# Automatic Wheelchairs

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Automatic wheelchairs refers to devices equipped with wheelchairs, which can move automatically. Automatic wheelchairs have evolved in terms of instrumentation and control, improving the mobility of people with physical disabilities. The different wheelchair control techniques are divided into two categories: sensor technology non-invasively placed on the user and wheelchair instrumentation.

Keywords: automatic wheelchair ; control ; instrumentation ; intelligent wheelchair

## 1. Introduction

Technical aids allow the improvement of mobility in people with physical disabilities that affect their functional performance. In addition, it has to be considered how healthy or positive a person's environment is and, thus, how their quality of life can be improved[1]. For this reason, a person is recognised within a sociocultural environment which is different from that of those who do not suffer from neuromusculoskeletal deficiencies and those related with mobility or others[2]. However, recent data show that there is still a field to explore and great concern regarding the numbers related with disability. For example, according to the World Health Organization (WHO), "Around 10% of the world population suffer from physical disabilities", that is, about 650 million people [3]. From this percentage of the population who live with disabilities, 10% require the use of a wheelchair, but only a small number have access to them, and very few have access to the appropriate type of wheelchair[4]. Moreover, the "World Report on Disability" shows that 15% of the global population have some kind of disability, a number that is on the rise[3].

The people who have larger incomes have better access to manual or automatic wheelchairs than people with small incomes, including people over 65 years of age. On the other hand, there is evidence that disabled people often have limited living situations which can lead to them acquiring habits that damage their health[5]. In Colombia, according to the National Administrative Department of Statistics (DANE, by its acronym in Spanish) and the Ministry of Health and Social Protection (2012–2018), 2.9% of the total population have a disability of some kind, which represents 1,448,889 people. Out of this number, 34% of them exhibit a disability in the movement of the body, hands, arms or legs, representing a total of 496,522 people[5]. These figures call for a detailed study to be carried out regarding mobility and a solution to this problem.

A limitation in mobility significantly influences the lives of people as they cannot carry out their daily activities normally and require technical aids to improve their quality of life. In a report by the "Sala Situacional de Personas con Discapacidad en Colombia" (a registry of disabled persons in Colombia) of the Ministry of Health of Colombia [5], it is mentioned that there are 341,465 people that require assistance with mobility, representing 24% of the population with a disability in their upper or lower limbs. These figures lead to the conclusion that a wheelchair would be a solution to this problem, helping people with mobility issues in their upper or lower limbs, or both. Using one can significantly improve their quality of life.

On the other hand, the elements that make up a wheelchair depend on its type, be it manual or automatic. Nevertheless, manual wheelchairs require the strength of the user, which is why they are not recommended. A wheelchair should accommodate to the person so that they don't have to use their energy to adapt to it.

Those people who have a physical disability in their upper limbs require the assistance of another person to move. For this reason, automatic wheelchairs have been designed which allow the user to move around without a companion. These wheelchairs include a pair of motors for movement, as well as batteries to run the motors and a control system which varies depending on the needs of the person. If it is a commercial wheelchair, it often uses a joystick for movement.

The control characteristics of wheelchairs is based on the current state of research and its implementation. Thus, the authors propose the following question, with the purpose of carrying out an adequate search of the scientific articles to review: Are the control systems that have been developed between 2012 and 2019 adequate for people with disabilities in their upper or lower limbs, or in both?

# 2. Control Systems and Electronic Instrumentation Applied to Autonomy in Wheelchair Mobility

## 2.1 Discussion on Instrumentation Non-Invasively Placed on the User

Non-invasive methods refer to the instrumentation placed on the user’s body for the control of the wheelchair. The cost is low, but it depends on the technique used for capturing body signals. For example, BCI systems require electrodes for the capturing of EEG signals, which are expensive and the extraction is complex as, due to their nature, they require the filtering and amplification of the signals. However, they are very useful for people who suffer from a disability in their lower and upper limbs.

For their part, MEMS are easy to place on the user’s body due to their physical characteristics, however, the control system should have special care with the calibrations of said sensors. There are 8 articles related to MEMS, but they are less frequently found in comparison to articles that implement BCI. The reason for this may be the increase, in recent years, in the number of interfaces which interact with the person through sensors non-invasively placed on the user’s body.

Concerning the types of sensors which extract body characteristics, those that collect EOG signals can be mentioned. They are useful for people with no mobility in their lower and upper limbs. In this type of systems, it is important to define if they are active or not, given that the user should know when they are operating the system using body movements and when a natural action which does not interfere with the control of the wheelchair is being executed. These signals also present the characteristic of previous conditioning due to their nature.

Voice recognition systems are based on commands recognised by the controller and that are associated with a control action of the wheelchair. Nonetheless, they should be activated though an interface, in order to know if the controller is active or not.

The types of HMI should be separated from other types of control because of the interaction they have with the user. Thus, HMI normally presents a system which is inherent to the sense organs of the person. For this, the graphic interfaces which are described in these articles should be designed for users with specific characteristics, given that not all wheelchairs are generic, that is, each designer develops their system thinking about the needs of a type of user and the pathologies or disabilities they have.

In the same way, the design of controllers not only focuses on the mobility of the wheelchair but also on the user’s comfort, the situations of risk they must be faced with, and the person’s environment. Said controllers can be suitable, depending on the characteristics of the user, the processing characteristics and the elements used to execute the controller, and the cost of the designs. Below, a comparison is presented of the characteristics mentioned in the articles with the more frequent control strategies that were dealt with in this investigation:

- **Characteristics of the User**

The designs created for specific users guarantee the full functioning of the controller, as well as the prior training to operate the wheelchair through thoughts or emotions. However, the manufacturing of generic controllers may present flaws, as indicated in Ng et al.[6]and Carrillo et al. [7], where the participation of 60 individuals indicates that the control did not work for most of the participants. Conversely, concerning MEMS sensors, the characteristics of the user are not as important as they are in the case of BCI, given that the sensors acquire movement signals which any user can generate. Yet, the user does require previous training to learn about the angles of movement of the head or hands. In the case of sEMG and EOG, as reported in some articles in this review, the characteristics of the user were not mentioned as the testing of the controller with a considerable number of participants is not described. Still, the physical characteristics of the user can be a determining factor for the implementation of these methods.

- **Processing Characteristics and Design Computational Cost**

The computational cost is high when the controllers involve processing algorithms for EEG signals, as indicated in [8][9][10][11][12][13][14][6][7][15][16] and robust controls such as fuzzy logic and adaptive controllers, and the use of neural networks[6][11][17][18][19]. The computational cost is reduced when classic controllers are implemented, as is the case of the designs in[6][10][20][14][19]. With regard to controllers which involve MEMS or cameras to detect movement, [52,56,58,61] have a higher computational cost, due to the implementation of algorithms and neural networks, but the controllers based on thresholds present in the MEMS category have a lower computational cost. The computational expense in controllers which involve sEMG and EOG was higher in articles[21][22][23]. The rest of the controllers involve thresholds for the control and use of PID controllers.

As per the above, the controllers developed with input methods based on the user depend on the user's characteristics and the degree of mobility of the lower and/or upper limbs. They can also be implemented depending on the tools the designer has, such as the type of processor or microcontroller and the processing capacity. This review presents a wide variety of methods, algorithms, classic and robust controllers. The technological development has involved the use of artificial intelligence to predict behaviour, teach the system to make decisions through the use of neural networks, among others.

## 2.2 Discussion on Wheelchair Instrumentation

Obstacle detection and collision avoidance systems constitute a fundamental element in the design of a controller for a wheelchair, given that what is most important is the life and good health of the user. Hence, the system should always protect the person using the wheelchair. Detection systems are based on the use of sensors that measure distance or that receive signals from the external world about the presence of unknown objects. For this reason, this classification is made, knowing that the authors not only use sensors as a preventive measure but also as reference signals for the control of the wheelchairs. Artificial vision is an area openly explored in recent years, however, it requires considerable computational costs due to the resources used for the processing of the images. Additionally, the user needs this processing to be carried out in real time. For this, the use of FPGA is more common because it conducts parallel tasks which make processes significantly more agile. Although an FPGA can solve the problem, sometimes a more robust processor is required and, therefore, some of the systems described in this area carry a computer for its execution.

Finally, navigation systems give a general view about controllers which use communication protocols for the sending and receiving of data from sensors and actuators. They also improve the commercial systems of wheelchairs with a joystick or with tracking-systems for people and objects.

The articles presented in the area of instrumentation incorporated in wheelchairs mention important characteristics in the following manner:

- **Wheelchair Instrumentation and HMI**

The sensors included in this revision present information about wheelchairs, however, one of the principal motives is to guarantee the safety of the user. To this end, [6,10,11,14,16,18,20,23,32,33,36,38,40,42–44,50,58–60,64,67,71,74–77,81,87,88] include safety systems to avoid obstacles. This indicates that approximately 40% of the articles mention the use of algorithms with ultrasonic sensors, lasers, infrared, cameras, among others, in order to provide security in the movement of wheelchairs and avoid crashes. Nevertheless, those articles use another type of instrumentation to make their control more robust. Also, there are few studies that deal with the detection of obstacles, as it would require other types of input to control the wheelchair.

- **Computational Cost**

The controllers that process images have a high computational cost, and it is for this reason that they are developed in computers and the use of microcontrollers or small processors is not implemented. In the case of [44,87,94], image processing is carried out using FPGA, which includes a number of necessary resources and components for those designs. In the case of image processing in computers, it is difficult to execute in real time and the data processing is slow due to the sequentiality of the software. The controllers that use a classic control can be applied in smaller devices and do not require prior training. Also, it is highlighted that the communication systems are faster if they implement nodes, GSM networks that are not that much used at present and also Bluetooth modules.

Based on the analysis carried out previously, the controllers that use HMI are useful for people with disabilities in the lower and upper limbs, while those systems that use wheelchair instrumentation are mostly useful for people with little movement in their lower limbs. The controllers are efficient, depending on the instrumentation and the processing that they use. However, the controllers designed should have a automatic wheelchair; control; instrumentation; intelligent wheelchair safety system for the user, as any fall or crash could put the life of the user at risk.

Within the expectations for the future, a design of controllers is hoped for that will offer safety in the mobility of wheelchair users, a high degree of precision in wheelchair instrumentation and low costs, making use of the technologies and methods described in the reviewed literature. Also, the exploration and implementation of controls in open spaces is required, as the majority of those described in the literature were tested in closed environments or in laboratories.

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