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Promoting autonomy and improving the quality of life for wheelchair users with IoT

Promovendo a autonomia e melhorando a qualidade de vida de usuários de cadeira de rodas com IoT

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ABSTRACT

The quality of life of wheelchair users can be significantly affected by factors such as lack of accessibility, independence, and regular physical activity. This study proposes the development of an Internet of Things (IoT)-based system capable of quantifying the physical performance of wheelchair users through an inertial dynamometer equipped with sensors connected to an ESP32 microcontroller. The system uses acceleration and torque measurements to calculate the power generated during exercises and automatically shares the data with Google Sheets, enabling remote access by healthcare professionals. The methodology was based on previously validated models in the literature, with adaptations to enhance its portability and applicability in home environments. The results demonstrate the system's feasibility for both monitoring and training purposes. Based on the tests conducted, it was verified that it is possible to develop a product to serve wheelchair users in fitness centers for physical training, in schools for physical education activities, in hospitals and clinics for cardiorespiratory assessment, and also for high-performance athlete training, thereby promoting greater autonomy and quality of life for users.

Keywords: Internet of things; Wheelchair users; Biomechanics

RESUMO

A qualidade de vida de pessoas cadeirantes pode ser significativamente impactada por fatores como a falta de acessibilidade, independência e práticas regulares de atividade física. Este trabalho propõe o desenvolvimento de um sistema baseado em Internet das Coisas (IoT) capaz de quantificar o desempenho físico de cadeirantes por meio de um dinamômetro inercial acoplado a sensores conectados a um microcontrolador ESP32. O sistema utiliza medições de aceleração e torque para calcular a potência gerada durante os exercícios e compartilha os dados automaticamente com o Google Planilhas, facilitando o acesso remoto por profissionais da saúde. A metodologia adotada foi baseada em modelos previamente validados na literatura, com adaptações para ampliar sua portabilidade e aplicabilidade em ambientes domiciliares. Os resultados mostram a viabilidade do sistema tanto para monitoramento quanto para uso como ferramenta de treinamento. A partir dos ensaios realizados verificou-se que é possível construir um produto para atender cadeirantes em academias para treinamento físico, escolas para prática de educação física, em hospitais e clínicas para avaliação cardiorespiratória e também para treino de alto rendimento de atletas, o que promove maior autonomia e qualidade de vida para os usuários.

Palavras-chave: Internet das coisas; Cadeirantes; Biomecânica

1 INTRODUCTION

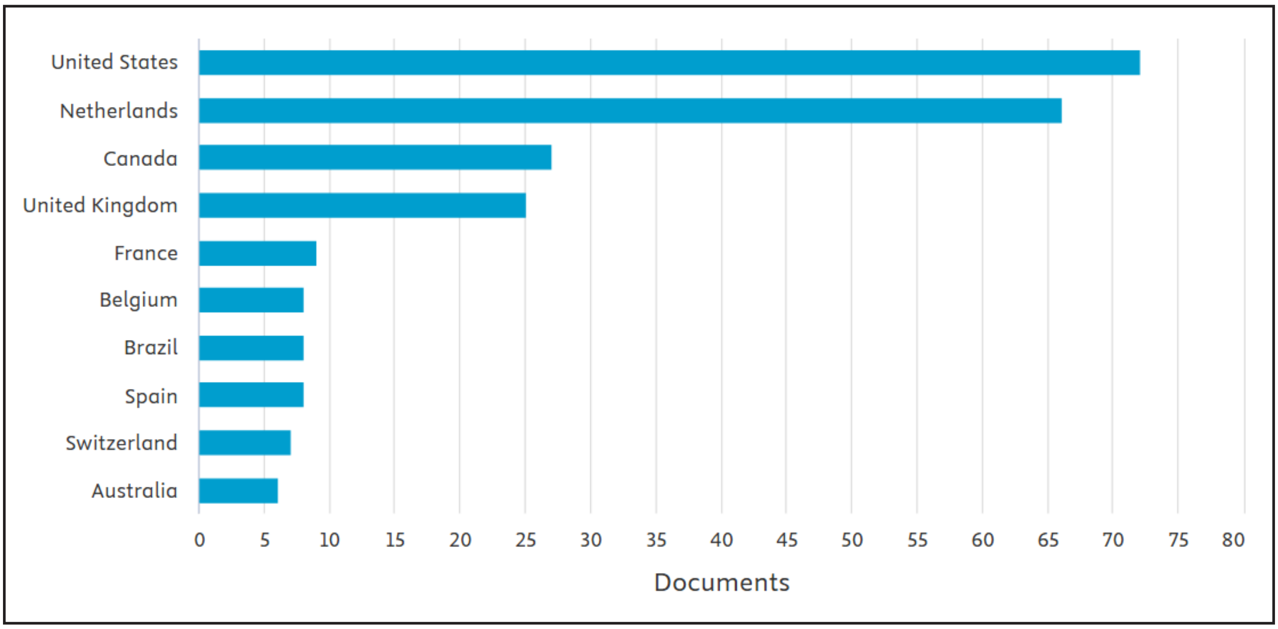
Quality of life is a broad concept that encompasses various dimensions of human existence, such as emotional, psychological, mental, spiritual, and physical aspects (WHOQOL, 2012). In this context, issues that affect these attributes, such as obesity, can significantly compromise quality of life. However, conditions like these can be alleviated through regular physical activity (Da Mota & Zanesco, 2007).

Regarding physical exercise, Medeiros et al. (2018) showed in their results that exercise positively contributed to the lives of wheelchair users, both physically and biologically. Gomes et al. (2017) describes other factors that influence the quality of life of wheelchair users, such as performance with the chair, lack of accessibility, and absence of autonomy. When combined, these factors negatively and significantly impact the lives of people with disabilities.

Despite its significant importance, there is a lack of studies in this area, especially in Brazil. Figure 1 shows a search in the Scopus database using the keywords “Wheelchair,” “biomechanics,” and “exercise.” In Brazil, this search yielded only 8 published papers.

At the same time, the use of the Internet of Things (IoT) has been changing everyday life, from the transition of in-person work to online formats to the popularization of various types of apps that provide comfort and convenience, positively impacting people’s quality of life (Brasileiro, 2022). In mechanical systems, this allows sensors to be connected in a way that their results can be remotely accessed by anyone, facilitating the sharing of results.

Figure 1 – Papers in the Scopus platform



Source: Authors (2025)

Due to the scarcity of research in this field, coupled with the challenges this population faces, such as lack of physical exercise and accessibility, a problem arises that requires technological intervention. Therefore, the objective of this work is to develop a device capable of exercising wheelchair users and facilitating access through IoT, aiming to improve their quality of life.

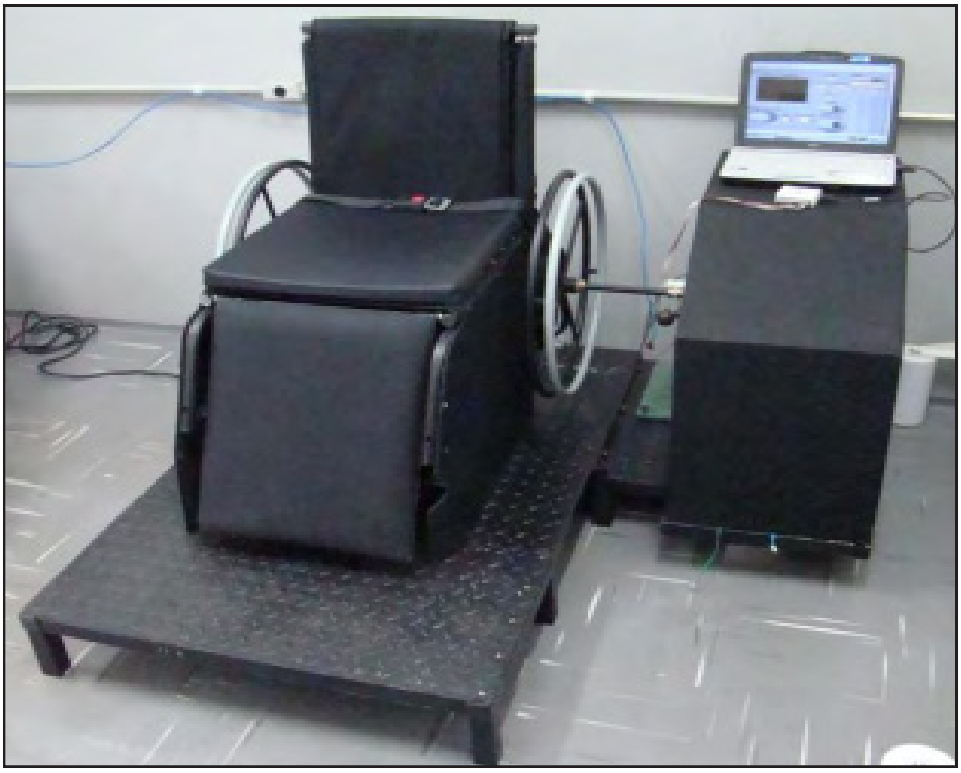
1.1 Existing Prototypes

According to Brunetti (2018), dynamometer tests are conducted after the construction of an engine to measure its performance. The operation of these devices is based on the application of force by the motor on a shaft, which meets an opposing force of a certain nature. This resistance can have various origins. García (2014), for example, compares the advantages and disadvantages of several types of dynamometers, including those powered by alternating current motors, direct current motors, eddy currents, and friction.

Another frequently used model is the inertial mass type, employed by Rech (2024), who uses the inertia of a roller to calculate the required effort. In addition to using inertial mass, this model was designed for use by wheelchair users. Although dynamometers are commonly used to measure the power of vehicles such as cars and motorcycles, Rech (2021) states that they can also be used to assess the performance of individuals in wheelchairs.

In the literature, there are some prototypes built to assess the performance of wheelchair users. Denize Vilela Novais (2010) developed a prototype, shown in Figure 2, which consists of a chair where the wheel axle is connected to an electromagnetic resistance system capable of providing resistance to the movement.

Figure 2 – ERG-CR09 Ergometer Prototype

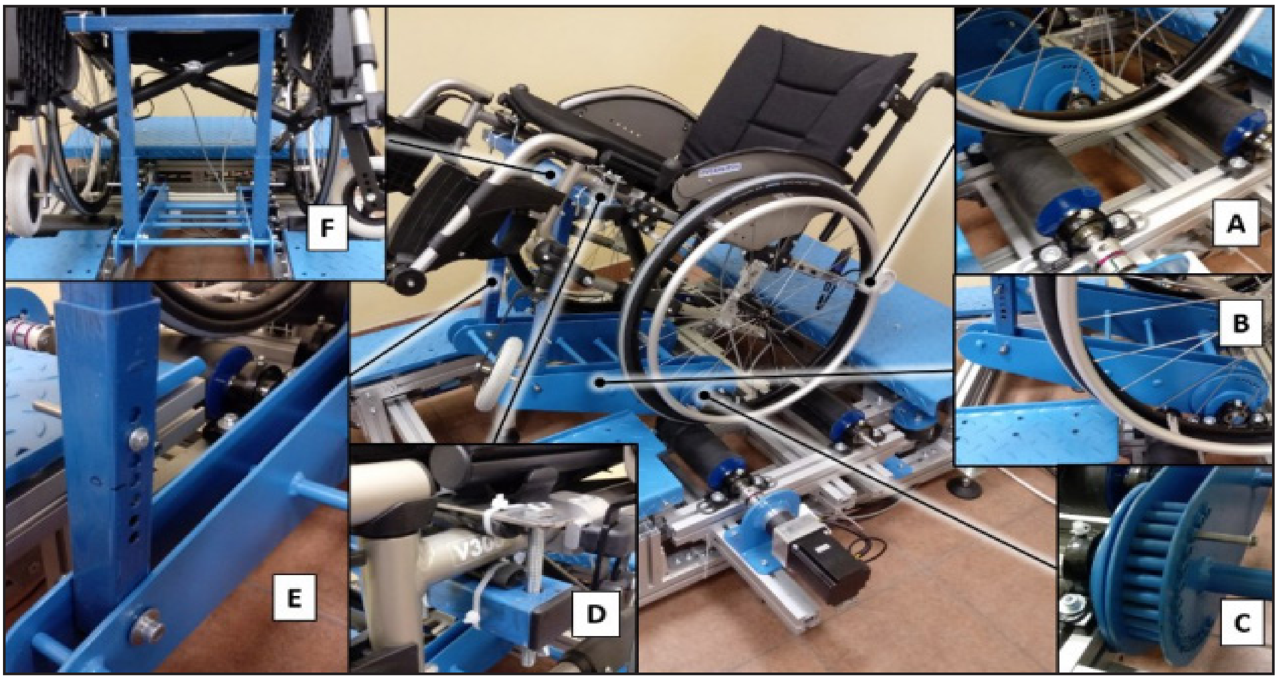


Source: (Novais D. V., 2010)

Through the applied resistance, it is possible to assess the user's performance, and the system includes an adjustment for the leg support inclination. In addition to this prototype, the model by Wieczorek & Warguła (2019) allows for a comprehensive analysis of various parameters, such as biomechanical parameters, the position of the center of mass, wheelchair speed, acceleration, propulsive force, electromyographic activities of muscles, and other analytical parameters.

The test bench used is shown in Figure 3. This prototype features a wheelchair tilt system (B), and to maintain the balance of the center of mass, parts F and C serve as adjustments to provide stability for the wheelchair user.

Figure 3 – Wieczorek and Warguła Prototype

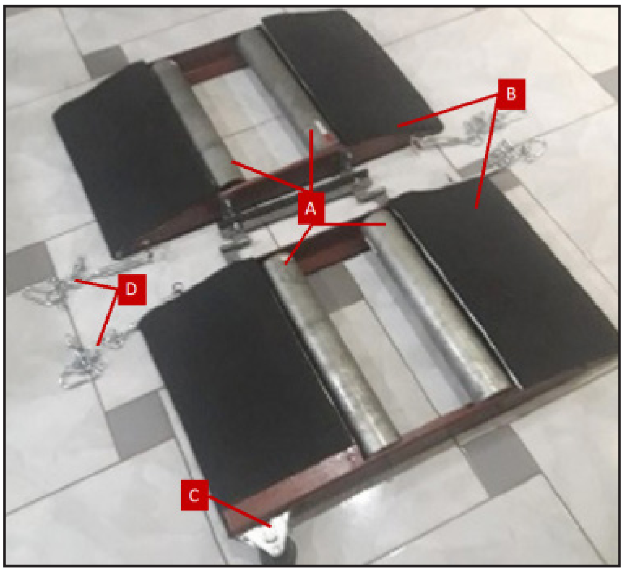


Source: Wieczorek & Warguła (2019)

In addition to the tilt system, the prototype includes a BLDC motor (brushless direct current motor) located in the front cylinder (A), which helps reduce inertia and generate an opposing load to the movement, making the simulation more realistic.

Another prototype developed by De Melo et al. (2023) has superior mobility compared to the previously presented ones, and the resistance mechanism for the wheelchair is based on inertia (Figure 4).

Figure 4 – De Melo Prototype



Source: Melo (2023)

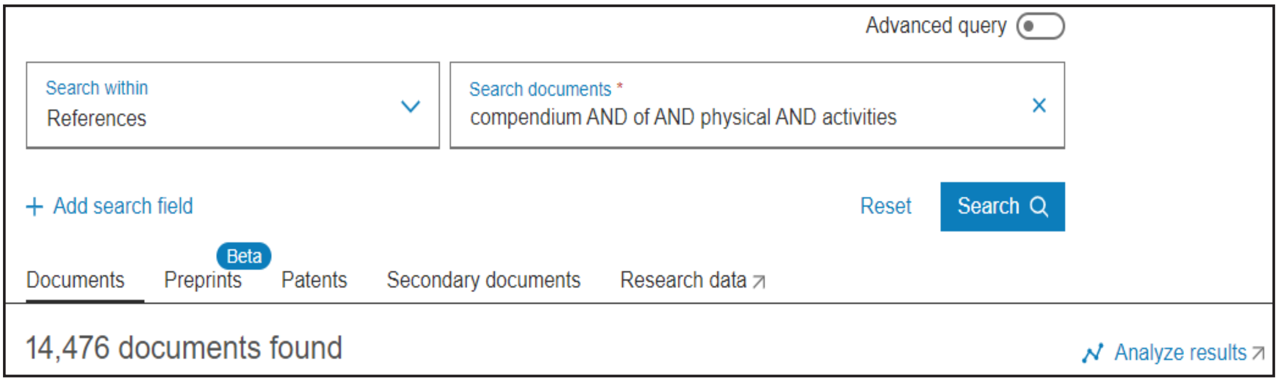
Due to its simplicity, this prototype is highly portable, making it ideal for home use. This characteristic makes it particularly relevant for wheelchair users, as not all environments offer adequate accessibility conditions.

1.2 Performance Metrics

When conducting physical performance tests, depending on the equipment or the objective of a study, a specific unit is used to quantify a given effort. Collins et al. (2010) conducted a study involving individuals with SCI (Spinal Cord Injury), who performed physical and/or daily activities using a device that measured oxygen consumption. From this data, the following measurements were obtained: inhaled oxygen in mL/min, oxygen intake relative to body mass in mL/kg·min, and energy expenditure (kcal/min). These values were used to calculate the number of METs (Metabolic Equivalents) for individuals with SCI (1 MET = 2.7 mL/kg·min).

Studies involving MET values or their calculation are related to the *Compendium of Physical Activities*, which provides MET values for a wide range of activities. These values are derived from various research studies and serve as a reference for future work. A search on the Scopus platform for references to the *Compendium of Physical Activities* yields more than 14,000 results, as shown in Figure 5.

Figure 5 – Search Results



Source: Authors

Using data from this compendium, it is possible to determine the MET value for a given activity. For example, the compendium establishes an equivalence value of 1 MET for wheelchair users (MET wc) as 0.992 kcal/kg/h. Based on this, Table 1 presents the energy expenditure of wheelchair propulsion on a treadmill at specific speed ranges.

Table 1 – Energy Expenditure

Activity Code	MET WC	Activity Description
90165	2.4	Treadmill Wheeling 2.2-2.9 km/h
90166	2.8	Treadmill Wheeling – 3.0-3.9 km/h
90167	3.4	Treadmill Wheeling – 4.0-4.9 km/h
90168	3.4	Treadmill Wheeling – 5.8 km/h
90169	3.5	Treadmill Wheeling – 6.0 km/h
90170	4.2	Treadmill Wheeling – 7.0-7.9 km/h

Source: Compendium of Physical Activities

There are also other ways to assess the performance of wheelchair users beyond MET values. Biduski, G. M. et al. (2023) and Ünüvar, B. S. & Sanioğlu, A. (2021) used torque itself to evaluate wheelchair users' performance. Furthermore, Rech (2024) suggests that performance can be measured by power output derived from torque.

2 METHODOLOGY

To quantify the performance of a wheelchair user, the method proposed by Strelow (2021) was adopted. This method is based on the use of a specific inertial roller, the same one employed in the present study. From the variation of the signal captured by an encoder and the time measurements obtained using an ESP32 microcontroller, the system's angular acceleration can be determined. Torque is then calculated based on the total resistive load associated with the angular acceleration, while power is obtained from the angular velocity of the shaft. This approach was previously implemented and validated by Rech (2024).

To ensure real-time access to the collected data, the system was integrated with an online data-sharing platform capable of managing and storing this information. Google Sheets was selected due to its free version offering higher storage limits and update frequency compared to similar tools. Furthermore, its interface facilitates the manipulation and organization of the data. As a result, qualified professionals can access the results from any location, allowing for immediate interpretation and quicker diagnostics.

To implement Internet of Things (IoT) functionalities, a library was used to enable data sharing to a spreadsheet. However, due to the mismatch in speed between data acquisition and upload to Google Sheets, a laptop was used to temporarily store the data before forwarding it.

3 RESULTS AND DISCUSSIONS

Due to the use of serial communication, some data is lost during the process. This issue has a dual impact: it affects both the storage of the data and the retransmission back to the microcontroller. A portion of the spreadsheet results is shown in Table 2, where the "*" symbols represent values lost during serial communication. It is important to note that the data presented below do not correspond to a real person, they are part of a test conducted to validate the data transmission methodology using the Internet of Things (IoT).

Table 2 – Result taken from Google Sheets

Time (ms)	Speed (RPM)	Acceleration (rad/s²)	Torque (N·m)	Power (W)
*	8.33	14.54	*	*
4,780.00	22.22	-48.48	4.75	5.65
4,810.00	8.33	-14.54	-15.84	45.38
4,840.00	26.39	33.94	-4.75	11.52

Source: Authors

As a proposed improvement, the use of a laptop could be replaced with a more compact and integrated solution for temporary data storage, such as a microcontroller with microSD card support or a USB flash drive. This modification would enable the development of a portable dynamometer attachment, allowing the system to be taken directly to the homes of wheelchair users, thereby expanding accessibility. Additionally, the prototype could incorporate relevant features identified in the literature review, such as the portability emphasized by De Melo (2023) and the adjustable support mechanisms described by Wieczorek & Warguła (2019). In this way, the system would not only eliminate the inconvenience of user displacement but also allow for real-time data sharing with trainers, physiotherapists, and other healthcare professionals.

4 CONCLUSIONS

The developed system demonstrated some data loss due to the use of serial communication, however, the test confirmed its feasibility for data sharing via IoT. The proposed improvements, such as the integration of alternative data storage solutions, would allow the elimination of serial communication, thereby removing this source of data loss. With these modifications, it is believed that the tool could be suitable for use as a home training device. In this way, the system is expected to contribute to promoting autonomy and improving the quality of life of wheelchair users, while expanding access to physical monitoring and rehabilitation technologies.

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