CIÊNCIA^e NATURA

ISSN 2179-460X
OPEN ACCESS

Ci. e Nat., Santa Maria, v. 46, spe.3, e87029, 2024 • https://doi.org/10.5902/2179460X87029
Submitted: 08/03/2024 • Approved: 17/05/2024 • Published: 08/11/2024

**II Feira de Ciências, Tecnologia e Inovação da UFSM-CS**

# A new device for cardiopulmonary exercise testing and exercise training for wheelchair users through the IoT. Instrumentation of a wheelchair training device using IoT

## Um novo dispositivo para teste de exercício cardiopulmonar e treinamento de exercício para usuários de cadeira de rodas por meio da IoT. Instrumentação de um dispositivo de treinamento em cadeira de rodas usando a IoT

**Charles Rech[I], Simone Ferigolo Venturini[I], André Francisco Caldeira[I], Cristiano Frandalozo Maidana[I], Carine Cristina Callegaro[II], Arthur Sandri Lunkes[I], Mathias Verdum de Almeida[I], Maximiliano Silveira de Souza[I]**

[I] Universidade Federal de Santa Maria, Cachoeira do Sul, RS, Brazil
[II] Universidade Federal de Santa Maria, Santa Maria, RS, Brazil

## ABSTRACT

Exercise training is fundamental to maintaining and improving the quality of life for wheelchair users. However, the practice of exercise training could be affected by the lack of accessibility, irregularities in the surface of the sidewalks, weather conditions, and especially the lack of ergometers specifically designed for the physical training of wheelchair users. The objective of this study is to develop a device capable of allowing wheelchair users access to both exercise training and cardiopulmonary exercise testing. The treadmill uses an encoder connected to an ESP32 microcontroller to transmit the angular variation of rotation, which, after mathematical processing, displays the torque and power values developed by the individual and is sent to the cloud via the Internet of Things (IoT). This device could enable social inclusion of people with disabilities during exercise training in gyms, as well as measure physical performance for medical evaluation and exercise prescription.

**Keywords**: Treadmill; Wheelchair; Exercise training; Internet of Things; People with disabilities

## RESUMO

O treinamento físico é fundamental para manter e melhorar a qualidade de vida dos cadeirantes. Contudo, a prática de exercícios físicos pode ser prejudicada pela falta de acessibilidade, irregularidades

Published by Ciência e Natura under a CC BY-NC-SA 4.0 license.

no piso das calçadas, condições climáticas e principalmente pela falta de ergômetros projetados especificamente para o treinamento físico de cadeirantes. O objetivo deste estudo é desenvolver um dispositivo capaz de permitir o acesso de cadeirantes tanto ao treinamento físico, quanto ao teste de esforço cardiopulmonar. A esteira utiliza um encoder, conectado a um microcontrolador ESP32 para transmitir a variação angular da rotação, que, após processamento matemático, exibe os valores de torque e potência desenvolvidos pelo indivíduo, enviado para a nuvem via Internet das Coisas (IoT). Esse dispositivo poderá possibilitar a inclusão social de pessoas com deficiência durante exercícios físicos em academias, bem como medir o desempenho físico para avaliação médica e prescrição de exercícios.

**Palavras-chave**: Esteira ergométrica; Cadeira de rodas; Exercícios de treinamento; Internet das Coisas; Pessoas com deficiência

## 1 INTRODUCTION

According to data from the Brazilian Institute of Geography and Statistics, Brazil in 2019 had a portion of 3.8% of the population with motor difficulties in the lower part, that is, people who lack mobility. This lack of mobility is often lifelong and a challenge to overcome on a daily basis. Therefore, improving mobility and accessibility is important to make everyday life easier for people with motor disabilities.

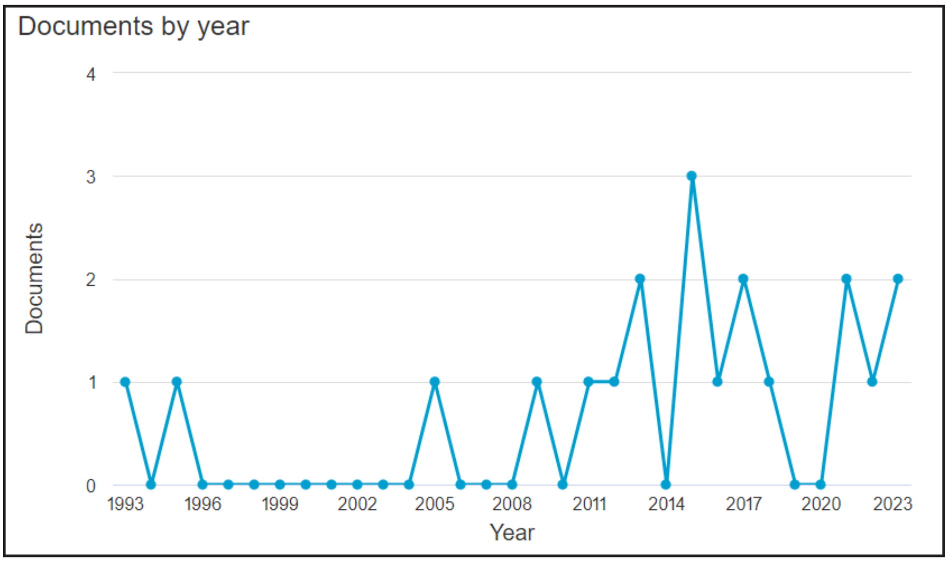
People with motor disabilities need adaptations to be able to perform basic tasks autonomously. The high school and elementary school curriculum in Brazil requires the completion of a number of physical education hours that are severely impaired for wheelchair users. In the study by Remião (2012), access to the sports field was difficult for students with motor difficulties, who were unable to complete these physical education hours.

A certain level of physical fitness is required to meet the challenges of daily life, such as going to the grocery store or to work. This physical fitness is achieved through exercise, which helps with mobility, health issues and quality of life. This is evident from the study carried out by Medeiros, Motta, Mariano, Menguer and Silva (2018), which concluded that the practice of swimming in wheelchair-bound women with polio resulted in physical improvements, quality of life and biochemical standards. In addition, Najafabadi, Shariat, Anastasio, Khah, Shaw and Kavianpour (2023) stated that the practice of physical exercise causes an improvement in mental and physical health.

As previously highlighted, people with disabilities face difficulties in their daily lives that could be alleviated by improving accessibility to exercise training in centers, gyms and public areas, providing a better quality of life. Thus, the present work aims to implement a device capable of providing exercise training to wheelchair users and quantifying their performance.

With this work proposition, the existence of similar works was verified using the Scopus platform. To carry out the search, 3 keywords were stipulated: wheelchair, quality of life and dynamometer. With these, some synonyms were written in order to find a larger portion of works with a similar subject. Through the keyword search, the first filter was: “handicapped” OR “wheelchair user” OR “wheelchair”, the second filter was: “dynamometer” OR “treadmill” and the third was: “quality of life” OR “life quality” OR “autonomy”. The result was Figure 1.

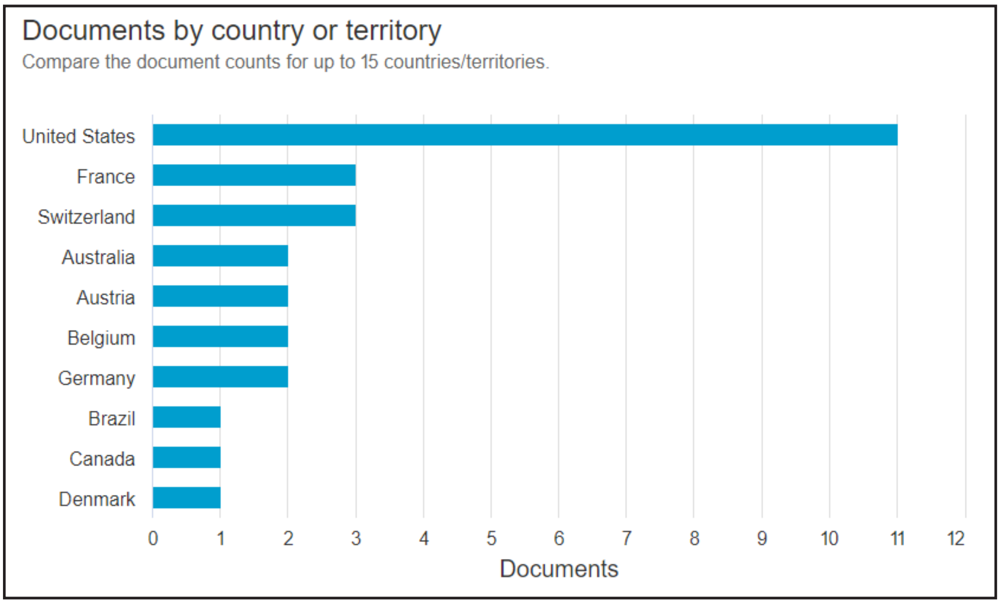
Figure 1 – Chart of documents over the years




Source: Authors (2024)

Through this Scopus search, in the last 30 years there have been only 20 works on this subject. Furthermore, the Scopus platform shows that in Brazil there was only 1 research project on this subject in the entire period observed, as shown in Figure 2.

Figure 2 – Documents by territory




Source: Authors (2024)

Based on the results obtained in Scopus, the lack of research in this area became evident and, combined with the need to practice physical exercises and the lack of accessibility for wheelchair users, the objective of designing an instrumented training device was proposed. This equipment would focus on exercising wheelchair users in gyms, in addition to having the ability to measure performance, and could be used by athletes who wish to quantify their effort. Another advantage of this equipment is that it avoids the need to visit places such as streets and sidewalks that are not suitable for wheelchair users.

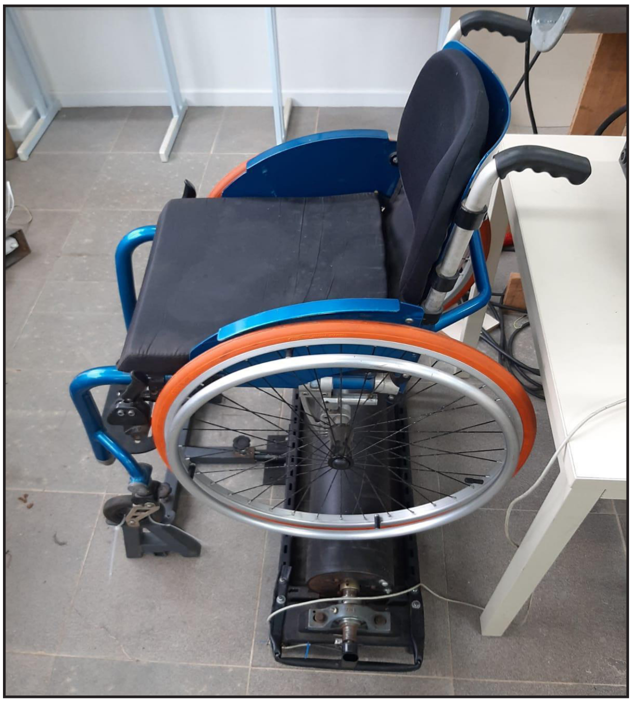
Therefore, with the central idea established, to achieve it, it was defined that initially the device would be sizing, that is, determining which sensor is suitable to carry out the measurement. Afterwards, the sensor signal would be captured using a microcontroller and with the help of a mobile device, monitoring and quantifying the physical performance of the wheelchair user. The designed system works wirelessly, that is, communication between the microcontroller and the mobile device is carried out using the Bluetooth protocol, based on the Internet of Things concept. The choice of this protocol is due to the practicality of not using wires, in addition to allowing results to be obtained remotely and exported to a cloud, which eliminates the need for a specialist to be present at the training site.

## 1.1 Theoretical Reference

### 1.1.1 Physics of the measurement process

The equipment consists of an inertial roller that serves as a support for a wheelchair, where only the rear wheels are supported on it. The front wheels are fixed to another connected support on which the cylinder is located. The model is represented in Figure 3.

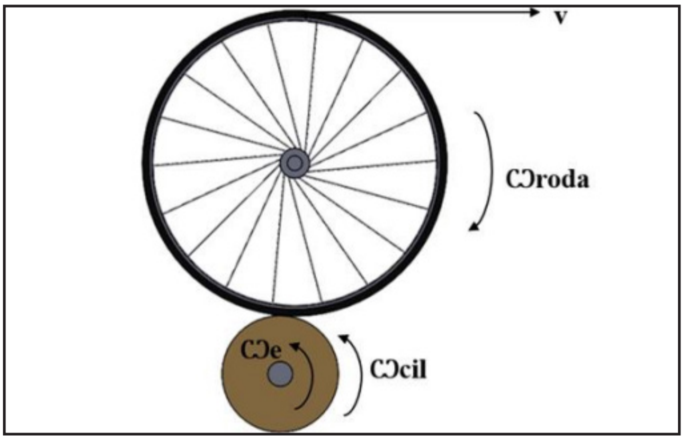
Figure 3 – Equipment Prototype



Source: Author's/ Authors' private collection (September, 2023)

To quantify the system, it is analyzed at the desired location, which consists of the point of contact of the chair wheel with the inertial roller, this situation being represented by Figure 4.

Figure 4 – Wheelchair system representation




Source: Strelow (2021)

As highlighted in Figure 4, the force that the wheelchair user exerts on the wheel is transferred to the inertial roller at the point of contact and this movement is captured by the encoder that computes the data. Some factors need to be considered when quantifying the movement, such as the moment of inertia of the cylinder and the mass of the chair and the wheelchair user.

The inertia caused by the mass of the cylinder is related to the variation in angular velocity (Beer, 2019, p.1111), therefore, during moments of acceleration and deceleration, the body will be influenced by inertia. In addition to this factor, the weight that the wheelchair user and their chair exert on the roller is converted into frictional force on the support bearings. The sum of the two factors, inertia and friction, is defined as the total load of the system (Rech, Balafa & Oliveira, 2021, p. 11).

### 1.1.2 Mathematics of the measurement process

To understand the transfer of forces that occurs in the system, it is essential to understand the functioning of angular movement. In a system involving rotations, angle measurement is used, locating positions along a circle, where it is always in comparison with an origin. In this way, analyzing the change of position as a function involving time, it is possible to determine the angular velocity, shown in equation (1)

(Halliday, Resnick, & Walker, 2023, p.263):

$$\frac{d\theta}{dt} = \omega \quad (1)$$

In this same reasoning, being the speed present at one instant and compared with another instant, the angular acceleration is obtained, that is, how much the speed varied over a period of time (Halliday, Resnick, & Walker, 2023, page 263), see equation (2).

$$Te = \frac{1}{\omega r}\left[ea(\theta r)ia \ + eb(\theta r)ib \ + ec(\theta r)ic\ \right], \quad (2)$$

However, the wheelchair is an object that performs both angular movements present in the wheels and linear movements, so that the rotation of the wheel projects the chair forward. Therefore, a relationship between these two movements is necessary to determine the speed at which the chair moves forward, this equation is provided by Beer (2019, page 982).

$$V = \omega\ .r \quad (3)$$

From this relationship, it is possible to transcribe the rotation of the wheel to the rotation of the encoder, seen in Figure 4, the point of contact of the roller with the wheel and the module of linear speeds is identical. In this way, it is possible to transcribe the angular velocity of the wheel into the angular velocity of the cylinder. Considering wheel and wheel as the angular velocity and radius of the wheel, respectively, and cylinder as components of the inertial roller, through equation (3) we arrive at equation (4). It is worth mentioning that the angular velocity of the cylinder and its axis are identical.

$$\frac{\omega\, roda\ .\ r\, roda}{r\ cilindro} = \omega\ cilindro \quad (4)$$

With the speed and angular acceleration data, it is necessary to obtain the total load of the system, that is, the unwanted action of the moment of inertia together with the friction force arising from the weight force. This load can be obtained by an equation developed by Strelow (2021). This total load equation was obtained from the interpolation of several equations that describe the acceleration movement provided by a falling weight, with different masses on the wheelchair. The result of the union of these functions is represented by equation (5), where mc is the mass on the wheelchair.

$$Ct = 449{,}72(mc)^3 - 19{,}7(mc)^2 + 0{,}9623(mc) + 0{,}0882 \tag{5}$$

With the resistive load of the system obtained, it is possible to obtain the torque using equation (6) (Budynas and Nisbett as in Strelow, 2021, p.28).

$$T = Ct.\alpha \tag{6}$$

Now using the calculated torque and the previously obtained angular velocity, we find the power of the wheelchair user, equation (7) (Beer, 2019, p.1188).

$$Pot = T.\omega \tag{7}$$

Furthermore, Beer (2019, page 804) states that power, time variation and work are related by equation (8), carrying out an integration by time on both sides it is discovered that the lower area of the function that governs the behavior of power in a given time interval is equivalent to work.

$$Pot = \frac{d\,Trabalho}{d\,t} \;\therefore\; \int_{t2}^{t2} Pot\,dt = Trabalho \tag{8}$$

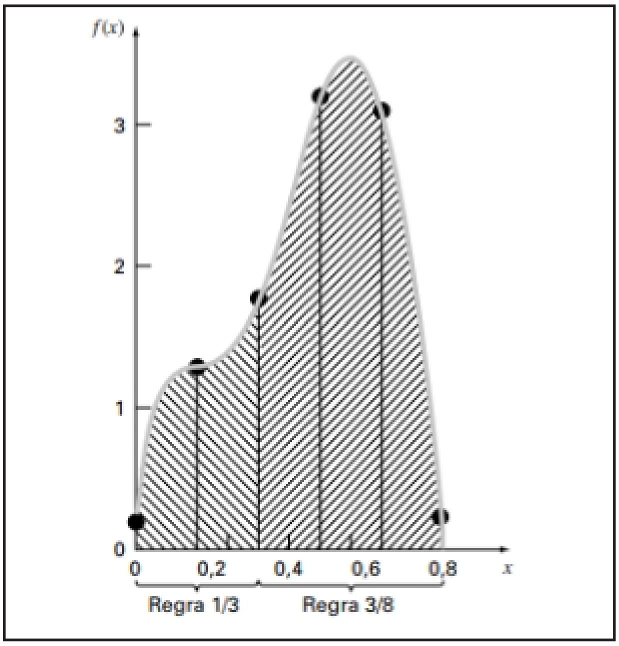
1.1.3 Measurement data processing

As previously mentioned in the description of equation (8), to carry out the final quantification of a wheelchair user it is necessary to carry out several integration processes. Bearing in mind that the movement of a wheelchair user is limited to energy insertion processes, which are followed by a brief deceleration before energy is inserted into the system again. Due to the equation, the angular acceleration rises to a peak, followed by a drop, this decrease being unnecessary in the measurement process, as it will not be quantified performance but rather the forces that reduce movement when the wheelchair user does not provide energy for rotation.

Since equation (8) has an integral, it is necessary to use some numerical method to determine an approximate value of the work performed by the wheelchair user. The processes used are Newton-Cotes formulas, which are schemes that approximate a value of a complicated function with another that is simpler to integrate (Chapra and Canale, 2016, page 541).

The three most used methods are the trapezoid approximation, Simpson's and Simpson's , according to Chapra and Canale (2016, page 565). The authors also comment that the trapezoid rule has more exact applications when the approximate equation is of the lower degrees, when it is a first-degree equation, its error is zero, but when the equation is of higher degrees, its error makes it more expressive. The suggested recommendation is to use Simpson's methods, which are more accurate.

Figure 5 – Example of an integration




Source: Chapra e Canale (2016, page 562)

Therefore, as represented in the previous image, when using one of Simpson's methods, it is likely that in some cases it will be necessary to use both. Bearing in mind that Simpson's method, equation (9), is an approximation that uses 3 points and two intervals and Simpson's , equation (10), uses 4 points and 3 intervals. Therefore, depending on how many intervals the set has, it is necessary to use a mix of both methods (Brasil, Balthazar and Góis, 2015, page 103).

$$Área = \frac{1}{3}h[f(x0) + 4f(x1) + f(x2)] \tag{9}$$

$$Área = \frac{3}{8}h[f(x0) + 3f(x1) + 3f(x2) + f(x3)] \tag{10}$$

On the other hand, when dealing with these methods, the approximation process may contain errors due to any irregularity that the function may present. Therefore, there are two equations that are used to calculate the error of the integration process. Equation (11) refers to Simpson's process and equation (12) to Simpson's (Chapra and Canale, 2016, page 542-546).

$$Et = -\frac{1}{90}h^5 f^4(\xi) \tag{11}$$

$$Et = -\frac{3}{80}h^5 f^4(\xi) \tag{12}$$

## 2 METHODOLOGY

### 2.1 Sizing

Sizing is the process by which an association is made between the order of magnitude to be measured and the meters (sensors), the objective of this connection being to determine whether the sensors have the appropriate specifications to supply the desired measurement. For this, the maximum value that can be found during the measurement process is stipulated, using this value to determine the prerequisites of the sensors.

Thus, first the speed that a wheelchair user could reach using a wheelchair was stipulated; for this, record data from the Brazilian Paralympic Committee was selected.

Among those collected are: time, distance covered and modality, all referring to the T-54 category. The results are presented in Chart 1.

Chart 1 – Test data

| Gender | Race (m) | Time (s) | Average Speed (m/s) |
|---|---|---|---|
| Masculine | 100 | 14.21 | 7.037 |
| Feminine | 100 | 17.07 | 5.858 |
| Masculine | 200 | 25.60 | 7.812 |
| Feminine | 200 | 30.49 | 6.559 |
| Average | | | 6.816 |

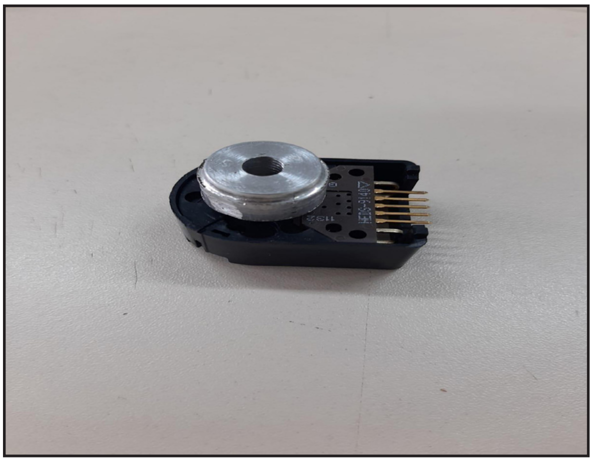
Source: records | Atletismo. (2023)

Organized by the authors (2023)

With the average linear speed defined, it is necessary to convert it to the rotation that the inertial roller will undergo. For this, equation (3) is used to replace it in equation (4). With the value of the measured cylinder radius (0.17m), it is possible to calculate the angular velocity of the inertial roller. Thus, as the angular velocity of the inertial roller and the roller axis are equal, the speed is obtained, approximately 766 RPM.

With the calculated speed, it is possible to search for a sensor that adapts to the project conditions. The encoder selected was the HEDS-5645 model, represented in Figure 6, and some of its specifications are presented in Chart 2.

Figure 6 – Encoder HEDS-5645



Source: Author’s/ Authors’ private collection (September, 2023)

Chart 2 – Encoder data

| Temperature (°C) | Voltage (V) | CPR (counts per revolution) | maximum speed (rpm) | maximum acceleration (rad/ |
|---|---|---|---|---|
| -40 até 100 | 4.5 até 5.5 | 360 | 30,000 | 250,000 |

Source: BROADCOM (2021)

Organized by the authors (2023)

As seen in Chart 2, the maximum operating speed of the sensor is 30,000 RPM, therefore the selected sensor has the capacity to measure the desired phenomenon.

## 2.2 Calibration

When using a sensor to measure some phenomenon, it is necessary to question the veracity of the measured value, several factors can influence the result, so the calibration process can reduce the measurement error. The calibration process, according to Fernando, Fabricio, Trevisan, Lixandrão and Lima (2018, page 26), is the comparison of the values displayed by the sensor and a known value and based on the analysis, a correction process is stipulated to reduce the measurement error.

The work carried out by Strelow (2021) aims to find the calibration for the prototype used in this project, therefore, his work is focused on removing the uncertainty caused by the inertia and friction force of the measurement. To this end, he developed equation (5), which, using the mass of the wheelchair user, makes it possible to determine the resistive forces, removing them from quantification.

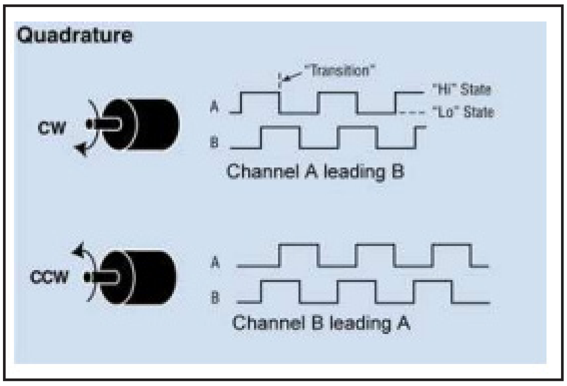
## 2.3 Measurement Method

The measurement will begin with the rotation of the inertial cylinder, which, by changing the angle position, the encoder will capture through the rotation of a disc that has several equally spaced windows, separated by bars and distanced from the axis with the same radius. The disk separates a LED from a photodetector and, due to the rotation, it is possible to detect the movement, sending the data to an ESP-

32 microcontroller, which is responsible for interpreting the data received from the encoder by performing a pre- processing.

The connection between them is made by 4 cables, 2 of which are binary data outputs, connected to the ESP-32 on pins 34 and 35. The data output sent by the encoder is represented in quadrature format, which is interleaving the torque values and that, by comparison with the previous output, it is possible to determine the direction of rotation. This process is represented in Figure 7.

Figure 7 – Operation of an encoder




Source: Vargas (2023)

According to the manufacturer Broadcom, the HEDS-5645 G13 model has a 360 CPR resolution, which defines CPR as counts per revolution, meaning that in 360° mechanics, there is a fixed number of counts. In this case, 1 counts is said to be a pair of a window and a bar, characterizing an interruption and release of the light beam. This interpretation, in turn, implies in binary language a 0 and a 1, which can be represented graphically in Figure 7.

To carry out quantitative, the angular position is initially identified as shown in Figure 7 in a clockwise direction, joining the signal from channel A and B, it becomes: 00, 10, 11 and 01 (equivalent to 1 count), this sequence being in infinite repetitions. For the counterclockwise direction, which channel B anticipates A, we have: 00, 01, 11 and 10, the same sequence with the opposite direction, therefore, to quantify and determine the direction, the set of current values is compared with the previous value.

Now it is necessary to attach a value to change the sequence, with 360° of a revolution being related to 360 CPR of a revolution, leaving 1° with 1 CPR. As previously mentioned, 1 count is equivalent to a bar and a window, which together with the other channel is summarized as a complete cycle, so the previously measured sequence is equivalent to 1 degree.

## 2.4 Uncertainty Analysis

With the acquired data, it is necessary to know the uncertainty linked to them. With processing, Simpson's and Simpson's numerical integration methods are used. These methods, as explained previously, have an error linked to the calculation, and through this the uncertainty of the process is determined, shown in equations (14) and (15).

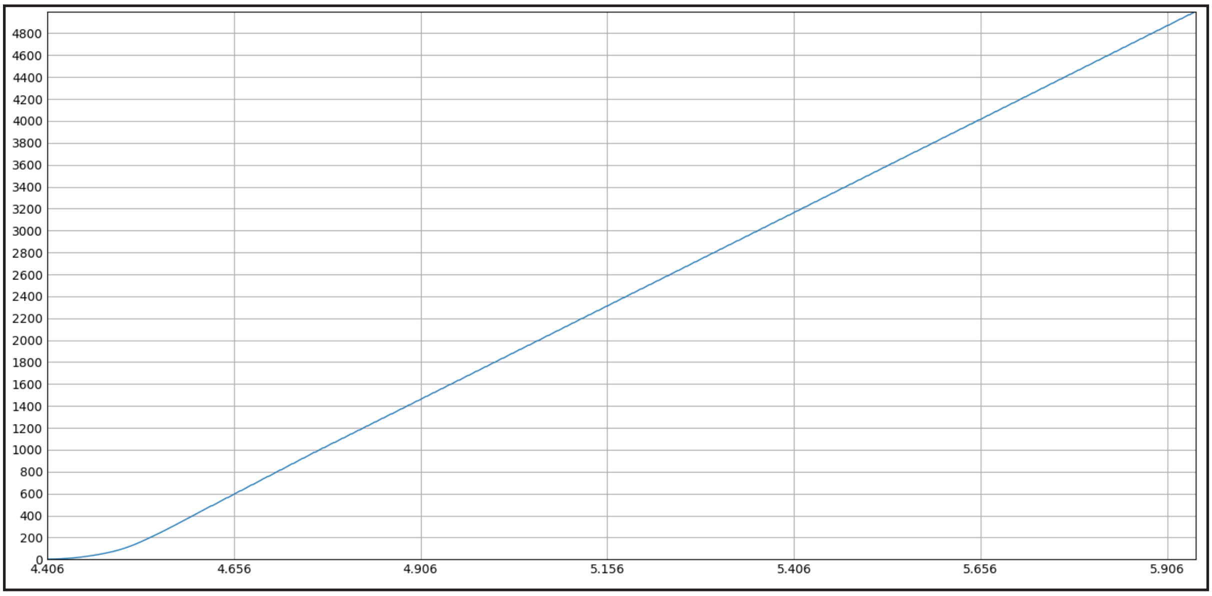
## 2.5 Results and discussions

To check whether the system built can measure the data coming from the encoder, a code was created for the esp-32, aiming to count the pulses coming from the encoder. To do this, it is necessary to provide a known rotation, generating a previously calculated number of pulses.

Using a screwdriver with a maximum speed of 550 RPM and knowing that the encoder has 360 counts per revolution, that is, 360 high pulses in one revolution, it is possible to determine the number of pulses. Using the encoder resolution and speed, pulses per minute are determined by multiplying the speed by the resolution and then dividing by 60, going from pulses per minute to pulses per seconds. In this way, it provides 3300 Hz, or as previously mentioned, a count, or pulse, is equivalent to one degree, thus reaching a speed of 3300 degrees per second.

Once the measurement is carried out, the data is sent to be analyzed and placed on a graph using a Python code, the result is evident in Figure 8. In the figure, the y axis is the angular position, or the number of pulses and in x axis is the variation in time since the first measurement, with the delay caused by the time it takes to initialize the system and start rotating the screwdriver. To determine the speed reached, it is obtained by differentiating two points as in equation (1).

Figure 8 - Data Graph




Source: Authors (2024)

It should be noted that in the calculation itself, the time resolution is in microseconds, with the value being rounded to 3 decimal places in the graph. The linear format indicates that the speed is constant, and the speed calculation can be applied to any instance of the straight line. The curve at the beginning indicates that the encoder was able to capture the acceleration coming from the screwdriver.

The measurement uncertainty is mainly due to the acceleration of the system, considering that the previously mentioned integration methods predict that in first-degree equations the uncertainty caused by the calculation is zero. Furthermore, if the system was able to capture the speed along with its variation, it is possible to assume that it can quantify the performance of a wheelchair user, keeping in mind that the next calculation steps depend only on mathematical manipulation.

However, the functioning of the system may be impaired if it is run on hardware that does not have sufficient data processing capacity, as some tests carried out cause the mobile device to restart. In this way, it is still possible to improve the code used in some areas with the aim of making it more accessible, allowing more wheelchair users to be able to use a training device.

## 3 CONCLUSIONS

Through this study it was possible to develop a system capable of quantifying wheelchair users' performance, taking another step towards training devices for physically disabled people. In order to continue development, a hardware system can be built and optimized to fix in the structure, with a process of measurement in the Equipment Prototype. The parts included will remove the need to assemble a hardware system when anyone is going to use it.

## ACKNOWLEDGEMENTS

Projelmec Ventilação Industrial Ltda. for donating materials and carrying out the project.

## REFERENCES

Beer, F. (2019). *Mecânica vetorial para engenheiros: dinâmica (11th ed.)*. Grupo A. https://integrada.minhabiblioteca.com.br/books/9788580556186

Brasil, R.M.L.R. F., Balthazar, J. M., & Góis, W. (2015). *Métodos numéricos e computacionais na prática de Engenharias e Ciências*. Editora Blucher. https://integrada.minhabiblioteca.com.br/books/9788521209362

BROADCOM. *Incremental Encoders*. (2021). Retrieved from: https://www.broadcom.com/products/motion-control-encoders/incremental-encoders/transmissive-encoders/heds-5645i13.

Budynas, R., & Nisbett, J. K. (2016). *Elementos de máquinas de Shigley (10th ed.)*. *Grupo A*. Retrieved from: https://integrada.minhabiblioteca.com.br/books/9788580555554

Chapra, S. C., & Canale, R. P. (2016). *Métodos numéricos para engenharia (7th ed.)*. Grupo A. Retrieved from: https://integrada.minhabiblioteca.com.br/books/9788580555691

Fernando, P.H. L., Fabricio, D.A. K., Trevisan, L., Lixandrão K. C. de L., Lima, C. R. G. de (2018). *Metrologia*. Grupo A. Retrieved from: https://integrada.minhabiblioteca.com.br/books/9788595025295

Halliday, D., Resnick, R., & Walker, J. (2023). *Fundamentos de Física - Mecânica - Volume 1 (12th ed.)*. *Grupo GEN*. Retrieved from: https://integrada.minhabiblioteca.com.br/books/9788521638551

Medeiros, M. S., Motta, J., Mariano, S., Menguer, L., & Silva, L. A. da .. (2018). Estudo de caso de um programa individualizado de natação em cadeirante portador de poliomielite: análise de parâmetros bioquímicos, qualidade de vida e capacidade física funcional. *Revista Brasileira De Ciências Do Esporte*, *40*(1), 94–99. Retrieved from: https://doi.org/10.1016/j.rbce.2018.01.010

Najafabadi, M. G., Shariat, A., Anastasio, A. T., Khah, A. S., Shaw, I., & Kavianpour, M. (2023). Wheelchair basketball, health, competitive analysis, and performance advantage: a review of theory and evidence. *Journal of exercise rehabilitation*, *19*(4), 208–218. https://doi.org/10.12965/jer.2346216.108

*Pessoas com Deficiência e as Desigualdades Sociais no Brasil | IBGE*. (n.d.). Retrieved from: Www.ibge.gov.br.https://www.ibge.gov.br/estatisticas/sociais/populacao/34889-pessoas-com-deficiencia-e-as-desigualdades-sociais-no-brasil.html?=&t=resultados.

Rech, C., Balafa, P. N., Oliveira, C. R. (2018). Esteira Ergométrica Para Cadeirantes. *6º Encontro Nacional de Engenharia Biomecânica (ENEBI 2018), 2018,* Águas de Lindóia, São Paulo, Brasil.

Comitê Paralímpico Brasileiro. *Recordes | Atletismo*. (n.d.). CPB. Retrieved from: https://cpb.org.br/modalidades/atletismo/recordes/ . Acesso: 10 dez. 2023

Remião, J. L. (2012). *Acessibilidade em ambientes escolares:dificuldades dos cadeirantes.* [Tese Graduação em Engenharia Civil, Escola de Engenharia da Universidade Federal do Rio Grande do Sul] Repositório Institucional da UFRGS. Retrieved from: https://lume.ufrgs.br/bitstream/handle/10183/63191/000863847.pdf

Strelow, E. M. A (2021). *Dimensionamento de um Dinamômetro Inercial para Pcd Cadeirantes*. [Tese de Graduação em Engenharia Mecânica, Universidade Federal de Santa Maria] Repositório Institucional da UFSM. http://repositorio.ufsm.br/handle/1/24260

Vargas, N. A. *Sensor óptico em quadratura: leitura via Arduino* - Universidade Tecnológica Federal do Paraná, Cornélio Procópio, PR. Retrieved from: http://paginapessoal.utfpr.edu.br/avargas/courses-1/processos_em_engenharia/et66c-processos-em-engenharia/copy_of_experiencia14.pdf.

## Authorship contributions

### 1 – Charles Rech

PhD in Mechanical Engineering, Professor of the Mechanical Engineering Course, Federal University of Santa Maria – Cachoeira do Sul.
https://orcid.org/0000-0001-8523-6300 • charles.rech@ufsm.br
Contribution: Conceptualization, Methodology, Writing - original draft preparation, Formal analysis and investigation

### 2 – Simone Ferigolo Venturini

Master's Degree in Mechanical Engineering, Professor of the Mechanical Engineering Course, Federal University of Santa Maria – Cachoeira do Sul.
https://orcid.org/0000-0002-9439-0008 • simone.venturini@ufsm.br
Contribution: Conceptualization, Methodology, Writing – original draft preparation– review & editing

### 3 – André Francisco Caldeira

PhD in Electrical Engineering Professor of the Electrical Engineering Course, Federal University of Santa Maria – Cachoeira do Sul.
https://orcid.org/0000-0002-4939-2709 • andre.caldeira@ufsm.br
Contribution: Review & editing

### 4 – Cristiano Frandalozo Maidana

PhD in Mechanical Engineering, Professor of the Mechanical Engineering Course, Federal University of Santa Maria – Cachoeira do Sul.
https://orcid.org/0000-0003-3137-6177 - cristiano.maidana@ufsm.br
Contribution: Review & editing

### 5 – Carine Cristina Callegaro

PhD in Cardiovascular Sciences, Professor of the Postgraduate Program in Human Communication Disorders and at the Department of Physiotherapy and Rehabilitation, Federal University of Santa Maria.
https://orcid.org/0000-0001-9482-5457 - carine.callegaro@ufsm.br
Contribution: Review & editing

### 6 – Arthur Sandri Lunkes

Mechanical Engineering Academic, Federal University of Santa Maria – Cachoeira do Sul
https://orcid.org/0009-0005-7750-8421 - arthur.lunkes@acad.ufsm.br
Contribution: Conceptualization, Methodology, Writing - original draft preparation - Review & editing

### 7 – Mathias Verdum de Almeida

Mechanical Engineering Academic, Federal University of Santa Maria – Cachoeira do Sul
https://orcid.org/0009-0002-5371-9441 - mathias.verdum@acad.ufsm.br
Contribution: Review & editing

**8 – Maximiliano Silveira de Souza**

Mechanical Engineering Academic, Federal University of Santa Maria – Cachoeira do Sul.
https://orcid.org/0009-0000-5236-0196 - maximiliano.silveira@acad.ufsm.br
Contribution: Review & editing

## How to quote this article

Rech, C., Venturini, S. F., Caldeira, A. F., MaidanaI, C. F., Callegaro, C. C., Lunkes, A. S., Almeida, M. V. & Souza, M. S. (2024). A new device for cardiopulmonary exercise testing and exercise training for wheelchair users through the IoT. Instrumentation of a wheelchair training device using IoT. *Ciência e Natura*, Santa Maria, v. 46, spe.3, e87029. DOI: https://doi.org/10.5902/2179460X87029