SUPPORT SYSTEM TO HELP PARKINSON'S PATIENTS READ BOOKS

FRANKLIN RICARDO PARRALES BRAVO

MÁSTER EN INGENIERÍA INFORMÁTICA. FACULTAD DE INFORMÁTICA
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Franklin Ricardo Parrales Bravo

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Resumen en castellano

Hoy en día, la aparición de avances tecnológicos ha dado lugar a la creación de un nuevo campo de investigación llamado "e-Health". Se define como la aplicación del desarrollo de la atención de salud con el apoyo de la utilización de tecnologías de la información y la comunicación, más comúnmente llamado TIC. Varios proyectos se han llevado a cabo en este campo con el fin de hacer las cosas más fáciles, como detectar diversas enfermedades o problemas (medicina preventiva).

Con todo lo anterior y dada la urgente necesidad de que los pacientes que sufren de la enfermedad de Parkinson puedan tener una herramienta vital para la adquisición de conocimientos a través de texto impreso, nos enfrentamos al reto de utilizar las ventajas que nos ofrecen las herramientas existentes en el mercado con un propósito práctico. Por tanto, se ha desarrollado una solución para la lectura de un libro físico con el kit Mindstorms EV3, complementada con una interfaz grafica en Android para la gestión del sistema.

Nuestra investigación también incluye las mediciones de precisión, consumo de energía que nos proporciona la batería y distancias a las que hay que colocar el brazo robótico que permite pasar las páginas. Con todo esto, se contribuirá a mejorar la calidad de vida y la accesibilidad de los contenidos al colectivo de enfermos de Parkinson.

Palabras clave

E-Health, Mindstorms EV3, Android, Parkinson

Abstract

Nowadays, the emergence of technological advances has led to the creation of a new research field called "e-Health". It is defined as the deployment of health care supported by the use of information and communications technology, more commonly called ICT. Many projects have been carried out in this field in order to make things easier, as detecting various diseases or problems (preventive medicine).

In order to help Parkinson's patients acquire knowledge through printed text, we face the challenge of using the advantages the existing tools in the market provide us. Hence, a platform for reading a book has been developed with the EV3 Mindstorms kit. Moreover, this has been complemented with an Android graphic interface responsible for managing the system.

Our research also includes measurements of accuracy, battery energy usage and the proper distances to place the robotic arm that allows turning pages. All in all, a contribution to improve the Parkinson's patients quality of life and accessibility shall be presented.

Keywords

E-Health, Mindstorms EV3, Android, Parkinson

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Dedicatoria

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> ¿Quieres vender agua azucarada el resto de tu vida, o quieres hacer historia?
>
> Steve Jobs

Preface

The use of information and communication technologies to improve the quality of life in various diseases is a high relevance issue in our days. Thus, we can observe that they have allowed the creation of a new scientific field named e-Health to address all matters related to data processing and health.

This work has found its motivation in helping Parkinson patients improve their quality of life, by means of a supporting platform to read books in an easy manner for them. To address all the details concerning this project six chapters are presented.

Chapter 1 explains what is involved in Parkinson's disease. Moreover, it provides some statistics to motivate this project. Furthermore, it formulates the problem and describes the objectives and methodology.

Chapter 2 presents a review of the literature about existing projects and systems in the area of e-Health. Besides, several hardware platforms are evaluated and finally, the selected platform is presented.

Chapter 3 defines the system flow, its components, roles and behavior. For this purpose, several diagrams are provided.

Chapter 4 gives details about the system implementation, as the arms construction or the remote interface development. Moreover, the programming environment configuration as well as the system set-up are described.

Chapter 5 presents the experimental results to prove the efficiency of the proposed system. Several tests have been run to extract data regarding the failure rate when turning pages or the battery usage. Furthermore, the system results are compared with the state-of-the-art platform.

Finally, chapter 6 summarizes the main contributions of the project and gives some remarks about it. Furthermore, it provides some future work open lines.

Chapter 1

Introduction

As an introduction to this research, what is involved in Parkinson's disease is explained. Furthermore, the rates of occurrence of this disease in Europe, and more specifically in Spain are indicated. This chapter also reviews the existing technology, regarding both hardware and software. Additionally, the reasons that led us to study this issue are mentioned. In the latter part of the introduction, the objectives and methodology of this research work are explained.

1.1 Parkinson's disease

Parkinson's Disease (PD) is a degenerative disorder first described in 1817 by James Parkinson. It is a disease that affects the nervous system, specifically the neurons that are located in the *substantia nigra* (heterogeneous portion of the midbrain located in the basal ganglia). The function of these neurons is related with learning and movement in humans. With their degeneration, a certain amount of dopamine is not produced. Consequently, this opens the way to an incorrect motricity; although messages are sent about how and when to move, these are transmitted with error. [1]

The disease also affects other neurotransmitters such as serotonin, norepinephrine and acetylcholine, which implies the emergence of several non-motor symptoms of the disease.

In spite the fact that at the beginning the symtoms usually occur in one side of the patient's body, PD is a degenerative disease. This means that the symptoms become worse as the patient grows [2].

Symptoms are quite heterogeneous, and they range from tremors to slow movement onset, stiffness and even bradykinesia. Bradykinesia is related to the loss of spontaneous and automatic movement, which provokes slowness in all actions. This cannot be predicted and is arguably the most disabling and disappointing consequence of the disease, as patients cannot usually perform conventional actions, such as reading a book, for instance [3]. Furthermore, there are other secondary symptoms which, although do not affect every patient, cause major disruptions as the main symptoms get worse. In the following, a brief overview of the most common symptoms will be given: [4]

- Tremor. This is a rhythmic movement which goes back and forth. It is usually first located in the hands, but sometimes it previously affects the feet or the jaw. It sharpens at rest or under stressful situations, and tends to disappear during sleep [4]. It may affect only one side or part of the body.
- Rigidity. This symptom is manifested as a resistance or lack of muscle flexibility. All muscles possess an opposing muscle. Their movement is possible because, when activated a muscle, the opposite one relaxes. When this balance is disrupted, muscles tighten and constrict, causing inflexibility and weakness.
- Bradykinesia. This consists of the loss of spontaneous and automatic movement and carries the slowness in all actions. The slowness is unpredictable and it is likely among the most disabling symptoms. Patients become unable to easily perform many movements that were previously almost mechanical.
- Instability. The postural instability causes patients to lean forward or backward and even to easily fall. The head and shoulders move forward and hence the gait wors-

ens. Patients give short, quick steps to maintain the balance, or they remain literally "planted" halfway, unable to move.

- Depression. This is a common problem to all chronic diseases. Moreover, it is worsened by the medicines used to combat the disease. This can be mitigated by using antidepressants, but their combination with the aforementioned medicines may be damaging to the body.
- Swallowing and chewing. Malfunction of muscles hinders this daily task, favoring the accumulation of saliva and food in the oral cavity. As a consequence, choking and drooling become common.
- Diction. At least 50% of patients suffer slurred speech: they speak softly, hesitate before speaking, repeating words or speak too fast.
- Urinary problems. The shortcomings of the nervous system that regulates muscle activity cause some patients to suffer incontinence or have problems while urinating.
- Constipation. The progressive slowness intestinal and abdominal muscles is the main cause of constipation, although it is also influenced by diet or low physical activity.
- Sleep disorders. Drowsiness and nightmares, although usually associated to drugs, are secondary symptoms in this disease.
- Face expression loss. The muscle rigidity in the face provokes this lack of expression. Moreover, PD patients have difficulty keeping his mouth shut.
- Akinesia. This consists of total immobility, which appears suddenly and may last from a few minutes to an hour.

On the other hand, the Foundation for Parkinson's Disease (pdf.org) [5] in the United States has reported that the incidence of this disease is around 10 million people diagnosed worldwide. It also mentions that PD affects 1.5X more men than women. According to the European Foundation for Parkinson's Disease (EPDA), the population suffering PD is estimated around 6.3 million. It quantifies 1.2 million people suffering PD in Europe, approximately 260,000 in Germany, 200,000 in Italy, 150,000 in Spain, 120,000 in England, 117,000 in France, 63,000 in Poland, 28,000 and 23,000 in Holland and Belgium. In other words, the incidence in Europe varies from 9 to 22 cases per 100,000 inhabitants per year [6].

In Spain there are two main opinions. EPDA argues that there are approximately 150,000 cases [6], while a report prepared by Doctors Rocío García-Ramos, Eva López-Valdés, Loreto Ballesteros, Silvia de Jesus and Paul Mir, reveals that Spain might have about 300,000 patients diagnosed with Parkinson, twice what was estimated before [7]. This report evaluates in depth the impact of PD and is based on existing data on epidemiology, morbidity, dependence and economic impact of the disease in Spain. Dr. Rocío García-Ramos mentions that *"estimates of prevalence and incidence of Parkinson worldwide may vary in different studies, mainly due to methodological differences, but also genetic and environmental differences between the different studied populations. However, we believe that the data pointed to by the report are closer to reality, something especially important not only as a source of epidemiological information, but basic for resource planning"*. Another author of the report, Dr. David A. Perez, added that *"although Parkinson's is a motor disorder, disability can be caused by many factors, in fact, depression, dementia, psychosis and other non-motor symptoms of the disease have a major impact on the quality of life of patients and families, even to the point that they are the leading cause of morbidity and reason for hospitalization in most cases"*.

1.1.1 Reading a Book

The intellect is not affected in the PD but in the latter stages. What is altered, however, is the verbal expression, which becomes slow and hesitant [8]. Additionally, patients have difficulties reading a physical book when the font size is small, and trying to turn the pages. As a result of this disability while performing conventional easy tasks, patients become highly depressed [9, 10], which is not the best status to face a disease.

The main problems while reading a book are derived from the aforementioned tremor, rigidity and bradykinesia symptoms. Due to the facial rigidity, small fonts [11] are quite difficult to read. Moreover, a PD patient cannot turn a single page with full precision. Usually, several pages are jointly twisted. A possible solution to address the small fonts problem is to obtain books with larger fonts, through enlarged authorized photocopies to make your content more visible. Nevertheless, the major problem of turning pages must be solved.

On the one hand, ebooks could be a solution. Nonetheless, many books have its digital version in PDF format, which requires zooming letter in order to read. This represents difficult actions that people with PD cannot perform. A conversion to another format could be done as well. However, the generated document is not always perfect, and sometimes part of the document structure is lost [12].

Additionally, there are several scientific studies arguing that it is more difficult to understand text in digital format than in conventional books. Poorer comprehension, and slowly reading are problems associated with ebooks. For example, the Norwegian professor Anne Mangen [13] has published a study realized over two groups of students (belonging to the same course and similar academic levels). They had read each text in digital format or printed book. Later, she raised a number of questions to students. When she checked their results, as she supposed, those who had used the computer had answered slightly worse than their classmates. She concluded that the brain has to face additional difficulties which are not present when using with a conventional book, as learning to cope with a text which we cannot interact physically with. Moreover, other authors [14] revealed that physical books provide a sense of control over the text and object manipulation (underlined, bent, etc.)

that helps us better understand the text. That is why the proposed system will be deployed over physical books.

It is therefore essential to develop a support system that enables the patient to read books. This system must deal with the book pages, allowing the patient to decide when to turn a page accurately. Furthermore, this must be done using an accessible interface for PD patients.

1.2 The platform Lego Mindstorms

The Mindstorms platform is a robotics kit produced by Lego which is basically aimed at children. This kit contains basic robotic blocks, as well as junction elements. Moreover, it is possible to program the actions performed by all these components. In order to find the first version of this product, we must go back to 1998, when RCX appeared. Since then it has noticeably evolved. In 2006, NXT was released, and in August 2013 EV3 made its appearance [15].

This project has been developed based on an EV3 platform. This kit is composed of many Lego plastic blocks, several sensors and actuators, and a main block or *brick* which can be programmed. This brick contains a 300 MHz ARM9, model AM1808 Sitara (Texas Instruments) [16]. Using these components, it is easy to build prototypes and complete systems. Furthermore, there are various graphical Integrated Development Environments (IDEs) [17] which make it easier to implement the programs that control the blocks. In addition to these IDEs, various Application Programming Interfaces (APIs) can be encountered. They support the basic functionality of the system components, as for example the rotation of a servomotor or the information collection by means of a sensor. The Mindstorms EV3 retail kit (Also called *Home edition*) includes 550 Lego Technic elements that allow to create amazing robots. Moreover, this set contains 1 EV3 programmable brick, 2

Large Motors, 1 Medium motor, 1 Touch Sensor, 1 Color Sensor, 1 Infrared Sensor and an infrared remote, as shown in Fig. 1.1. The set also contains 7 connector wires and a USB cable for programming.

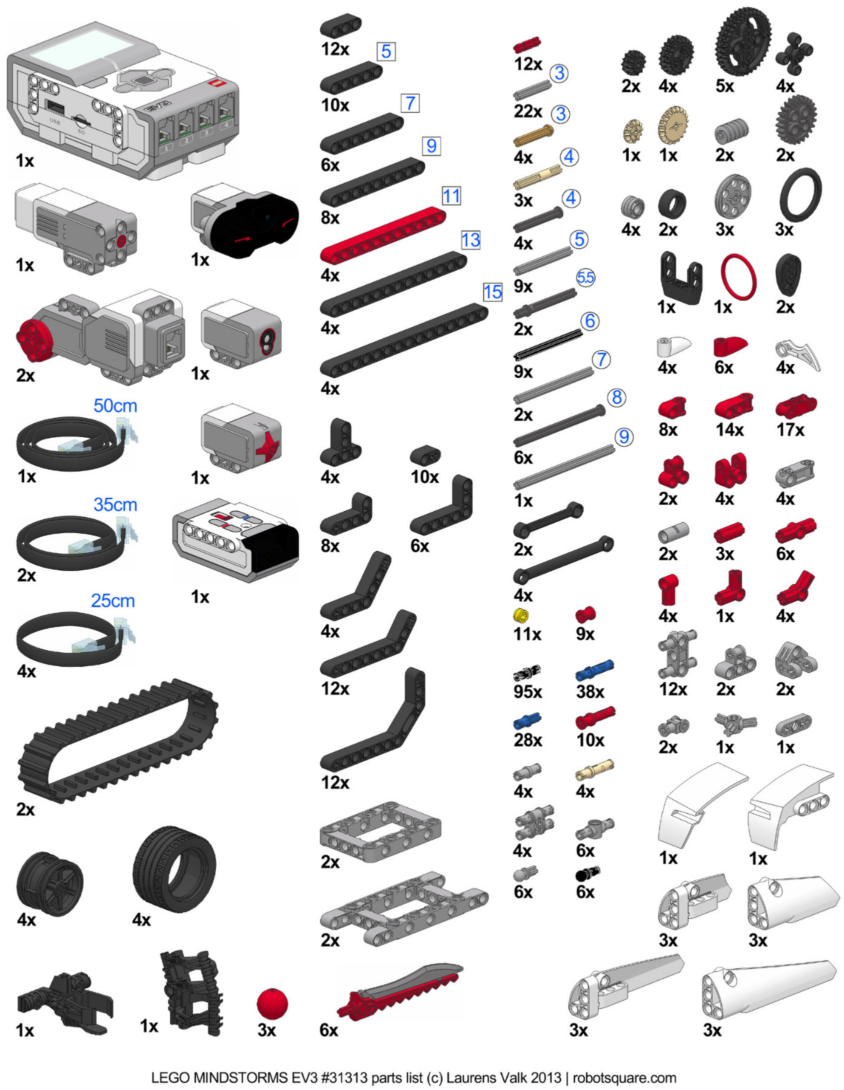


Figure 1.1: Lego Mindstorms EV3 Home Edition Parts list.

Here is a brief description about the main components that can be found within the EV3 kit.

- A programmable brick. It serves as the heart and brain of EV3 robots. It features an illuminated six-button interface that changes color to indicate the brick's active state, a high-resolution black and white display, built-in speaker, USB port, a mini SD card reader, four input ports and four output ports.

- Two large motors. They use tacho feedback for precise control within one degree of accuracy, providing full or half turns, which are controlled by software.
- A medium motor. It is suitable for lower loads, higher speed applications and when faster response times are required.
- A touch sensor. It can detect when an object is reached.
- A color sensor. It detects different colors and light intensity.
- An infrared sensor. The sensor detects proximity to the robot and reads the signals emitted by the EV3 Infrared Beacon.
- An infrared beacon. It emits an infrared signal which the sensor can track. This can also be used as a remote control for the EV3 brick through signals sent to the infrared sensor.
- The set also includes 7 connector cables and a USB cable for programming.

1.3 Motivation

Nowadays, the emergence of technological advances had led engineers and doctors to the creation of a new research field called **e-Health** [18]. It is defined as the development of health care supported by the use of information technology and communication, more commonly called ICT [19], that is, based on the utilization of elements such as computers, mobile phones, satellite communications, patient monitors [20], etc. Various projects have been carried out in this field in order to make it easier to detect diseases or just symptoms (preventive medicine). As an example, we can cite the Personal ECG Monitor (PEM) for early detection of cardiac ischemia and arrhythmia [21, 22], an outpatient treatment and telemonitoring system for patients suffering PD [23], or even electronic devices to help diabetes patients control their vital signs (e.g. blood glucose level) [24].

A different approach to the aforementioned projects is the "Butler Project", which is an e-Health platform that connects multiple users via internet to get suggestions about health care for older people. This system is composed of three levels: diagnosis (mood monitoring, alert system, managing reports) therapy (induction training in positive moods, working memory), and entertainment (email, chat, video, photo albums, music, friend forums, access to Internet) [25].

Hence, due to the PD patients problems presented during the previous subsections, and considering the advantages that the e-Health field brings us, I have decided to implement a system able to help these patients in their routine life. Concretely, my purpose is to develop a system to provide the PD patients with the satisfaction of reading a book. In order to do this, I have selected the EV3 Mindstorms kit, because on the one hand it contains sensors, servo motors and many blocks to easily build the hardware component, and on the other hand it possesses several APIs and software support to program the blocks. Additionally, an interface for Android devices will be developed, in order to allow the patients remotely controlling the system.

Furthermore, the purpose of this research is also to study different parameters and implementation options within the system. For instance, it is quite interesting to measure the energy consumption in order to extend the battery duration or the distances between the robotic arm and the book.

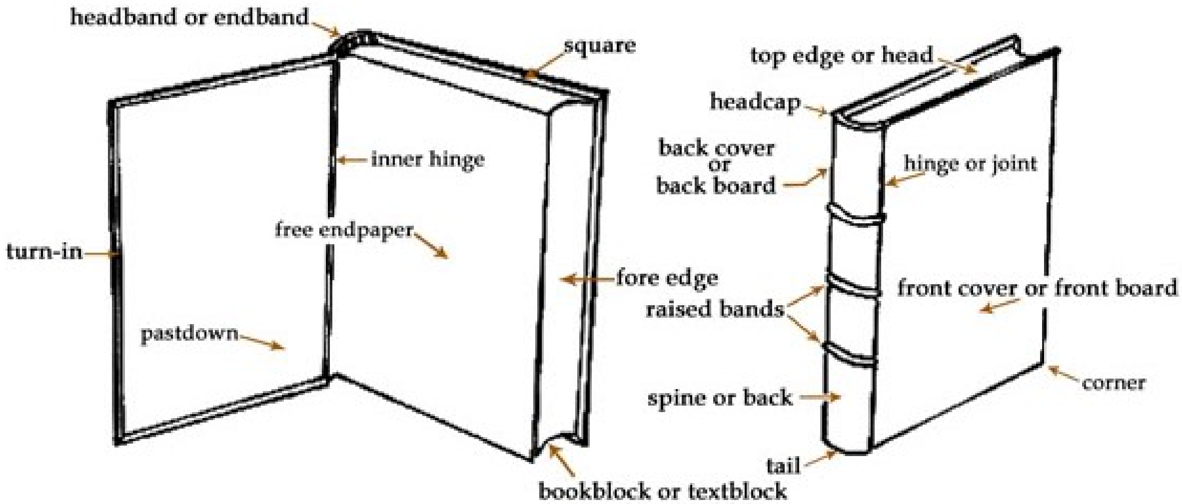


Figure 1.2: Parts of a book

1.4 Problem Description

The purpose of this project is to provide an automated system for PD patients to turn pages in a clean way. In order to do this, several problems must be faced:

- First, the book spines need to be considered. The Mindstorms EV3's linear actuator (servomotor), is fed with 9V and reaches a no load speed of 160 rpm, and with a load of 115 N / cm reaches to 120 rpm. Therefore, it is capable of delivering a maximum torque of 25 N / cm at 60 rpm, although is recommended not exceed 15 N / cm for prolonged periods because this might cause fatigue to the actuator [26, 27]. As shown above, the PD's robotic arm can have problems turning pages in books that do not possess well defined spines as the case of bound rustic (see Fig. 1.2). Likewise, the weight of the pages that have already been read (those that are turned to the left side of the book) are accumulated, being unable to select more pages. Therefore, ring bound books have been considered to first tackle the problem, because of stability that this kind of books offers when a page have been turned to left side.

- The second limitation to be faced is the robotic arm precision. Pages need to be selected one by one in order to be read. This requires to be quite accurate because only one page needs to be selected.
- Third, the weight of the pages should also be considered, as heavy pages are more difficult to be selected.
- Fourth, it is necessary to think about the inclination of the book. Typically users try to improve their vision while reading by inclining the book. For this reason, the project should work with books that have an inclination angle.
- Finally, the size of the pages is another parameter to be studied. The distance at which the robotic arm should be placed for a successful selection of pages depends on the pages length.

1.5 Objectives

In this research, the following objectives will be pursued:

- Design of a hardware system able to follow instructions related to turning the pages of a book. This system will be implemented based on the Lego Mindstorms EV3 kit.
- Development of a software for controlling the robotic arm.
- Development of a remote interface to control the system.

1.6 Methodology

In order to develop this research, the next steps shall be considered:

- Study of the problem. First, literature about motor problems of PD patients will be revised. This information will be very important for designing the robotic arm according to their necessities.

- Construction of the first prototype. A first robotic arm version will be developed with the purpose of selecting a piece of paper at a time.

- Development of the software to test the hardware blocks and their interconnection. A simple software will be developed to perform simple actions using the robotic arm.

- Debugging the initial prototype. After deploying the first hardware and software solution, the limitations and failures will be evaluated to iterate the prototype until getting a fully functional selecting arm. Moreover, the second arm will be incorporated to the platform in order to turn the selected page.

- An Android interface for remote instructions. A friendly and clear interface will be developed to allow PD patients easily interact with the platform.

- Measurements. Some tests will be performed in order to evaluate different system parameters. For instance: to check battery usage optimization and page selection accuracy; to set the appropriate arm location in order to correctly select the pages.

Chapter 2

State of the Art

This chapter presents a review of the literature about existing projects and systems in the area of e-Health that help PD patients improve their quality of life. Additionally, several hardware platforms are evaluated with the purpose of selecting the best option to build the solution.

2.1 Other tools which help PD patients

E-health is changing the landscape of clinical practice and health care. The innovations in the area of e-Health are based on technologies. E-health applications facilitate clinical decision making, improve the quality and efficiency of care, involving experts in making clinical decisions, and create the possibility of adopting healthy behaviors [28]. In the following subsections, several projects which facilitate the diagnosis, treatment and improvement quality of life in PD patients will be described.

2.1.1 PatientsLikeMe

PatientsLikeMe (see Fig. 2.1) is an online community founded by a family affected by the *Amyotrophic Lateral Sclerosis* (ALS) to allow recording the disease progression of patients through clinically validated results [29], share their experiences with others [30], the creation of inferred information (aggregate level) [31], and finally, to promote the progress of research in the area of crowd-sourcing indicating what works and what does not [32]. Although initially it was oriented to the study of ALS and multiple sclerosis, PatientsLikeMe has also been used to detect the side effects of medication and disease variability in PD [33, 34]. However, there are some controversies regarding the information provided by the patient to indicate in his own criteria how sick they are, or to measure their disease progression, which normally has been defined by doctors.

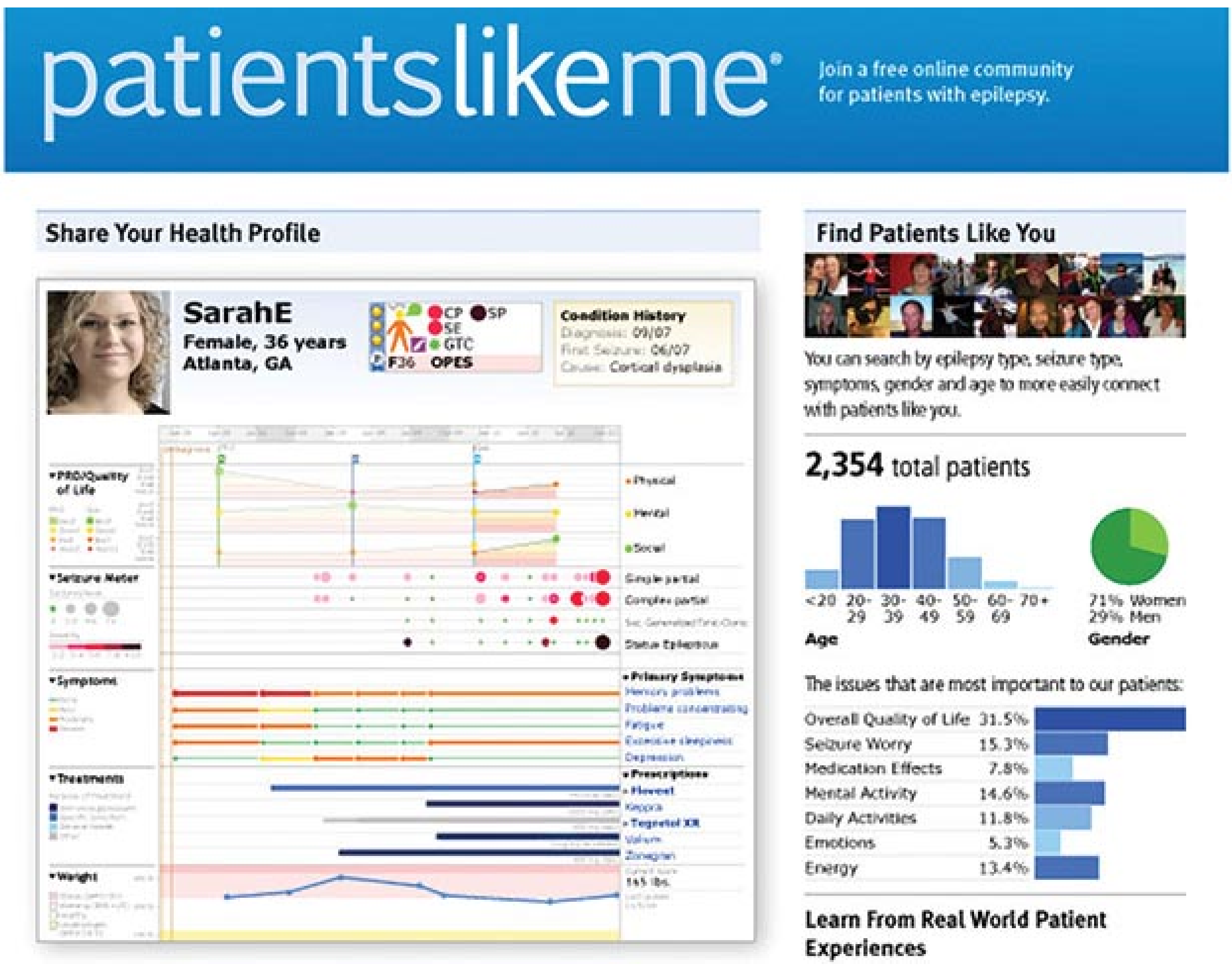


Figure 2.1: A screenshoot of PatientsLikeMe

2.1.2 23andMe

23andMe (see Fig. 2.2) is an online community [35] which makes less use of the subjective disease progression perception. Instead, it emphasizes on genetic data extracted from saliva samples collected by mail and analyzed by single nucleotide polymorphisms (SNPs) based techniques [36]. After the SNPs have been analyzed, 23andMe provides customers with access to a website where they can visualize what their results mean and calculate their predicted risk [37] of suffering diseases such as Alzheimer's or Parkinson's [38]. Also there is a discussion forum where patients can give their opinions about the results. 23andMe members are allowed to share their results with the limitation that they can only be shared within a dataset of SNP which excludes patients whose health is worse. 23andMe provides an important advance since it breaks traditional barriers by allowing patients to understand their own health risks.

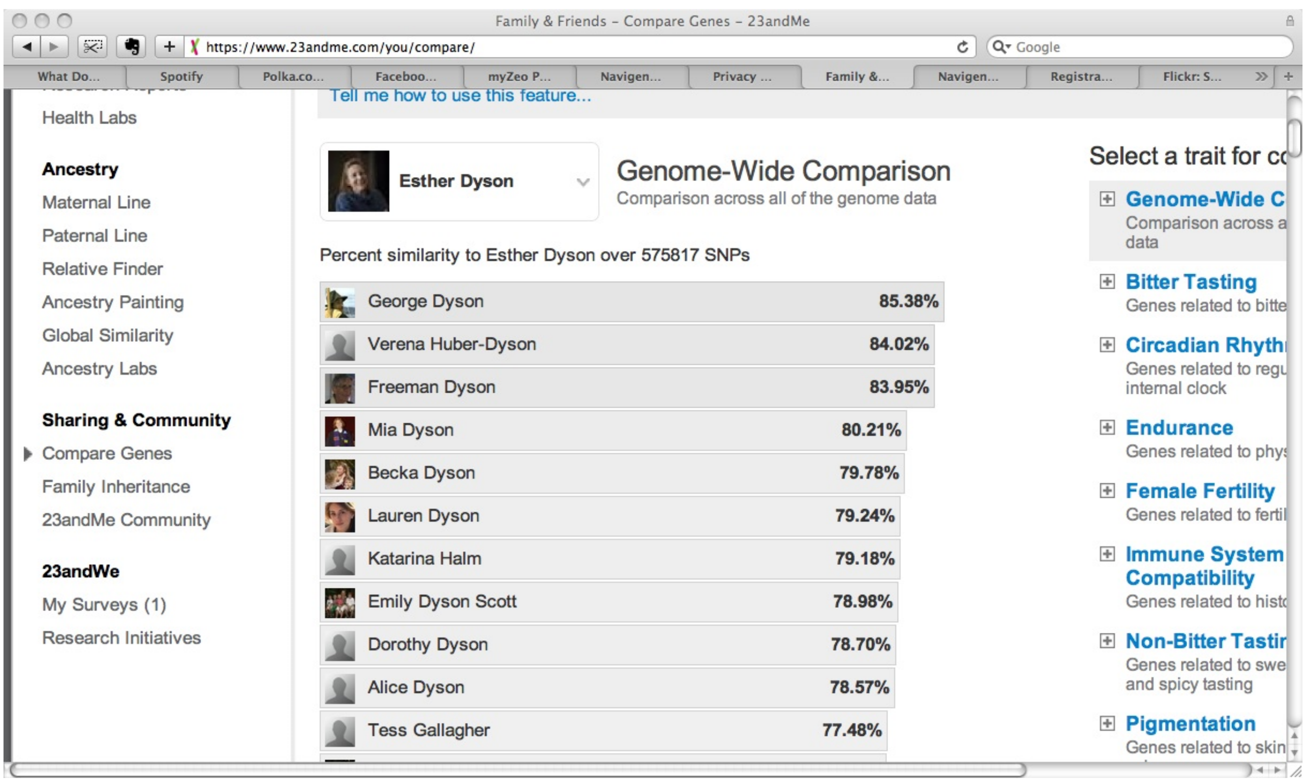


Figure 2.2: A screenshoot of 23andMe

2.1.3 Assessment of Tremor Activity

The most disabling feature in PD is tremor [1], which consists of a motor disorder. It is therefore essential to detect and monitor this symptom in PD patients. The diagnosis is usually realized by a clinical evaluation to verify the degree of difficulty in capturing objects and resting muscles. The project presented in [39] is concerned to automate a method for the tremor diagnosis in both resting position and movement, by using a set of accelerometers located in different body positions of the patient. The estimation of the tremor (resting/action postural) and its gravity are calculated based on the obtained data and several Markov models. This research has been evaluated with an experiment conducted on 23 subjects (18 patients with PD and 5 control subjects). Authors have obtained results that validate its investigation, and have concluded that their methodology: 1) quantifies the intensity of shaking with 87% accuracy, 2) discriminates rest of postural tremor, and 3) discriminates tremor among other motor symptoms of Parkinson during daily activities.

2.1.4 Mobile speech therapy application

This project based its motivation [40] on the next statement: approximately 70% of people with PD suffers communication difficulties. Most of them have lost the ability to control the volume of their voice and their speech also becomes progressively slower. To counteract these effects and improve their quality of life, language therapy is used, but often the availability of therapists is limited or too expensive.

The purpose of the application is to provide visual feedback about the voice volume, so that users receive an explicit signal for adjusting their volume. In order to know if the application objectives have been reached, several tests have been realized on PD patients. After analyzing the volume values during a prolonged amount of time, the conclusion was that PD patients can reinforce their therapy to control their voice volume just by using this application in their smartphones.

2.2 HW platforms to implement the system

There are free initiatives such as Arduino or Raspberry Pi, which are widely used today to carry out projects in various fields. Both approaches have become the basis for many electronics fans [41] for several reasons. These boards are small, powerful, and inexpensive components which have made it possible to build a wide variety of applications and complex systems, such as sensor networks, for instance.

On the other hand, Lego Mindstorms EV3 is another robotic kit initiative that need to be considered for implementing this project. Mark Rollins in his book about Mindstorms EV3 mentioned that *"The LEGO MINDSTORMS collection, first introduced in 1998, is one of LEGO's top best-selling sets/series. The reason for its success is the same as the reason for LEGO's success before its release: the chance to kick your creativity up a notch."* [15]

In the next subsections, the aforementioned platforms will be described in detail and finally, the reasons for selecting one of them shall be discussed.

2.2.1 Arduino

The Arduino board is an open source hardware used for building electronic projects. As its web page say: *"Arduino is an open-source electronics platform based on easy-to-use hardware and software. It's intended for anyone making interactive projects. Arduino senses the environment by receiving inputs from many sensors, and affects its surroundings by controlling lights, motors, and other actuators".* [42] In addition, an *IDE* is provided for writing and downloading binary code to the physical board [43]. The Arduino project was first introduced in 2005 and was designed with the purpose of making the hardware and software easier to use and available to the widest audience possible. Thus, the promise of this project is that people do not have to be an electronics experts to use the Arduino. [41].

Different kinds of Arduino boards are available on the market, each of them designed with different processors and memory configurations, as pointed by Fig. 2.4. Some of these boards are considered official Arduino boards because they are manufactured by the own Arduino.cc [42]. The basic layout of an Arduino board consists of the following components: the power connector, the USB connection, the reset switch, the microcontroller, several General Purpose Input/Output pins, and a standard spaced set of headers for attaching shields.

Regarding the Arduino advantages, it is very easily programmable, as it uses its own C language [42]. Furthermore, this platform provides many free code libraries [44] that will let the users concentrate on testing their ideas instead of spending our time building supporting circuitry or writing lines of low level code. Another advantage is the plug-and-play ability, as it is very easy to hook up components directly on the Arduino or indirectly via expansion boards.

Some projects have made use of the aforementioned advantages to contribute to the e-Health area , as for example: a monitoring data system to indicate when medical assistance is required in a home care setting scenario [45], the enhancement of a body area network to support smart health monitoring [46], a system for pressure ulcer risk assessment [47], a platform for remote monitoring of diabetics patients throughout the mobile network [48], or a remote functional mental stress analyzer [49].

The main disadvantage about developing this research with Arduino, is that is more difficult to build a robot that possesses precision when a page is selected for turning. This task requires finding the necessary components and accessories, and checking the compatibility of these with the selected model of Arduino.

2.2.2 Raspberry Pi

The Raspberry Pi board consists of a credit card-sized single-board computer that was developed in the UK by the Raspberry Pi Foundation, with the original purpose of promoting the teaching of basic computer science in schools [50]. They wanted to increase the numbers and skills of students applying for Computer Science in the University of Cambridge [51]. The initial team was formed by Eben Upton, Rob Mullins, Jack Lang and Alan Mycroft at the Computer Laboratory of their University.

The Raspberry Pi [52] is based on the Broadcom BCM2835 System on Chip (SoC), which contains a VideoCore IV GPU, an ARM1176JZF-S 700 MHz processor, and originally worked with 256 megabytes of RAM and 2 USB ports. Later on the memory was upgraded to 512 MB in models B and B+, and the number of USB ports increased to 4. Similar to Arduino, the Raspberry possesses several GPIOs. Also, it has a Secure Digital socket (SD) in models A and B, and a MicroSD socket in models A+ and B+ for booting an operating system and persistent storage [53]. In February 2015, the Raspberry Pi 2 was released. This new board is more powerful than its predecessor. It is based on the Broadcom BCM2836 SoC, which contains a quad-core ARM Cortex-A7 CPU, a VideoCore IV dual-core GPU, and 1 GB of RAM as major improvements, while the rest of the specifications remain similar to those of model B+ [54]. A comparison among the different models is depicted in Fig. 2.5 [55].

There are several examples of projects in the area of e-Health based on this board. Among them, the following can be mentioned: a multimodal acquisition platform for human-robot interaction affective studies [56], a bluetooth low energy system for patient-centric healthcare service [57], an emergency clinic multi-sensor continuous monitoring prototype [58], a real time e-Health system for continuous care [59], or an e-Health sensor platform based on both Arduino and Raspberry Pi, which allows to run biometric and medical applications [60].

Despite of the Raspberry size, it is a powerful computer with a relatively low price.

Another of its advantages is its low power consumption, as it requires from 1 to 4 W to work, depending on the model. Furthermore, there exist numerous devices available for the Pi at affordable prices. Moreover, there is a huge supporting community for Raspberry Pi. [61]. On the other hand, this board needs to work together with Arduino or Lego Mindstorms EV3, as it does not possess robotics elements.

In this sense, the BrickPi [62] initiative helps to use both: Raspberry Pi board and Lego Mindstorm sensors, motors, as well as parts to build a robot that can connect to the web to send or receive information, with remote control, or even be networked together. Some interesting projects have been developed with this initiative [63], for example: "APL Picker" Robotic Arm, "Rigraptor" Model Tank, and others. But the most similar one to our approach is Bookreader 2 [64] (see Fig. 2.3). Nevertheless, it presents some limitations that will be solved with our approach. The location of the wheel that allows the selection of pages, does not provide a good control when it comes to reading last pages of a book because of low pressure. Moreover, the BookReader 2's project was designed to read books using OCR (Optical Character Recognition) and it does not possess an interface to help people interact with the system. BookReader 2's uses two large servo motors to lift and turn the book pages. A priori it can be considered as advantage because of battery consumption but some experiments have been realized and described in chapter 5. So, the problem of this model is the low pressure in the lifting arm. In addition, it has a vertical structure in order to support the camera. It does not consider some degree of inclination in the book to facilitate the visualization of pages for PD patients. The inclination stability could be given with the use of a device that may be anchored to a Lego base or a flat base in general, but its large vertical pieces do not support some inclination without losing stability. Finally, this project have not considered any process in order to recovery a bad selection of pages.

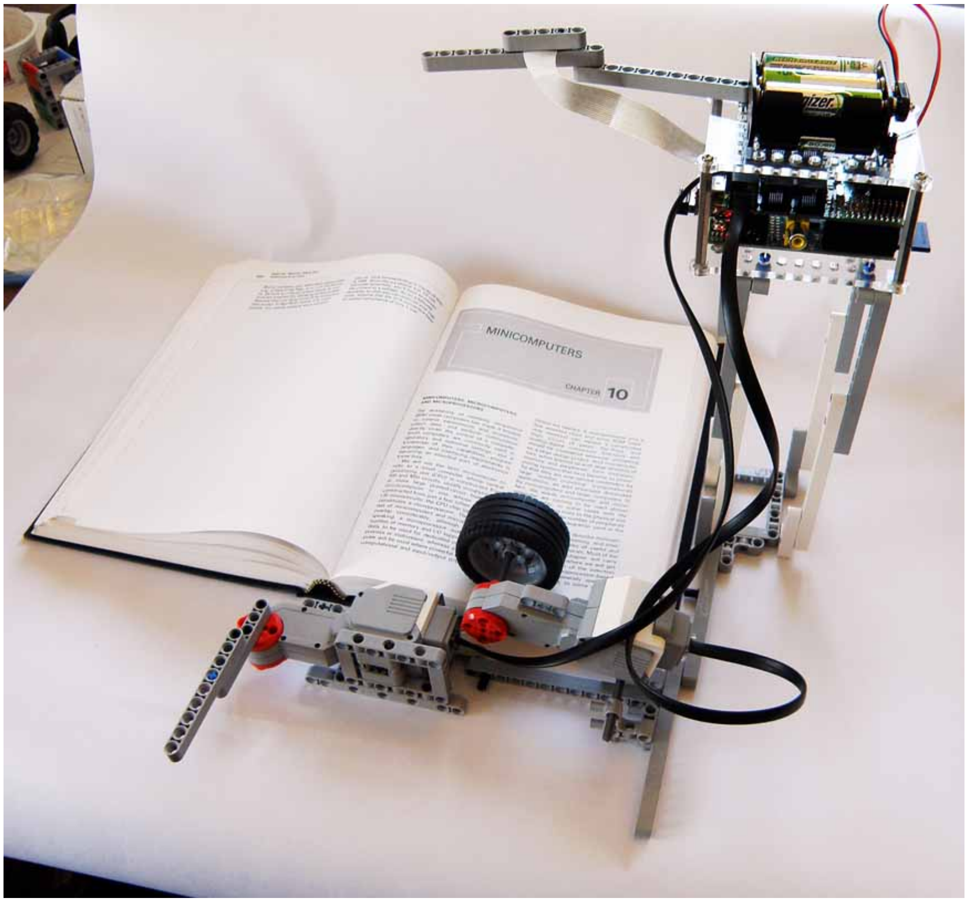


Figure 2.3: BrickPi BookReader 2's design

2.2.3 Lego Mindstorms EV3

The Lego Mindstorms EV3 is an educational platform aimed at the rapid construction of robotic prototypes for kids. One of its main objectives is that children can learn to easily design robotics solutions. Besides, this kit allows them the opportunity to write their first programs using a graphical environment. In this sense, different educational robotics programs for schools [65, 66, 67] and methodologies for teaching robotics [68, 69] have been proposed.

Nevertheless, Mindstorms is not only useful for children, as it has be considered to help undergraduate students develop engineering skills and embedded systems design capabilities as well as begin programming [70, 71, 72]. It has even been proposed to learn teamwork skills through group competitions [73, 74], and improve creativity in students [75].

The major advantage of Mindstorms is its capability to quickly build robotic projects by only joining Lego pieces. Lego components are very easy to assemble as well as very durable [76]. Moreover, it is quite easy to program these blocks, as there are several graphical development environments, APIs, and operating systems. For example, Mindstorms blocks can be programmed using: Java with *LeJOS* API [77, 72], OCaml-Mindstorms [78], Python [79], or LabView [80].

On the other hand, there are some disadvantages as well. First, the rechargeable battery module has a long size. Second, the price: an Arduino kit [81] costs a quarter of the Mindstorms EV3 price [82]. However, this price difference is mitigated by the fact that it is necessary to buy expansion boards for Arduino and various compatible components to build the whole project. It requires a long search, installation and configuration process.

Some interesting projects which have been constructed using this kit are the following: Cubestormer 3 (a Rubik's cube solver) [83] , a Sudoku solver [84], a distributed symphony orchestra [85] or a braille printer [86].

2.2.4 Platform selected

A good solution could be to design the system using Arduino or Raspberry Pi. However, it would be necessary to buy expansion boards and various compatible components to carry out the project. In consequence, this involves searching time and and accurate testing of actuators and other elements.

On the other hand, the main advantage of Lego Mindstorms is that it is very easy to build prototypes just by connecting hardware components (Lego Mindstorms EV3 pieces) such as sensors and actuators. In addition, there are several IDEs and libraries to make programming easier.

Furthermore, I have had the previous experience of working with the Mindstorms Lego kit. Besides, the "GreenDisc" [87] research group, within the department of Computers Architecture and Automation, acquired a Lego Mindstorms EV3 kit and gave me the opportunity to use it. In consequence, I have selected this option.

Name	Processor	Operating Voltage/Input Voltage	CPU Speed	Analog In/Out	Digital IO/PWM	EEPROM [KB]	SRAM [KB]	Flash [KB]	USB	UART
Uno	ATmega328	5 V/7-12 V	16MHz	6/0	14/6	1	2	32	Regular	1
Due	AT91SAM3X8E	3.3 V/7-12 V	84 MHz	12/2	54/12	-	96	512	2 Micro	4
Leonardo	ATmega32u4	5 V/7-12 V	16MHz	12/0	20/7	1	2.5	32	Micro	1
Mega 2560	ATmega2560	5 V/7-12 V	16MHz	16/0	54/15	4	8	256	Regular	4
Mega ADK	ATmega2560	5 V/7-12 V	16MHz	16/0	54/15	4	8	256	Regular	4
Micro	ATmega32u4	5 V/7-12 V	16MHz	12/0	20/7	1	2.5	32	Micro	1
Mini	ATmega328	5 V/7-9 V	16MHz	8/0	14/6	1	2	32	-	-
Nano	ATmega168 ATmega328	5 V/7-9 V	16MHz	8/0	14/6	0.512 1	1 2	16 32	Mini-B	1
Ethernet	ATmega328	5 V/7-12 V	16MHz	6/0	14/4	1	2	32	Regular	-
Esplora	ATmega32u4	5 V/7-12 V	16MHz	-	-	1	2.5	32	Micro	-
ArduinoBT	ATmega328	5 V/2.5-12 V	16MHz	6/0	14/6	1	2	32	-	1
Fio	ATmega328P	3.3 V/3.7-7 V	8MHz	8/0	14/6	1	2	32	Mini	1
Pro (168)	ATmega168	3.3 V/3.35-12 V	8MHz	6/0	14/6	0.512	1	16	-	1
Pro (328)	ATmega328	5 V/5-12 V	16MHz	6/0	14/6	1	2	32	-	1
Pro Mini	ATmega168	3.3 V/3.35-12 V 5 V/5-12 V	8MHz 16MHz	6/0	14/6	0.512	1	16	-	1
LilyPad	ATmega168V ATmega328V	2.7-5.5 V/2.7-5.5 V	8MHz	6/0	14/6	0.512	1	16	-	-
LilyPad USB	ATmega32u4	3.3 V/3.8-5V	8MHz	4/0	9/4	1	2.5	32	Micro	-
LilyPad Simple	ATmega328	2.7-5.5 V/2.7-5.5 V	8MHz	4/0	9/4	1	2	32	-	-
LilyPad SimpleSnap	ATmega328	2.7-5.5 V/2.7-5.5 V	8MHz	4/0	9/4	1	2	32	-	-
Yun	ATmega32u4	5 V	16MHz	12/0	20/7	1	2.5	32	Micro	1

Figure 2.4: Features of some Arduino models available on the market

				
Raspberry Pi:	Model A+	Model B	Model B+	2, Model B
Price:	$19.99	$39.99	$29.99	$39.99
Availability:	Add to Cart	Add to Cart	Add to Cart	Add to Cart
Quick summary:	Cheapest, smallest single board computer.	The original Raspberry Pi.	More USB and GPIO than the B. Ideal choice for schools	Newest, most advanced Raspberry Pi.
Chip:	Broadcom BCM2835			Broadcom BCM2836
Processor:	ARMv6 single core			ARMv7 quad core
Processor Speed:	700 MHz			900 MHz
Voltage and Power Draw:	600mA @ 5V			650mA @ 5V
GPU:	Dual Core VideoCore IV Multimedia Co-Processor			
Size:	65x56mm	85x56mm		
Memory:	256 MB SDRAM @ 400 MHz	512 MB SDRAM @ 400 MHz		1 GB SDRAM @ 400 MHz
Storage:	Micro SD Card (not included)	SD Card (not included)	Micro SD Card (**included**)	Micro SD Card (not included)
GPIO:	40	26	40	
USB 2.0:	1	2	4	
Ethernet:	None	10/100mb Ethernet RJ45 Jack		
Audio:	Multi-Channel HD Audio over HDMI, Analog Stereo from 3.5mm Headphone Jack			
Make: coverage:	First look		First look	First look In-depth Windows support

All of these Raspberry Pi Models share the following features:
Operating Systems: Raspbian RaspBMC, Arch Linux, Rise OS, OpenELEC Pidora
Video Output: HDMI Composite RCA
Supported Resolutions: 640x350 to 1920x1200, including 1080p, PAL & NTSC standards
Power Source: Micro USB

We hope you find this chart useful. If you have any questions, comments, or corrections, please email us at help@makershed.com.

Figure 2.5: Features of some Raspberry models available on the market

Chapter 3

Design of the Assistance System to Read Books

This chapter details the design of the support system for PD patients. The architecture of the system, its components, roles and behavior of each one are explained in depth. Furthermore, several diagrams are provided to describe the operations that our system must perform.

3.1 Components

Fig. 3.1 shows the system components, namely:

- The hardware elements belonging to the Lego Mindstorms kit.
- The interface developed for Android systems, which has been designed considering the motor limitations of PD patients.
- The type of connectivity that enables the remote control between the interface and the hardware components.

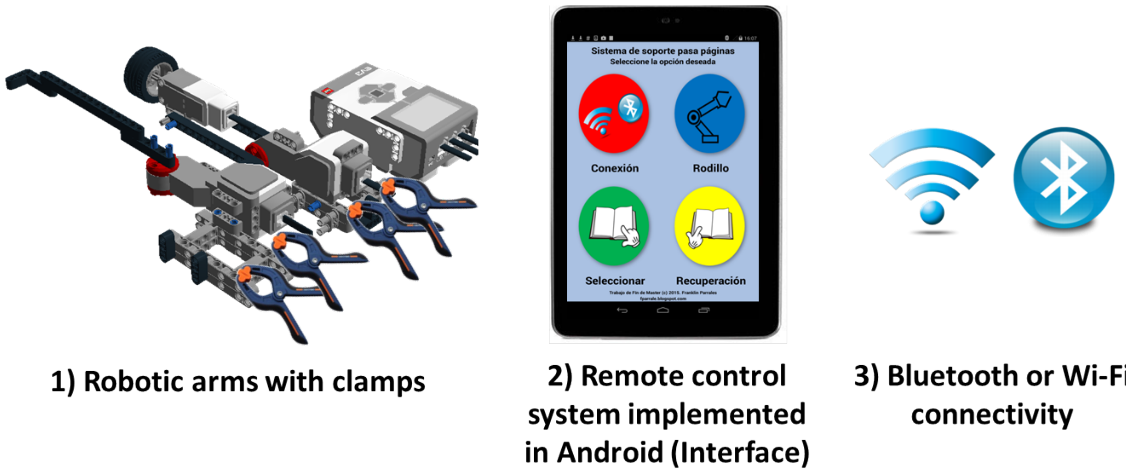


Figure 3.1: Components of this project

3.2 Roles

Two kind of users have been considered to interact with the system:

- The assistant, which is the person that sets the configuration of the system, placing it properly with the suitable distance between the robotic arm and the book. Also, the assistant is responsible for establishing the Bluetooth or Wi-Fi connection between the Android device and EV3 brick. Finally, this person will describe the operating instructions of the remote interface to the patient.
- Parkinson's patients, who handle the interface to turn the book pages in order to read. This user is who will interact with the system in a more direct way.

3.3 Modeling the behavior of the System

The behavior that the system must possess is represented in the workflow of Fig. 3.2. Solid ellipses represent the actions to be carried out in order to properly turn a page. First, the

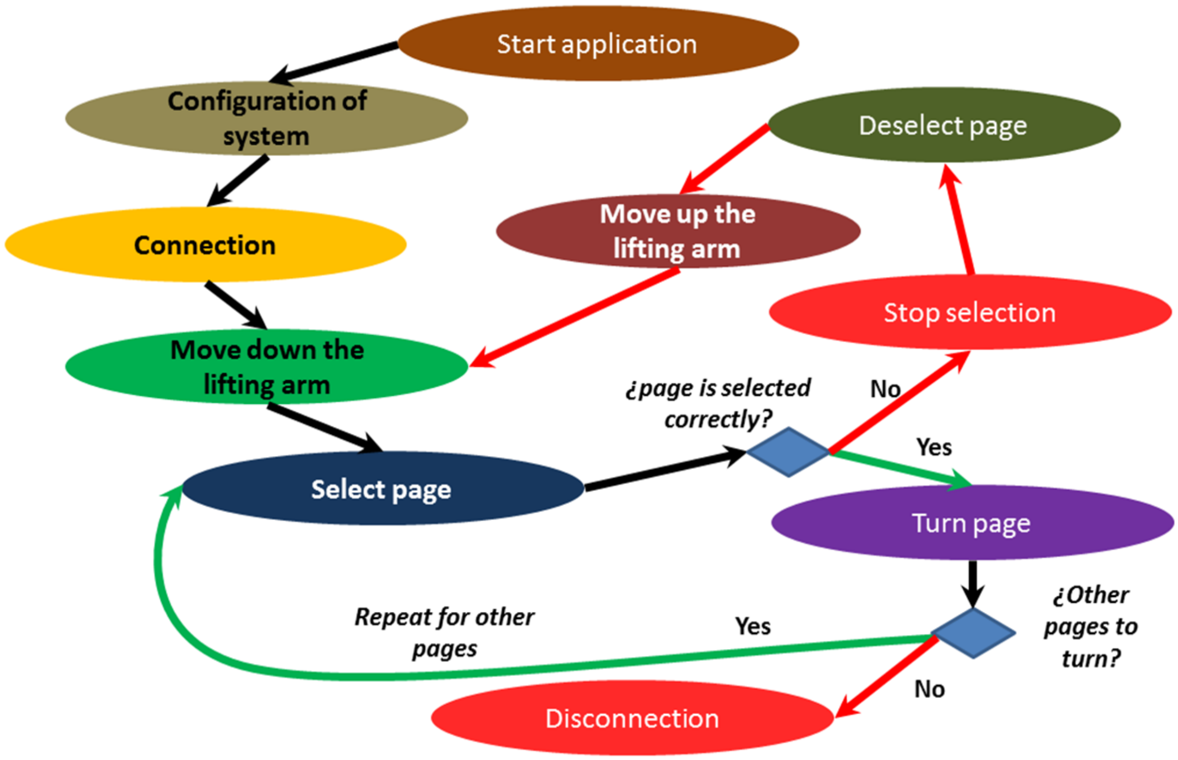


Figure 3.2: Workflow of system

page selection must be performed. If this selection is successful, we will proceed to the page turning. Otherwise, the position of the arm will be corrected to perform a finer page selection.

Moreover, the system connectivity must be configured previously through WiFi or Bluetooth between the Android device and the EV3 brick. Furthermore, the robotic arms need to be placed in a suitable distance with respect to the book. This position may vary depending on the book dimensions and paper quality, so it shall be evaluated in the experimental section. In this way, the system can select and turn pages in a proper way. These steps are shown in 3.3.

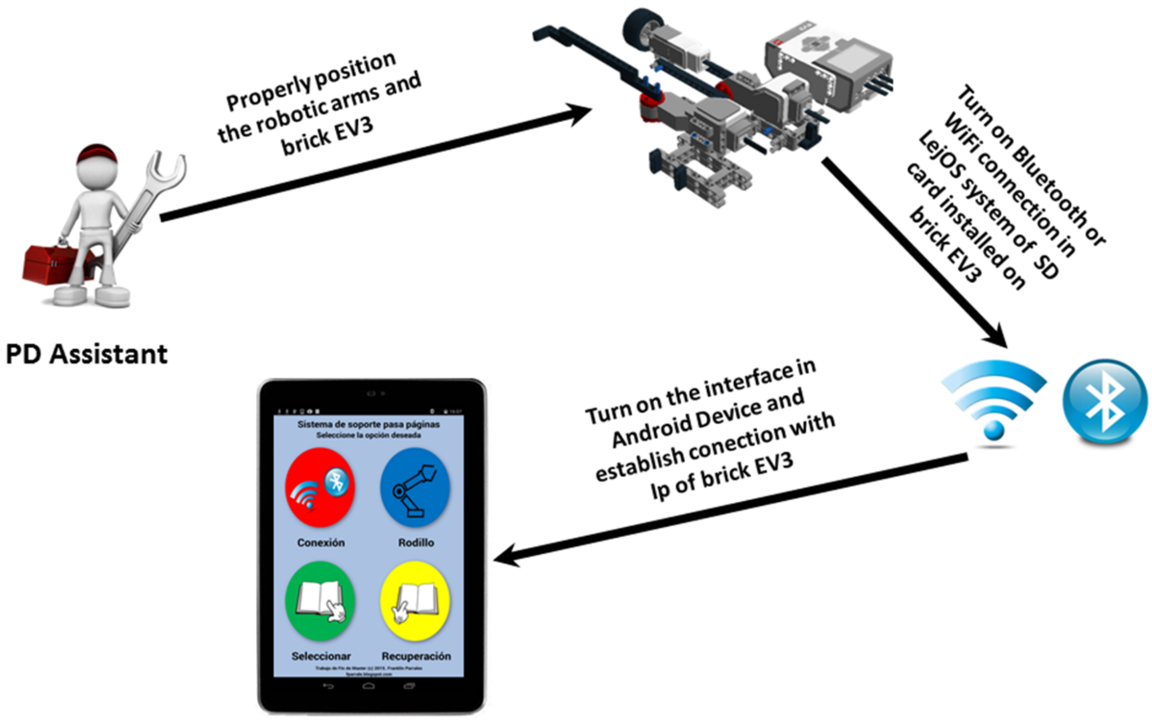


Figure 3.3: Configuration's workflow

3.4 Use Cases

In this section, the most important use cases which take place within our system will be described in detail thanks to several sequence diagrams. The use cases diagrams for PD patients and PD assistant are shown in Fig. 3.4

3.4.1 Configuration of the system

After placing the robotic arms, the Android application must be initialized by the PD assistant. Next, the connection must be set by editing the IP of the EV3 programmable brick and clicking on the "Conectar" (Connect) option, within the connection screen options. With this action, the system is ready to work. All the configuration steps are shown in Fig. 3.5

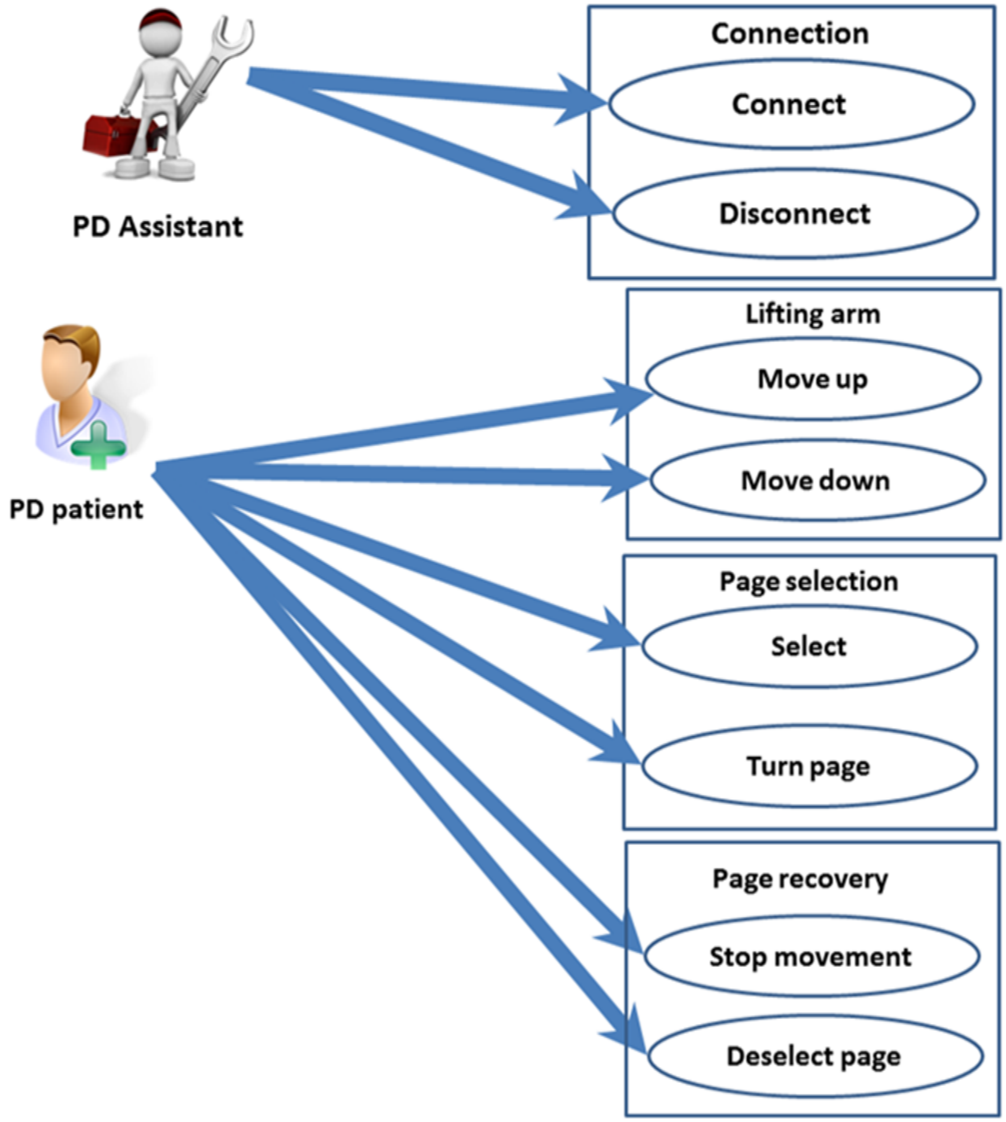


Figure 3.4: Use case diagram

3.4.2 Turning the page

The actions related to the page turning are just performed by the PD patient. To accomplish this, the user must click on the "Rodillo" (Lifting arm) button located in the main menu to display the lifting arm handling menu. Next, the patient must click on the "Bajar rodillo" (move down) option in order to increase the pressure of the lifting arm over the page to properly select just one. After locating the selection arm in a suitable pressure point, the user

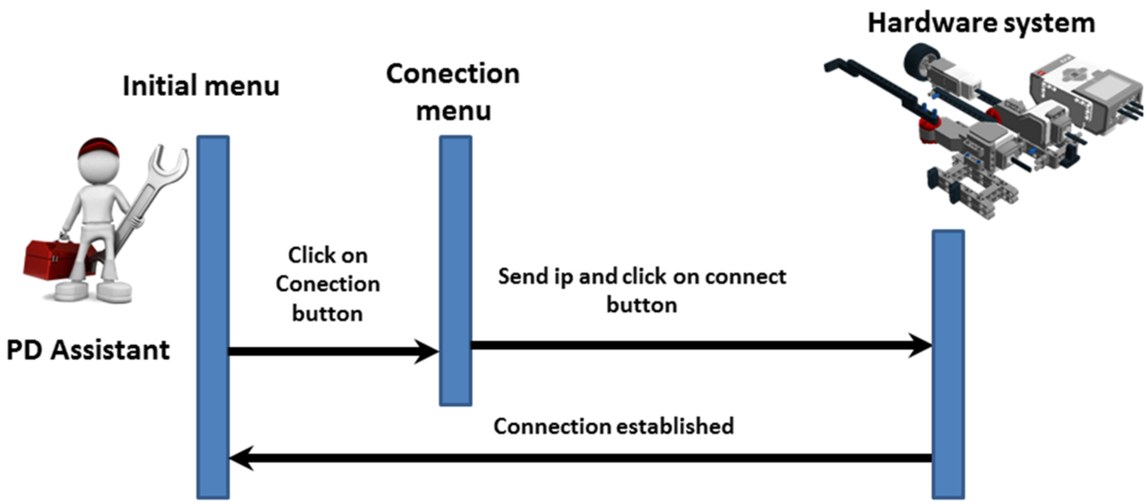


Figure 3.5: System configuration sequence diagram

must return to the main menu. Then the patient must click on the "Seleccionar" (Selection) button to go to the selection menu. Then, the "Seleccionar" (Select page) button needs to be clicked to slightly fold a page. In order to pause the wheel movement the PD patient needs to click on the "Pasar pagina" (Turn page) button. After doing this, the selection wheel will stop its movement, and the turning arm will turn the page. The whole sequence is represented in Fig. 3.6.

3.4.3 System recovery in case of a bad selection of page

The main factor responsible for a poor page selection is the lack of pressure of the wheel over the page. Taking this into account, a use case has been devised for those cases in which a page has been wrongly selected, e.g. two pages are jointly selected. The sequence diagram showing the corresponding steps is depicted in Fig. 3.7. Starting from the main menu, the user must click on the "Recuperación" (Recovery) option to display the recovery handling menu. After this, the user must stop the movement of the wheel by clicking on the "Parar" (Stop) button, deselect the page by using the "Deseleccionar" (Deselect) button and stop the movement of the wheel again by clicking on the "Parar" (Stop) button. Afterwards, the

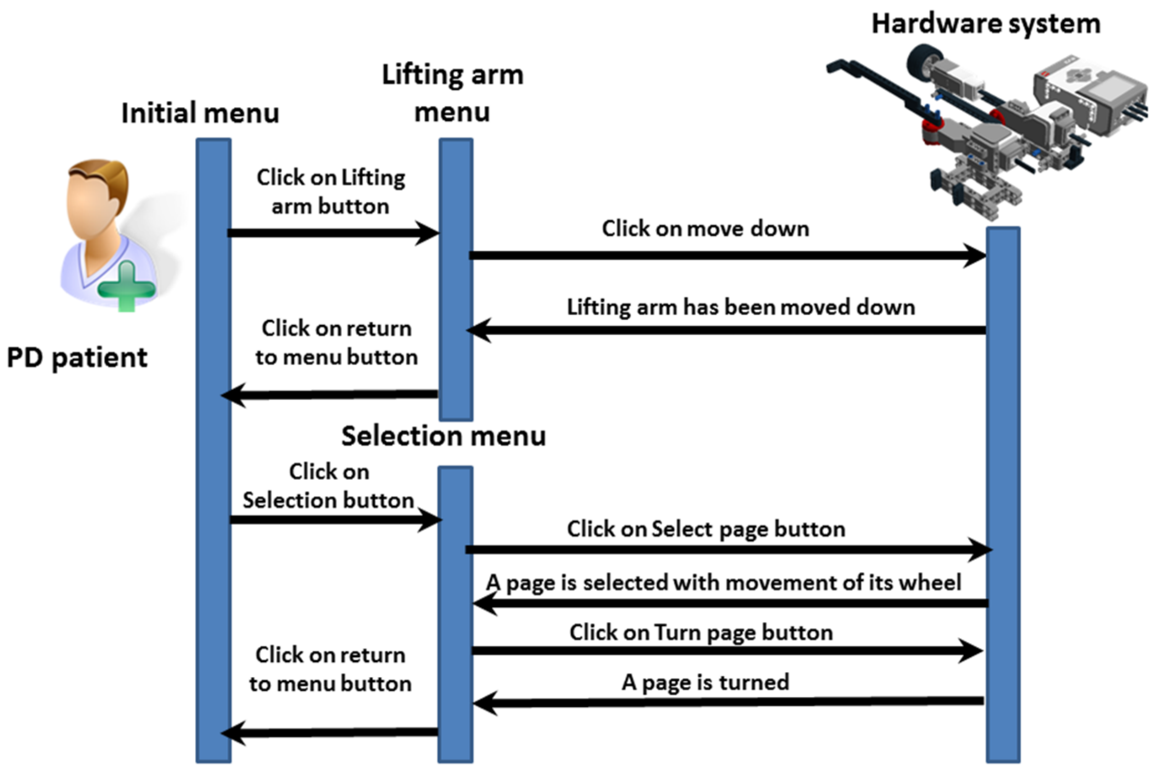


Figure 3.6: Page turning sequence diagram

user must click on the "Volver al menu" (return to menu) button and select the "Rodillo" (Lifting arm) button located in the main menu to display the lifting arm handling menu. Next, the patient must click on the "Subir rodillo" (move up) option in order to free the pressure of the robotic arm over the page. Finally, the user must return to the general menu by clicking on "Volver al menu" button (Return to menu) in order to perform another selection, by following the steps described in Fig. 3.6.

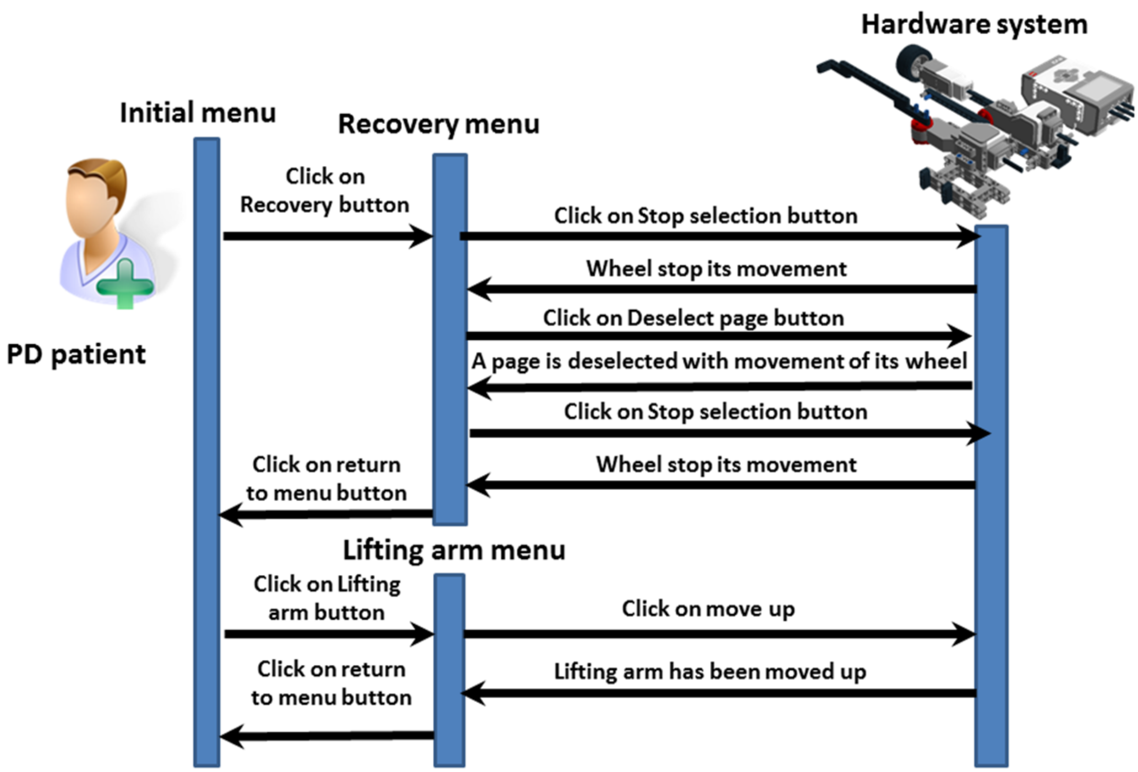


Figure 3.7: Modeling the sequence of the system recovery after a bad selection page

Chapter 4

Implementation of the Assistance System to Read Books

This chapter details the implementation process of the support system for PD patients. Firstly, the construction of the arms is described. Secondly the development of the application that controls the arms is explained, and thirdly, the interface details have been clarified. Besides, the configuration of the environment, programing and other remaining features have been described in depth.

4.1 Buiding the robotic arms

In order to construct our system with Lego pieces, two robotics arms have been built. An arm has the function of capturing a page (Lifting arm). The other is responsible for turning the page (Turning arm).

The main change in comparison with the BookReader 2's project [64] is in the design of the lifting arm. Our lifting arm has included a large servo motor for allowing both up and down movements. These movements will handle the pressure over the page, contributing to a finer page selection and to the recovery method in case of a bad page selection. Besides, the pressure handling allows a higher precision when working in an inclined scenario in

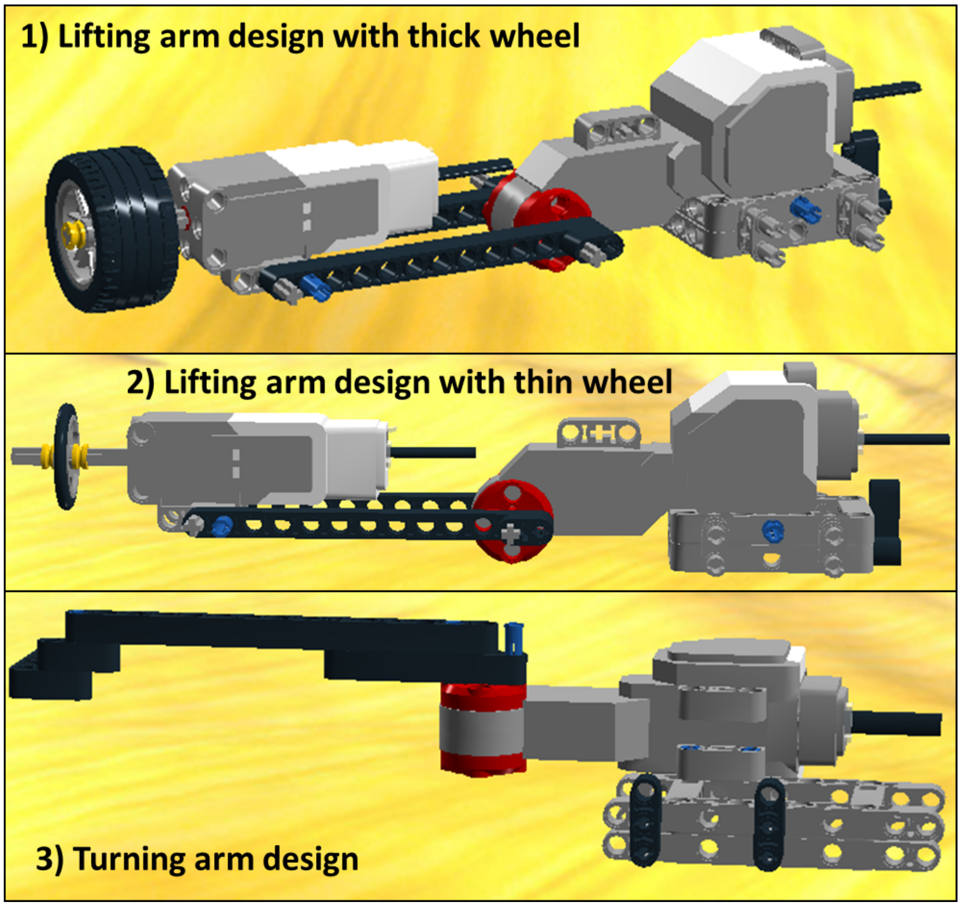
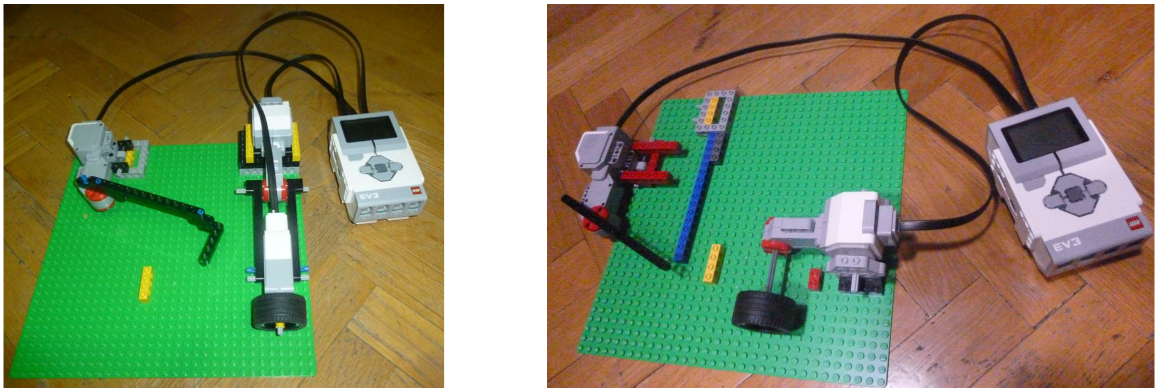


Figure 4.1: Implementation of the robotic arms

experiments of 5. On the other hand, the medium servo motor responsible for the selection of pages is similar to the one used by BookReader 2. An alternative selection method which consists of using a thin wheel (see Fig. 4.1) has also been considered. However, this alternative arm only works over glossy and lightweight pages and presents less precision than the conventional thick wheel. This will be proved in the experimental section. The turning arm consists of a large Lego studless beam joined with a large servo motor and other small pieces.

Finally, it must be pinpointed that the aforementioned arms need to be anchored to a table or a Lego flat base for getting stability and the correct pressure in page selection. This is shown in Fig. 4.2.



(a) Thick wheel model (b) BookReader 2 model

Figure 4.2: Arms anchored to a Lego base

4.2 Configuring the environment

In order to deal with the two robotic arms that compose the system, it is necessary to program the EV3 brick. But before programming the intelligence of the platform, it is necessary to set up the developing framework and provide the EV3 with some libraries.

In order to set the programming environment on the computer, first it is necessary to install the Java Virtual Machine for Embedded Systems [88] via a microSD memory card inserted in the programmable EV3 block. Moreover, it is required to configure the programming environment (Eclipse [89]) with its corresponding plugins and install the LeJOS libraries. Furthermore, the Android Development Tools (ADT) [90] need to be installed and configured in Eclipse in order to implement the Android application for remote control (code and screen interface).

LeJOS [77] is a firmware replacement for Lego programmable bricks. LeJOS includes an EV3 API and a full Java run time system. The most important advantage of this API is that it runs on the Java Virtual Machine. In consequence, it inherits the benefits of this environment such as object-oriented programming, multithreading, recursion, synchronization, exceptions, multidimensional arrays, Java types including float, long, and String, most of the java.lang, java.util and java.io classes, and more. Besides, it possesses a vast amount of documentation and has a large community support.

4.3 User Interface for controlling the robotic arms

In order to implement the remote interface for dealing with the robotic arms, it is necessary to first select the mobile operating system. Nowadays, Android and iOS are widely used around the world (see Fig. 4.3). One of Android advantages consists of its open source nature. Another important feature is its supporting community and its java based programs with some xml details (app layout and design). Thus, an Android application structure is mainly composed of Activities (similar to web pages in web applications or screens in desktop applications) and java code. Each activity has an xml file that defines its design (buttons, labels and other elements), and this is linked with its java class responsible for its behaviour in the AndroidManifest.xml file.

Smartphone OS Use by Country, January 2015

Country	1st	2nd	3rd
China	72.8%	25.4%	0.8%
USA	51.9%	42.8%	4.3%
Brazil	90.8%	3.9%	3.8%
UK	51.5%	40.1%	7.4%
Japan	52.4%	45.4%	1.3%
France	65.3%	20.2%	13%
Australia	46.9%	42.4%	8.7%
Mexico	85.2%	5.3%	4.7%
Germany	71.1%	18.7%	8.9%
Argentina	83.5%	9.1%	3.4%

Key - Android, iOS, Windows, Blackberry, Other

Data taken from kantarworldpanel.com/smartphone-os-market-share/

Figure 4.3: Smarthphone OS use by country

Furthermore, the LejOS API has been developed in java language. Therefore, choosing an Android-based device is more beneficial because it depends on java programing too. Concretely, I have utilized the Nexus 7 tablet.

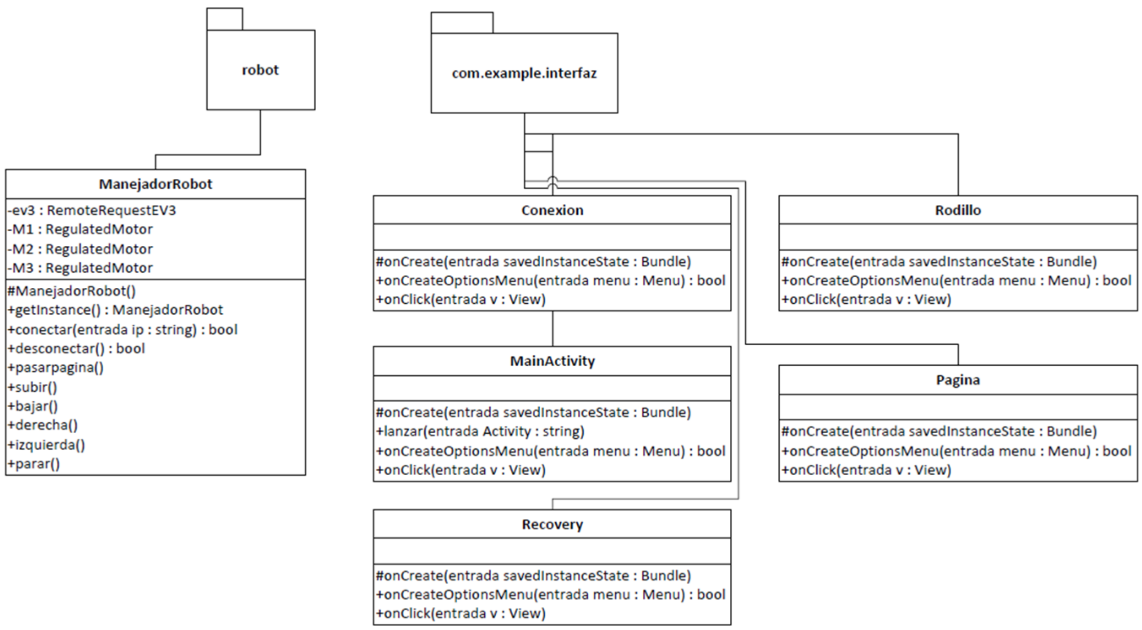


Figure 4.4: User Interface class diagram

All in all, the software which handles and communicates with the robotic platform is composed of two java packages (see class diagram of Fig. 4.4). One of these packages is responsible for the Android Activities (com.example.interfaz), and the other contains the "ManejadorRobot" class, which implements the methods for remote connection and robot behaviour control. This class is implemented using the Singleton design pattern, restricting the instantiation of this class to just one object.

4.4 Graphic User Interface

In order to allow PD patients to achieve a good interface visualization, some issues need to be considered. First, the EV3 buttons cannot be operated easily by PD patients, because of the PD motor limitations. In contrast to this limitation, smartphones possess an easier interaction, as their screen requires less pressure than the EV3 buttons. Second, the font size needs to be larger than for a conventional application. It is necessary to adapt the font size because of the patients motion and vision difficulties [11, 91]. This involves the use of large buttons and fonts. maximizing the use of the whole screen to make the interactions easier. Finally, the PD patient difficulties to see can be lessened by using different colors in the button backgrounds. All these features are shown in the proposed interface in Fig. 4.5.

The interface is composed of five screens. The main menu is the first screen. It is composed of four buttons for connection, going to the roller movement (lifting arm) menu, the page selection menu and the page recovery menu. The connection screen, has been designed for configuring the connection between the EV3 brick and the Android device. The third screen controls the lifting arm movements. The fourth screen controls the selection and turning action of pages. The fifth screen controls the deselection of pages as well as the stopping of the selection wheel. The functionalities of these menus correspond to the sequence diagrams previously shown in chapter 3.

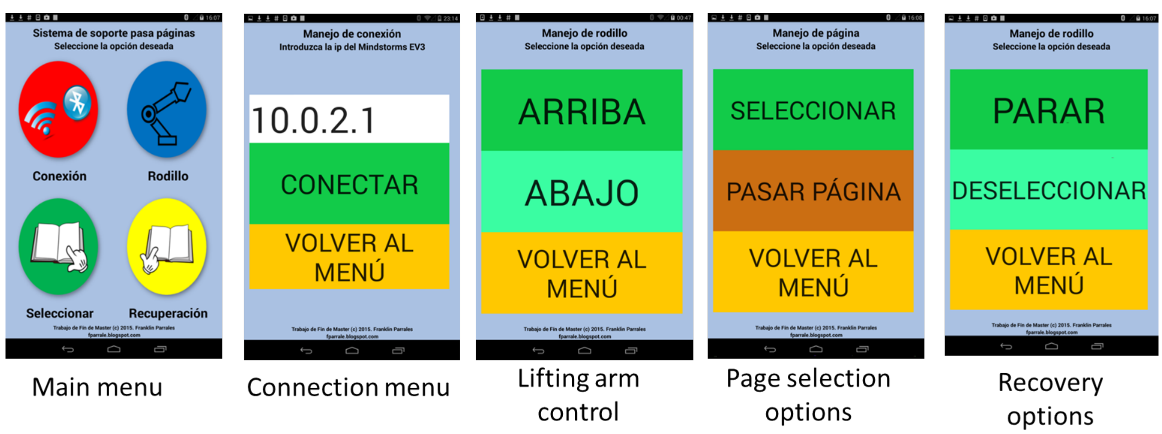


Figure 4.5: Screenshots of the user interface proposal

Chapter 5

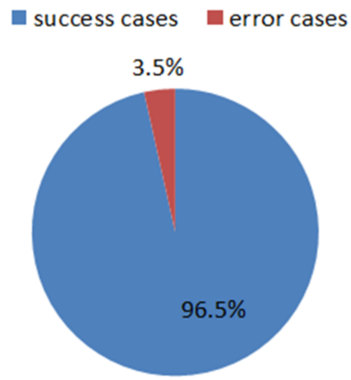
Experiments

In this chapter, the experiments that have been carried out with the reading support system for PD patients are described. These experiments have consisted of: analyzing the battery use, studying the system average response time in seconds, and counting the number of failures when the system turns a page. Moreover, experiments on an inclined surface have been considered. Each of these experiments has been performed using the two different designs proposed in chapter 4 (thick and thin wheels). Furthermore, a BookReader-based design has been used for comparison too.

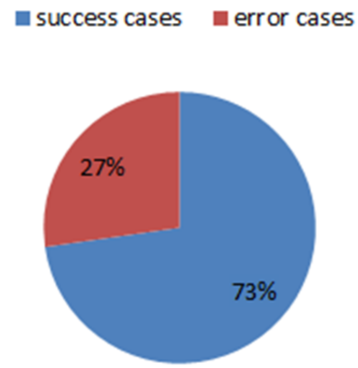
5.1 Error rate

In this experiment, 200 observations have been realized in order to get the error rate. This experiment was tested with 80 gr/m^2 and A4 size paper. The results are shown in Fig. 5.1a. Using the proposed design, i.e. thick wheels, we have achieved 193 successful cases in contrast to 7 failures. The error rate was then 3.5%. Five of these failures have been solved by deselecting and selecting the page once again. The remaining two errors have been solved by moving down the roller for adding more pressure.

In the same scenario, the BookReader 2 model gets worse results. These can be observed in Fig. 5.1b. Concretely, 146 successful cases and 54 failures have been obtained. It is very



(a) With thick wheel model



(b) With BookReader 2 model

Figure 5.1: Error rate using non glossy surface paper

important to mention that this model cannot correctly select the first and the last pages (4 cases) of the book, because it does not have a servo motor for adding pressure as our thick model. Regarding the rest of the errors, the majority of failure cases (45 cases) consisted of two pages jointly selected. Hence, this justifies the use of the second motor in our design. The rest of failures (5 cases) consisted of not rising properly the page, prior to turning it. Therefore, the introduction of a recovery mechanism is necessary, as these results point out.

The thin wheel model does not work with this type of paper. In general, this model does not work unless glossy and lightweight pages are being utilized. Hence, different types of paper have been tested. For example, a magazine paper with A4 size and 65 gr/m^2 and a glossy surface. The results of these tests can be observed in Fig. 5.2. In this case, the use of the thin wheel model is more effective than the thick wheel one because it produces less failures (7% vs 31%) when selecting the pages.

Papers possessing a weight below 65 gr/m^2 are not recommended because of multiple pages selection failures. For instance, the Bible (50 gr/m^2) has been tested using the thin wheel. As can be observed in Fig. 5.3, the error rate is high (80%) with this type of paper. With the use of the thick wheel or the BookReader 2 model the number of errors is close to 100%. For this reason, in the future it is necessary to deploy other model to deal with

(a) With thin wheel model (b) With thick wheel model

Figure 5.2: Error rate using a glossy surface paper

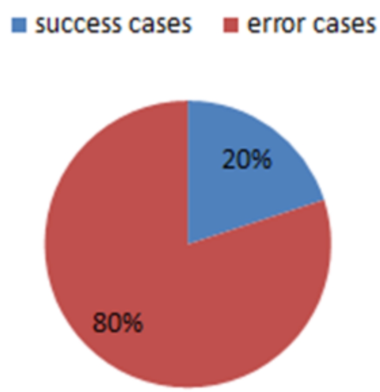


Figure 5.3: Error rate using bible-like paper and the thin wheel model

lightweight pages.

5.2 Battery usage

The main objective of this experiment is to establish the number of pages that can be correctly turned before recharging the battery. This requires to mention that the EV3 battery level ranges from 8.0 to 6.5, where 8.0 indicates that the battery level is high while 6.5 is the latest battery level prior to turning the EV3 brick off. Hence, at this level the battery needs to be recharged.

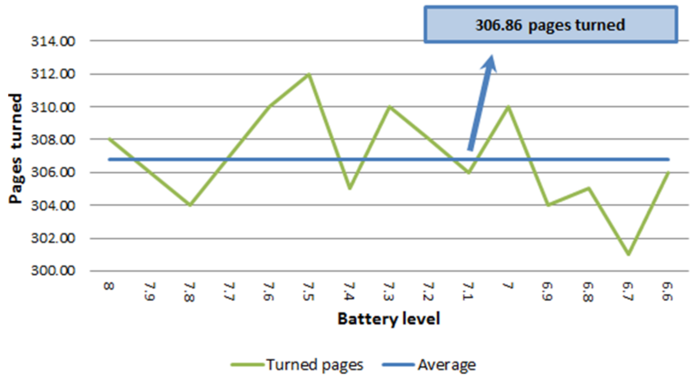
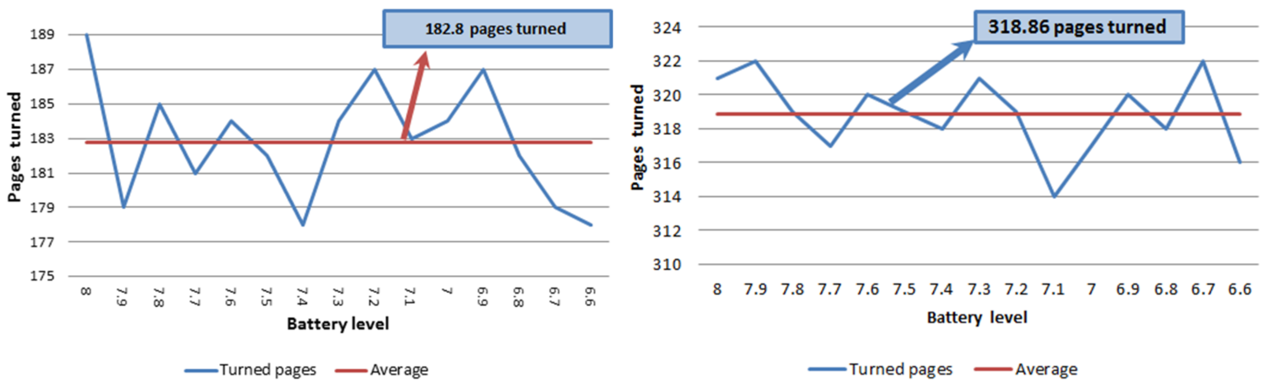


Figure 5.4: With thick wheel model and non glossy 80 gr/m^2 pages



(a) With thin wheel model and glossy pages (b) With thick wheel model and non glossy pages

Figure 5.5: Battery consumption in 65 gr/m^2 pages

The thick wheel model has been tested using 80 gr/m^2, A4 size paper without glossy surface. The results are depicted in Fig. 5.4. The average number of turned pages was 306.86 pages. Overall, it was possible to turn around 4600 pages before recharging the battery.

The thin wheel model has been evaluated too, but considering glossy A4 pages with 65 gr/m^2 weight. With this model, 182.8 pages per battery consumption level are obtained on average. Overall, it was possible to turn 2742 pages before recharging the battery. The results are shown in Fig. 5.5a. The main reason for this pages decrease stems from the fact that the thin wheel requires more time to select a page. In the case of non glossy A4 pages the thin model does not work properly. Using the thick model in this scenario but with non glossy paper, 318.86 pages per battery consumption level are obtained on

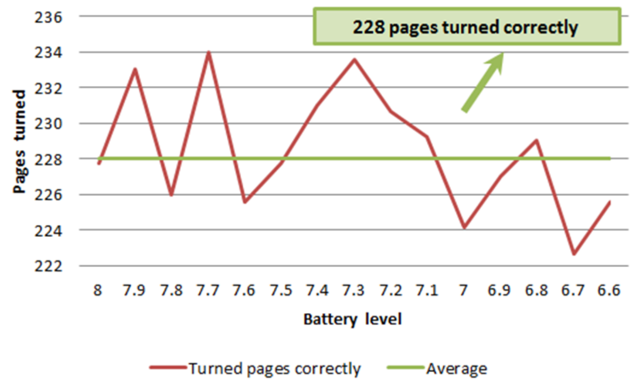


Figure 5.6: Battery consumption in BookReader 2 model

average. The results are depicted in Fig. 5.5b. As observed, there is a slight increase in terms of turned pages with respect to 80 gr/m^2 pages, which is quite reasonable because of the weight difference. In conclusion, thin wheel model is necessary for dealing with glossy surfaces, while the thick wheel model is better for non glossy pages.

Furthermore, the BookReader 2 model has also been tested with A4 sized, 80 gr/m^2 weight and non glossy pages. The number of correctly turned pages is depicted in the Fig. 5.6. As observed, the number of turned pages is lower (228 vs 306) than in the proposed model, because the error rate is higher than in our case. Hence, our model can correctly turn more pages prior to recharging the battery. Therefore we can conclude that our model is more energy efficient than the BookReader 2 based model because of precision.

5.3 Average time when turning a page

The goal of this experiment is to know how much time is necessary when using the platform for turning pages. A very important point to consider is that this experiment has been realized by people without motor limitations. Thus, in the case of PD patients the time could be increased depending of the disease degree.

The thick wheel model has been tested with 200 observations (only successful turning

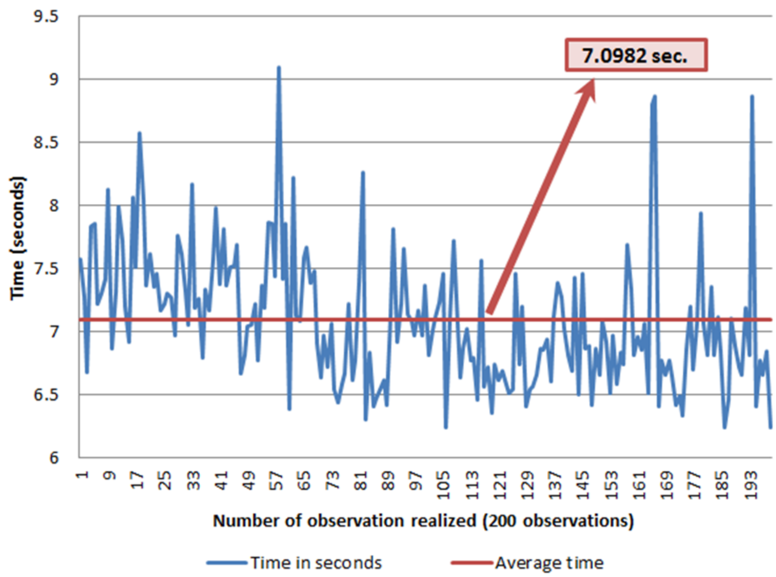


Figure 5.7: Average time in the thick wheel model

cases), using 80 gr/m^2 and A4 sized pages. The time has been measured in seconds, using a chronometer. The overall elapsed time is comprised from the selection page action to the moment when the lifting arm has finished its downwards movement after turning a page. The average time that has been obtained is 7.0982 seconds per page, which means that the system is able to turn around 500 pages per hour (507.16 pages in 3600 seconds). These results are depicted in Fig. 5.7.

Different results have been obtained in the case of the thin wheel model with 65 gr/m^2 and A4 sized glossy paper. The average time is 11.6123 seconds per page, higher than with the thick wheel, which means that the system is able to turn near to 310 pages per hour (310.016 pages in 3600 seconds). The results are shown in Fig. 5.8. The increase in time is a consequence of the page selection time augmentation when using the thin wheel model. Nevertheless, it must be reminded that the thin wheel model achieves a greater precision when considering glossy lightweight pages.

The BookReader 2 model has been tested too, using 80 gr/m^2, A4 sized paper without glossy surface. The results are shown in Fig. 5.9. The average time is less than when

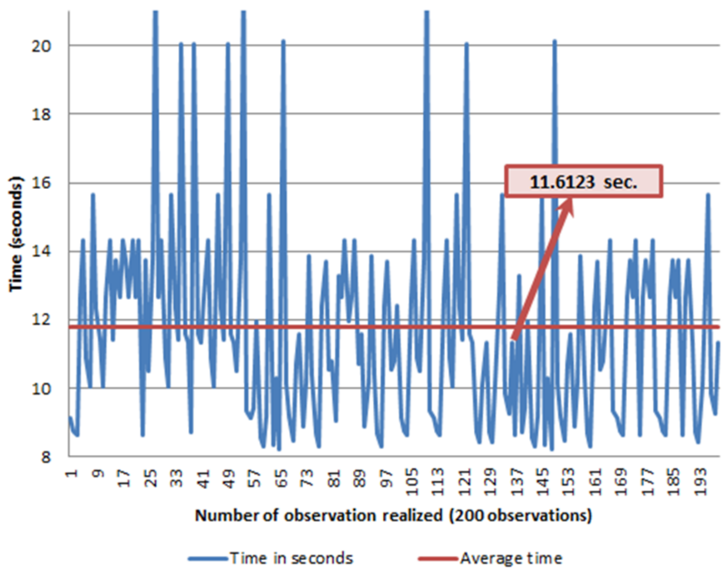


Figure 5.8: Average time in the thin wheel model

considering the other models, as the selection action does not involve two servo motors, but just one. However, it must be pinpointed that the error rate is greater than in our proposal. Besides, this noticeable average time decrease is due to that only correctly turned pages are being considered in this study.

5.4 Arms location

It is very important to establish a relationship between the book dimensions and the robotic arms position in order to get a successful page selection. This test has been realized over differents ring bound books because of the stability that they offer when a page has to be turned to left side. Each test has been performed over 100 A4 sized pages (21x29.7 cm). In addition, glossy and non glossy surfaces have been considered, using the thin wheel model for glossy pages and the thick wheel model for non glossy pages. Fig. 5.10 shows how the system has been deployed and the three distances that have been evaluated. The results are shown in table 5.1.

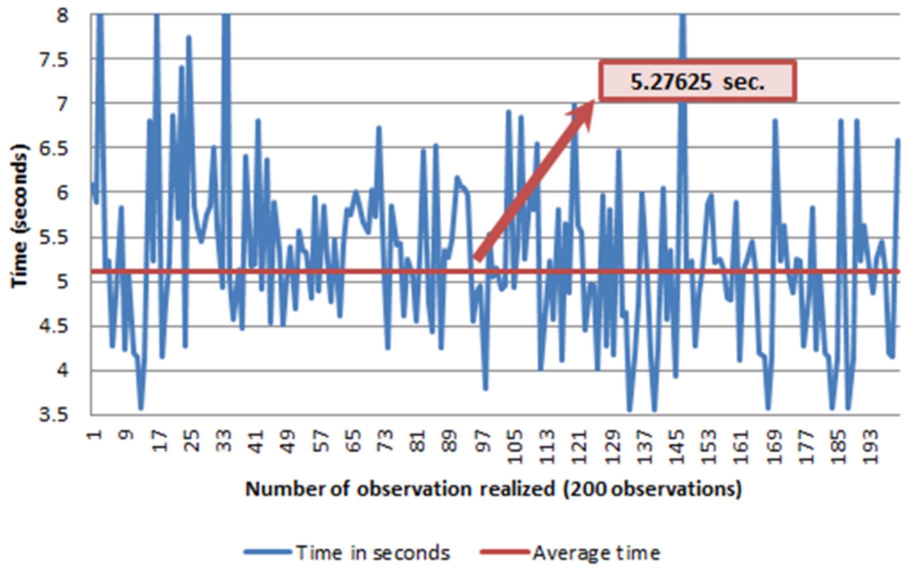


Figure 5.9: Average time in the BookReader 2 model

The distance between the robotic arms is fixed to 15 cm, and the distance between the book and the Lego base is fixed to 19 cm. The reason for using these distances is the fact that with other values the tested book gets damaged when turning pages or the wheel position obstructs the pages view. With a larger distance we have observed that it is not possible to correctly perform the page selection with A4 sized pages.

According to the obtained results, it can be concluded that the most suitable distance between paper and lifting arm for A4 non glossy paper is 12 cm, as it achieves the best results in terms of average time and success rate for pages with 65, 70 and 80 gr/m^2 weight. In the case of lightweight and glossy paper, the tests have been performed with 65,70 and 80 gr/m^2 A4 pages, and the most suitable distance in this case is 10 cm because it achieves the best results in terms of success rate.

With the same distances between the robotic arms (15cm) and between the book and the Lego base (19cm), other unusual scenarios have been evaluated. Concretely, the following results in terms of lifting arm distance have been achieved:

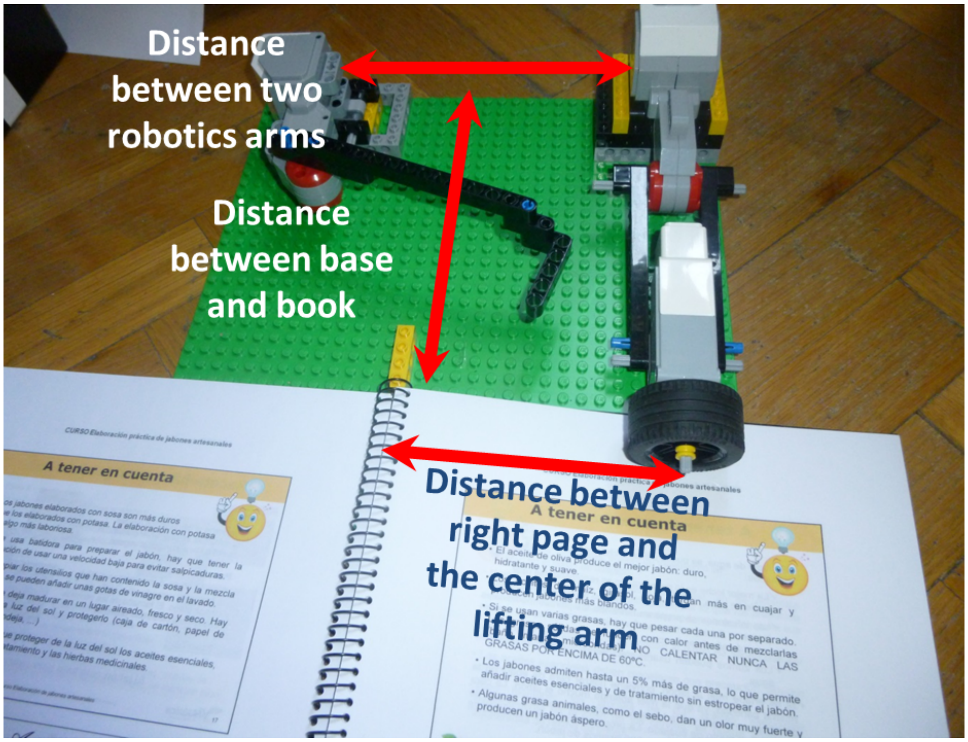


Figure 5.10: Location of distances between book and robotic arms

- 14 cm of distance between the lifting arm and the right page in the case of 20.5x14 cm , considering non glossy pages and a weight of 120 gr/m^2.
- 12 cm for 16.7 cm width, 80 gr/m^2 of weight and non glossy pages.

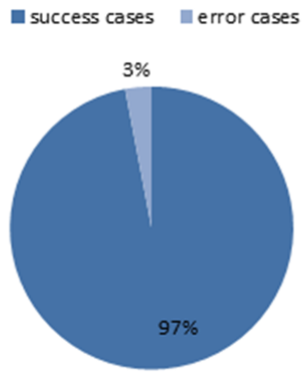
In conclusion, the optimum arm position depends on the paper dimensions and the gloss, rather than the weight. In the most common case, i.e. A4, it seems that there exist two optimum distances, 12 cm and 10 cm depending on the gloss, but in the general case there is not a straightforward relationship among the aforementioned three parameters.

5.5 Testing over an inclined surface

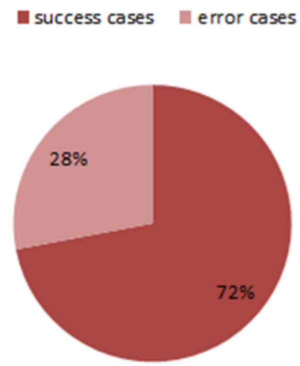
The goal of this experiment is to measure the error rate when the BookReader 2 model and the proposed model are turning pages in a scenario with certain slope. These two models

Weight (gr/m^2)	Glossy page	Distance between the center of the lifting arm and right page (cm)	Average time	Successful rate
80	Yes	10	12.8562	94%
80	Yes	11	12.9456	83%
80	Yes	12	13.0127	75%
80	Yes	13	12.8754	69%
80	Yes	14	12.8652	57%
80	No	10	7.0124	87%
80	No	11	7.0235	92%
80	No	12	7.0982	96%
80	No	13	7.1623	92%
80	No	13	7.2156	91%
70	Yes	10	11.2156	92%
70	Yes	11	11.6879	82%
70	Yes	12	11.9564	74%
70	Yes	13	11.8754	65%
70	Yes	14	11.6523	48%
70	No	10	7.2156	93%
70	No	11	7.3956	93%
70	No	12	7.4181	95%
70	No	13	7.4536	91%
70	No	14	7.5689	90%
65	Yes	10	11.4948	93%
65	Yes	11	11.2244	84%
65	Yes	12	11.8509	83%
65	Yes	13	11.2208	62%
65	Yes	14	11.1031	54%
65	No	10	8.1256	95%
65	No	11	8.2378	96%
65	No	12	8.2965	97%
65	No	13	8.3546	92%
65	No	14	8.5645	88%

Table 5.1: Tests for distances between the platform and the book



(a) Thick wheel model

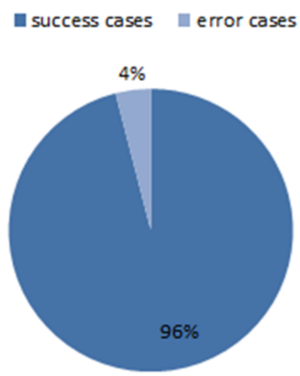


(b) BookReader 2 model

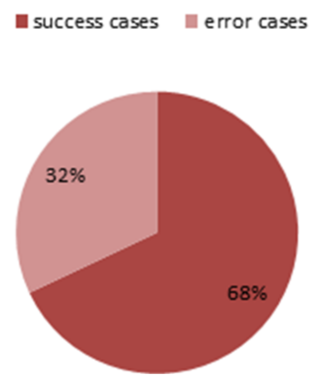
Figure 5.11: Error rate on 10 degrees inclined surface

have been evaluated with 10 and 20 degrees of inclination, 100 non glossy pages with A4 size and a weight of 80 gr/m^2. The results are depicted in Fig. 5.11 and Fig. 5.12. When the slope is moderate, i.e. 10 degrees, both approaches get similar results to those obtained over a non-inclined surface. However, the BookReader 2 model noticeably produces more failures with 20 degrees than when working on a horizontal surface (32% vs 27%). In contrast to this accuracy loss, the proposed model maintains a similar error rate than when working over a conventional non-inclined surface.

In conclusion, an inclined scenario requires the system to put some pressure over the pages, which motivates the introduction of the second motor in our lifting arm, in contrast to the Book Reader 2 design.



(a) Thick wheel model



(b) BookReader 2 model

Figure 5.12: Error rate on 20 degrees inclined surface

Chapter 6

Conclusions and future work

In this chapter, the main contributions of the project are summarized. Moreover, the conclusions about the work are drawn. Finally, some future work planned for the project is also presented.

6.1 Contributions and conclusions

The main contribution of this work in the e-Health field is the development of a hardware and software platform for assisting the reading process of patients suffering the Parkinson's disease. The purpose of our platform is to help patients improve their quality of life, by making the reading activity easier.

This project has been developed using the Mindstorms EV3 Lego kit. In addition, an Android application for remote control and easy user interaction has been developed. Different hardware platforms and APIs have been studied prior to deploying our system. Afterwards, the behaviour of the system has been defined by means of different diagrams and use cases.

Several tests have been performed in order to establish the suitability and configuration of our system. Concretely, the error rate, battery usage, page turning average time and inclined surface experiments have proved that our platform is more efficient than the state-of-the-art Book Reader 2. Furthermore, the correct location of the robotic arms has been studied to properly set our platform up.

Finally, it must be pinpointed that the utilization of the thin wheel has allowed us to tackle heterogeneous scenarios, as glossy and non-glossy surfaces, by just changing the wheel responsible for selecting the page.

6.2 Future work

This support system has only considered the most common type of book pages, with a weight ranging between 65 and 80 gr/m^2. Besides, the gloss of the surface has been evaluated. However, results have indicated that neither our system nor the Book Reader 2 are able to properly deal with lighter than 65 gr/m^2 pages. Hence, this problem requires a careful study to deploy a more accurate system.

Other types of bounds need to be considered too as an expansion of this work. Our tests have considered ring bound books as an initial approach to the problem. However, rustic thick books present additional problems, as the non-returning of already turned pages or the height variation between the set of pages that have already been turned, and the ones that have not been turned yet.

Finally, it is very important to test the system with PD patients in order to determine their satisfaction degree while utilizing our platform. In fact, it must be mentioned that some tests have been scheduled in "La Princesa" hospital in Madrid.

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