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SISCMot: Situation Inference and Monitoring System for Intelligent Motorized Wheelchairs

Pedro Abrantes Tavares [**Univesidade Católica de Pelotas | pedro.tavares@sou.ucpel.edu.br**]
Rodrigo Real [**Freedom Veículos Elétricos | rreal@freedom.ind.br**]
William Manzolli [**Univesidade Católica de Pelotas | william.manzolli@sou.ucpel.edu.br**]
Adenauer Correa Yamin [**Universidade Federal de Pelotas | adenauer.yamin@inf.ufpel.edu.br**]
Giancarlo Lucca [**Universidade Católica de Pelotas | giancarlo.lucca@ucpel.edu.br**]

Centro de Ciências Sociais e Tenológicas (CCST), Mestrado em Engenharia de Computação (MEEC). Universidade Católica de Pelotas, R. Gonçalves Chaves, 373 - Centro, Pelotas - RS, 96015-560.

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Abstract Assistive technologies aim to enhance independence and social inclusion for individuals with motor disabilities. Leveraging the Internet of Things (IoT), this study introduces SISCMot, an innovative monitoring and inference system tailored for intelligent motorized wheelchairs. SISCMot incorporates real-time data acquisition from the wheelchair's electromechanical components, enabling context-aware analysis through IoT-connected dashboards. This system benefits a comprehensive range of stakeholders—including users, caregivers, technical support, and manufacturers—by providing critical insights into component performance, user mobility, and potential maintenance needs. Additionally, SISCMot offers a unique edge in preventive maintenance by monitoring key mechanical and electrical metrics, thereby extending the wheelchair's operational lifespan. Evaluation based on the Technology Acceptance Model (TAM) confirms high usability and perceived value among target users, underscoring the system's practical contribution to the assistive technology landscape.

Keywords: Internet of Things (IoT), Assistive Technologies, Motorized Wheelchair Monitoring, SISCMot, Context Awareness

1 Introduction

According to the World Health Organization (WHO) in a report published in 2022, approximately 1.3 billion people (about 16% of the global population) have some type of disability [World Health Organization, 2022], which is a broad term encompassing impairments, activity limitations, and participation restrictions in certain activities. Assistive Technologies comprise a set of devices, software, and systems aimed at enhancing the quality of life and autonomy of people with disabilities. They are designed to enable users to overcome physical, cognitive, sensory, or mobility barriers that may prevent them from performing daily tasks, interacting with the environment, and fully participating in society. Among these devices, wheelchairs are among the most effective and widely used in the world.

The origins of wheelchairs date back to the 4th century B.C., evolving over the centuries to become self-propelled. With advances in electric power technology, motorized wheelchairs emerged as a solution for people with upper limb disabilities, who are unable to manually propel the wheels. George J. Klein developed the first electric motorized wheelchair while working for the National Research Council of Canada, in a program assisting veterans injured during World War II [Bourgeois-Doyle, 2004]. With industrial advancements, wheelchairs have become lighter and more flexible, yet there remain vast unexplored technical and scientific opportunities in this field.

The paradigm of the Internet of Things (IoT), initially introduced in [Ashton, 2009], has experienced significant growth and, consequently, an increase in importance over the years, becoming one of the most impactful and promising technological trends in the world today.

The context, defined as the circumstance in which an action occurs, complements and gives meaning to this action, aiding in its understanding. In distributed computing, especially where mobility and broader operational variations are involved, context is crucial for a better understanding of the conditions in which different devices are operating. Situation Science, in turn, studies the combination and projection of these contexts over time to better support decision-making [Temdee and Prasad, 2018].

The objective of this work is to propose an architecture called SISCMot (Situation Inference and Monitoring System for Intelligent Motorized Wheelchairs), which consists of an approach for contextual data acquisition and situation inference capable of benefiting all stakeholders involved: manufacturers, technical support, caregivers, and especially wheelchair users. The architecture proposed in this work provides the collection of sensor information from electromechanical components of wheelchairs in a soft real-time perspective through IoT, making this information available on Internet-accessible dashboards as well as processing it through rules to evaluate its behavior over time.

For a better understanding of SISCMot, this article is organized as follows: Section 2 discusses the related works. Section 3 presents the detailed architecture of SISCMot. After that, Section 4 provides the evaluation of the system and finally, Section 5 provides the final considerations of the work.

2 Related Work

Various approaches have been proposed to explore IoT and continuous sensing in the realm of wheelchairs to bring new benefits to wheelchair users. As part of the study and research efforts concerning the design of the SISCMot approach, a literature review was conducted. From this review, the Related Works (RW) discussed in this section were selected, with the primary criterion being their close relevance to SISCMot.

The work of [Cho *et al.*, 2023] (RW1) proposes the development of a multimodal wireless sensor system for continuous measurement of pressure, temperature, and hydration of patients in wheelchairs. The goal is to provide constant and ubiquitous health monitoring of users, aiming to improve the care and quality of life of these individuals. Test results show that the system is capable of collecting precise and reliable data continuously, allowing for detailed health monitoring of patients in wheelchairs.

The study by [Dsouza *et al.*, 2019] (RW2) presents the development of an IoT-based intelligent wheelchair equipped with seat and back pressure sensors, temperature and humidity sensors, heart rate sensors, and inertial sensors. The system is designed to collect and monitor vital data of the user, as well as data related to the wheelchair environment, in order to provide more personalized care and improve the quality of life for wheelchair users.

The proposal by [Tavares *et al.*, 2020] (RW3) introduces a sensing system using FBG-based (Fiber Bragg Grating) devices to prevent pressure ulcers in wheelchairs. The aim is to provide effective and continuous monitoring of the pressure exerted on the wheelchair surface to prevent the development of pressure ulcers in users who spend long periods seated. The proposed system has demonstrated to be a compact and reliable solution for the prevention of pressure ulcers in wheelchairs, becoming an adequate alternative to existing conventional electronic sensors with the advantage of being immune to electromagnetic interference and usable in humid environments.

The work of [Sheikh and Jilani, 2023] (RW4) addresses the development of a ubiquitous system for fall detection in wheelchairs, using low-cost inertial sensors and an unsupervised machine learning algorithm. The goal is to offer an efficient and accessible solution to identify falls in wheelchair users, aiming to improve safety and assistance for these mobility devices. The results of experimental tests are promising; however, the need for further research and improvements is pointed out to optimize performance and ensure system reliability in diverse real-world situations.

The proposal by [Kanade *et al.*, 2021] (RW5) presents an IoT-based intelligent wheelchair system capable of providing a safe and efficient way for wheelchair users to move autonomously and receive assistance in case of emergency or medical needs. The system uses sensors to monitor various health-related information of the user, such as heart rate, body temperature, blood pressure, blood oxygen level, and wheelchair position. The work encourages further research and developments in this area to enhance the technology and expand its application to a larger number of elderly individuals, although it does not utilize more sophisticated cloud-based machine learning algorithms to analyze the collected data, opting for direct alerts via the edge layer.

The work described in [Ashraf *et al.*, 2021] (RW6) consists of the development of an IoT-based electric wheelchair with advanced biomedical data logging capabilities and emergency contingency services. Sensors are used to collect data on heart rate, body temperature, blood oxygen level, and the wheelchair user's position. These sensors are connected through a gateway to a GPRS module for data transmission, enabling constant monitoring and rapid detection of emergency situations to ensure the user's safety. The objective is to create an intelligent solution that allows comprehensive health monitoring of wheelchair users and enables rapid detection of emergency situations to ensure their safety. Although it makes the wheelchair safer and more reliable, the proposal does not fully leverage the advantages of an IoT-based architecture, as all system intelligence is centralized in the gateway, and the information sent to the cloud is used only to redirect wheelchair location data to a third registered user.

The TrailCare [Barbosa *et al.*, 2018] (RW7) is a computational system that employs sensing to determine the location of the wheelchair, providing recommendations for accessible and safe routes. The project implements an accessibility support system by suggesting contextually accessible resources for wheelchair users. Additionally, it offers a simple approach for trail recognition and registration of previously traveled paths, using a relational database for context history storage and processing. The proposal presented in [Arshad *et al.*, 2023] (RW8) describes a framework for sensor-equipped wheelchairs capable of monitoring the user's vital signs and detecting posture using machine learning techniques. The system encompasses a comprehensive IoT solution, enhancing user mobility and well-being by providing obstacle control and detection, posture correction, and vital sign monitoring.

The study by [Tavares *et al.*, 2022] (RW9) describes the development of a system based on a network of sensor cells to detect pressure, temperature, and position in wheelchair users, aiming to improve comfort, safety, and prevent pressure ulcers. The authors highlight the system's effectiveness in posture detection, although the proposal does not include an IoT architecture to provide real-time feedback to the user or alerts for posture corrections. Moreover, there is no cloud solution to analyze collected data and generate a user history.

It can be observed that the related works aim to (i) improve the health and well-being of wheelchair users, (ii) enhance user safety by providing methods to mitigate risk situations, and (iii) assist wheelchair users in navigating uncontrolled environments.

The approach proposed in this article differs from these works by using sensing of the electrical and mechanical parts of the wheelchairs, with the objective of protecting their components and increasing their lifespan. In this way, it is possible to improve the performance of components and ensure greater safety for the wheelchair user, reducing the risk of accidents due to hardware failures and increasing the avail-

Table 1. Comparative Analysis of Related Work.

	Q1	Q2	Q3	Q4	Q5	Q6
RW1	Yes	Yes	No	Pressure, Temperature, and Hydration Sensors	Health	No
RW2	Yes	Yes	No	Pressure, Temperature, Humidity, Heart Rate, and Inertial Sensors	Health	No
RW3	Yes	No	No	Pressure and Temperature Sensor	Health	No
RW4	Yes	Yes	No	Inertial Sensors	Security	No
RW5	Yes	Yes	No	Heart Rate, Temperature, Blood Pressure, CO Concentration, and CO2 Concentration Sensors	Health and Security	No
RW6	Yes	Yes	Yes	Heart Rate, Temperature, Blood Oxygenation, Pressure, Proximity, Torque, and GPS Sensors	Health and Security	No
RW7	Yes	Yes	Yes	Inertial, Pressure, and GPS Sensors	Navigation	No
RW8	Yes	Yes	No	Heart Rate, Blood Oxygenation, Temperature, Humidity, Proximity (Ultrasound), and Pressure (FSR) Sensors	Health, Security and Navigation	No
RW9	No	No	No	FBG Pressure and Temperature Sensors	Health	No

ability of wheelchair usage. Continuous monitoring of battery behavior is also highlighted in this proposal, providing crucial information on autonomy, especially in external and uncontrolled environments. This sensing of the electromechanical aspects of the wheelchair is made possible by the author being a professional at Freedom Veículos Elétricos[1] (the first Brazilian manufacturer of intelligent motorized wheelchairs), a project partner, which granted access to the wheelchair hardware/software for research purposes.

2.1 Analyzing the related works

For the purpose of identifying the research objectives and outlining the knowledge gaps it seeks to address, questions were formulated to highlight and categorize the central elements presented in the Related Works. These questions are presented below:

- **Q1:** Does the proposed system perform real-time monitoring?
- **Q2:** Does the proposed architecture have a complete IoT structure (Device + Gateway + Cloud + Mobile/Web Application)?
- **Q3:** Does the proposed system use GPS (Global Positioning System)?
- **Q4:** What types of sensors were used?
- **Q5:** What is the main objective of the sensing proposed in this work?
- **Q6:** Is one of the goals of the proposed sensing to assist with battery autonomy or to infer potential issues with the wheelchair's electrical or mechanical components?

Based on the observed characteristics and functionalities and through the questions presented, a table was created to provide a comparative analysis of the Related Works. Table 1 presents this comparison to support and substantiate the development of SISCMot.

It is possible to observe that the vast majority of works, like SISCMot, leverage the benefits of IoT to provide real-time monitoring of sensors connected to the wheelchair and also offer remote access to this data via some type of mobile application or web interface.

[1] https://www.freedom.ind.br/

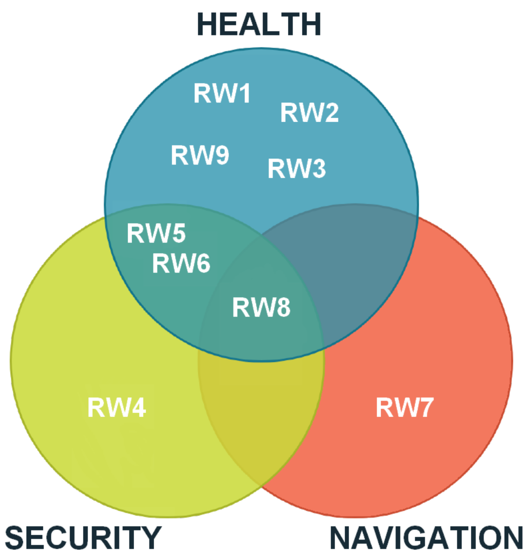

Figure 1. Diagram of Related Works by sensor objective.

It can also be highlighted that only two (RW6 and RW7) of the nine works analyzed use GPS sensors, as this is a widely used resource in mobile systems within the IoT world. In the context of assistive technology, the precise location of the wheelchair is an essential feature for applications focused on safety and navigation.

Grouping the Related Works by the objective of each proposal in a Venn Diagram (Figure 1) reveals a strong concentration in the Health set, suggesting that most works prioritize the physical well-being and health monitoring of wheelchair users, aiming for improvements in aspects such as vital signs monitoring or management of specific medical conditions. Overall, the diagram demonstrates a robust focus on health but also an understanding of the importance of a holistic approach, where safety and navigation complement healthcare to promote a complete and safe user experience.

Based on this analysis, it is possible to conclude that the main distinguishing feature of SISCMot compared to the evaluated works is that it is the only one proposing sensing of the electrical and mechanical parts of the wheelchair, aimed at protecting its components, identifying potential failures, and thus prolonging the equipment's lifespan. This preventive approach not only ensures the wheelchair's integrity but also contributes to its safety and reliability. The improvement in component performance and increased level of wheelchair protection directly benefit the user, as it reduces the risk of accidents due to hardware failures and considerably increases the availability of the wheelchair, an essential device for the mobility and well-being of individuals with disabilities.

Moreover, the continuous monitoring of battery behavior by SISCMot sensors, both during charging and discharging (when the motors are engaged), provides autonomy information that is crucial when the wheelchair user is moving in external and uncontrolled environments. This low-level sensing differentiation is only possible within this work thanks to the author's position as a professional at Freedom Veículos Elétricos, a partner company in this project, which allowed direct access to this data for research purposes.

In addition to these differentiators, it is important to highlight the significant and unique challenges involved in sensing for battery autonomy estimation and early detection of electrical or mechanical issues in powered wheelchairs—challenges that differ substantially from those addressed by the related works, which are primarily focused on user health monitoring, security, posture, or GPS-based tracking. Measuring battery autonomy with high reliability is a complex task, particularly in mobile assistive devices, where energy consumption fluctuates considerably due to factors such as terrain, user weight, driving behavior, and environmental conditions.

Implementing this functionality was only possible due to a close collaboration with the manufacturer, which granted access to low-level telemetry and the internal hardware/software stack of the equipment, something rarely available to external researchers. Moreover, engineering a dependable current sensing mechanism required the development of a specialized module capable of precisely measuring current draw in real time, even under rapidly changing motor loads. This involved careful design and calibration to ensure accurate data acquisition, low energy consumption, and secure transmission to the cloud.

Further complexity arose from the variability among lead-acid battery models, particularly regarding their capacity and aging profiles, which directly influence autonomy predictions. The system needed to adapt to these variations in order to provide meaningful and reliable information to users and caregivers.

None of the reviewed related works addresses these low-level electromechanical sensing challenges. Instead, they focus on higher-level sensing dimensions, such as vital signs or environmental awareness. In contrast, the main scientific contribution of SISCMot lies in the design and implementation of a context-aware monitoring system deeply integrated with the wheelchair's internal architecture, enabling both preventive diagnostics and precise autonomy estimation. These capabilities are critical for real-world usability and safety and remain largely unexplored in the current literature.

3 SISCMot Approach: Design and Implementation Aspects

In contrast to the works discussed above, SISCMot introduces a modular and integrated architecture tailored to the specific demands of motorized wheelchair monitoring. This section presents the design of the SISCMot approach, characterizing the modules that compose its architecture, as well as the framework that enables the user interface. Although SISCMot was conceived as a modular and abstract architecture—potentially adaptable to a variety of mobility-related devices—this work focuses specifically on its application to powered wheelchairs. The architecture is divided into three main parts: (i) SISCMot Edge, (ii) SISCMot Cloud, and (iii) SISCMot User, as shown in Figure 2. Each of these parts has clearly defined modules and interfaces, making the overall approach generalizable; however, to demonstrate feasibility and practical relevance, we present an integrated view of both the architectural proposal and its concrete implementation for powered wheelchairs.

The decision to combine the architectural description with implementation details was made to provide the reader with a realistic understanding of the system's operation and to reflect the maturity of the prototype, which has already undergone functional testing and evaluation. Furthermore, this combined description approach was also chosen due to space limitations that would make a strict separation of architecture and implementation less practical.

3.1 SISCMot Edge

This module, called SISCMot Edge, is responsible for collecting data from wheelchair sensing and autonomously sending it to SISCMot Cloud via wireless communication, without user interaction. SISCMot Edge operates under the Edge Computing paradigm [Cao *et al.*, 2020].

It consists of three components: (i) the Freedom Motorized Wheelchair, which has its own built-in sensors, (ii) the sensor sub-module, which allows integration of new sensors into the system, and (iii) the SISCMot Gateway, which collects sensing data, processes it, and synchronously or asynchronously sends it to SISCMot Cloud via Wi-Fi or 4G/GPRS. The SISCMot Gateway was implemented on the ESP-32 microcontroller, coded in C language using the manufacturer's development environment[2].

The main modules designed to integrate SISCMot Gateway's architecture are: (i) CAN transceiver, used to make the electrical connection between the gateway and the wheelchair's CAN bus, (ii) 3V3 power supply, responsible for powering the gateway, (iii) shunt sensor, responsible for measuring the electric current in the wheelchair batteries, during both charging and consumption, (iv) A/D - I2C converter, an external integrated circuit that reads the A/D value with 10-bit resolution from the shunt sensor and sends the readings to the ESP-32, and (v) the LILYGO TTGO T-SIM7000G board, the main module of SISCMot Gateway, which has an ESP-32 microcontroller that runs the firmware managing the module. In addition to the microcontroller,

[2] https://docs.espressif.com/projects/esp-idf/

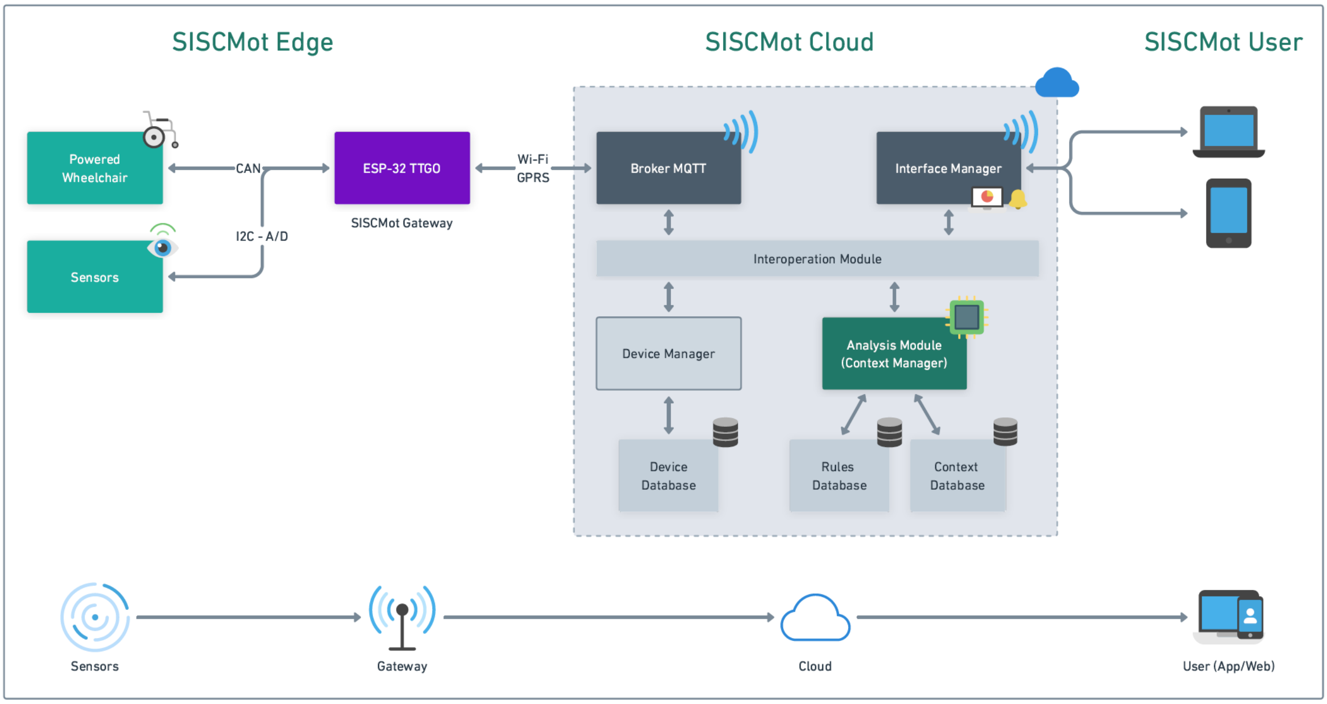

Figure 2. Architecture of the SISCMot Approach

the LILYGO TTGO T-SIM7000G is equipped with a SIM Card reader to access LTE/GPRS connectivity from a telecom provider and a SIMCom SIM7000G modem responsible for connecting the SISCMot Gateway to LTE/GPRS and GPS networks, both necessary within the scope of this approach. The architecture of the SISCMot Gateway is shown in Figure 3.

Sensor Data Collection: The gateway collects data from the wheelchair through different interfaces: CAN bus, where, using an API that maintains data confidentiality, telemetry information and status from the sensors and wheelchair electronics can be obtained; I2C Interface, for data from the shunt sensor, crucial for calculating the wheelchair's autonomy; and directly on A/D pins. The firmware enters stand-by mode if no messages are detected on the CAN bus, saving energy.

Collected Data Processing: The data collected is processed by the firmware to generate contextual information. This includes calculating the battery charge using the electric current measured by the shunt sensor. The Riemann integral method is used to calculate the battery energy in ampere-hours. SISCMot Gateway collects readings from the shunt sensor every 100 milliseconds and calculates the accumulated charge, sending data to SISCMot Cloud every 10 seconds. This reading frequency only occurs when the wheelchair is in motion. SISCMot Cloud uses this information for consumption analysis and autonomy predictions based on the user's consumption history.

Alert Detection: The SISCMot Gateway processes some alerts at the edge layer, avoiding the need for cloud analysis. This enables SMS notifications without needing a connection to SISCMot Cloud, via the SIMCom SIM7000G modem. Alerts include overvoltage, undervoltage, overcurrent, electrical contact issues in the motors and brakes, among others. New alerts, such as motor overheating, can be added with appropriate sensors.

GPS Data Collection: The ESP-32 firmware was designed to send AT commands to the SIMCom SIM7000G Modem every 10 seconds, requesting geolocation data. Raw latitude and longitude data, accurate to eight decimal places, are received and processed before being sent to ESP-32. If ESP-32 does not receive the data after 10 attempts, a reboot command is sent to the modem. Geolocation is essential for generating context in SISCMot Cloud, allowing it to infer the location and possible unusual situations, such as the wheelchair remaining stationary in an outdoor location for an extended period.

Data Formatting for Transmission to SISCMot Cloud: Sensor data is serialized into a JSON file and sent to the SISCMot Cloud MQTT broker. There are two messages that the gateway can send: Status Message, sent every 10 seconds, containing general data on the wheelchair, sensors, and geolocation; and Event Message, sent immediately after event detection, such as alerts. Both messages have a unique gateway identifier and a timestamp indicating the moment of transmission to SISCMot Cloud. If SISCMot Cloud stops receiving status messages, it is assumed that the gateway is offline, which may occur due to power or communication issues.

Data Transmission via LTE/GPRS or Wi-Fi: SISCMot Gateway can transmit data via Wi-Fi in indoor environments and LTE/GPRS in outdoor environments, ensuring connection maintainability during wheelchair movement. The firmware initially attempts to connect to Wi-Fi and, if successful, remains on it until the connection fails, at which point it switches to LTE/GPRS. During LTE/GPRS use, ESP-32 periodically checks Wi-Fi availability and returns to it if possible, prioritizing it for better connection quality and user data plan savings.

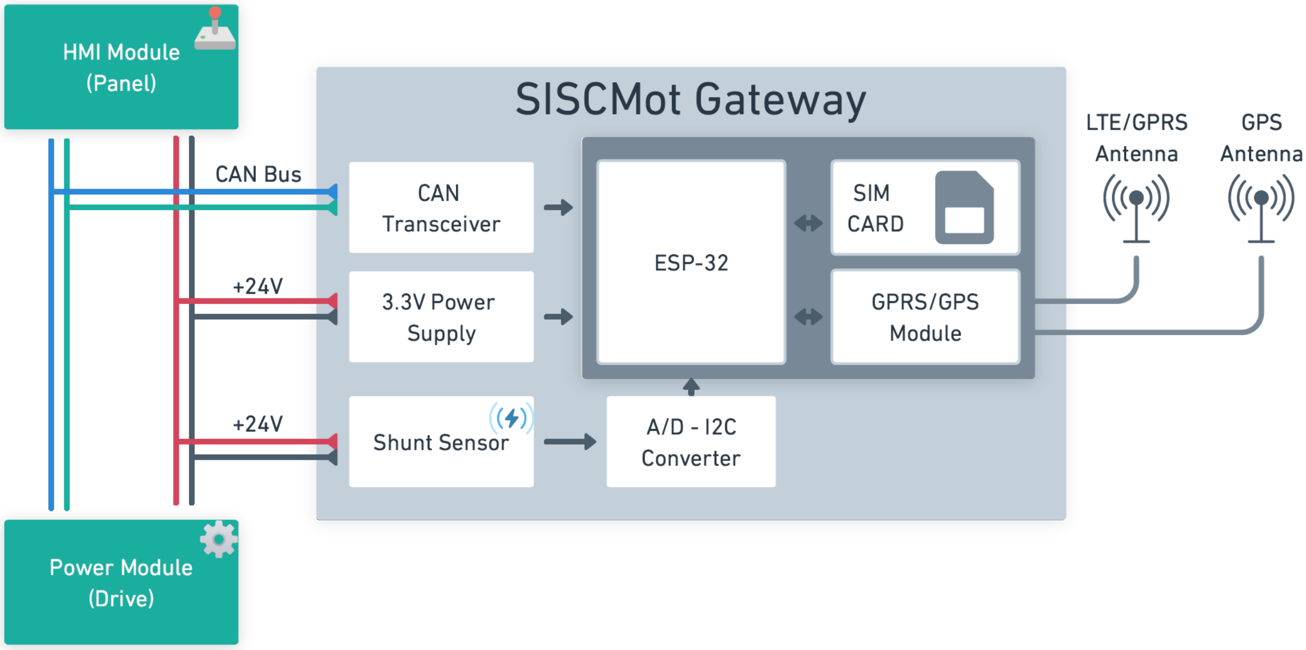

Figure 3. Architecture of the SISCMot Gateway module

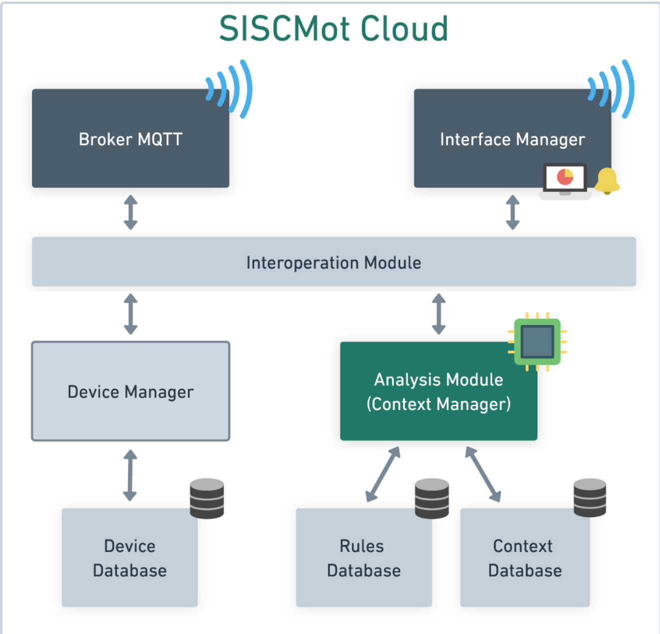

Figure 4. Architecture of the SISCMot Cloud module

3.2 SISCMot Cloud

The architecture designed for SISCMot Cloud (Figure 4) comprises the following organization: (i) two modules that communicate with external modules - MQTT Broker and Interface Manager, (ii) two modules that manage external devices - Device Manager and Device Database, (iii) three modules forming the context server - Context Manager (Analysis Module), Rules Database, and Context Database, and finally, (iv) an integration module - Interoperation Module. This module operates from a Cloud Computing perspective [Shukur *et al.*, 2020].

MQTT Broker: module that manages MQTT message exchanges between SISCMot Gateway and SISCMot Cloud, encoding messages in JSON with information on devices and values collected by sensors. The data is organized into topics and sent for persistence in databases. New devices or sensors can be dynamically registered when new JSON messages arrive at the broker, without manual registration. Furthermore, the MQTT broker provides SSL (Secure Sockets Layer) encryption to enhance the security of transmitted information.

Device Manager: responsible for making sensor data available and storing it. It receives data from the broker in JSON format and stores it hierarchically in temporal data tables, and devices registered in device tables. When the Analysis Module requests data, the Device Manager locates, formats, and makes it available for analysis. Additionally, it organizes information, linking sensors to the corresponding devices.

Device Database: persistently stores device and sensor data. It uses a relational model and provides an SQL interface for read and write operations. All data has a timestamp and a sensor identifier, allowing for the creation of histories and analyses of variations over time.

Context Manager (Analysis Module): processes contextual information and performs real-time inferences on devices. It can perform different types of analyses: (i) Boundary Context Analysis: Tests sensor values against predefined limits, and the conclusions can be combined using ”AND” and ”OR” clauses; (ii) Rate of Context Change Analysis Over Time: Evaluates how contextual information changes over time; and (iii) Context History Analysis Over Time: Compares current data with historical data to detect deviations and generate alerts.

Analyses are performed as soon as data is received, with results immediately sent to update dashboards and alert the user. Synchronous analyses can also be scheduled on SISCMot Cloud.

Rules Database: stores rules used by the Analysis Module. It uses a relational model with an SQL interface to store script codes, limits, applicable sensors, and whether they generate alerts or are only informational. The rules are requested by the Analysis Module when new sensor data arrives at SISCMot Cloud or in executions with predefined periods, triggering alerts or only providing information.

Context Database: stores contextual information about the environment, users, sensors, and devices related to the wheelchair. It uses the same relational model with an SQL interface. Some data is raw, obtained directly from SISCMot Edge sensors, while others are post-processed by the Analysis Module to extract relevant information. All data has timestamps, enabling the creation of context histories.

Interface Manager: provides a web interface between the user and SISCMot, organizing device information into easily understandable visual widgets. These widgets may include graphs, indicators, tables, texts, images, and maps, allowing real-time visualization of sensor data and contextual information processed by the Analysis Module. The Interface Manager can also indicate alerts and request immediate notifications to users via SISCMot User.

Interoperation Module: this module is a message broker that integrates and manages information exchange between SISCMot Cloud modules. It ensures that updated sensing data is simultaneously available to all interested modules, such as the Device Manager, Analysis Module, and Interface Manager, enabling parallel processing and system efficiency.

SISCMot Cloud was implemented using resources from the IoT platform TagoIO[3], with rules in the Context Manager coded in JavaScript.

3.3 SISCMot User

The main function of this module is to provide a visual interface that allows users to monitor, manage, and interact with connected wheelchairs in real-time. Data is presented in a dashboard format and can be accessed via the internet through a browser or a smartphone application.

Data is presented in components called widgets, updated in real-time as new data arrives and is processed by SISCMot Cloud. The widgets used to display data in SISCMot User, both in the web version (Figure 5) and in the smartphone application (Figure 6), may have the following formats:

- **Numeric Value Widget**: this component displays a numeric value of the magnitude being measured by the sensor and is typically used to show the current value or the last measured value. Examples: Battery Voltage, Battery Current, Motor Current, Battery Autonomy.
- **Status Widget**: this widget displays a status value considering the current context of the wheelchair. It provides information that has already been processed and abstracted into language that is easier for the user to understand. Examples: Wheelchair Status (IDLE, MOVING, CHARGING, ALERT, etc.), Communication Status (Online, Offline), Battery Charge Percentage.
- **Graph**: this widget shows data over time in a dynamic chart where the time interval can be manually selected by the user. Examples: Motor Currents, Battery Voltage.
- **Table**: similar to the previous widget, data is displayed over time, but in a table format. This type of component is important for showing multiple types of data at a specific point in time. Examples: Motor Current, Temperature, Battery Current at a specific moment.
- **Map**: in this component, the wheelchair's real-time location and the last received status are shown visually on a dynamic photo map. Through this widget, it is also possible to set up a geographical boundary, also known as a geofence, which will take a circular shape with a radius from a central point defined by the user. If the wheelchair crosses the geofence limits, the user can configure the system to receive alert notifications.

[3]https://tago.io/

Table 2 shows the information that can be directly viewed by the user via SISCMot User:

Table 2. Data on the SISCMot User Dashboard

Measured Value	Unit
Battery Charge	Battery Percentage (%)
Battery Voltage	Volts (V)
Battery Current	Amperes (A)
Left Motor Current	Amperes (A)
Right Motor Current	Amperes (A)
Battery Autonomy	Ampere-hour (Ah)
Recent Consumption	Ampere-hour (Ah)
Temperature	Celsius Degrees ($^\circ$C)
Humidity	mBar (millibars)
Information	**Possible Values**
Gateway Status	Online, Offline
Wheelchair Status	IDLE, Moving, Charging, Alert, Diagnostic mode, Brake-off, Off

Additionally, SISCMot User has panels to inform users about active alerts as well as a history of wheelchair alerts. If the wheelchair shows a low battery alert, the status panel will indicate that the wheelchair is in ”Alert” status, and the error panel will display the specific active alert (”Undervoltage”). If the user is using the smartphone application, they will receive a push notification to inform them of the event. It is also possible to configure contextual notifications where, for example, the user will only receive a notification if the wheelchair runs out of battery outside the area defined by the geofence. Notifications can be enabled or disabled individually through a specific settings screen.

Table 3 lists the alerts that can generate notifications for the user (some depend on context while others do not):

SISCMot User also provides the option for users to configure which widgets are of interest to them. Since the system can be used by different types of users, some parameters may be more relevant to some than to others. For example, for the wheelchair user, battery autonomy information is extremely useful, while for a caregiver, geolocation information, geofence events, and alerts are of greater interest. This customization capability demonstrates that SISCMot is a flexible system that easily adapts to the user's needs.

Following the implementation of the SISCMot architecture, an initial evaluation was conducted to assess its usability and perceived usefulness. The evaluation methodology and results are presented in the next section.

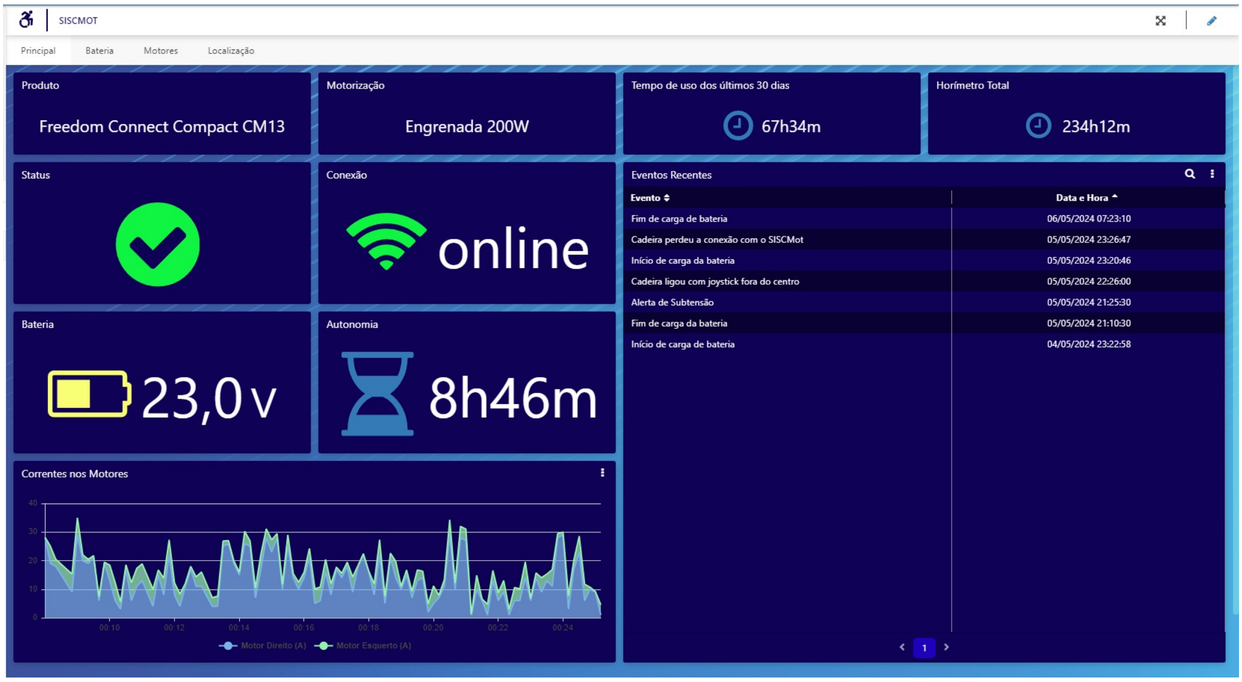

Figure 5. SISCMot User Web (Main Screen).

Table 3. Alerts and Events of SISCMot User

ID(hex)	Alert/Event
0x01	Undervoltage
0x02	Overcurrent
0x03	Overvoltage
0x04	Can Bus Error
0x05	Joystick Missing
0x06	Joystick With Open Channel
0x07	Left Motor Missing
0x08	Right Motor Missing
0x09	Left Motor Short Circuit
0x0A	Right Motor Short Circuit
0x0B	Left Brake Missing
0x0C	Right Brake Missing
0x0D	Current Sensor Error
0x0E	Joystick Calibration Error
0x0F	Gateway Offline
0x10	Wheelchair Outside Geofence
0x11	Wheelchair Alert Outside Geofence

4 SISCMot Evaluation

This section describes the system evaluation. To do so, we have employed the Technology Acceptance Model (TAM) which was originally proposed by [Davis, 1989], and it was developed as an extension of a previous model proposed in [Davis, 1985]. It was created with the goal of understanding and predicting the acceptance and adoption of technologies, particularly in information systems and software technologies, by users. This model is a widely recognized theoretical approach in the field of research in information technology and information systems.

Recent studies have successfully employed TAM and its variations in the evaluation of embedded assistive technologies, reinforcing its suitability in contexts similar to SISCMot. For instance, [Albandes *et al.*, 2024] applied TAM to assess an IoT-based remote monitoring system for peritoneal dialysis, demonstrating how perceived usefulness and ease of use influence acceptance in clinical environments. [Kang and Hwang, 2022] extended TAM to explore continued usage intentions of healthcare wearable devices, emphasizing the model's effectiveness in capturing user attitudes and behavioral intentions in health-related IoT contexts. Similarly, [Yin *et al.*, 2022] adopted a modified UTAUT framework (an evolution of TAM) to evaluate user acceptance of wearable intelligent medical devices, highlighting the importance of context-aware design and the role of empirical validation. These works illustrate the relevance of TAM-based approaches in assistive and medical technology scenarios, providing a solid foundation for the evaluation strategy adopted in this study.

To apply the TAM model within the scope of this proposal, 20 potential users of SISCMot were selected to complete a questionnaire involving system usability questions. This questionnaire presents various statements where the respondent should choose one of five response options, with extremes of ”Strongly Disagree” and ”Strongly Agree.” This response scale, known as the Likert scale [Likert, 1932], provides a greater degree of precision in responses, as opposed to binary ”yes” and ”no” answers.

The TAM model focuses on understanding the reasons that lead users to accept or reject a technology, as well as identifying ways to improve the acceptance of that technology. Furthermore, it is important to assess the consistency of the data collection instrument. This consistency refers to the degree of correlation between the items on the instrument and the overall survey result, which indicates the instrument's reliability. One of the statistical methods widely used to measure consistency is Cronbach's coefficient, proposed by Lee J. Cronbach in 1951 [da Hora *et al.*, 2010], represented in Equation 1.

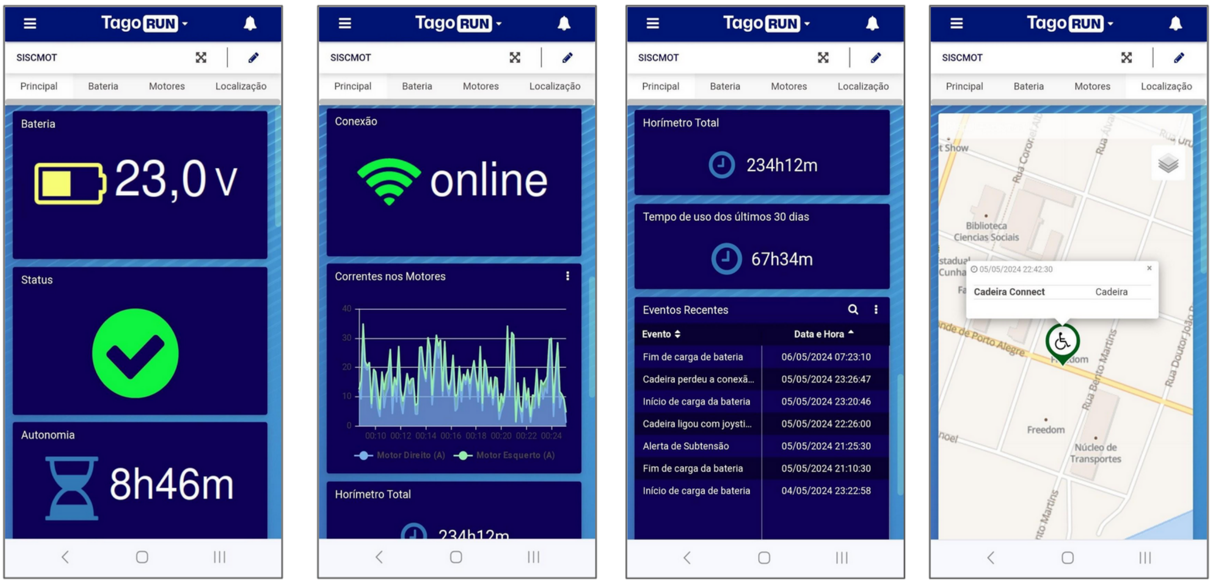

Figure 6. SISCMot User App.

$$\alpha = \frac{k}{k-1}\left[1 - \frac{\sum V_i}{V_t}\right] \quad (1)$$

Where k = number of items on the form, V_i = variance of each item, and V_t = variance of the total sum for each participant.

A research instrument is considered reliable when the Cronbach's alpha coefficient value is between 0.7 and 0.9 [Streiner, 2003]. Very high reliability values (above 0.9) may suggest redundancy in the items, indicating that they are overly correlated. The interpretation of Cronbach's alpha coefficient values is presented in Table 4.

Table 4. Interpretation of Cronbach's Alpha

Cronbach's Alpha	Interpretation
< 0.6	Low reliability
$0.6 \leq \alpha < 0.7$	Acceptable reliability, but improvable
$0.7 \leq \alpha < 0.9$	Good reliability
> 0.9	Very high reliability (possible redundancy)

To calculate Cronbach's coefficient, the qualitative values of the Likert scale must first be transformed into quantitative values through normalization, following a scale from 0.0 (Strongly Disagree) to 1.0 (Strongly Agree), with increments of 0.25 between each response as shown in Table 5.

Table 5. Conversion of the Likert scale to normalized numerical values

Item	Value
Strongly Disagree	0.00
Partially Disagree	0.25
Neutral	0.50
Partially Agree	0.75
Strongly Agree	1.00

As illustrated in Figure 7, SISCMot encompasses different user profiles, from the wheelchair user, who receives the most direct benefit, to the manufacturer, who can collect valuable data to improve and expand product usage. However, for the application of this questionnaire, only users associated with Freedom Veículos Elétricos were selected, specifically from Technical Support and Engineering, as both groups provide a more critical and specialized analysis of the motorized wheelchair artifact.

This careful selection of participants aims to ensure that the feedback obtained is technically grounded and that the improvement suggestions genuinely meet the practical and everyday requirements of SISCMot. The combined perspective of Technical Support professionals, who have direct contact with end users and are familiar with daily challenges, and Engineering, focused on improvements and innovations, enables a broader and more detailed evaluation. The critical analysis from these sectors allows not only the identification of specific adjustments but also the collection of insights on the system's evolutionary potential, promoting the development of more robust functionalities aligned with the needs of wheelchair users.

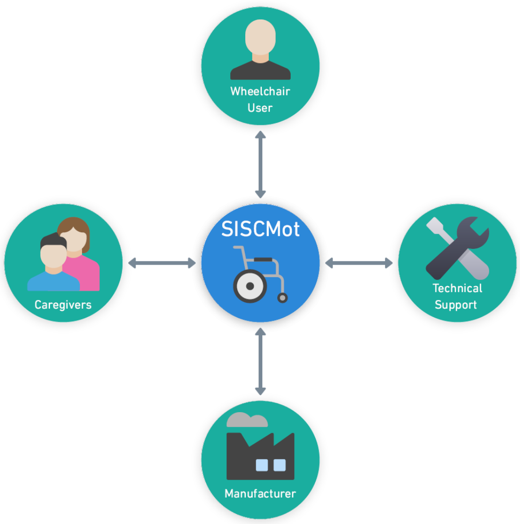

Figure 7. SISCMot Users.

For this evaluation, all SISCMot functionalities were presented to the participants, as well as all features of SISCMot User, including both the web interface and the smartphone application. The participants did not directly operate the wheelchair or use the SISCMot system in a real-world scenario. Instead, all functionalities were demonstrated in detail through guided presentations, which included real-time examples of the system in use, interactive dashboards, and explanations of the alerts, data flows, and interface behaviors. This approach was chosen because the participants - technical support and engineering professionals from the wheelchair manufacturer - already had prior familiarity with the wheelchair platform and were technically qualified to assess the system's relevance, usability, and functionality. Their feedback was particularly valuable for identifying strengths and limitations from a development and operational support perspective.

After the demonstration, participants were invited to complete a digital questionnaire, which included a set of statements aligned with the TAM model, divided between perceived ease of use and perceived usefulness (see Table 6). To ensure clarity for the intended audience, all statements were positively framed. This choice was made to reduce the potential for confusion or misinterpretation, especially given the technical profile of the respondents. While the inclusion of negatively worded items is sometimes recommended to control for response bias, prior studies indicate that such items may compromise consistency in short-form instruments, particularly when used with non-academic participants [Suárez-Álvarez *et al.*, 2018].

The questionnaire also included an open-ended field for comments and suggestions. The responses collected were largely informal, focusing on minor interface improvements or additional features. As the qualitative input did not generate substantial new insights or influence architectural revisions, these responses were not included in the main body of the article to preserve focus and clarity.

The selection of participants for this initial phase was deliberate. At this stage of development, evaluation was limited to professionals directly involved with the design, integration, and support of the wheelchair platform. This decision aligned with safety and intellectual property protocols established within the industrial partnership, which required internal validation prior to broader deployment. A second evaluation phase involving end users—such as wheelchair users and caregivers—is planned for future implementation, once the platform reaches higher maturity in terms of stability and interface readiness.

The participant group consisted of 20 individuals. In terms of gender distribution, 75% were male (15 participants) and 25% were female (5 participants). The ages ranged from 23 to 53 years, with a mean age of approximately 30 years. Most participants were in their mid-to-late twenties or early thirties, reflecting a young professional demographic typically found in technical and engineering environments.

The results collected from the 20 respondents are summarized in Table 7. The table also presents the variance associated with each questionnaire item, along with the total variance calculated from the sum of each respondent's scores. These values serve as the basis for computing Cronbach's alpha coefficient.

The Cronbach's coefficient calculated to validate the consistency of the questionnaire used for the evaluation of SISCMot is shown in Equation 2.

Table 6. Questionnaire Related to the TAM Model

	Statement
Perceived Ease of Use	1 - I consider the use of SISCMot clear and straightforward. 2 - I find the information presented on the SISCMot dashboard easy to understand. 3 - I consider the alert technologies easy to use.
Perceived Usefulness	4 - The functionalities offered by SISCMot are relevant for wheelchair users. 5 - The functionalities offered by SISCMot are relevant for family members and caregivers. 6 - The functionalities offered by SISCMot are relevant for the manufacturer and technical support.

Table 7. Evaluation Questionnaire Results

Respondent	Questionnaire Item						Total
	1	2	3	4	5	6	
1	1.00	0.50	0.50	1.00	1.00	1.00	5.00
2	1.00	1.00	1.00	1.00	1.00	1.00	6.00
3	0.75	0.75	1.00	1.00	0.75	1.00	5.25
4	1.00	0.75	1.00	1.00	1.00	1.00	5.75
5	1.00	1.00	1.00	1.50	0.75	1.00	6.25
6	1.00	0.75	1.00	0.75	0.75	1.00	5.25
7	1.00	0.75	1.00	1.00	0.75	1.00	5.50
8	0.75	1.00	0.75	1.00	1.00	1.00	5.50
9	1.00	0.75	1.00	1.00	1.00	1.00	5.75
10	1.00	0.50	1.00	1.00	0.75	1.00	5.25
11	1.00	0.75	1.00	1.00	1.00	1.00	5.75
12	1.00	0.50	0.75	1.00	1.00	1.00	5.25
13	1.00	1.00	1.00	1.00	1.00	1.00	6.00
14	1.00	1.00	1.00	1.00	1.00	1.00	6.00
15	1.00	1.00	1.00	1.00	1.00	0.75	5.75
16	1.00	1.00	1.00	1.00	0.75	1.00	5.75
17	1.00	1.00	0.75	0.75	1.00	1.00	5.50
18	1.00	1.00	0.75	1.00	1.00	1.00	5.75
19	1.00	0.50	1.00	1.00	0.75	1.00	5.25
20	1.00	0.50	1.00	0.75	0.75	1.00	5.00
Variance	0.010	0.040	0.034	0.028	0.012	0.008	**0.359**

$$\alpha = \frac{6}{6-1}\left[1 - \frac{0,131}{0,359}\right] = \mathbf{0{,}761} \quad (2)$$

The resulting value, located in the range of 0.7 to 0.9, demonstrates that the research instrument used in this study has good reliability.

Based on the data collected for each individual item using the Likert scale, the consolidated average score is calculated, ranging from 0 to 1.0. According to the TAM model, averages above 0.75 indicate agreement with the perceived ease of use and usefulness. The total average score was **0.915**, with **0.896** as the average for items related to Perceived Ease of Use and **0.933** as the average for items on Perceived Usefulness. This final score reflects the acceptance of SISCMot by the respondents.

Additionally, Figure 8 presents the response distribution for each of the six statements evaluated using the TAM questionnaire. The stacked bar chart shows the percentage of participants who selected each response on a five-point Likert scale, ranging from "1 Strongly Disagree" to "5 Strongly Agree." The results reveal a clear concentration of responses in the upper range of the scale, particularly around "4 Partially Agree" and "5 Strongly Agree," indicating a generally positive perception of the system's usefulness and ease of

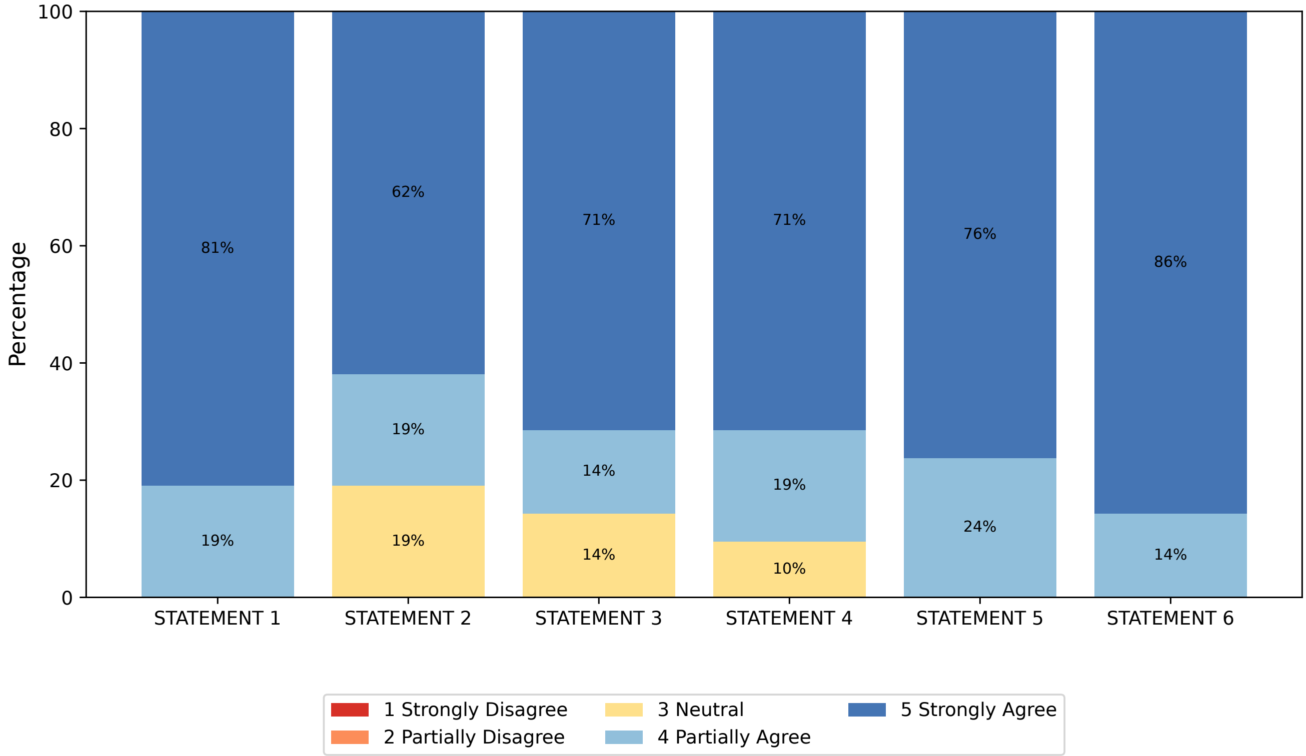

Figure 8. Response Distribution per Statement.

use. The visual representation helps highlight not only central tendencies but also the consistency of agreement across statements, supporting the reliability of the questionnaire results and reinforcing the acceptance of the SISCMot system among the participants.

The analysis of results using the TAM model revealed not only a high acceptance rate but also a positive evaluation of the usability and functionality of SISCMot by the respondents. The consolidated score, close to the maximum value, suggests that the system satisfactorily meets user expectations and needs, being well received in terms of ease of use and practical utility. Furthermore, the correlation between the specific averages for the dimensions of Ease of Use and Perceived Usefulness reinforces that SISCMot has managed to overcome typical barriers encountered in assistive technologies, adding significant value and reliability to the daily lives of its users. Thus, the adoption of this system not only fulfills its initial purpose of assisting the user but also opens new opportunities for improvements and broader dissemination of supportive technologies in motorized wheelchairs.

5 Final Considerations

The results of the SISCMot architecture and its initial evaluation support a broader reflection on the technological landscape in which this work is situated. The growing consolidation of the Internet of Things continues to reshape how devices, data, and services interact, particularly in the field of assistive technologies. Projections indicate that by 2025, more than 30 billion interconnected devices — encompassing a wide range of applications and functionalities — will be integrated into global networks. This continuous expansion of interconnected technologies drives the advancement of innovative research initiatives such as SISCMot, which explores both the opportunities and challenges within the Assistive Technologies sector to address the real needs of individuals with mobility impairments.

Considering this scenario, SISCMot will explore IoT and Context Science concepts to expand the resources offered to users of motorized wheelchairs. The proposed architecture in this work will encompass: (i) a platform for data acquisition from intelligent motorized wheelchairs; (ii) support for nomadic computing, with data collected from wheelchairs sent even while in motion to a cloud computing infrastructure; (iii) a framework for contextual processing and creation of specific inference rules; and (iv) an interface for viewing information and receiving user commands via IoT.

To clarify the current status of development, the core SISCMot architecture has already been fully implemented and validated by domain experts from Freedom Veículos Elétricos. This includes integration with hardware components such as sensor modules, current sensing, battery telemetry, and communication gateways. Functional testing has been carried out through laboratory simulations and internal evaluations, including stress scenarios and fault conditions relevant to real-world usage. However, testing with actual end users, such as wheelchair users or caregivers, has not yet been conducted, and remains planned for a subsequent evaluation phase. This approach follows internal safety and intellectual property protocols within the industrial partnership, which require technical validation before broader public or clinical deployment.

The main distinguishing feature of this proposal compared to Related Works is that SISCMot is the only one with a proposal for sensing the electrical and mechanical parts of the wheelchair, aimed at protecting its components and increasing their useful life. The improved performance of these components and the increased level of protection for the wheelchair result in direct benefits for the wheelchair user, as it reduces the risk of accidents due to hardware failures and considerably increases the availability of the wheelchair, an essential device for the mobility and well-being of individuals with disabilities. Furthermore, the continuous monitoring of battery behavior, both during charging and discharging, provides autonomy information that is crucial when the wheelchair user navigates in external and uncontrolled environments.

This low-level sensing differentiation was only possible within this work because the author is a professional at Freedom Veículos Elétricos, a partner company in this project, which allowed direct access to this data for research purposes.

The application of the TAM Model in the context of SISCMot use allowed an effective systematization of user opinions, verifying the real contributions of the approach's design in its usage environment. Through this tool, it was possible to assess the usefulness and ease of use of the proposed architecture, confirming that the planned functionalities were well received and validated by the target audience. Thus, the results demonstrated that the overall proposal was satisfactory and that SISCMot achieved a high level of acceptance among users.

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Authors' Contributions

All authors contributed to the writing of this paper, read and approved the final manuscript.

Competing interests

The author(s) declare(s) that they have no competing interests.

Availability of data and materials

The data and source code used in this study are available from the corresponding author upon reasonable request.

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