering, Infusion pump, Safety mechanisms.

INTRODUCTION

Infusion pumps play a vital role in clinical settings, where even small errors in volume delivery can have serious consequences. For biomedical engineering students, understanding calibration and control principles is therefore essential. However, commercial devices are costly and inaccessible for routine training.

Our prototype, developed with Arduino Uno and mechanical components costing under $50, demonstrates reliable volumetric control and safety functions. The project not only replicates key elements of professional infusion pumps but also allows students to observe the inner workings of the system, experiment with calibration, and understand how electronic control translates into medical functionality. While originally built as part of a bachelor’s thesis, the device also shows potential value as an educational demonstration platform, bridging the gap between theoretical knowledge and practical implementation.

I. RELATED WORK

Commercial infusion pumps are highly precise but are generally closed systems, preventing students and researchers from exploring their inner architecture. This lack of accessibility makes them unsuitable for training and experimentation outside clinical use.
Prior low-cost or DIY designs of infusion pumps often omit safety mechanisms or calibration features, limiting their realism and usefulness. Some prototypes focus only on basic volume delivery without addressing reliability. To our knowledge, this is the first functional infusion pump prototype at our university that combines affordability with essential features such as calibration, bubble detection, and occlusion monitoring, making it both a research tool and a learning aid.

II. PROPOSED METHOD

The pump operates with a stepper motor driving peristaltic fingers, controlled by an Arduino-based system. A rotary encoder provides user input for setting infusion parameters, while a 16×2 I2C LCD gives real-time feedback on infusion progress, calibration status, and alerts.

Safety mechanisms are implemented using two types of sensors:

1. **Air bubble detection** – The system uses an **ultrasonic air bubble sensor**, the same type used in commercial infusion pumps. It detects air bubbles in the fluid based on changes in ultrasonic wave transmission through the tubing. When a bubble passes, the sensor reading changes sharply, triggering an immediate alarm and stopping the motor.
2. **Occlusion/pressure monitoring** – The pump uses Load cell and signal amplifier for arduino to detect presseure differential properly. It continuously monitors pressure inside the tubing. Sudden increases beyond the calibrated threshold indicate an occlusion. The system halts infusion and alerts the user, ensuring safe operation.

This combination of digital control, ultrasonic air bubble detection, and pressure feedback provides a fully functional model of medical infusion pumps. Users can observe how sensors interact with motor control, demonstrating real-world safety and automation principles in biomedical devices.

III. ALGORITHM DESCRIPTION (OR SYSTEM ARCHITECTURE)

A core element of the system is calibration. The motor executes a fixed number of steps, after which the user enters the measured dispensed volume. The system then calculates steps-per-milliliter using the following code snippet:

```
float volume = enterVolumeValue(19.99, 2,
2);
if (volume >= minVolumeML) {
    stepsPerML = (float)CALIBRATION_STEPS
/ volume;
    calibrated = true;
    saveCalibrationToEEPROM();
```

This ensures that subsequent infusions deliver accurate volumes regardless of speed or duration. Once calibrated, the value is stored in memory, so the device does not require recalibration every time it is powered on.

In addition to volume calibration, the system includes **occlusion calibration** for safety validation. During this procedure, the pump runs normally while pressure sensor readings are collected to record the baseline fluctuation of the system under non-occluded conditions. The user is then instructed to intentionally occlude the tube, producing a sharp rise in pressure. This difference allows the system to compute a **threshold voltage**, which is stored and later used to reliably detect occlusions during real infusion runs.

The modular design allows each subsystem—motor, encoder, calibration logic, pressure sensing, and LCD interface—to be studied independently. Together, these elements reinforce concepts of control, feedback, and safety monitoring in biomedical devices, offering students both theoretical and practical perspectives.

.

IV. EVALUATION

Experiments were conducted with test volumes ranging from 2 mL to 20 mL at different motor speeds. Results showed deviations consistently within ±5%, which is acceptable for a prototype device, confirming both accuracy and repeatability of operation. The reliability of calibration was also tested by repeating the same infusion cycles multiple times; the results demonstrated stable delivery with minimal drift, validating the robustness of the steps-per-milliliter computation.

The safety mechanisms were further evaluated under controlled conditions. Simulated air bubbles of different sizes were introduced into the tube. The system successfully identified bubbles above its detection threshold and triggered alarms while halting the motor. Similarly, deliberate occlusions of the tubing caused measurable pressure changes, which were consistently detected by the monitoring algorithm. These results highlight that the device not only ensures volumetric precision but also offers dependable safety monitoring.

Overall, the evaluation demonstrates that the prototype achieves accuracy, repeatability, and reliability suitable for use in laboratory demonstrations and educational training.

V. CONCLUSION

This Arduino-based infusion pump combines affordability, functionality, and safety into a compact prototype. It shows how low-cost electronics and sensors can be configured to replicate essential aspects of complex medical devices. While originally created as a bachelor's thesis project, its modular design and reproducible results make it an effective platform for academic training, practical exercises, and proof-of-concept studies in biomedical engineering.

The project demonstrates that with minimal investment, students and researchers can gain direct experience with calibration principles, sensor integration, and feedback control—skills highly relevant to the development of real-world medical technologies.

Future work may include refining the mechanical design for greater durability, improving the accuracy of air bubble detection, and integrating multi-step calibration for higher precision. Adding wireless connectivity or data logging functions could further enhance its educational value. By making the design open-source, the prototype can also serve as a foundation for future research and student projects, extending its impact beyond a single academic thesis.

Wearable fall detector

A. Tskitishvili, Supervisor: M. Meskhia

***Abstract*— Falls among elderly and disabled individuals are a significant public health concern, highlighting the need for effective and accessible detection systems. This paper presents a wearable fall detection device that integrates an accelerometer and gyroscope to monitor motion in real time. A custom multi-criteria algorithm processes sensor data to accurately identify falls while minimizing false alarms. The system incorporates Wi-Fi connectivity to provide immediate emergency notifications and location tracking. Designed with low-cost, compact hardware, the prototype balances affordability with high detection accuracy. Experimental evaluation demonstrates reliable performance across various fall scenarios, suggesting its practical potential for everyday use. This work contributes a foundation for future research in assistive technologies and highlights the feasibility of deploying real-time, wearable fall detection systems that can improve safety and independence for at-risk populations.**

***Index Terms*— accelerometer, gyroscope, elderly care, fall detection, wearable devices, real-time monitoring, Wi-Fi alerts, assistive technology, sensor-based system, health monitoring.**

I. INTRODUCTION

Falls among adults aged 65 and older represent a major public health concern, as they are the leading cause of both fatal and nonfatal injuries in this population. Each year, approximately one in four older adults experiences a fall, resulting in over 14 million incidents annually. While not all falls lead to injury, nearly 37% of these events cause harm that requires medical attention or limits daily activities, contributing to an estimated nine million injuries every year [1]. Beyond the personal impact, falls impose significant burdens on caregivers and healthcare systems, both in terms of cost and resource utilization.

Given the frequency and severity of falls, reliable detection systems are essential to improve safety, prevent serious injuries, and facilitate timely assistance. Wearable fall detection devices have emerged as practical solutions, enabling continuous monitoring in daily life without restricting mobility. This paper introduces a wearable fall detection system that combines accelerometer and gyroscope sensing with a multi-criteria algorithm. The device evaluates six motion-based thresholds in real time and enters a monitoring phase to confirm true falls before issuing Wi-Fi–based notifications with the user's location. The key contributions include a cost-effective hardware design, an efficient algorithm that reduces false alarms, and rapid alert capabilities, providing a practical and accessible tool for fall prevention among older adults.

II. RELATED WORK

Fall detection has been extensively studied, with solutions generally classified into vision-based systems, wearable sensor-based systems, and smart home technologies. Vision-based approaches use cameras to monitor individuals, achieving high accuracy but raising privacy concerns and requiring controlled environments [2]. Smart home systems, including floor vibration and ambient sensors, reduce user involvement but are limited to specific locations, are expensive, and cannot monitor outdoor activities [3]. Wearable devices, which integrate accelerometers and gyroscopes, offer continuous monitoring in daily life. Many wearable systems rely on single-threshold methods, which are prone to false alarms, or complex machine learning models that demand high computational resources and increase costs [4].

Our work builds upon wearable sensor-based systems but introduces a multi-criteria algorithm that evaluates six gyroscope and accelerometer thresholds in real time. Additionally, the system incorporates a monitoring phase to distinguish between true falls and false alarms, ensuring reliable notifications. Wi-Fi connectivity enables immediate emergency alerts and location tracking, combining affordability, accuracy, and practical usability for everyday scenarios.

III. PROPOSED METHOD

The proposed fall detection system integrates a wearable hardware platform with a real-time algorithm to accurately identify fall events. The device collects motion data from an accelerometer and gyroscope along multiple axes, which is processed continuously on the embedded ESP32 microcontroller. Unlike simple threshold-based methods, our approach evaluates multiple criteria—including acceleration, orientation (pitch and roll), and Z-axis sign changes—simultaneously to distinguish true falls from normal activities, thereby reducing false positives. Upon detecting a fall, the system immediately sends a Wi-Fi–based notification with the user's location, enabling rapid response from caregivers or emergency services. This integrated design emphasizes low-cost hardware, efficient real-time processing, and user-friendly operation, providing a practical solution for continuous fall monitoring in both home and outdoor environments.

IV. ALGORITHM DESCRIPTION (OR SYSTEM ARCHITECTURE)

The fall detection algorithm system continuously monitors accelerometer and gyroscope data from the wearable device to identify potential falls in real time. Sensor readings along multiple axes are sampled at a fixed interval and pre-processed to reduce noise. The algorithm evaluates six criteria simultaneously: X-, Y-, and Z-axis gyroscope thresholds, total acceleration impact, dramatic roll changes, and Z-axis sign change. A fall is confirmed if at least three of these criteria occur within 1–1.5 seconds.

Once a potential fall is detected, the system enters a monitoring mode for 10 seconds to determine if the individual recovers. If the person returns to a normal posture, a false alarm is identified, and a recovery notification is sent. If the person remains down, an urgent alert with GPS location is transmitted via Wi-Fi to caregivers or emergency services.

The logic can be summarized in pseudocode as follows:

```
read sensor data (ax, ay, az, gx, gy, gz)
  compute roll and pitch
  evaluate six fall criteria (gyro X, gyro Y, gyro Z, total
acceleration, roll change, Z-axis sign change)
  count criteria met
  if criteriaCount >= MIN_CRITERIA_FOR_FALL:
      enter monitoring mode
      send initial alert
      if recovery detected:
          send false alarm notification
      else:
          Send urgent fall alert with GPS location
```

V. EVALUATION

We evaluated the proposed fall detection system using the ESP32-based wearable prototype in both indoor and outdoor scenarios. Sensor readings from the accelerometer and gyroscope were processed continuously on the microcontroller, with the main loop executing at approximately roughly every 100 ms (≈10 Hz sampling rate). The multi-criteria algorithm was tested across various simulated fall events and normal daily activities, including walking, sitting, and bending. The system successfully distinguished true falls from normal movements, generating only a minimal number of false alarms and demonstrating the effectiveness of the monitoring phase. Wi-Fi–based alerts, including the user's location, were sent immediately upon confirmed falls. The hardware operated reliably for extended periods on a single 18650 battery, indicating practical energy efficiency for real-world use.

VI. CONCLUSION

We presented a wearable fall detection system that integrates a multi-criteria algorithm with low-cost hardware for continuous monitoring of elderly and disabled individuals. By evaluating acceleration, orientation, and Z-axis sign changes simultaneously, the system reliably distinguishes true falls from normal activities while minimizing false alarms. Wi-Fi–based notifications with location information enable rapid response, enhancing user safety. The prototype demonstrated stable performance in both indoor and outdoor scenarios and operated efficiently on a single 18650 battery. Future work includes expanding the algorithm for broader populations, integrating additional sensor modalities, and optimizing energy consumption for longer battery life.

REFERENCES

[1] B. Moreland, R. Kakara, and A. Henry, "Trends in Nonfatal Falls and Fall-Related Injuries Among Adults Aged ≥65 Years — United States, 2012–2018," *MMWR Morbidity and Mortality Weekly Report*, vol. 69, no. 27, pp. 875–881, Jul. 10, 2020.

[2] A. Benkaci, L. Sliman, and H. N. Dellys, "Vision-based human fall detection systems: A review," *Procedia Computer Science*, vol. 241, pp. 203–211, 2024.

[3] A. P. Kaur, E. Nsugbe, A. Drahota, M. Oldfield, I. Mohagheghian, and R. A. Sporea, "State-of-the-art fall detection techniques with emphasis on floor-based systems—A review," *Biomedical Engineering Advances*, vol. 9, p. 100179, Jun. 2025.

[4] C.-K. Tseng, S.-J. Huang, and L.-J. Kau, "Wearable fall detection system with real-time localization and notification capabilities," *Sensors*, vol. 25, no. 12, p. 3632, Jun. 2025.

Forecasting State Macroeconomic Indicators with Artificial Intelligence Tools

Georgian Technical University
Zurab Tuskia

Abstract

In an era of rapid advances in artificial intelligence (AI), innovation increasingly shapes many domains of human activity. Public administration is no exception: across the world, governments are adopting AI for forecasting and planning-from the Baltic states' e-Governance platforms to Southeast Asia's "smart state" initiatives (e.g., Singapore) and national AI programs in the Middle East. The shared goal is to raise the quality of forecasts and to make planning, crisis management, and economic policy more responsive to change.

This paper presents a practical, step-by-step methodology for producing targeted, one-year forecasts of state macroeconomic indicators. The approach combines time-series analysis and neural networks with deep learning (BiLSTM + Attention), using efficient, iterative procedures that systematically increase forecast accuracy.

Kywords

Time Series; Deep Learning (BiLSTM-Attention); ETS; ARIMA; Deep Learning with feedback-nudging; Forecasting of Macroeconomic Indicators.

Methodology

Data- We use primary data from Georgia's National Statistics Office covering 17 key macroeconomic indicators. For this study, we selected eight: GDP, GDP per capita, imports, state revenues, broad money (M3), average USD/GEL exchange rate, number of employees, and agricultural production output. The sample spans 2008–2023 with quarterly observations (Q1–Q4). The task was to produce a 2024 forecast achieving an average accuracy above 90% for the chosen indicators, F=Ffull={All quarters 2008–2023}.

$$x_f^{\min} = \min_t x_{t,f}, \qquad x_f^{\max} = \max_t x_{t,f}, \qquad R_f = \max\big(x_f^{\max} - x_f^{\min},\, \varepsilon\big).$$

$$\tilde{x}_{t,f} = \frac{x_{t,f} - x_f^{\min}}{R_f} \in [0,1],$$

All 2008–2023 quarterly data were preprocessed using Min–Max normalization, then split into TRAIN (2008–2022) and TARGET (2023).

We formed sliding windows and targets for a four-quarter horizon: the previous four quarters as inputs and the subsequent four as targets (for each admissible index within TRAIN).

$$X_i = \left[\tilde{z}_i,\ \tilde{z}_{i+1},\ \ldots,\ \tilde{z}_{i+W-1}\right] \in \mathbb{R}^{W \times F}.$$

First pass (global model) - We remove a strong stationary component via a naïve "hold-last" baseline and train a global, multi-output model on the residuals. We then construct a *teacher* for future quarters and run quarter-level models with warm-starts. In brief: Full matrix, normalized by Min–Max- (2008–2023). Window width W, last index $t = i + W - 1$

$$\hat{Z} \in [0,1]^{T \times P}$$

Baseline & residuals- The "hold-last" (naive) forecast serves as a baseline; the model learns to predict residuals. p_k— **colum index in** matrix $\hat{Z}$,

$$\mathrm{naive}_{i,h,k} = \tilde{z}_{\,i+W-1,\,p_k}.$$

$$\mathrm{resid}_{i,h,k} = Y_i[h,k] - \mathrm{naive}_{i,h,k}.$$

Deep model (BiLSTM + Attention, multi-output)

$$e_t = \mathbf{v}^{\top} \tanh(\mathbf{W}\, h_t), \qquad \alpha_t = \frac{\exp(e_t)}{\sum_{j=1}^{W} \exp(e_j)}, \qquad c = \sum_{t=1}^{W} \alpha_t\, h_t.$$

Encoder: BiLSTM(64) → Dropout(0.2) → BiLSTM(32, return_sequences)
Head: Dense(64, ReLU) → Dropout(0.2) → Dense → reshape (multi-horizon outputs).
Loss: horizon-weighted MAE.

$$\mathcal{L} = \frac{1}{N}\sum_i \frac{1}{HT}\sum_{h=0}^{H-1}\sum_{k=1}^{T} w_h \left|\widehat{\mathrm{resid}}_{i,h,k} - \mathrm{resid}_{i,h,k}\right|, \qquad \sum_h w_h = 1.$$

$$\widehat{\mathrm{resid}}^{(\mathrm{ens})}_{i,h,k} = \frac{1}{M}\sum_{m=1}^{M} \widehat{\mathrm{resid}}^{(m)}_{i,h,k}.$$

Ensembling-Train multiple replicas with different random seeds and average the predictions.

Seasonal profile & teacher (grid-search)- We assume a seasonal profile based on average quarterly values on TRAIN; combine it with the residual model to create a stable *teacher* for the TARGET quarters.

$$\text{naive}_{h,k}^{\text{future}} = \tilde{z}_{\text{last},\,p_k}$$

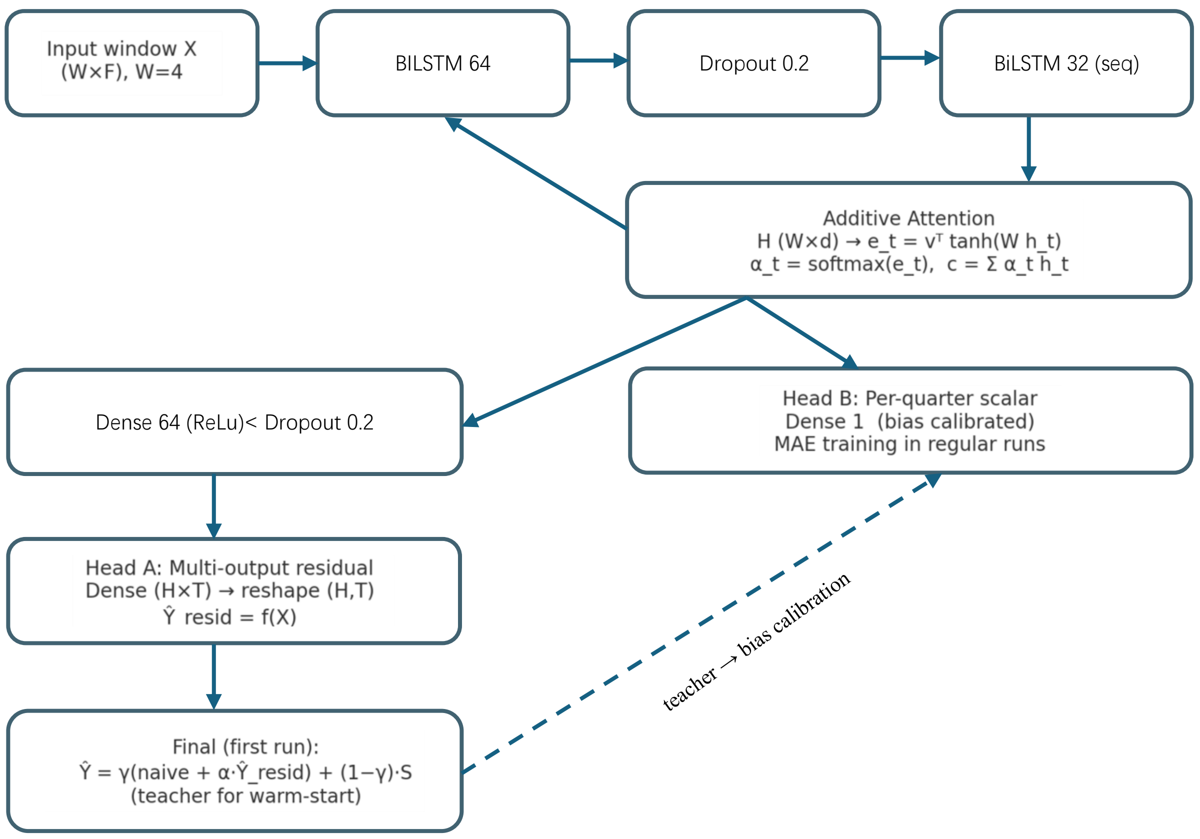
Composition- Choose among candidate compositions by minimizing MAE on TRAIN windows.

$$\widehat{Y}_{h,k}^{\text{teach}} = \gamma\Big(\text{naive}_{h,k}^{\text{future}} + \alpha \cdot \widehat{\text{resid}}_{h,k}^{(\text{ens})}\Big) + (1-\gamma)\, S[h,k],$$

Warm-start quarterly heads - Transfer the encoder to compact scalar heads (per target and quarter) and calibrate only the output bias to align with the teacher at initialization. The global model learns residual structure; blending with the seasonal component stabilizes the teacher; quarterly heads start from a well-calibrated bias.

$$\hat{y}_{k,q}(X_{\text{future}}) = \widehat{Y}_{q,k}^{\text{teach}}.$$

DL Model (BiLSTM + Attention)



Regular reruns with feedback and a nudge-controller-
For each (target, quarter) pair:

- If feedback is **GOOD**, the quarter's head is *locked* and excluded from further training.
- If **BADUP/BADDOWN**, perform local adaptation with controlled step size and a trust region.

Feedback classification- Threshold θ is set to 0.99 (i.e., 99%).

$$\mathrm{acc} = 1 - |\hat{y} - y|.$$

$$\mathrm{GOOD} \;\Leftrightarrow\; \mathrm{acc} \geq \theta, \qquad \mathrm{BADUP} \;\Leftrightarrow\; \hat{y} < y, \qquad \mathrm{BADDOWN} \;\Leftrightarrow\; \hat{y} > y,$$

Local reinforcement- For BADUP/BADDOWN, increase the weight of the last TRAIN window and perform a small, bounded update.

$$y^{\star}_{\mathrm{last}} = \begin{cases} y_{\mathrm{last}}\,(1+\delta), & \mathrm{BADUP} \\ y_{\mathrm{last}}\,(1-\delta), & \mathrm{BADDOWN} \end{cases}, \qquad \delta = \texttt{FEEDBACK\_SHIFT},$$

Bounded nudge without TARGET leakage -Use an adaptive base push; a seasonal *anchor*; a minimal step; and a trust corridor around the planned target. In the late *POLISH* phase, updates are one-sided (BADUP only upward; BADDOWN only downward).

$$\mathrm{BADUP}: \; p_{\mathrm{nudged}} = p + k(1-p), \qquad \mathrm{BADDOWN}: \; p_{\mathrm{nudged}} = p - kp,$$

$$p_{\mathrm{anch}} = (1-\lambda)\, p_{\mathrm{nudged}} + \lambda\, S_q, \qquad \lambda \in [0,1].$$

Using the controlled sequence of steps "push → anchor → minimal step → confidence corridor," and **without** training on the current TARGET year's data (2023 in this case), we achieved **GOOD** values of the feedback metric for all quarters and saved the stable models into a single model file. Using the stored quarterly weights ("GOOD-locks"), we built the forecast for the next year (2024 in this case) in **RAW** units. We formed $X_{\mathrm{future}}$from the last $W = 4$quarters of the full history (TRAIN + TARGET). For each target $k$and quarter q, we loaded the weights and computed the normalized forecast $\hat{y}^{\mathrm{norm}}_{(k,q)}$. Transition to the RAW space:

$$\hat{y}^{\mathrm{raw}}_{(k,q)} = \hat{y}^{\mathrm{norm}}_{(k,q)} \cdot R_{p_k} + x^{\mathrm{min}}_{p_k},$$

where R_{p_k} and $x_{p_k}^{\min}$ are the min–max normalization parameters for the corresponding target column p_k.

Results

With the proposed methodology, the **average forecast accuracy for 2024 reached 93.22%**. To benchmark, we uploaded the same macro data to emulated models on several platforms (ChatGPT, Amazon AWS, Microsoft Azure) to obtain their 2024 forecasts. We then compared quarterly accuracies per indicator and the overall average:

Feature	Year	Quarter	Forecast Accuracy GPT CHAT %	Forecast Accuracy AMAZON AWS %	Forecast Accuracy MS AZURE %	Forecast Accuracy Our Project %
GDP (MILLION $)	2024	I	73.61	92.01	92.01	97.88
GDP (MILLION $)	2024	II	71.27	91.37	91.37	97.37
GDP (MILLION $)	2024	III	66.78	86.93	86.93	88.58
GDP (MILLION $)	2024	IV	69.16	90.45	90.45	92.89
GDP PER CAPITA $	2024	I	75.76	90.99	90.99	98.16
GDP PER CAPITA $	2024	II	72.71	90.35	90.35	96.06
GDP PER CAPITA $	2024	III	67.93	85.96	85.96	88.67
GDP PER CAPITA $	2024	IV	70.15	89.85	89.85	90.57
IMPORTS (MILLION $)	2024	I	82.23	98.58	98.58	92.02
IMPORTS (MILLION $)	2024	II	73.37	92.21	92.21	97.44
IMPORTS (MILLION $)	2024	III	73.09	92.15	92.15	95.57
IMPORTS (MILLION $)	2024	IV	71.70	84.23	84.23	85.33
STATE REVENUES (MILLION $)	2024	I	60.12	82.50	82.50	84.32
STATE REVENUES (MILLION $)	2024	II	63.36	92.03	92.03	97.36
STATE REVENUES (MILLION $)	2024	III	66.22	88.55	88.55	92.45
STATE REVENUES (MILLION $)	2024	IV	67.91	90.70	90.70	77.65
BROAD MONEY M3 (MILLION $)	2024	I	74.64	87.71	87.71	93.84
BROAD MONEY M3 (MILLION $)	2024	II	74.81	88.31	88.31	94.03
BROAD MONEY M3 (MILLION $)	2024	III	72.64	87.19	87.19	93.44
BROAD MONEY M3 (MILLION $)	2024	IV	72.68	89.64	89.64	90.56
AVERAGE EXCHANGE RATE USD-$	2024	I	82.75	95.88	97.81	92.25
AVERAGE EXCHANGE RATE USD-$	2024	II	85.63	95.62	95.99	94.47
AVERAGE EXCHANGE RATE USD-$	2024	III	83.75	98.89	99.06	98.43
AVERAGE EXCHANGE RATE USD-$	2024	IV	84.19	97.46	98.06	98.99
NUMBER OF EMPLOYEES	2024	I	96.18	95.56	95.56	98.21
NUMBER OF EMPLOYEES	2024	II	96.98	95.82	95.82	96.85
NUMBER OF EMPLOYEES	2024	III	98.17	96.14	96.14	97.10
NUMBER OF EMPLOYEES	2024	IV	99.48	96.36	96.36	96.72
AGRICULTURAL PRODUCTION OUTPUT (MILLION $)	2024	I	86.54	95.90	95.89	89.29
AGRICULTURAL PRODUCTION OUTPUT (MILLION $)	2024	II	81.88	96.39	96.39	88.65
AGRICULTURAL PRODUCTION OUTPUT (MILLION $)	2024	III	90.77	96.17	96.17	92.48
AGRICULTURAL PRODUCTION OUTPUT (MILLION $)	2024	IV	83.96	90.28	90.28	95.45
Average Forecast Accuracy			77.83	91.94	92.04	93.22

What's Innovative

Our methodology blends several practices known from classical modeling, but using them as a unified ensemble yields distinctive advantages:

1. **Two-stage architecture ("global encoder → quarterly heads").**
   Rather than training "one big network," we train a single multi-task (BiLSTM + Attention) model on residuals, transfer its encoder into small quarterly heads (per target and quarter), and then perform calibration with reinforcement-style updates.
2. **Controlled, monotonic correction without data leakage.**
   In reruns we do *not* feed TARGET-year data to the network. Instead, we adjust only the output bias of the quarterly head with small, controlled steps toward the planned point. Modes (TURBO/AGGR/POLISH) adapt automatically based on the shortfall to the GOOD threshold; the nudge intensity and trust interval width are adjusted accordingly. Once a (target, quarter) crosses the threshold, we lock that head, preventing later degradation.
3. **Micro-models ("quarter × target") instead of a monolithic head.**
   Quarters behave differently in practice. Splitting heads by quarter yields natural localization and faster convergence to accurate forecasts.

Conclusion

In today's environment-where economic stability and well-targeted investment decisions are prerequisites for national development-forecasting plays a crucial role. Using macroeconomic data from 2008–2023, we set out to build a model capable of rationally predicting 2024 indicators (we chose 2024 specifically to allow straightforward accuracy verification). The challenge required not only capturing historical trends but also uncovering the internal logic and interrelations among those trends. Our streamlined, practical pipeline couples time-series analysis with a neural baseline and then refines it through carefully controlled deep-learning adjustments, reaching 90–95% accuracy. The resulting next-year forecasts achieved **93.22%** average accuracy in this study-useful for planning and for optimizing the management of public resources.

References

1. 2021 - Hyndman & Athanasopoulos "Forecasting: Principles and Practice (FPP3)"
2. 2023 - Defu Cao, Yixiang Zheng, Parisa Hassanzadeh… "Large Scale Financial Time Series Forecasting with Multi-faceted Model"
3. 2014 - Bahdanau, Cho, Bengio "Neural Machine Translation by Jointly Learning to Align and Translate",

4. 2002 - Hyndman, R. J., Koehler, A. B., Ord, J. K., & Snyder, R. D. A state space framework for automatic forecasting using exponential smoothing.
5. 2015 - Box, G. E. P., Jenkins, G. M., Reinsel, G. C., & Ljung, G. M. Time Series Analysis: Forecasting and Control