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## DATA ACQUISITION SYSTEM FOR PROSTHETIC MOTION SIMULATION

## СИСТЕМА ЗБОРУ ДАНИХ ДЛЯ МОДЕЛЮВАННЯ ДИНАМІКИ РУХУ ПРОТЕЗІВ

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**Abstract.** The human hand, with its complex sensory capabilities, is an integral part of our daily interaction with the world. This remarkable organ contains a variety of natural sensors that enrich our experience by allowing us to perceive touch, determine position, and sense temperature. These natural sensors work in harmony to provide a rich sensory experience, enabling us to distinguish different textures, assess grip strength, identify the position of our fingers without visual observation, feel the temperature of objects upon contact, and detect whether surfaces are wet or dry. This intricate sensory system forms the foundation of our ability to manipulate objects, explore our environment, and interact with the people around us. In this article, we summarize the findings from research conducted in our laboratories over an extended period and present our conclusions regarding the restoration of sensory data acquisition related to movement trajectories and positions of hand parts. The combination of hardware solutions for sensors with data accumulation and visualization technologies opens new avenues for enhancing sensory feedback in prosthetic hands, promising improved functionality and a closer approximation to the natural sensory experience for individuals with amputations.

**Анотація.** Людська рука з її складними сенсорними можливостями є невід'ємною частиною нашої щоденної взаємодії з навколишнім світом. Цей дивовижний орган містить різноманітні природні рецептори, які збагачують наш досвід, дозволяючи сприймати дотик, визначати положення та відчувати температуру. Ці природні сенсори працюють злагоджено, забезпечуючи багатий чуттєвий досвід, що дає змогу розрізняти текстури, оцінювати силу захвату, ідентифікувати положення пальців без візуального спостереження, відчувати температуру об'єктів при контакті та визначати вологість поверхонь. Ця складна сенсорна система є основою нашої здатності маніпулювати предметами, досліджувати довкілля та взаємодіяти з людьми навколо нас. У цій статті ми узагальнюємо результати досліджень, проведених у наших лабораторіях протягом тривалого періоду, і представляємо висновки щодо відновлення збору сенсорних даних, пов'язаних із траєкторіями руху та положенням частин руки. Поєднання апаратних рішень для сенсорів із технологіями накопичення та візуалізації даних відкриває нові шляхи для вдосконалення сенсорного зворотного зв'язку в протезах рук, обіцяючи покращену функціональність і максимальне наближення до природного сенсорного досвіду для осіб з ампутаціями.

**Keywords:** data acquisition, prosthetic motion, simulation, biomechanics, kinematics, prosthetic devices, user interaction.

**Ключові слова:** збір даних, рух протеза, симуляція, біомеханіка, кінематика, протезні пристрої, взаємодія з користувачем.

### I. INTRODUCTION

The processing of sensor data in prosthetics is a rapidly evolving field that holds significant implications for enhancing the functionality and user experience of prosthetic devices. The relevance of this research lies in the increasing prevalence of limb amputations and the growing demand for advanced prosthetic solutions that can seamlessly integrate into users' daily lives. As technology advances, the ability to collect and analyze data from various sensors embedded in prosthetic



devices becomes crucial for improving control systems, ensuring better adaptability, and ultimately enhancing the quality of life for individuals with disabilities.

The primary objective of this study is to investigate the methodologies and technologies involved in processing sensor data from prosthetic devices, focusing on how these processes can be optimized to improve user interaction and control. This research aims to develop a comprehensive framework that integrates sensor data processing techniques with machine learning algorithms to facilitate more intuitive and responsive prosthetic movements.

The object of this research encompasses the various types of sensors utilized in prosthetic hands, including accelerometers, gyroscopes, and myoelectric sensors. These sensors play a vital role in capturing real-time data related to user movements and intentions. The subject of this study is the algorithms and techniques employed to process this sensor data effectively, transforming raw measurements into actionable commands that enhance the functionality of prosthetic devices.

By addressing these aspects, this research not only contributes to the academic understanding of sensor data processing in prosthetics but also aims to provide practical solutions that can be implemented in clinical settings, ultimately benefiting users through improved device performance and user satisfaction.

## II. LITERATURE ANALYSIS

Sensors in bionic prostheses play a crucial role in ensuring their functionality and adaptation to user needs. They facilitate data collection that allows for accurate interpretation of muscle signals and their conversion into movements. It is essential to analyze existing research and aspects of data accumulation from prosthetic sensors. The automation of the electric drive of hand prostheses is being explored by many researchers. Studies describe various control systems for electric drives that utilize accumulated signals to distinguish movements, thereby enhancing the efficiency of prosthetic control. Data collection on the use of prostheses in home settings can aid in developing new solutions for users. Research [1] has shown that users are willing to share data about their prosthetic usage with clinicians. The SocketSense project [2] focuses on integrating sensor technologies into prosthetic sockets for monitoring dynamic conditions and optimizing their fit to individual user needs. Additionally, research [3] presents an open dataset containing information about the kinematics of transfemoral prosthesis users, allowing for the analysis of their movements and improvement of prosthesis design.

Sensing and control technologies for prosthetic hands, including their application in clinical studies and evaluations, have been discussed in recent paper [4]. The assessment of prosthetic effectiveness often relies on subjective user feedback, which can lead to data bias. Objective metrics may lack clarity or fail to account for all aspects of prosthesis functionality. Furthermore, data collection [5] is hindered by several factors, such as limited access to technologies and issues with sensor battery life. However, potential solutions to these problems or alternative approaches to data collection are not discussed. Research [6] proposes a new method for determining functional and non-functional use of upper limbs in amputee patients. This study may have limitations due to the use of restricted activity assessment methods for prosthetic users. While the authors propose a new approach to measuring functional use, the absence of a comprehensive analysis that includes both quantitative and qualitative data may lead to an incomplete understanding of actual patient activity. An emphasis on quantitative indicators, such as movement counts or duration of prosthesis use, may not reflect the quality of task performance or user satisfaction.

Researchers [7] discuss various approaches to prosthesis management, including machine learning algorithms and adaptive control systems that can improve the accuracy and responsiveness of prostheses to user commands. Studies [8] conducted in controlled laboratory conditions may not account for real-world variables that can affect sensory feedback and user experience, such as external factors or individual user differences. The use of acoustic and force sensors [9] in devices like the Southampton Hand enables automatic responses to changes in the environment. The effectiveness of proposed slip detection strategies may depend on the limitations of current sensor technologies. If the sensors used in the research have limited sensitivity or reliability, this could impact the accuracy of slip detection and consequently affect the performance of the prosthetic hand. Evaluations conducted on unilateral transfemoral amputees may be limited in scope, necessitating broader clinical trials to validate results.

The sensors data acquisition in bionic prostheses is a vital aspect of their development and enhancement. Research in this area contributes to creating more adaptive and sensitive devices that can significantly improve users' quality of life.

## III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

### 3.1. The interaction between biomechanical and neural systems in the control of the whole body.

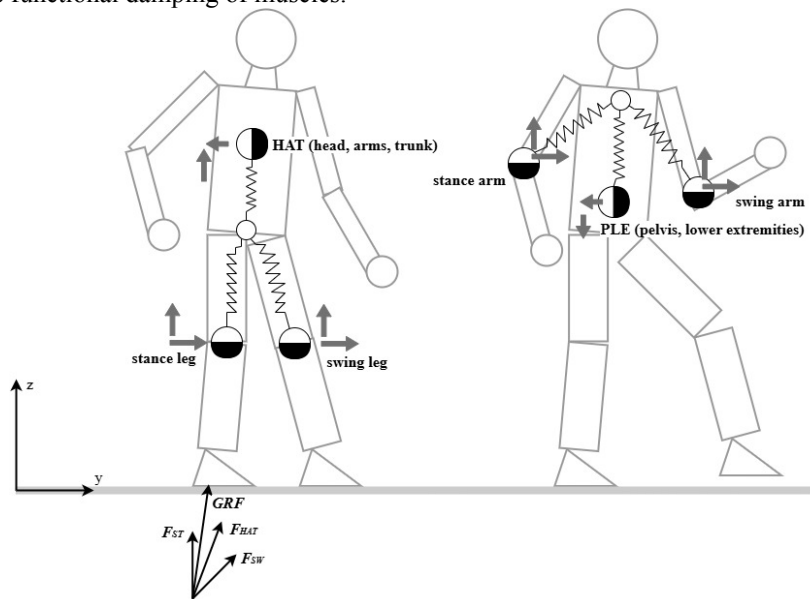
The necessary coordination of distributed body masses during movement can be illustrated with a simple model. Imagine two masses aligned vertically and connected by linear springs (Fig. 1). These masses can represent leg segments, such as the stance leg and the swing leg, as well as the torso, which includes the upper body, head, arms, and trunk. For instance, during walking, we cyclically move the masses up and down.

Even if the spring stiffness is adjusted almost perfectly, the masses will gradually fall out of phase due to inertia and system dynamics. In biology, such mechanical interference can pose a significant challenge to effective movement control. To illustrate this principle using an example from civil engineering, consider walking on a flexible bridge with a resonance frequency close to the natural frequency of your body during walking. This situation can be very difficult to control and uncomfortable. In this case, lateral oscillations of the bridge were caused by the synchronization of individual



walking patterns, leading to the closure and redesign of the bridge due to unwanted synchronization.

To synchronize the movement of masses, a small amount of damping can be added to the springs. In reality, this effect is achieved through the functional damping of muscles.



**Fig. 1. The mechanical connection between the upper body (head, arms, and trunk) and the lower body (swing leg and stance leg) during walking.**

However, damping can reduce the amplitude of initial oscillations. To maintain continuous movement, the damping must be compensated for by active muscle control. By adjusting the activation signal, the spatiotemporal pattern of muscle forces generated by the Central Neural System (CNS) can be modulated to keep the musculoskeletal system in constant motion. For cyclic movements, these neuromechanical patterns require proper tuning by the neural system, which can result in coordinated movements of different body parts, as observed during locomotion. Without such active contribution to damping control, it is impossible to achieve the successful functioning of two or more spring-mass systems if they are connected to the same base, as in the case of the vertebra being inserted into the hip.

In biological systems, the CNS achieves damping control by learning when and which muscles to activate to the required degree. To do this, the CNS must track the phase of the cyclic movement and update the muscle activation patterns accordingly. All sensors distributed throughout the body are utilized to monitor these phases and the biomechanical effects generated by muscle activity patterns. Sensory information sent to the spinal cord influences the state of the spinal interneuron network and becomes a key component of the neuromechanical pattern generator. Through the learning process, the CNS is able to approximate optimal neuromechanical templates for actions such as running, jumping, walking, and more. An efficient neural system should allow for a good approximation of these neuromechanical activity models or functions with minimal costs in terms of neural circuitry infrastructure.

If a system aims to minimize the utilization of neural network capabilities for each required function, the CNS can generate more movement patterns or movement parameters using limited resources. Spinal interneurons are closely connected to the cerebellum, which plays a crucial role in learning and adding additional motor components or parameters to movement models to achieve a higher level of control. For example, maintaining balance is a constant challenge in nature, where smooth horizontal surfaces, often used in laboratories, are rare. In natural conditions of biological locomotion, information from the vestibular system in the inner ear is one of the key inputs that must be continuously integrated into the neuromechanical pattern generator.

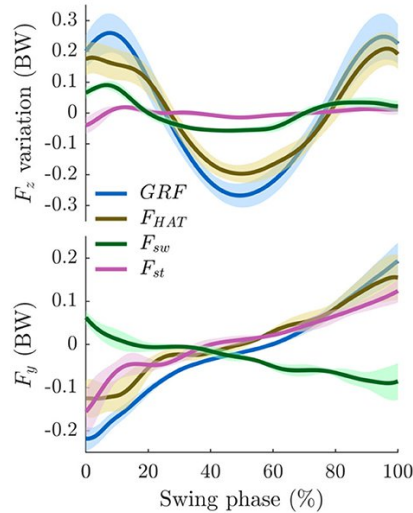
### 3.2. Biomechanical observations

When the body moves, inertial forces act between its various masses. The body's mass can be defined as the mass of any individual body segment. Studying the interaction and coordination of the upper body, swing leg, and stance leg will help us better understand the mechanisms of connection between different masses/parts of the body during walking. A key feature of the dynamics of human walking is that the swing leg moves in phase with the upper body in the vertical direction but out of phase with it in the horizontal direction. The inertial dynamics in the stance leg are less pronounced. These mechanisms offer several functional advantages: they help generate inertial vertical forces (leading to ground reaction forces), reduce the risk of slipping, and make the walking speed more stable, which contributes to energy efficiency.

The Fig. 2 illustrates the contribution of the movements of the GRF (Ground Reaction Forces), swing leg, and stance leg to the overall ground reaction force during the single-support phase of walking, i.e., when the swing leg is in the air. The GRF and swing leg create synchronous M-shaped force patterns in the vertical direction ( $F_z$  in Fig. 2).



Since the swing leg must move forward, inertial forces act on the entire body. The muscles must adequately respond to these forces to provide the necessary damping. The swing leg contributes about 25% to the formation of the M-shaped vertical component of the GRF (Fig. 2). The vertical force generated by the stance leg does not exhibit a pronounced M-shape, as it remains almost constant, meaning it has little impact on walking dynamics. In the horizontal direction, the swing leg creates a non-phase structure of forces, while the stance leg generates a co-phase force pattern relative to the GRF force ( $F_y$  in Fig. 2). Thus, the forces of the swing leg and stance leg in the horizontal direction counterbalance each other, reducing the risk of slipping. Therefore, the results show that the movement of the swing leg does not worsen but rather supports the dynamics of walking.



**Fig. 2. The forces are normalized to body mass (BM).  $F_z$  and  $F_y$  represent the inertial forces in the vertical and horizontal directions, respectively.**

These conclusions highlight the importance of the structure of biomechanical walking patterns for efficient movement. Using these patterns, it is possible to generalize the dynamics of the human body, which has a large number of degrees of freedom, into models with a limited number of functional parameters. In the stance leg, with an extended knee angle, the stiffness of the leg is determined not only by the muscles of the stance leg but also by the coordinated action of the swing leg and upper body. Variations in this composition can differ depending on the direction, such as vertical versus horizontal forces. The swing leg contributes to the overall "leg stiffness," which is represented in the inverted pendulum model with spring loading, describing the motion of the body's center of mass during movement and the verticalization of ground reaction forces, as described in the virtual pivot point model. This explains the requirements for maintaining postural balance, i.e., keeping the body in an upright position during movement. Therefore, the swing leg functions as an "auxiliary system" to achieve locomotor sub-functions, such as maintaining position and balance.

### 3.3. Prosthetic motion modeling

The development of technologies in the field of prosthetics plays a crucial role in improving the quality of life for people with disabilities. Modern technologies open up new possibilities for creating prostheses that can accurately mimic the movements of the human body. Traditional prostheses often face problems such as poor controllability and lack of sensory feedback. The lack of tactile sensory information forces prosthetic users to rely on random visual and auditory signals, leading to discomfort and limitations in daily life. At the same time, smart prostheses, which are controlled by microprocessors, provide significant advantages to users, including enhanced functionality and better adaptation to daily life.

Using advanced technologies and algorithms, the hardware-software system for motion modeling will collect data from numerous sensors placed on the prosthesis. This information will help improve the prosthesis control algorithms, ensuring more natural and intuitive movement.

Traditional amputation affects both efferent and afferent signaling. While efferent signaling can still trigger muscle contractions, the muscles themselves are unable to generate the natural dynamics of the limb due to surgical placement aimed at preventing neuromas and ensuring optimal prosthetic attachment. Afferent proprioceptive signaling is negatively impacted by the pathological changes at muscle insertion sites and the loss of distal tissues. This process is further complicated by mechanisms such as phantom limb pain in the amputated limb.

Illustrative muscle reinnervation and targeted sensory reinnervation are specialized neuro-muscular and skin-mechanoneuronal interface techniques applied to individuals with amputations, aimed at controlling muscles and providing somatosensory feedback. During targeted muscle reinnervation, foreign peripheral nerves are surgically



connected to denervated but vascularized muscles. In targeted sensory reinnervation, sensory nerves or their bundles are directly connected to skin tissue or to nerves that innervate the skin.

During the creation of regenerative peripheral nerve interfaces, denervated and severed muscle grafts wrap around the cut motor nerves. These grafts then begin to reinnervate over several months, with the aim of functional restoration. The agonist-antagonist myoneurological interface involves the mechanical connection of muscles that act as agonists and antagonists to transmit signals both from the brain to the muscles (efferent pathway) and in the reverse direction (afferent pathway). This connection allows native mechanoreceptors, such as muscle spindles and Golgi tendon organs, to provide proprioceptive feedback through the stretching mechanisms of muscles and tendons, according to their functional needs.

Using described platform, users will benefit from the following advantages:

- Improved control: Prostheses will become more sensitive to user commands, enabling more precise and controlled use.
- Sensory feedback: Users will be able to feel the prosthesis as part of their body, significantly improving adaptation and comfort. Tactile feedback will enable faster control, helping to reduce compensatory reactions after unexpected changes in weight.
- Adaptation to different usage conditions: Prostheses will adapt to various conditions, ensuring high efficiency in any situation.

#### IV. RESULTS

For the development of a hardware-software system for prosthetic motion simulation, various technologies and tools are utilized. Let's explore the key technologies used to achieve the main goal of the study, which is to create a system for simulating prosthetic movement. The MPU6050 module (Fig. 4) was selected for the research. This module includes two main components: a gyroscope and an accelerometer (an accelerometric sensor). The gyroscope measures the rotational speed (rad/s), which represents the change in angular position over time along the X, Y, and Z axes (roll, pitch, yaw) (Fig. 4). This enables the determination of an object's orientation.

The sensor's power supply can operate at voltages of 3.3V and 5V. The GND pin has standard functionality. The SCL and SDA pins are used for I2C communication. The XDA and XCL pins are used to connect additional I<sup>2</sup>C sensors to the MPU6050. The AD0 pin is used to change the I2C address. The INT pin can indicate the presence of new measurement data. The software development for the ESP8266 NodeMCU board, an inexpensive and affordable device [10], was carried out using the Arduino IDE. There are various ways to obtain sensor readings. The Adafruit MPU6050 library is used. To use this library, the Adafruit Unified Sensor and Adafruit Bus IO Library must also be installed. The ESP8266 must be connected to the MPU6050 sensor by wiring the SCL pin to GPIO 5 and SDA to GPIO 4, as shown in Fig. 4.

Let's examine how the program code works as part of a program for the ESP8266 microcontroller, which is used for Wi-Fi connectivity, executing HTTP requests, and working with the MPU6050 accelerometer/gyroscope sensor. The ESP8266WiFi.h library enables the ESP8266 microcontroller to connect to a Wi-Fi network. The WiFiClient.h library is used to create a client that can connect to servers over Wi-Fi.

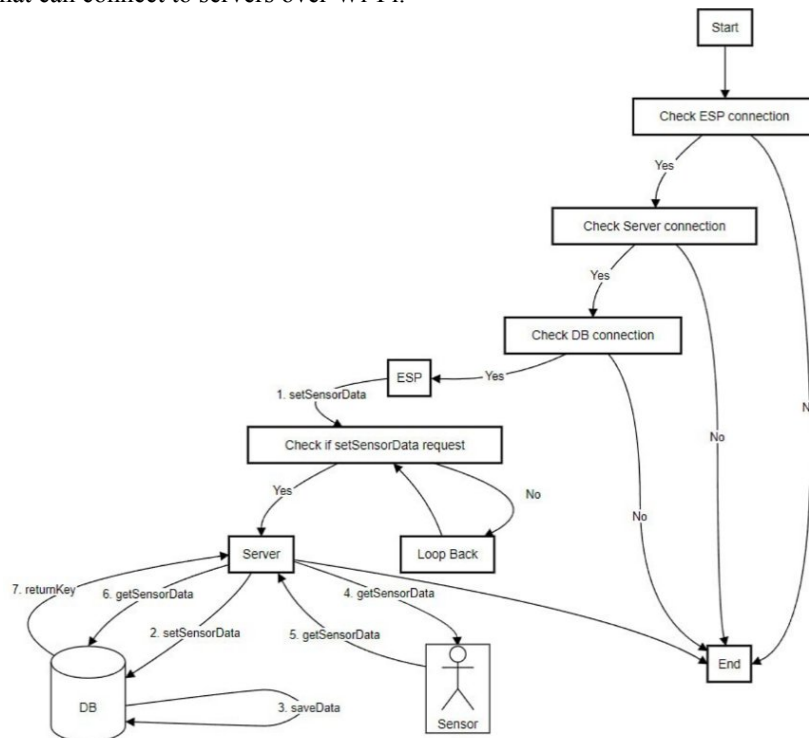


Fig. 3. Flowchart for data acquisition system software.



The ESP8266HTTPClient.h library is used for executing HTTP requests (GET, POST, etc.) with the ESP8266, simplifying work with the HTTP protocol. The ArduinoJson.h library is used for parsing and generating JSON data, which is convenient for data exchange with web servers. The WiFiClientSecureBearSSL.h library is used to create a secure Wi-Fi client using SSL/TLS, ensuring a protected connection for data transmission.

The Adafruit MPU6050.h library is responsible for working with the MPU6050 sensor, which includes an accelerometer and a gyroscope, and provides an interface for reading sensor data. The Adafruit Unified Sensor library is a general-purpose sensor library that ensures a standardized interface for reading sensor data. The Wire.h library is designed for working with the I2C bus, which is used for connecting and communicating with peripheral devices such as the MPU6050. The research and debugging process confirmed that the set of libraries enables the ESP8266 microcontroller to connect to Wi-Fi, process JSON data, interact with web servers, and accumulate sensor data obtained from the MPU6050 sensor.

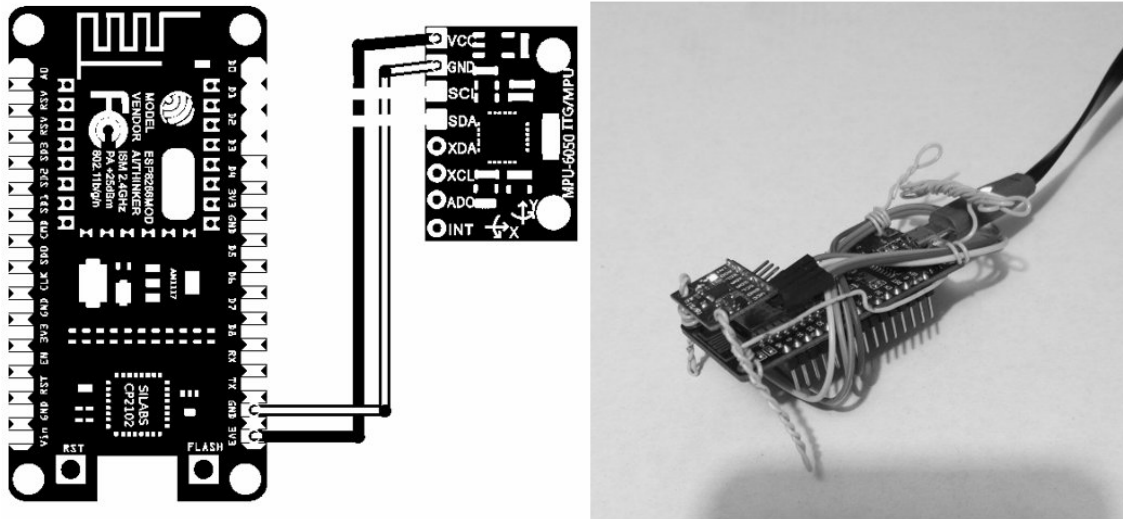


Fig. 4. Mockup and prototype based on ESP8266 NodeMCU with MPU6050

To ensure reliable data transmission, the program code for the ESP8266 microcontroller sets variables for connecting to the Wi-Fi network and interacting with the web server. The mpu object will be used to read data from the MPU6050 sensor. The code will include logic for connecting to Wi-Fi, gathering data from the sensor, and sending this data to the specified server. The Adafruit MPU6050 mpu; line creates an object mpu for interacting with the MPU6050 sensor using the Adafruit library. The Fig. 3 shows functions that were created to store the SSID of the Wi-Fi network that the ESP8266 will connect to. To make these functions work, you need to fill in the variables: one for the SSID of the Wi-Fi network, one for the Wi-Fi password, and one for the URL of the server (for example, a Node.js application) to which the ESP8266 will send data. You also need to fill in the server URL and a variable to store the sensor ID. This sensor ID can be used for identifying the sensor if multiple sensors are sending data to the same server. The motion sensor prototype software configures a secure Wi-Fi connection, initializes the MPU6050 sensor, and can output initialization results to the serial monitor in debugging mode. The client object of type WiFiClientSecure is necessary to establish a secure connection via SSL/TLS. The std::unique\_ptr is used to ensure automatic memory management and prevent memory leaks. The http object of type HTTPClient is used to make HTTP requests (GET, POST).

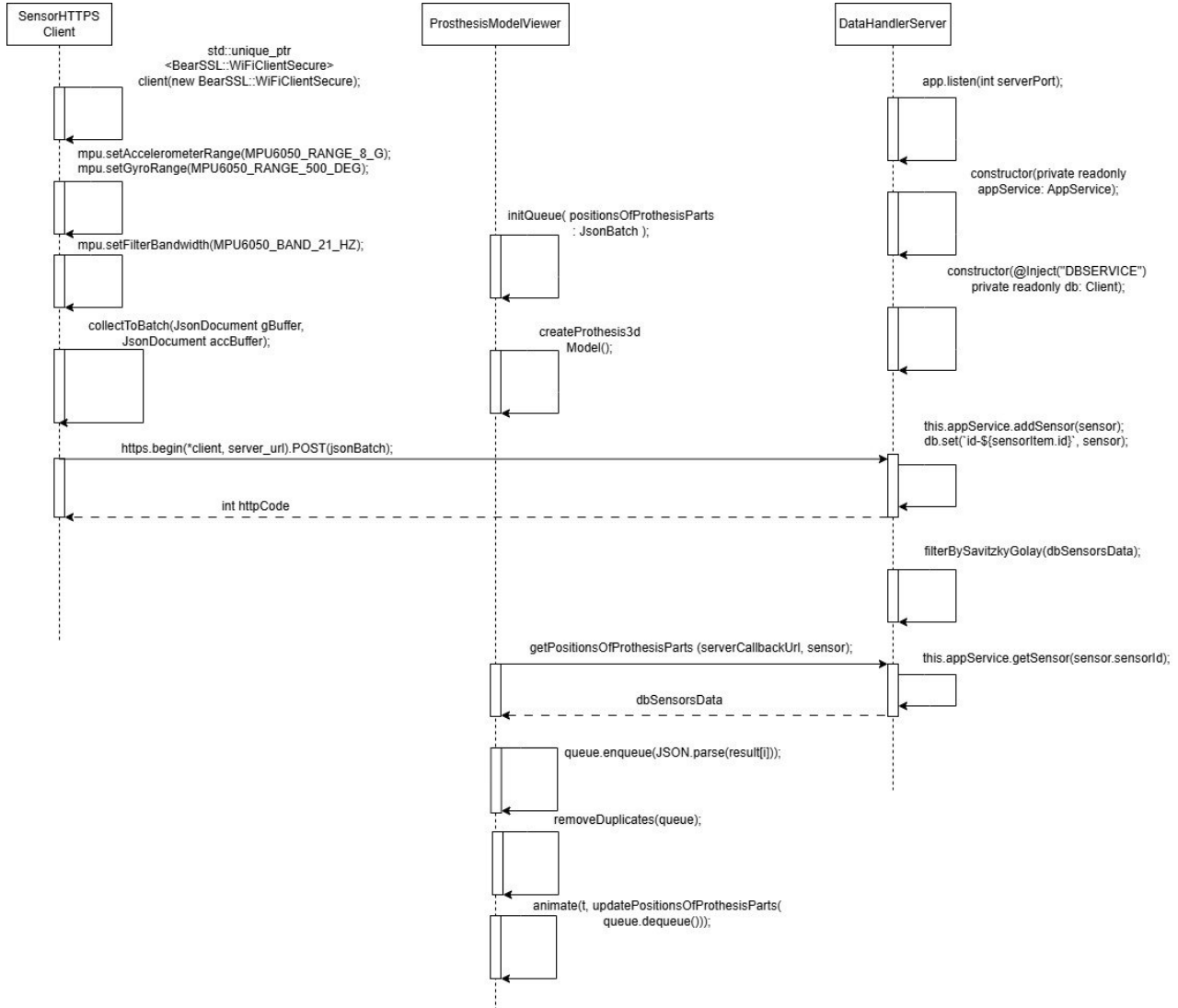
For the correct operation of the entire architecture of the complex network solution, the program code sets the MPU6050 accelerometer measurement range to  $\pm 8G$  and outputs a message to the serial monitor indicating the set range. The technical specialist responsible for servicing the motion sensor collection for prosthetic limbs checks the current accelerometer measurement range and displays the corresponding value on the serial monitor.

This allows the technical specialist to ensure that the accelerometer's range is properly configured and matches the expected value. For proper operation, the MPU6050 gyroscope measurement range must be set to  $\pm 500$  degrees per second, with the ability to view a message about the set range on the serial monitor. The implemented software enables the technical specialist to verify that the gyroscope range is correctly configured and matches the expected value. The software of the prosthetic limb motion simulation system (Fig. 5) includes network architectural solutions and components to ensure the functionality of the server application. The dependencies required for the operation of our server application, the configuration of the server environment, request processing methods, database interaction, and measures to ensure data security are outlined. The server application uses the following essential dependencies, which are specified in the package.json file.

The @nestjs/common library contains general utilities and classes used in NestJS applications, which simplify the development of server applications based on a modular architecture. The core package @nestjs/core of the NestJS



framework provides tools for creating and managing servers, enabling the organization of code into modules, controllers, and services. The @nestjs/platform-express platform integrates Express.js with the NestJS framework, allowing the use of all Express capabilities for handling HTTP requests. The lightweight @replit/database is used for cloud data storage and provides a simple interface for interacting with the Replit database. The reflect-metadata library utilizes metadata in TypeScript and JavaScript. It is necessary for decorators, which are widely used in NestJS for defining routing, dependency injection, and other aspects. The rxjs library is essential for working with asynchronous events and data streams, providing tools for reactive programming. It is used in NestJS for managing asynchronous operations and data streams.



**Fig. 5. Sequence diagram of interaction between components of the prosthetic motion simulation system**

To configure the server environment, the following steps implemented:

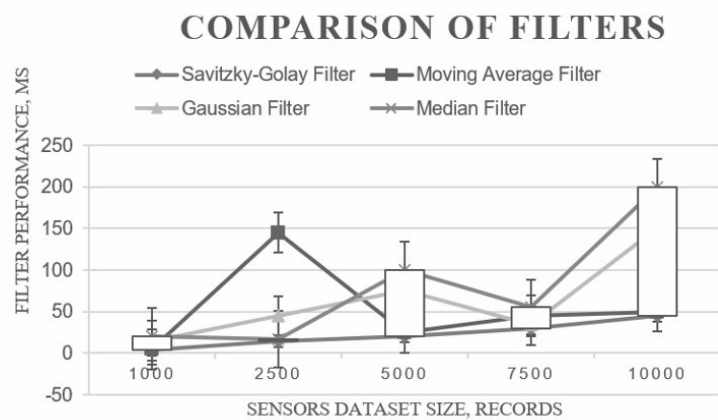
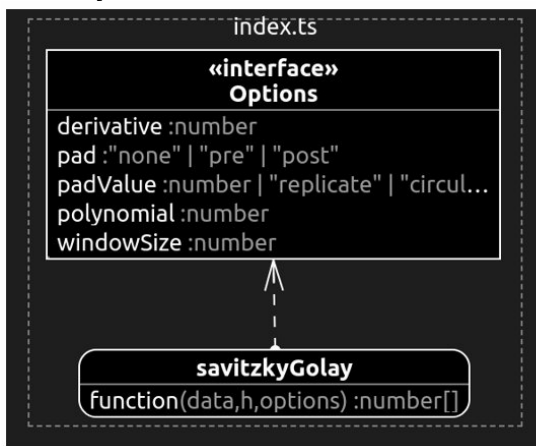
- Install the required dependencies using the command npm install.
- Create initial project files, including the configuration file for the server, modules, controllers, and services.
- Configure the database and ensure its integration with the application.
- The server application will handle HTTP requests sent by client applications. The server application will include defining routes to handle different types of requests (GET, POST, PUT, DELETE). During operation, controllers will be created to process the requests and send responses to the client, while the service layer will handle business logic and interact with the database.
- The application will use the Replit database for storing and retrieving data. The database connection has been configured. Data models have been created to structure the information. CRUD operations (Create, Read, Update, Delete) have been implemented using services to interact with the database.
- To ensure the security of the server application, methods for user authentication and authorization, protection against SQL injection and other types of attacks, and data encryption during transmission between the server and clients have been implemented.



The structure of the server-side software is as follows:

- src/main.ts: This is the main executable file of the project, which creates the server, starts its main execution loop, and also performs the necessary configurations.
- src/app.service.ts: This file contains the service logic for working with sensors. It handles their addition, provides getters, and includes a method that returns a message indicating the successful startup of the project.
- src/app.module.ts: This file contains the logic that links the application service and configures dependency injection for the database service.
- src/app.controller.ts: This file defines the controller for the NestJS application, which contains the logic for handling HTTP requests related to the sensors.
- src/app.controller.spec.ts: This file defines the test file for the AppController in the NestJS application. It uses the @nestjs/testing module to create a test environment and ensures the testing of the controller's functionality.
- src/dto/sensor.dto.ts: This file defines the SensorDto interface for transmitting sensor data in the NestJS application. The interface ensures the typing of sensor objects that will be used in the application.

The Savitzky-Golay filter is a digital filter (Fig. 6 - diagram) that can be applied to a set of digital data points for the purpose of smoothing the data, that is, to increase the signal-to-noise ratio without greatly distorting the signal. This filter is particularly useful in various scientific and engineering applications, including signal processing, spectroscopy, and data analysis.



**Fig. 6. Class diagram for implemented Savitzky-Golay filter at server-side and performance comparison of filters**

The Savitzky-Golay filter fits a polynomial of a specified degree to a moving window of data points. This polynomial is used to smooth the data by replacing each data point with the value of the polynomial at that point. The filter uses a moving window of a specified width. The window slides over the data, and the polynomial is fitted to the data points within the window. The central point of the window is then replaced by the value of the polynomial.

One of the key advantages of the Savitzky-Golay filter is its ability to preserve features such as peaks, valleys, and widths in the data. This is achieved by fitting a polynomial that closely follows the original data points within the window. The filter effectively reduces noise in the data (Fig. 6 – chart) by averaging out the fluctuations within the moving window. This results in a smoother signal with a higher signal-to-noise ratio. The Savitzky-Golay filter is flexible in terms of the polynomial degree and window size. Users can choose the degree of the polynomial and the size of the window based on the characteristics of the data and the desired level of smoothing. The filter can handle edges of the data set by using different strategies, such as mirroring the data or using a smaller window size at the edges. This ensures that the filter can be applied consistently across the entire data set.

## V. CONCLUSIONS

The development of advanced technologies, particularly the Internet of Things (IoT), opens new opportunities for creating more effective and functional prosthetics. Prosthetics equipped with such technologies can collect data on movement, track their functionality, and provide users with greater control options. This significantly facilitates their social integration and improves quality of life, allowing them to engage more actively in daily activities. Movement prosthetics enable patients to return to work, education, and an active lifestyle, contributing to their rapid rehabilitation and reintegration into normal life. The use of hardware-software systems for simulating prosthetic motion can greatly enhance the accuracy and responsiveness of prosthetics to user actions, which is crucial for improving their quality of life. Research into motion control algorithms for prosthetics is a key aspect of enhancing their functionality and effectiveness. Investigating optimal design parameters and control algorithms can significantly improve the quality of prosthetics, making them more adaptive to various usage conditions. Among these aspects, the following can be highlighted:

- Optimization of motion detection algorithms using inertial sensors;



- Utilization of machine learning for predicting motion interactions;
- Development of interfaces for communication between prosthetics and mobile applications.

The Savitzky-Golay filter is computationally efficient and can be implemented

using convolution operations. This makes it suitable for real-time applications where quick processing is required, so after implementation the time for filtering in range [1000, ..., 10K] sensors records decreased by 4% .

The use of hardware-software systems for simulating prosthetic motion allows for an expanded understanding of the interaction between technology and the human body, which is important for further medical research and the development of new therapeutic methods. This enables the creation of more precise and effective medical devices that can greatly enhance patients' lives. Thus, the development and implementation of innovative technologies in prosthetics open new possibilities for improving the quality of life for individuals with amputations, providing them not only with physical restoration but also with social integration and a return to an active lifestyle. As a result, individuals with amputations can lead fulfilling lives, engage in their favorite activities, and feel like integral members of society. In accordance with the technical specifications, the most suitable options for system development have been selected, and both front-end and back-end components of the software have been developed. Testing of the application has been conducted, and identified issues have been resolved. The result of this work is a hardware-software complex for simulating prosthetic motion, along with a demonstration of its interface functionality.

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