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IntellWheels - Data Acquisition System for an Intelligent Wheelchair

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January 23, 2012

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Abstract

As world population keeps growing older, the number of persons with mobility difficulties increases. To face this problem, the development of intelligent wheelchairs seems a viable response. The *IntellWheels* project is an adaptable intelligent wheelchair platform with usability, user safety and accessibility as its main goals. The platform is composed of a simulator, the software packages, the real wheelchair prototype and the hardware devices. To address the user safety issue, a data acquisition system was implemented in the *IntellWheels* platform in order to carry out both user and environment profiling. The acquisition system captures data from the input devices, sensors and simulator. Continuing the *IntellWheels* approach to usability, a Brain-Computer Interface was also implemented, so that the user can control the *IntellWheels* chair by use of facial expressions. It will also allow to control the intelligent wheelchair using thoughts in the future.

The following document exposes the current state in smart wheelchairs together with a review of the *IntellWheels* Project. After the initial presentation, the details of the acquisition system for the platform are explained and information about its implementation discussed. In order to test the implementation, user profiling tests were carried out. These are also explained and their results displayed, showing how the user profiling can be helpful to select between the different input devices, as different users have different proficiency regarding the devices. At the end of the document, possible future is outlined.

Resumo

À medida que a população mundial envelhece, o número de pessoas com dificuldades motoras aumenta. Para fazer frente a este problema, o desenvolvimento de cadeiras de rodas inteligentes parece uma resposta viável. O projeto *IntellWheels* consiste numa plataforma adaptável para cadeiras de rodas inteligentes com a usabilidade, segurança do utilizador e acessibilidade como objetivos principais. A plataforma é constituída por um simulador, os pacotes de *software*, um protótipo real da cadeira e pelos componentes de *hardware*. Para responder ao problema da segurança do utilizador, um sistema de adquisição de dados foi implementado na plataforma *IntellWheels* de maneira a poder executar o processo de *profiling* do utilizador. O sistema capta dados dos meios de controlo, sensores e simulador. Continuando com o aspeto da usabilidade da *IntellWheels*, uma *Brain-Computer Interface* foi adicionada como meio de controlo da cadeira, de modo a permitir ao utilizador usar expressões faciais como meio de controlo. No futuro, também irá permitir o uso de pensamentos para controlar a cadeira.

O seguinte documento expõe o estado atual das cadeiras de rodas inteligentes juntamente com uma revisão do projeto *IntellWheels*. Depois da apresentação inicial, os detalhes do sistema de adquisição de dados para a plataforma são explicados e informação acerca da respetiva implementação discutida. De modo a testar a implementação, foram levados a cabo testes de perfil de utilizador. Estes são também explicados e os seus resultados expostos, de modo a mostrar que o perfil de utilizador pode ajudar na escolha dos meios de controlo, sendo que diferentes utilizadores têm níveis diferentes de proficiência para cada meio de controlo. Para finalizar o documento, são feitos comentários acerca de possíveis trabalhos futuros.

Acknowledgements

For the support given, I would like to thank Professor Luís Paulo Reis, Mónica Faria, Marcelo Petry, Sérgio Vasconcelos, Abbas Abdolmaleki, Seraphin Miranda and Nuno Resende.
For different reasons, I would also like to thank Soraia Ferreira and Vítor Gonçalves, as well as Daniel Pina.
On a different note, I would also like to thank the Faculty of Engineering of the University of Porto and the Artificial Intelligence and Computer Science Laboratory for the opportunity to develop this project.

João Couto Soares

Contents

1 Introduction **1**
- 1.1 Context . . . 1
- 1.2 Problem . . . 1
- 1.3 Motivation . . . 2
- 1.4 Possible Solution . . . 2
  - 1.4.1 Environment Profile . . . 2
  - 1.4.2 User Profile . . . 3
- 1.5 Following Chapters . . . 4

2 Intelligent Wheelchairs **5**
- 2.1 Definition . . . 5
- 2.2 Relevant Prototypes . . . 5
  - 2.2.1 Portuguese Projects . . . 9
  - 2.2.2 Other Available Inputs . . . 10
- 2.3 Summary . . . 10

3 *IntellWheels* Project **11**
- 3.1 Inputs . . . 12
- 3.2 Sensors . . . 14
- 3.3 Other Hardware . . . 14
- 3.4 Architecture . . . 15
- 3.5 Multimodal Interface . . . 15
- 3.6 Control Application . . . 20
- 3.7 Simulator . . . 21
- 3.8 Comparison . . . 21
- 3.9 Summary . . . 22

4 Data Acquisition System **23**
- 4.1 Implementation . . . 23
- 4.2 Capturing Data From Input Devices . . . 25
  - 4.2.1 USB Joystick . . . 25
  - 4.2.2 Microphone . . . 26
  - 4.2.3 Wiimote . . . 27
  - 4.2.4 Brain-Computer Interface . . . 28
- 4.3 Capturing Data From Sensors . . . 31
- 4.4 Capturing Data From The Simulator . . . 31
- 4.5 User Profiler . . . 32
  - 4.5.1 Input Devices . . . 33

4.5.2 Simulator 37
4.6 Questionnaire 38
4.7 Summary 38

5 Experiments and Results **39**
5.1 Data Acquisition System 39
5.2 Users' Trials 39
5.2.1 Input Devices 41
5.2.2 Navigation Session on the Simulator 43
5.2.3 Questionnaire 44
5.3 Summary 46

6 Conclusions and Future Work **49**

A Material Used During the Tests **51**

References **59**

List of Figures

1.1 Different Environments where the *IntellWheels* can be inserted 3

2.1 Madarasz' prototype and Hoyer and Hölper's omnidirectional prototype 6
2.2 Wellman's two legged wheelchair prototype and *Tin Man I* prototype 6
2.3 *Tin Man II* prototype, *NavChair*'s initial prototype and *Wheelesley* circa 1997 . . 7
2.4 FRIEND's prototype, WATSON's prototype and ACCoMo's prototype 8
2.5 *MIT Intelligent Wheelchair*'s prototype, the *brain-controlled wheelchair*'s prototype, the *Tongue Drive System*'s prototype and the *"sighted" wheelchair*'s prototype 9
2.6 Portuguese Prototypes: the *ENIGMA*'s prototype, the *PalmIber* and the *Magic WheelChair*'s prototype 10

3.1 Input Devices currently implemented in the *IntellWheels* Platform 13
3.2 *IntellWheels*' U-Shaped Sensor Bar 14
3.3 Evolution Electronic by Vassilli 15
3.4 Architecture of the *IntellWheels* Platform 16
3.5 *IntellWheels*' Multimodal Interface 19
3.6 *IntellWheels*' Multimodal Interface Details 19
3.7 *IntellWheels*' Control Module 20
3.8 *IntellWheels*' Simulator 21

4.1 *IntellWheels*' Software Architecture 24
4.2 *IntellWheels*' System's Uptime Flow 24
4.3 EPOC's Sensors 29
4.4 *IntellWheels*' Simulator Improved First-Person View 32
4.5 *IntellWheels*' User Profiler 33
4.6 USB Joystick Button's Proficiency Test 34
4.7 Wiimote's Proficiency Test 34
4.8 Microphone's Proficiency Test 34
4.9 BCI's Expression Mirror 35
4.10 Association of Cerebral Palsy of Porto Circuit 37

5.1 Data that can be Acquired During the User Profiling 40
5.2 Data that can be Acquired During a Trial on the Simulator 40
5.3 First USB Joystick Session Results - Analog Stick 42
5.4 Graphic Representation of captured EEG Data 43
5.5 Wiimote Navigation Sessions 44
5.6 Default Facial Expressions' Commands Association Versus a User Specific One . 44

LIST OF FIGURES

List of Tables

4.1 Extract from an EEG Capture File 30
4.2 Extract from a Contact Quality File 30
4.3 Percentage of Recognition of Mirrored Expressions 36

5.1 Users' Characterization 41
5.2 First USB Joystick Session Results - Button Pressing 41
5.3 First USB Joystick Session Time - Analog Stick 42
5.4 First Wiimote Session Time 42
5.5 First Microphone Session Results 42
5.6 Score of the System Usability Scale For Each User After Each Trial 45
5.7 Order of preference of the Input Devices by Trial 46
5.8 Satisfaction Level Regarding the USB Joystick in "High-Level" Mode 46
5.9 Satisfaction Level Regarding the Microphone 46
5.10 Fatigue and Frustration - I Felt Tired After the Trial 48
5.11 Fatigue and Frustration - I Felt Frustrated After the Trial 48
5.12 Fatigue and Frustration - I Felt Bored During the Trial 48
5.13 Fatigue and Frustration - Thinking About the Actions is Tiresome 48
5.14 Fatigue and Frustration - Doing the Actions is Tiresome 48
5.15 Fatigue and Frustration - A Lot of Concentration is Required to Think About the Actions 48
5.16 Fatigue and Frustration - A Lot of Concentration is Required to Do the Actions . 48

LIST OF TABLES

Abbreviations

ACL	Agent Communication Language
API	Application Programming Interface
BCI	Brain-Computer Interface
EEG	Electroencephalogram
FIPA	Foundation for Intelligent Physical Agents
IW	Intelligent Wheelchair
SAPI	Microsoft Speech API
SUS	System Usability Scale
USB	Universal Serial Bus
XML	Extensible Markup Language

Chapter 1

Introduction

1.1 Context

As the world population keeps growing older and the projections point to an even higher number of elder citizens in the future [oED02, oED11], the number of people afflicted with mobility impairments already ascends to more than half a thousand million worldwide [KAP11]. As time goes by, and the number of senior citizens increases, so will the number of mobility disabled people. In fact, the elderly are more prone to develop illnesses that might affect their locomotion/autonomy.

It was facing this scenario that the concept to create an adaptable intelligent wheelchair (IW) platform arose: *IntellWheels*. Having as primary goals its usability, the safety of its user and the objective to make it as accessible as possible. But how to assure the user's safety and usability of the platform?

On the following sections, the problem (section 1.2) and motivation (section 1.3) for the work presented in this document will be addressed. Afterwards, an approach to solving the problem presented will be explained in section 1.4.

1.2 Problem

Looking at the core objectives of the *IntellWheels* project, two of them stand out: how to assure the usability of the platform and the safety of its user? They depend on a broad array of variables, and yet, they must be mandatory in order to protect the user.
A possible solution for this issue is explained in section 1.4. However, in order to implement said solution, a data acquisition system needs to be implemented in the *IntellWheels* platform. The information regarding user inputs, sensor measurements and simulator values can be processed in order to achieve the necessary data required for the solution of the user safety and usability problem. The implementation details of the data acquisition system are presented throughout chapter 4.

1.3 Motivation

The motivation for this work derives directly from the problem posed above and the social responsibility to those that lack the ability of walking around like any regular person does. It is an effort to help decrease the gap between those that lack locomotion ability and able-bodied people.
Also, as will be mentioned in subsection 1.4.2, user profiling is a technique heavily used in different areas, as several different types of information can be extracted from collected data. It is currently used in customization and adaptation of systems, such as online services, television, mobile phones operative systems, education or health care. Applying user profiling seems the next logical step for the *IntellWheels* platform.

1.4 Possible Solution

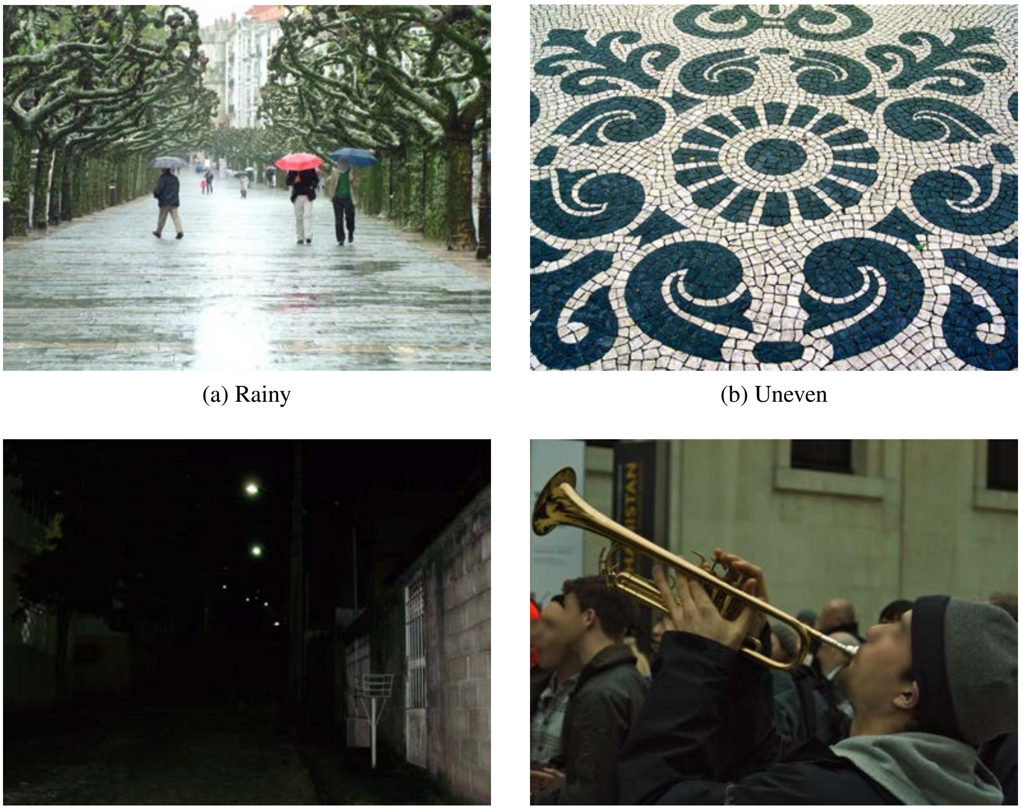
At first glance there are several issues that might influence the safety of the user, but the ones that have more influence are those related to the control of the chair. If the user manages to lose control of the *IntellWheels* chair it is extremely dangerous both to himself and to those surrounding him. Considering the control of the *IntellWheels* chair, there are two factors that can influence it: the user and the environment.

As the *IntellWheels* chair can rely solely on inputs from the user (fully manual controlling mode), assuming that users are not the same and do not have the same proficiency and easiness with dealing with the controls is of extreme importance.
The other factor that must be taken into account is the environment the *IntellWheels* chair is in while the user is operating it. One just needs to imagine the user in a noisy environment using voice commands, or some other place where there might be interference with the commands given by the user to the chair.

A possible approach to address these issues is to profile both the user and the environment, and use that information to advise on the safest input type available for that instance, as will be explained in the following subsections.

1.4.1 Environment Profile

As mentioned previously, the surroundings in which the *IntellWheels* chair is currently at, while being used, are of extreme importance to determine the safest input type available for that instance. While searching for possible environments that could interfere with the inputs from the user, one can come across several ones, like rainy (1.1a) or extremely dry environments, uneven pavements (1.1b), dark (1.1c) or excessively bright locations, noisy sites (1.1d) or situations where silence is mandatory. A depiction of possible environments the *IntellWheels* chair could operate at is presented in Figure 1.1.



(a) Rainy (b) Uneven

(c) Dark (d) Noisy

Figure 1.1: Different Environments where the *IntellWheels* can be inserted.

As an example, if the location the *IntellWheels* chair is operating at is extremely dry, using the newly implemented (as aid in the solution of the usability problem) facial recognition interface is not advised, as it relies heavily on the moisture of the *Brain-Computer Interface* (BCI) sensor pads. In subsection 3.1 a full description of the current available inputs is presented, but the most important idea to retain from the current subsection is that information about the environment is of most importance to determine the most appropriate, safety wise, input to use.

1.4.2 User Profile

The ability to command the *IntellWheels* chair will vary according to each user and to the input used. As such, measuring the competence of the specific user regarding the several inputs available is of high importance to be able to afterwards choose the safest interface possible for her/him.
Considering a case in which the user has lost the capacity to move her/his hands, advising the use of a joystick to control the *IntellWheels* chair as the safest interface because of environment measures is not acceptable under any circumstance. Also, considering a situation in which two or more inputs can be chosen, an extra variable must be used to sort them: the reliability the user has shown for the proposed interfaces.

1.5 Following Chapters

After this brief introduction to the theme of this work, a state-of-the-art regarding IWs is presented in chapter 2, as well as a small note on portuguese projects on the matter. Afterwards, in chapter 3, the *IntellWheels* project is presented in detail: its current state, the input devices implemented and sensors currently used, a view on its several modules and architecture followed by a comparison to other IW. In chapter 4 the bulk of the work done is presented, explaining how data from the input devices, sensors and the simulator was captured. The tests developed to profile the user are also detailed in the chapter. The results obtained from the tests carried out are summarized in chapter 5. Finally, chapter 6 presents a summary of the work done and offers ideas that could be implemented on the *IntellWheels* project.

Chapter 2

Intelligent Wheelchairs

The first smart wheelchairs appeared around 1980 [Sim05]. They were mainly a seat mounted on a mobile robot that had the capacity of taking the user to a previously defined location, like an office room in an office building by being provided only the room number [LCFM86]. The intelligent wheelchairs development has come a long way since then. In the following chapter, a closer look is taken upon on the current state of affairs regarding the current technologies used and features provided.

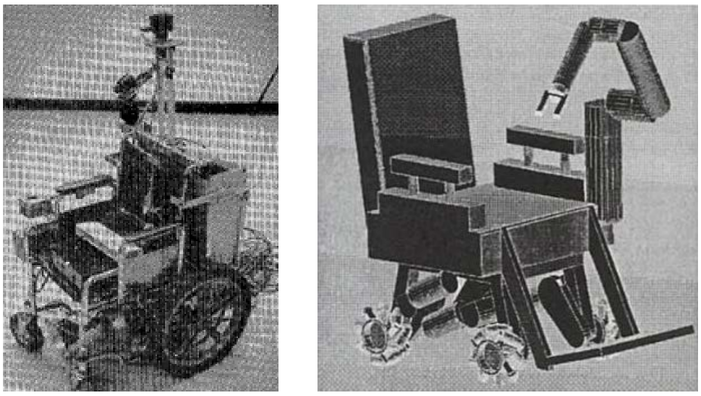
2.1 Definition

Intelligent wheelchairs (IW), or smart wheelchairs, are intended for persons who suffer from mobility impairment, as the safe operation of a standard power wheelchair is beyond their capabilities. This is especially true for persons who do not have any fine motor control or who also have partial vision loss [MS95], such as senior citizens and disabled users. Like other intelligent service robots, the IW might include autonomous navigation and planning capability, interface flexibility, extended human-machine interaction, obstacle avoidance modules among other features [BPRM11]. In the following section, *Relevant Prototypes*, a detailed explanation can be found. An IW is a locomotion device where an artificial control system augments or replaces the user's control [SLH+04]. Its main objective is to reduce or eliminate the user's task of having to control a motorized wheelchair [Far10]. Their interface with the user may consist of a conventional wheelchair joystick, voice based control, head movements recognition or even gaze tracking, among others.

2.2 Relevant Prototypes

As mentioned above, one of the first IW prototypes that appeared had the ability to take the user from one room to another previously mapped. This prototype was developed by Madarasz in

1986 [LCFM86]. It had a digital camera, an ultra-sound scanner and a micro computer. His primary objective was a vehicle that could navigate in populated environments without human aid. A picture of it can be found in Figure 2.1a. Later, in 1993, an open control architecture for an omnidirectional IW was introduced by Hoyer and Hölper [HH93], depicted in Figure 2.1b. It allowed for a flexible configuration of user required functionality.

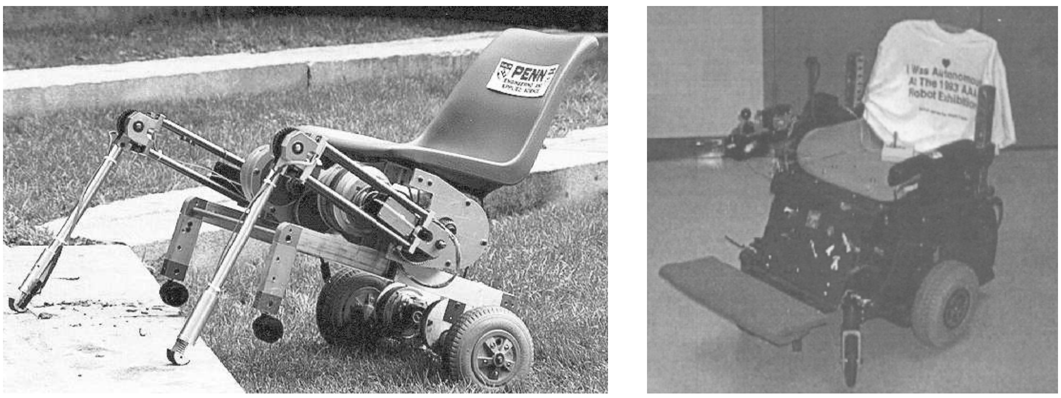


(a) Madarasz' prototype.

(b) Hoyer and Hölper's omnidirectional prototype.

Figure 2.1: Madarasz' prototype [Adapted from [LCFM86]] and Hoyer and Hölper's omnidirectional prototype [Adapted from [HH93]].

In mid 1994, a two legged IW prototype (Figure 2.2a) was unveiled by Wellman [WKK94]. The addition of the two legs to the chair allowed it to climb steps and to navigate easier on uneven terrain. *Tin Man I* (Figure 2.2b) was brought forth by Miller and Slack in 1995 [MS95, Mil98]. This IW had the capability of following a pre-defined track, to navigate to a specific point (X,Y) if it had knowledge of its surroundings and provided obstacle avoidance assistance while on manual operational mode.



(a) Wellman's two legged wheelchair prototype.

(b) *Tin Man I* prototype.

Figure 2.2: Wellman's two legged wheelchair prototype [Adapted from [WKK94]] and *Tin Man I* prototype [Adapted from [MS95]].

The *Tin Man II* (Figure 2.3a) was released afterwards. It was a cleaned up version of the original wheelchair which eliminated the mechanical joystick interface, but not only that, the main purpose of this new iteration was to decrease reliance on contact sensors, to modify the user interface to one more in accordance to the user community and increase the operating speed. It allowed to backtrack, store navigation information, wall following, door way passing and to dock in order to charge its battery. The *NavChair* [BBL+94] (Figure 2.3b) had its initial development in 1991 but suffered several updates up until 1999 [LBJ+99]. It initially sported 12 ultrasonic sensors and an on-board computer. It was capable of obstacle avoidance, wall following and doorway passing. A shared control system [SLB+98] was implemented which allowed the user to plan routes, manual navigation with assistance (regarding obstacle avoidance and doorway passage) and indicate direction as well as control the speed of voyage. Later on, a voice command module was added to this IW [SL97]. *Wheelesley* [YHP+95], pictured in Figure 2.3c is an IW that had the ability of being controlled by means of an eye tracking system (*EagleEyes* [GO96]) and a single switch. It had three control modules: "manual", "joystick" and "interface". The "manual" mode connected the joystick inputs directly to the motor without sensor mediation, "joystick" mode was almost the same as the "manual" mode with the exception that an obstacle avoidance module was activated. The "interface" mode allowed to control the IW by selecting commands from the user interface. This action could be done with the *EagleEyes* system or the single switch. If using the single switch input option, the control would highlight the possible commands one at the time and the user could activate it by pressing the switch.

(a) *Tin Man II* prototype.

(b) *NavChair*'s initial prototype.

(c) *Wheelesley* circa 1997.

Figure 2.3: *Tin Man II* prototype [Adapted from [MS95]], *NavChair*'s initial prototype [Adapted from [BBL+94]] and *Wheelesley* circa 1997 [Adapted from [whe06]].

FRIEND[1] (Figure 2.4a) appeared in 1999 [BBG99]. It was a robot for rehabilitation which consisted of a powered wheelchair and a mechanical arm. Both the vehicle and the arm were controlled by voice commands. Head gesture and gaze tracking are the inputs used by WATSON[2] [MIO01], where a stereo CCD camera pair is mounted on the wheelchair (as seen on Fig-

[1]Functional Robot arm with user-frIENdly interface for Disabled people

[2]Wheelchair for Advanced TranSportatiON

ure 2.4b) in order to capture the facial image of the user. The gaze tracking is used in some part to steer the IW (it's not the eyes that are being tracked, but the direction of the user's head, for safety reasons), while the head gestures serve to "start" and "stop" the IW. The speed is controlled through combining the direction of the face and where the user is looking at, if he is facing and looking in the same direction, the IW increases speed, otherwise, speed is decreased. ACCoMo[3] [HH04] from 2004, is a prototype of an IW that allows for safe movement in indoor environments. ACCoMo, in Figure 2.4c, is an agent based prototype with simple autonomous, cooperative and collaborative behaviours. These behaviours are acquired through the ACCoMo agents experiences in the real environment and the virtual one. The autonomous behaviour serves to navigate safely and effectively from observing the surroundings. The cooperative behaviour emerges from interactions with other ACCoMo dynamically. The collaborative behaviour aims to assist user operations by providing functions for connecting to various ubiquitous devices.

(a) FRIEND's prototype. (b) WATSON's prototype. (c) ACCoMo's prototype.

Figure 2.4: FRIEND's prototype [Adapted from [BBG99]], WATSON's prototype [Adapted from [MIO01]] and ACCoMo's prototype [Adapted from [HH04]].

Under development since 2005, the *MIT Intelligent Wheelchair* (MITIW) (Figure 2.5a) is equipped with an interactive interface that allows intelligent speech recognition, confirmation of orders and suggestion of new destinations that relate to the one given as input. It is capable of constructing its own map of the premises while it's operating or by taking a guided tour [HKRT11] of them. It allows to track other MITIWs on the map under certain conditions. An obstacle avoidance module is also featured. In 2006, the first working prototype of a brain controlled IW appeared [RBG+06] (Figure 2.5b). It used sensors that could measure electromagnetic waves from the brain, also known as a Brain-Computer Interface (BCI). It was able to navigate in a typical indoor environment or a hospital environment. It had a motion guidance strategy that provided a safe and efficient control without complex sensors or sensor processing. In 2008, an IW prototype using a tongue-operated assistive technology, now known as *Tongue Drive System* [HWG08], was unveiled (Figure 2.5c). It allows the user to fully control the movements of his chair by the use of his tongue alone. A magnet is placed on the tip of the tongue and an headset [PKH+11]

[3] Autonomous, Cooperative and Collaborative Mobile robot

captures the movements of the magnet inside the users mouth. Obstacle avoidance is implemented in the IW prototype. Very recently, an IW for blind persons made its debut[4,5]. The *"sighted" wheelchair* [FH10] (Figure 2.5d) can sense it's environment and transmit information to the user. The IW has a joystick for steering and a haptic robot that acts as a virtual white cane. A laser scanner is used to create a simplified 3D map of the IW surroundings, which is then transferred to the haptic robot, so that a visually impaired user can "feel or see" obstacles such as open doors or oncoming people, and navigate past them.

(a) MITIW's prototype. (b) The *brain-controlled wheelchair*'s prototype. (c) *Tongue Drive System*'s prototype. (d) *"sighted" wheelchair*'s prototype.

Figure 2.5: *MIT Intelligent Wheelchair*'s prototype [Adapted from [HKRT11]], the *brain-controlled wheelchair*'s prototype [Adapted from [RBG+06]], the *Tongue Drive System*'s prototype [Adapted from [HWG08]] and the *"sighted" wheelchair*'s prototype [Adapted from [FH10]].

2.2.1 Portuguese Projects

There are also some active IW projects in Portugal: the *IntellWheels*, which will be discussed in depth in the following chapter, the *ENIGMA* [Rib07] (Figure 2.6a), an omnidirectional wheelchair from the University of Minho, the *PalmIber* [pal09], a joint cooperation from Anditec, a portuguese company, the CENTIMFE[6], the spanish IAI [7] and IC NEURONIC, a spanish company, and the *Magic WheelChair* [mwc], part of the MagicKey Project from the Polytechnic Institute of Guarda, which is a gaze driven IW.

The *PalmIber* (Figure 2.6b) has a multi-detector of obstacles system (composed of ultrasonic sensors), a set of interfaces for the user, which allows controlling the vehicle through direct selection or selection by scanning, and a programmable interface that allows to assign different levels of complexity to the vehicle (speed, acceleration, different ways to avoid obstacles). The *Magic*

[4] www.sciencedaily.com/releases/2011/05/110512110851.htm
[5] www.youtube.com/watch?v=eXMWpa4zYRY
[6] Centro Tecnológico da Industria de Moldes, Ferramentas Especiais e Plásticos
[7] Instituto de Automática Industrial

WheelChair (Figure 2.6c) uses a high definition camera together with a software package that determines the direction the user is looking at. It also has ten sonars sensors placed around the IW, for obstacle avoidance, and two encoders, for real time speed value of each rear wheel.

(a) *ENIGMA*'s prototype. (b) *PalmIber*'s prototype. (c) *Magic WheelChair*'s prototype.

Figure 2.6: Portuguese Prototypes: the *ENIGMA*'s prototype [Adapted from [Rib07]],the *PalmIber* [Adapted from [pal09]] and the *Magic WheelChair*'s prototype [Adapted from [mwc]].

2.2.2 Other Available Inputs

Even though some of the IWs mentioned on the previous section could be used by a person with quadriplegia, there are also several type of inputs not mentioned previously that can be incorporated to facilitate the use of an IW by a person with severe mobility impairments.
The *Sip-and-Puff* system allows the user to control the navigation of a powered chair by mean of air flow using a straw. A *Lip Switch* is another input type that makes use of either the tongue or the lip to send commands to the powered chair. The *QuadMouse* is similar to the *Lip Switch* but also allows the use of the chin, besides the lip and the tongue. There is also a *Bite Switch*, which measures bite pressure and position of the bite, allowing to fully control the chair by means of mouth use only.
Another available option relies on *facial expression recognition*, both by visual feed and by sensors placed on the face, *Facial Muscle Detection* [WH11]. The user is able to control the IW by blinking or opening its mouth to different degrees.

2.3 Summary

On this chapter, a definition for intelligent wheelchairs was described, followed by the presentation of several IWs with their features and input types exposed. A view on other available inputs for persons with severe mobility difficulties was also presented as well as a note on portuguese projects.

Chapter 3

IntellWheels Project

IntellWheels is an on-going project being developed at the Artificial Intelligence and Computer Science Laboratory of the University of Porto in consortium with the School of Health Technology of Porto, the Association of Cerebral Palsy of Porto, the Institute for Systems and Computer Engineering of Porto and the Institute of Electronics and Telematics Engineering of Aveiro at the University of Aveiro.

The aim of the *IntellWheels* project is the development of an intelligent wheelchair (IW) platform [BPMR08a] that may be easily adapted to any commercial powered wheelchair in an unobtrusive way, in order to aid any person with special mobility needs [Far10]. The goal is to be achieved by research and design of a multi-agent platform, which will enable easier integration of sensors, actuators, devices for augmented interaction with the user [LBSM09, BPRM11], navigation methods and planning techniques, as well as methodologies for intelligent cooperation solving [BPMR08b, BPRM11]. The platform should also allow that real and virtual IWs interact with each other. These interactions will make highly complex tests with a substantial number of devices and IWs possible, in an inexpensive way, as there will be no need to manufacture a large number of real IWs [BPMR09, BPRM11]. The platform is to be the merge of a simulator, the software packages, the real wheelchair prototype and the hardware devices, to test, preview and simulate the behaviour of IWs [BPMR09].

Current State

At the moment, the *IntellWheels* project already has a substantial set of features implemented, such as support for several input devices, like facial expressions[1], voice and head movements recognition (exposed in section 3.1), a well defined sensor collection (section 3.2), a functional prototype of the IW (section 3.3), a simulator (section 3.7) and functions implemented to assist

[1] Details on the current implementation are available in subsection 4.2.4.

the user while controlling the *IntellWheels* chair to avoid collisions, to follow walls, to perceive unevenness in the ground, to communicate with other devices and a motion planner capable of generating behaviour/path commands, according to a previously defined map of the surroundings [LBSM09, BPRM11]. The shared control, the high-level planning algorithms and the device communication modules implemented in *IntellWheels* have been tested while operating in a simulated hospital environment [BPRO08, BMR10].
An application to control both the type of environment the *IntellWheels* connects to ("Real", "Simulated" or "Mixed") and the shared control is shown in section 3.6. A multimodal interface (section 3.5) which serves to interpret and control all of the input devices is also implemented.
The architecture of the *IntellWheels* platform is explained in section 3.4.

3.1 Inputs

A broad set of input options enables the *IntellWheels* chair to be easily controlled by users suffering from distinct disabilities [BPMR08b, BPMR08a]. Taking that idea in consideration, an USB joystick, a microphone, a Wiimote [Nin] and a Brain-Computer Interface (BCI) [EMO] were implemented as input devices. These devices allow the user to control the *IntellWheels* chair with the use of a single button or by using head movements and facial expressions [LBSM09].

The USB joystick (Figure 3.1a) allows the user to control the *IntellWheels* chair in two different ways, by button pressing or by using the analog stick. If the user chooses button control, he can associate any type of high-level order to a button or sequence of buttons, elaborate ones like "follow right wall" or "go to room" as well as basic commands such as "move forward" or "turn left". The *IntellWheels* chair will start functioning in an "autonomous" mode without the need for more inputs from the user until the order is completed or the user considers it completed and inserts a new command. In case the user opts for the use of the analog stick, the chair will be operated in a "manual" mode. In this mode, the user will have freedom to control speed or the turning degree of the *IntellWheels* chair.

The microphone (Figure 3.1b) makes use of a voice recognition API, the Microsoft Speech API (SAPI) [sap], to process the commands given by the user. Only the "autonomous" mode can be used on this way of controlling the *IntellWheels* chair, as a high-level order is associated to any word, or sequence of words, that the user chooses to.

The Nintendo's Wiimote current implementation allows the user to control the *IntellWheels* chair in a "manual" mode only. Head movements are measured along three axes via the accelerometers included in the device and translated to the direction, navigation speed and orientation of the *IntellWheels* chair. The device was mounted on a cap in order to facilitate its usage, as can be seen in Figure 3.1c.

The EMOTIV's EPOC [EMO] (Figure 3.1d), is the BCI currently being used in the *IntellWheels*.
The EPOC is a high resolution 14-channel electroencephalogram (EEG) headset system that allows to measure and detect facial expressions, specific cognitive data and emotional states in real-time.
The current implementation[2] on the *IntellWheels* allows for commanding the chair using facial expressions as inputs. A high-level order is associated to an expression or sequence of expressions, and when the expression or sequence is triggered, the *IntellWheels* chair executes the pre-defined command, as such, this device can only be used in the "autonomous" mode.

(a) USB Joystick

(b) Microphone

(c) Wiimote mounted on a cap

(d) Brain-Computer Interface

Figure 3.1: Input Devices currently implemented in the *IntellWheels* Platform.

As will be seen in section 3.5, one or more of these input devices can be used at the same time to control the *IntellWheels* chair and to create sequences that can be associated with high-level orders.

[2]Details of it are available in subsection 4.2.4.

3.2 Sensors

Since the difference between an IW and a robotic wheelchair is not just semantic, the visual impact of the *IntellWheels* sensors must not alter the powered wheelchair aesthetics and ergonomics as well as the comfort and workability of the wheelchair in its daily tasks. This approach limits the number and the kind of sensors that can be used due to size and assembly constraints [BPMR08b, BPRM11].
The *IntellWheels* chair has eight ultrasound sensors and twelve infrared sensors mounted in one U-shaped bar as seen on Figure 3.2 (used for obstacle detection and avoidance, following walls and perceive unevenness in the ground), two encoders (for odometry calculations like distance, speed and position) and one webcam (directed at the ground in order to read ground marks and refine the odometry values) [BPMR09, LBSM09, BPRM11].

A probabilistic odometry motion model is used to aid the localization system: When the uncertainty of the *IntellWheels* chair position, as given by odometry, grows to a certain threshold, the path planning changes the trajectory in a way that the *IntellWheels* chair passes near a landmark and is able to reset its position coordinates. This probabilistic model can also be used to decide how many landmarks are needed and where to place them [BPMR09].

Figure 3.2: *IntellWheels*' U-Shaped Sensor Bar with the Webcam also attached to it.

3.3 Other Hardware

The *IntellWheels* chair prototype currently uses a commercially available powered wheelchair, model Evolution Electronic by Vassilli [Vas] (Figure 3.3), as its base, but given the flexibility of the platform any other generic powered wheelchair could have been used.
The Evolution Electronic wheelchair is comprised of two differentially driven rear wheels, two passive castors at the front, two 160W batteries, a traditional Joystick and a power module.
The *IntellWheels* chair prototype also uses a control/data acquisition board to gather sensor information and send reference values to the power module to control both motors [BPRM11]. This board is also used to connect the platform to the host computer.

(a) Front view (b) Back view

Figure 3.3: Evolution Electronic by Vassilli.

3.4 Architecture

As previously stated, the *IntellWheels* platform makes use of a multi-agent system architecture. It does so in order to implement in an easier way new modules and for communication with other IW and devices.
The platform is comprised of four agents, as identified below:

- **Interface Agent** - responsible for the interaction between the user through the multimodal interface and the *IntellWheels* chair;

- **Intelligence Agent** - responsible for planning the actions of the *IntellWheels* chair and for cooperating with other IW;

- **Perception Agent** - responsible for reading sensor values, keep track of the *IntellWheels* chair location and environment mapping;

- **Control Agent** - responsible for basic actions, wheel control and obstacle avoidance;

These agents are heterogeneous and can collaborate with other agents of another IW.

As can be seen on Figure 3.4, a representation of the *IntellWheels* platform architecture, the previously described agents can control both the real *IntellWheels* chair and a simulated one.

3.5 Multimodal Interface

This module is responsible for handling all inputs from the user. As its name indicates, it allows to control the *IntellWheels* chair prototype using more than one input device, by combined use or not. This way, the user is offered the choice of selecting the input devices or device he feels more comfortable with. It also helps the *IntellWheels* platform become more robust, as different disabilities can be addressed with success using different input devices or a combination of them. This module permits the user to define input sequences and bind them to high-level orders in a

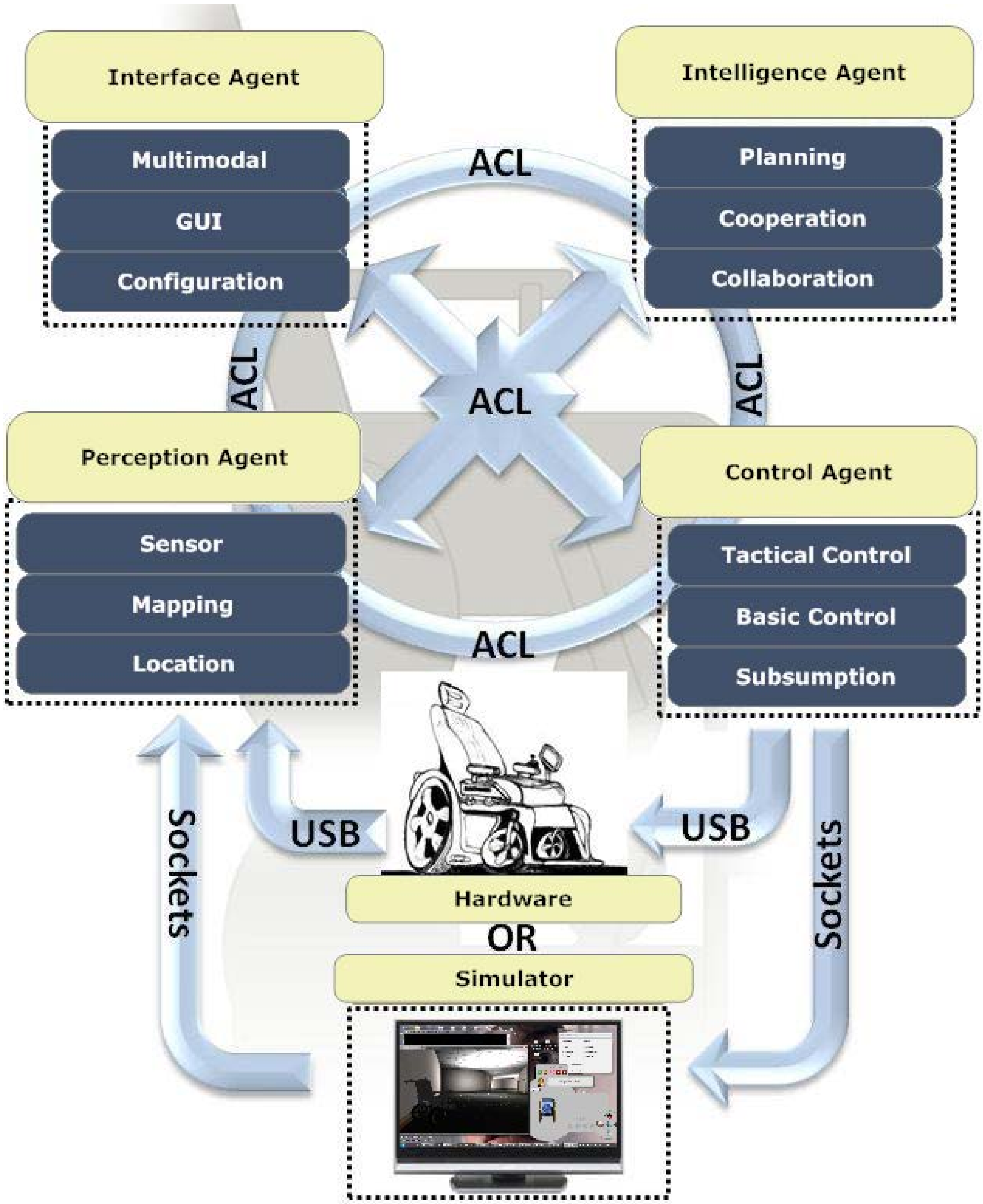


Figure 3.4: Architecture of the *IntellWheels* Platform [Adapted from [LBSM09]].

way that, during a defined time interval, if the sequence previously created is enacted by the user, the command associated with it is triggered. These input sequences do not need to be from the same input device, a mixture of distinct input devices is possible, like "facial expression: smirk left" and "voice: go" or any given sequence of inputs coming from different input devices. The sequences are only limited by the total number of inputs available [LBSM09].

Another property, not yet referenced, is the capability of defining a user specific vocabulary by use of the configuration files (example in Listing 3.1). With this specific vocabulary, the user can associate words of his choice to high-level actions. Currently, only english is supported as input language, due to restrictions of the SAPI version implemented.

```
<GRAMMAR LANGID="809">
  <RULE NAME="go_forward" TOPLEVEL="ACTIVE">
    <P>go forward</P>
  </RULE>
  <RULE NAME="go_back"  TOPLEVEL="ACTIVE">
    <P>go back</P>
  </RULE>
  <RULE NAME="turn_right"  TOPLEVEL="ACTIVE">
    <P>turn right</P>
  </RULE>
  <RULE NAME="turn_left"  TOPLEVEL="ACTIVE">
    <P>turn left</P>
  </RULE>
  <RULE NAME="right_spin" TOPLEVEL="ACTIVE">
    <P>right spin</P>
  </RULE>
  <RULE NAME="left_spin"  TOPLEVEL="ACTIVE">
    <P>left spin</P>
  </RULE>
  <RULE NAME="go_to_wc"  TOPLEVEL="ACTIVE">
    <P>go to wc</P>
  </RULE>
  <RULE NAME="go_to_elevator"  TOPLEVEL="ACTIVE">
    <P>go to elevator</P>
  </RULE>
  <RULE NAME="stop_wheelchair"  TOPLEVEL="ACTIVE">
    <P>stop</P>
  </RULE>
  <RULE NAME="yes"  TOPLEVEL="ACTIVE">
    <P>yes</P>
  </RULE>
  <RULE NAME="no"  TOPLEVEL="ACTIVE">
    <P>no</P>
  </RULE>
</GRAMMAR>
```

Listing 3.1: User Specific Vocabulary Example File

The configuration files also allow to store the sequences defined by the user (example in Listing 3.2) and the actions they are associated with (example in Listing 3.3).

```
<INTELLWHEELS>
  <SEQUENCES>
    <item>
      <id_seq>6</id_seq>
      <inputs>bci.left_blink</inputs>
    </item>
    <item>
      <id_seq>12</id_seq>
      <inputs>bci.smirk_left joystick.1</inputs>
    </item>
    <item>
      <id_seq>13</id_seq>
      <inputs>bci.right_blink microphone.go_forward</inputs>
    </item>
    <item>
      <id_seq>15</id_seq>
      <inputs>joystick.2</inputs>
    </item>
    <item>
      <id_seq>17</id_seq>
      <inputs>microphone.turn_left</inputs>
    </item>
  </SEQUENCES>
</INTELLWHEELS>
```

Listing 3.2: Sequences Defined by the User Example File

```
<INTELLWHEELS>
  <ASSOCIATIONS>
    <item>
      <id_seq>15</id_seq>
      <action>Manual</action>
    </item>
    <item>
      <id_seq>6</id_seq>
      <action>STOP</action>
    </item>
    <item>
      <id_seq>12</id_seq>
      <action>Left Turn</action>
    </item>
  </ASSOCIATIONS>
</INTELLWHEELS>
```

Listing 3.3: Actions Associated to the Sequences Example File

The Multimodal Interface (Figure 3.5) provides a graphical way of informing the user about the current action (Figure 3.6a) and input devices available (Figure 3.6b), the defined input sequences (Figure 3.6c) as well as the current sequence in course (Figure 3.6d).

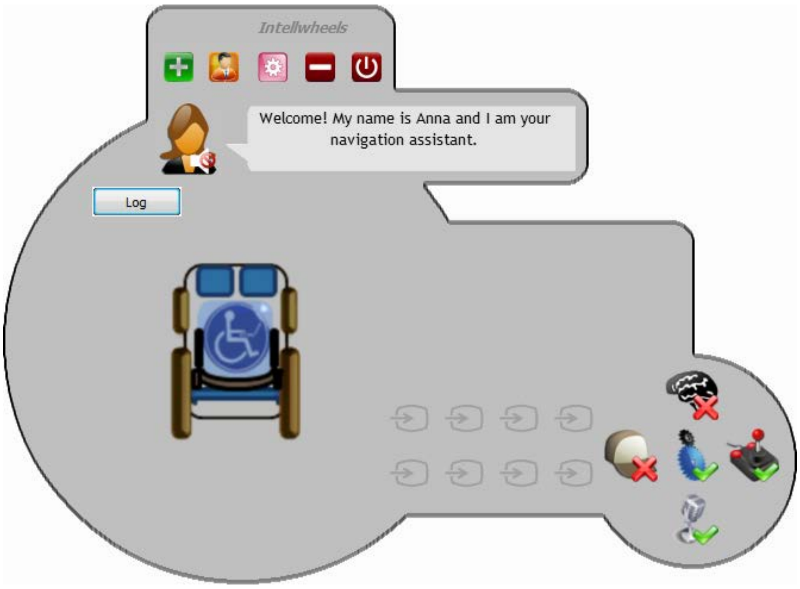
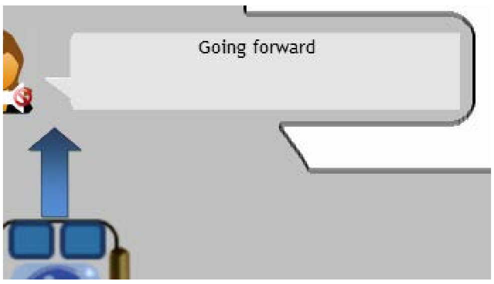
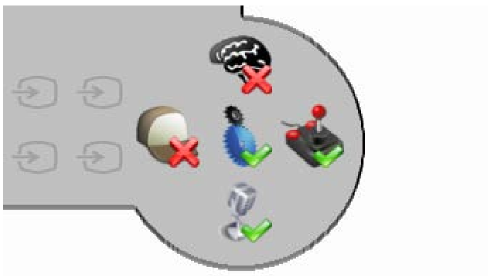


Figure 3.5: *IntellWheels*' Multimodal Interface.

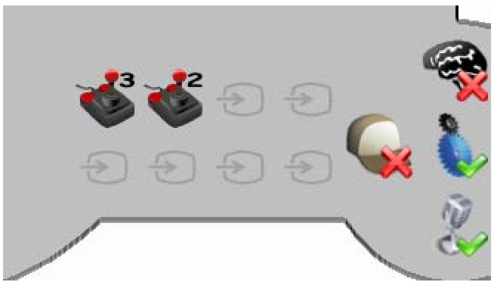


(a) Current Action



(b) Input Devices Available

(c) Defined Input Sequences



(d) Current Sequence

Figure 3.6: *IntellWheels*' Multimodal Interface Details.

Besides the graphical output of information, a text-to-speech module is also implemented.

3.6 Control Application

The Control (Figure 3.7) application manages all communications between the sensors and the *IntellWheels* chair, as well as the shared control mode.
Depending on the control interface mode set, it may operate using data from the real world, data from the simulator or a mixture of both of them [BPMR09].
As it allows for the use of a combination of values from the simulated and real world to be transmitted to the real *IntellWheels* chair prototype, an augmented reality is created. This mode, "Mixed", creates an interaction between virtual and real objects facilitating the test of complex situations between the *IntellWheels* chair prototype and other virtual IWs, obstacles or modeled devices.
In the "Simulated" mode, the system works only with virtual information. This is used to generate the same behaviour of a real wheelchair and to test control routines, navigation methods and planning techniques. It can also be used to train the future users of an *IntellWheels* chair.
When on the "Real" mode, all data is captured from the real world and all control output is done on the real *IntellWheels* chair prototype.

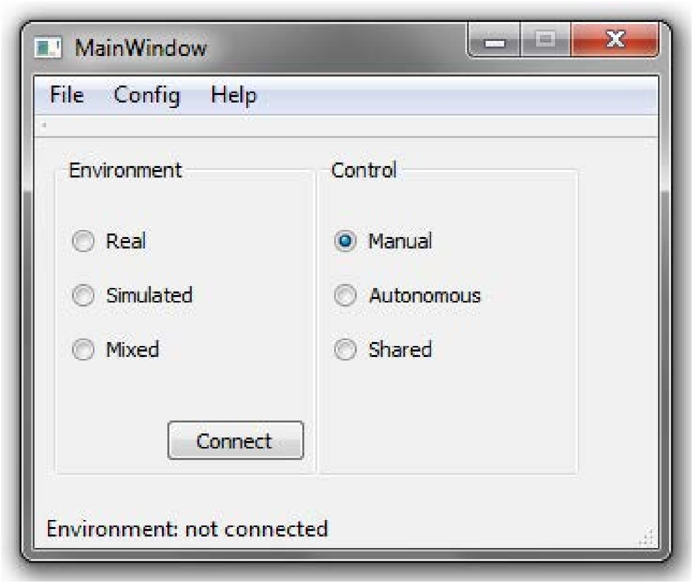


Figure 3.7: *IntellWheels*' Control Module.

The shared control can be activated on this module. It will allow the user to command the *IntellWheels* chair as normal, but will provide assistance to prevent collisions with obstacles [BPRO08].

3.7 Simulator

A virtual environment to preview, test, simulate and analyse the behaviour of IWs is also part of the *IntellWheels* platform (Figure 3.8). Currently, an adapted version of USARSim[3] [CLW+07] is used. This adapted version makes use of Unreal Engine 2 and the Karma physics engine, which are integrated in the Unreal Tournament 2004 game [unr].
USARSim has been validated for simulation of robots with realistically modelled dimensions and mass [OKS+08, TBMQ08]. It is also currently used at the ICRA[4] VMAC[5] Robot Challenge [oRA] and the RoboCup Rescue Virtual Robots competition [rob].
USARSim has a distributed architecture, so the agents that populate the simulation can be external applications. Because of this, it is possible to involve in a single simulation a vast number of intelligent agents, allowing the test of algorithms in a dynamic, complex environment, as required. In the real environment, every modification on the hardware or in the algorithms implies a high increase of monetary costs and development time, as such, using a simulator to test changes is of great importance.
Also, concerning the user safety, using a simulator helps to prevent dangerous situations during testing and training phases. It also enables the user to accommodate itself to the *IntellWheels* multimodal interface, the shared control and the several input devices available for controlling the IW, prior to using the real system. Together with a data acquisition system, using a simulator could also serve for skill assessment.

(a) Perspective view

(b) First-person view

Figure 3.8: *IntellWheels*' Simulator.

3.8 Comparison

As the *IntellWheels* project aims at a flexible multimodal platform to control any commercial powered wheelchair, the first difference that stands out is the fact that most of the IW projects discussed in the previous chapter, *Intelligent Wheelchairs*, have too specific architectures in order

[3]Unified System for Automation and Robot Simulation
[4]IEEE International Conference on Robotics and Automation
[5]Virtual Manufacturing Automation Challenge

to be used in other wheelchairs other than the one they were developed for.
Other aspect is that they are normally intended for a very specific type of medical affliction. This is not the case with the *IntellWheels*, as it allows the use of several input devices and also offers a flexible multimodal interface.
Regarding implementation of new modules or support for new input devices, as the *IntellWheels* is a multi-agent platform, it allows easier integration of devices for augmenting interaction with the user, in case it's necessary.

3.9 Summary

In this chapter, the *IntellWheels* platform concept was described, together with a review on its current state of development.
A description of its input devices and sensors, software package and simulator was also presented.

Chapter 4

Data Acquisition System

One of the objectives of the *IntellWheels* platform is the customization of the intelligent wheelchair (IW) to the user, regarding her/his necessities and impairments.
In order to achieve this degree of personalization of the *IntellWheels* chair, a real-time data collection system needs to be implemented in the platform. With the acquisition system in place, it is possible to conduct tests and gather data with the purpose of extracting the necessary information to adapt the *IntellWheels* chair to the user.

A data collection system for the *IntellWheels* platform will be presented in the following chapter. The user tests that were carried out, and that will later be used to assist in adapting the IW to the specific user, are also presented.

4.1 Implementation

Considering the concept of flexibility and multimodality of the *IntellWheels*, the required data to collect from the platform may come from many sources: input devices, sensors (both real and virtual) and the Simulator.
In Figure 4.1, the software architecture is exposed. As it can be seen on the next page, the Control application can connect to both the real IW and the Simulator, gathering and processing data from their defined sensors.
The control works as the server side regarding data communication with the Multimodal Interface, which in turn, acts as the server side regarding the input devices connections, as the Multimodal Interface manages all the input devices.
The data acquisition system is distributed among the Control application, the Multimodal Interface and the input devices bridge applications. As such, one file with captured data is created by each application.

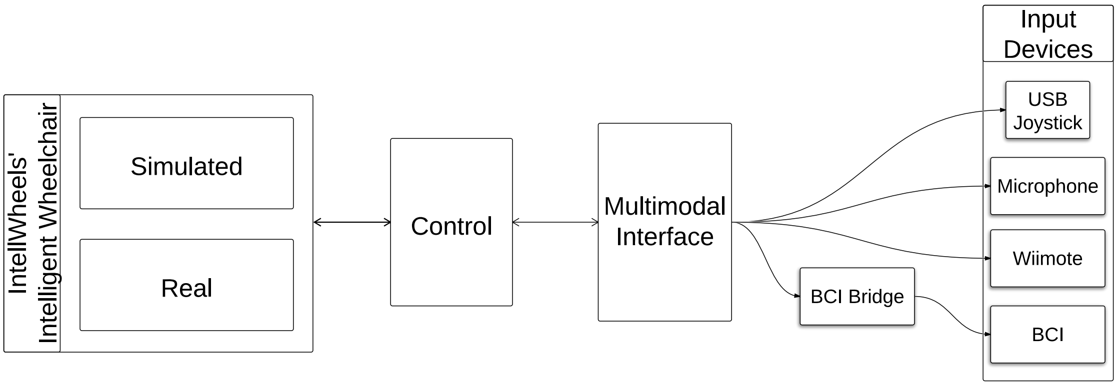


Figure 4.1: *IntellWheels*' Software Architecture.

Data Synchronisation

In order to synchronise the files, a *timestamp* is appended to each acquired information. As the time information required for the synchronisation is regarding the *IntellWheels* platform uptime and the applications are not executed at the same time, a flow to set the same uptime for all applications was created (Figure 4.2): the Control application, the first one to be executed, sends its uptime to the Multimodal Interface, which in turn sends this value to all input devices' bridge applications. Each application has a *timedelta* variable which stores the difference between its own uptime and the Control's uptime.
The *timedelta* variable is updated several times throughout the acquisition process, as after a certain amount of inputs received from the Multimodal Interface by the Control application, it again sends a message with its current uptime, that once more is distributed to all applications by the flow previously explained.

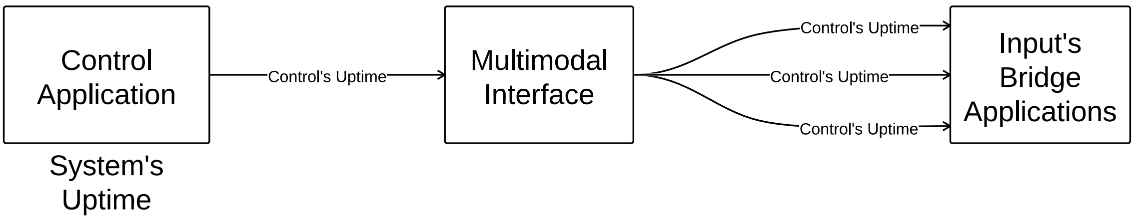


Figure 4.2: *IntellWheels*' System's Uptime Flow.

Data File Format

To save the data, an extensible markup language (XML) type file format was chosen to be used because of its flexibility.
On the start of the file, a *header* is created, containing the description of each type of data the application gathers. An example of an input data collected file can be seen in Listing 4.1.

```
<MMI_LOG>
  <INPUTS>
    <item>
      <id>wiimote</id>
      <label>VelX;VelY;VelZ;Button N;Battery Level %;Error</label>
    </item>
  </INPUTS>
  <DATA>
    <item>
      <timestamp>55.2430</timestamp>
      <input>wiimote</input>
      <values>-40;45;-10;;92;</values>
    </item>
    <item>
      <timestamp>55.2611</timestamp>
      <input>wiimote</input>
      <values>-35;40;-5;;92;</values>
    </item>
  </DATA>
</MMI_LOG>
```

Listing 4.1: Collected Input Data Example File

As one of the main objectives of the *IntellWheels* platform is to secure the safety of the user during navigation, additional data will also be collected in order to later be used to aid in the creation of an Environment Profiler module.

4.2 Capturing Data From Input Devices

One of the most important aspect of the *IntellWheels* project is concerned with how the user interacts with it.
Gathering information from the several devices is mandatory, and since the *IntellWheels* chair's interface is a multimodal one and several input devices can be used in conjunction to command the chair, the interpreted orders by the *IntellWheels* are also of extreme importance for later analysis. As the Multimodal Interface module controls all inputs from the user and also interprets them, the necessary data can be collected from it.

4.2.1 USB Joystick

The most basic input device that the *IntellWheels* chair offers is a generic joystick, which allows to control the IW by use of its buttons ("autonomous" mode) or by using the analog stick ("manual" mode).
While using this device in "autonomous" mode, the available data that can be collected are the activated buttons and when they're activated. while on "manual" mode, the coordinates of both

analog sticks according to the system uptime, is the information that can be acquired. An extract of an input data collected file of the USB joystick can be seen in Listing 4.2.

```
<MMI_LOG>
  <INPUTS>
    <item>
      <id>joystick</id>
      <label>Analogic 1;Analogic 2;Button N;Error</label>
    </item>
  </INPUTS>
  <DATA>
    <item>
      <timestamp>128.4882</timestamp>
      <input>joystick</input>
      <values>;;2;</values>     <<< The user pressed the button number 2 >>>
    </item>
    <item>
      <timestamp>166.8094</timestamp>
      <input>joystick</input>
      <values>(17,0);(0,0);;</values>     <<< The left analog stick is at x=17,y=0 >>>
    </item>
  </DATA>
</MMI_LOG>
```

Listing 4.2: USB Joystick Collected Input Data Example File

4.2.2 Microphone

The voice recognition module allows to register the voice command given and its percentage of recognition. Additionally, it is also possible to collect the noise level and interferences that affect the voice recognition module. These measures are also identified with the current system uptime at the time they were activated, as seen on Listing 4.3.

```
<MMI_LOG>
  <INPUTS>
    <item>
      <id>microphone</id>
      <label>Command;Percentage of Recognition;Noise Level;Interference</label>
    </item>
  </INPUTS>
  <DATA>
    <item>
      <timestamp>148.5762</timestamp>
      <input>microphone</input>
```

```
      <values>;;24;</values>     <<< The device detected a noise level of 24/100 >>>
    </item>
    <item>
      <timestamp>149.1349</timestamp>
      <input>microphone</input>
      <values>stop;0.93708;43;</values>     <<< The command "Stop" was recognised with 93.708% confidence >>>
    </item>
  </DATA>
</MMI_LOG>
```

Listing 4.3: Microphone Collected Input Data Example File

4.2.3 Wiimote

Regarding the head movement input device, the available data to capture is the three axes accelerometers and buttons pressed. Additionally, the battery level and an error identifying variable is also being registered. The current system uptime when they were activated is being registered. An example file can be seen on Listing 4.4.

```
<MMI_LOG>
  <INPUTS>
    <item>
      <id>wiimote</id>
      <label>VelX;VelY;VelZ;Button N;Battery Level %;Error</label>
    </item>
  </INPUTS>
  <DATA>
    <item>
      <timestamp>125.588</timestamp>
      <input>wiimote</input>
      <values>-20;10;5;;78;</values>     <<< The value of each accelerometer and battery level=78% >>>
    </item>
    <item>
      <timestamp>162.4345</timestamp>
      <input>wiimote</input>
      <values>;;;a;77;</values>     <<< The user pressed the "A" button and battery level=77% >>>
    </item>
  </DATA>
</MMI_LOG>
```

Listing 4.4: Wiimote Collected Input Data Example File

4.2.4 Brain-Computer Interface

Regarding the use of facial expressions to control the *IntellWheels* chair from the Multimodal Interface perspective, only the expression identified is acquired, along with the system uptime (as can be seen on Listing 4.5), but in order to connect the Brain-Computer Interface (BCI) to the Multimodal Interface application, an additional application is necessary.
On this bridge application it is possible to collect the percentage of recognition of the facial expression identified, among other information: contact quality about each of its fourteen sensor pads as well as raw EEG data for each channel, the wireless signal strength between the device and its USB receiver and the charge level of its battery. On Table 4.1 is an extract from an EEG capture file and on Table 4.2 a contact quality file for the same capturing session.

```
<MMI_LOG>
  <INPUTS>
    <item>
      <id>bci</id>
      <label>Expression</label>
    </item>
  </INPUTS>
  <DATA>
    <item>
      <timestamp>59.0307</timestamp>
      <input>bci</input>
      <values>left_blink</values>     <<< The user blinked with her/his left eye >
          >>
    </item>
  </DATA>
</MMI_LOG>
```

Listing 4.5: Brain-Computer Interface Collected Input Data Example File

On Figure 4.3, the position of the BCI's sensors and a graphic representation of the sensors quality is shown, spanning all possible contact quality values that can be read. The contact quality ranges from green (best contact possible), yellow (fair contact), orange (poor quality), red (very bad contact) to black (no signal received).

Brain-Computer Interface Implementation

Besides implementing the Data Acquisition System to the platform, a bridge application between the Multimodal Interface and a BCI was also developed. This bridge application connects to the Multimodal Interface as a client and sends the recognised facial expressions to be used as inputs in the Multimodal Interface. This allows to associate a high-level order to an expression or sequence of expressions on the Multimodal Interface. The bridge application accepts the facial expression recognised as valid, if during a defined period of time the expression is detected a certain amount of times with a recognition percentage that exceeds a defined threshold.

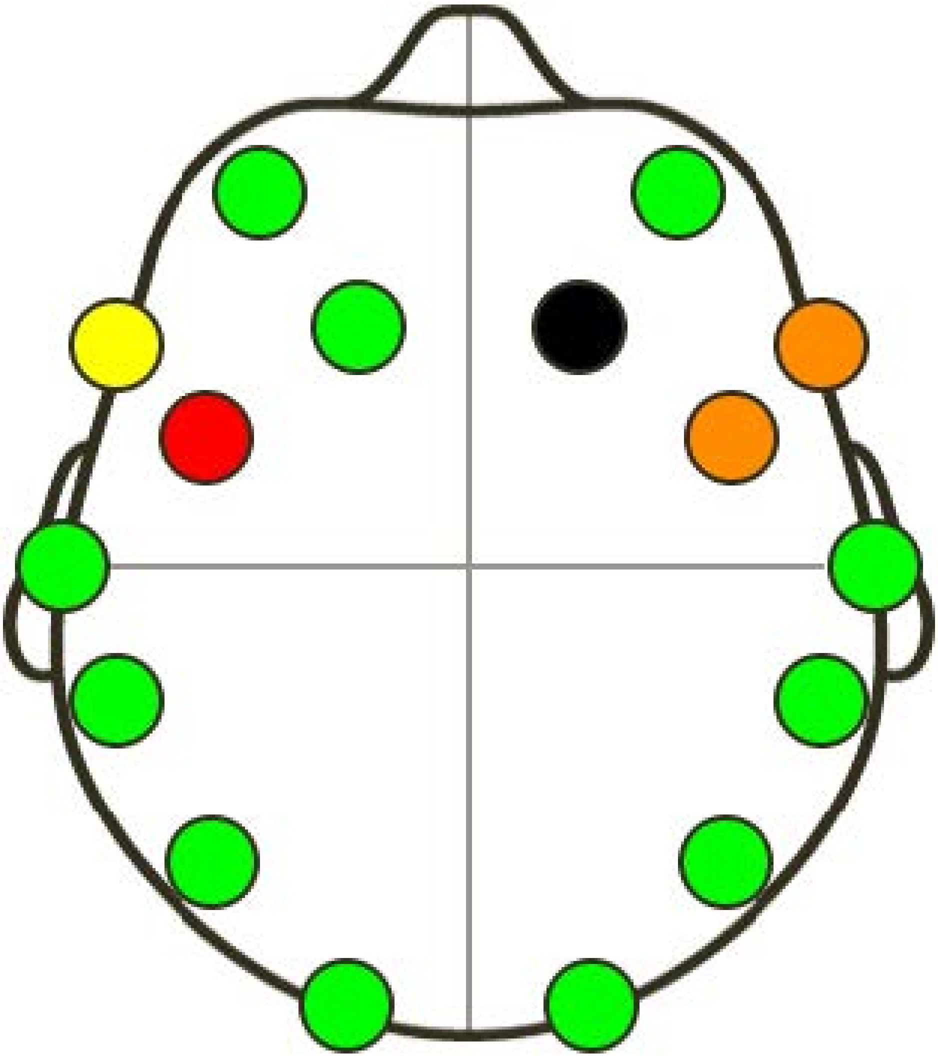


Figure 4.3: EPOC's Sensors.

Currently, only the facial expressions are used to control the *IntellWheels* chair, but the EPOC, a BCI from EMOTIV [EMO] used in the *IntellWheels*, also detects user specific cognitive data and emotional states in real-time.

Table 4.1: Extract from an EEG Capture File.

Timestamp	SampleN	AF3	F7	F3	FC5	T7	P7	O1	O2	P8	T8	FC6	F4	F8	AF4
125.591	0	3816.41	4560	4353.85	4195.9	4716.41	3944.1	3926.15	4226.15	4137.44	4652.82	4228.72	4679.49	4573.33	4045.13
125.591	1	3819.49	4561.03	4359.49	4198.46	4701.03	3934.36	3938.97	4235.9	4131.79	4653.33	4234.36	4678.46	4568.72	4047.69
125.591	2	3813.85	4549.23	4354.87	4189.23	4694.36	3932.82	3940.51	4240.51	4142.56	4656.41	4235.9	4678.97	4558.46	4047.18
125.591	3	3798.46	4530.77	4341.03	4174.87	4700	3945.64	3936.92	4236.41	4145.13	4650.26	4218.46	4676.41	4549.23	4033.85
125.691	0	3794.87	4531.79	4335.38	4176.41	4698.46	3944.1	3935.38	4235.9	4142.56	4642.56	4207.69	4676.41	4551.79	4027.69
125.691	1	3802.05	4537.95	4336.92	4183.08	4696.41	3936.41	3936.92	4240	4153.85	4644.62	4212.31	4676.41	4554.87	4033.33
125.691	2	3806.15	4541.03	4342.56	4184.62	4699.49	3935.38	3935.9	4233.85	4146.67	4652.31	4218.97	4678.46	4559.49	4040.51
125.691	3	3813.85	4550.77	4349.74	4187.69	4697.44	3934.36	3928.21	4220.51	4126.67	4651.28	4226.15	4682.05	4565.64	4047.18
125.691	4	3817.95	4550.77	4347.18	4186.67	4698.46	3933.33	3909.23	4204.62	4126.15	4641.54	4224.1	4676.41	4557.95	4047.18
125.691	5	3812.82	4541.54	4340	4180	4699.49	3927.69	3897.95	4198.46	4129.23	4642.05	4217.95	4675.38	4556.41	4047.69
125.691	6	3816.41	4546.67	4344.62	4181.03	4693.33	3920.51	3911.79	4214.87	4126.15	4650.26	4225.64	4677.44	4574.87	4057.95
125.691	7	3828.21	4554.87	4353.85	4187.69	4688.72	3920	3924.1	4227.18	4133.33	4654.87	4237.44	4676.92	4586.67	4065.13

Table 4.2: Extract from a Contact Quality File.

Timestamp	Wireless Strength	Charge Level	AF3	F7	F3	FC5	T7	P7	O1	O2	P8	T8	FC6	F4	F8	AF4
125.811	2	1	4	4	4	4	4	4	4	4	4	4	4	0	4	4
125.941	2	1	4	4	4	4	4	4	4	4	4	4	4	0	4	4
126.071	2	1	3	4	4	4	4	4	4	4	3	4	4	0	4	4
126.091	2	1	4	3	4	4	4	4	4	4	4	4	4	0	4	4
126.571	2	1	4	3	4	4	4	4	4	4	4	4	4	0	4	4
126.591	2	1	4	4	3	4	4	4	4	4	4	3	4	0	4	4
127.071	2	1	4	4	4	4	4	4	4	4	4	4	4	0	4	4
127.091	2	1	4	4	4	4	4	4	4	3	4	4	4	0	4	4
127.571	2	1	4	4	4	4	4	4	4	4	4	4	4	0	4	4
127.591	2	1	4	4	4	4	4	4	4	4	4	4	4	0	4	4
127.941	2	1	4	4	4	3	4	4	4	4	4	4	4	0	4	4

4.3 Capturing Data From Sensors

The Control application is the bridge between the sensors and the *IntellWheels* chair, in all of its available operating modes ("Real", "Simulated" and "Mixed"), so all the sensor data can be collected from it.

Each cycle of the Control application was set to take 100 milliseconds, so the capturing resolution is the same.

An example of a sensors data collected file can be seen in Listing 4.6.

```
<IWC_LOG>
  <SENSOR id="groundTruth" label="X;Y;Z;Roll;Pitch;Yaw" />
  <SENSOR id="sonar" label="Name;Range" />
  <SENSOR id="encoders" label="Left;Right" />
  <DATA timestamp="81.893" sensor="groundTruth" values="-4.49;4.2;1.39;0;0.03;1.93" />
  <DATA timestamp="81.893" sensor="encoders" values="229;-16" />
  <DATA timestamp="81.893" sensor="sonar" values="F1;4.5089" />
  <DATA timestamp="82.045" sensor="groundTruth" values="-4.39;3.97;1.39;0;0.03;1.88" />
  <DATA timestamp="82.046" sensor="encoders" values="294;37" />
  <DATA timestamp="82.046" sensor="sonar" values="F1;5" />
  <DATA timestamp="82.146" sensor="groundTruth" values="-4.33;3.8;1.39;0;0.03;1.84" />
  <DATA timestamp="82.146" sensor="encoders" values="342;77" />
  <DATA timestamp="82.146" sensor="sonar" values="F1;4.9956" />
  <DATA timestamp="82.246" sensor="groundTruth" values="-4.28;3.63;1.39;0;0.03;1.79" />
  <DATA timestamp="82.247" sensor="encoders" values="30;118" />
  <DATA timestamp="82.247" sensor="sonar" values="F1;5" />
  <DATA timestamp="82.347" sensor="groundTruth" values="-4.22;3.44;1.39;6.28;0.03;1.74" />
  <DATA timestamp="82.347" sensor="encoders" values="83;160" />
  <DATA timestamp="82.347" sensor="sonar" values="F1;5" />
  <DATA timestamp="82.448" sensor="groundTruth" values="-4.18;3.23;1.39;6.28;0.03;1.68" />
  <DATA timestamp="82.448" sensor="encoders" values="139;205" />
  <DATA timestamp="82.448" sensor="sonar" values="F1;4.9997" />
</IWC_LOG>
```

Listing 4.6: Collected Sensor Data Example File

4.4 Capturing Data From The Simulator

To extract data from the simulator, one can configure the functions to work as a sensor, so collecting information from the simulator is similar to acquiring data from the sensors, as is also the

Control module that connects the *IntellWheels* chair to the simulator, in its "Simulated" mode.
The Simulator is set to rerun the sensors cycle at the maximum interval of 200 milliseconds, but as the Control application has its cycles set to last 100 milliseconds, the data capturing resolution is 100 milliseconds.
The same file example from the previous section, *Capturing Data From Sensors*, can be used here (Listing 4.6).

Improving the First-Person View on the Simulator

The Simulator already provided a first-person view, but it was a static one. By use of the second analog stick on the USB joystick, it is now possible to control the view perspective, as shown in Figure 4.4.

(a) Left View

(b) Right View

Figure 4.4: *IntellWheels*' Simulator Improved First-Person View.

This kind of facility provides the user a higher amplitude of movement and vision of the surroundings.

4.5 User Profiler

Tracing a user diagnostic can be very useful to adjust certain settings, allowing for an optimized configuration and improved interaction between the user and the multimodal interface.
The Multimodal Interface has incorporated a space for user profiling [FVRL12]. This module is divided in two components (Figure 4.5). One dedicated to the BCI inputs such as facial expressions and thoughts and the other for the rest of the inputs like the USB joystick analog stick and buttons, the voice commands and the Wiimote.
In order to later adjust the *IntellWheels* chair to the specific user, a batch of tests was performed to measure the user proficiency regarding the input devices (a description of the tests can be found in subsection 4.5.1). A "hands-on" approach was also carried out in the simulator (subsection 4.5.2) for each available input device.
Data acquisition was performed during the execution of these tests. The outcome of the tests can be seen on Chapter 5.

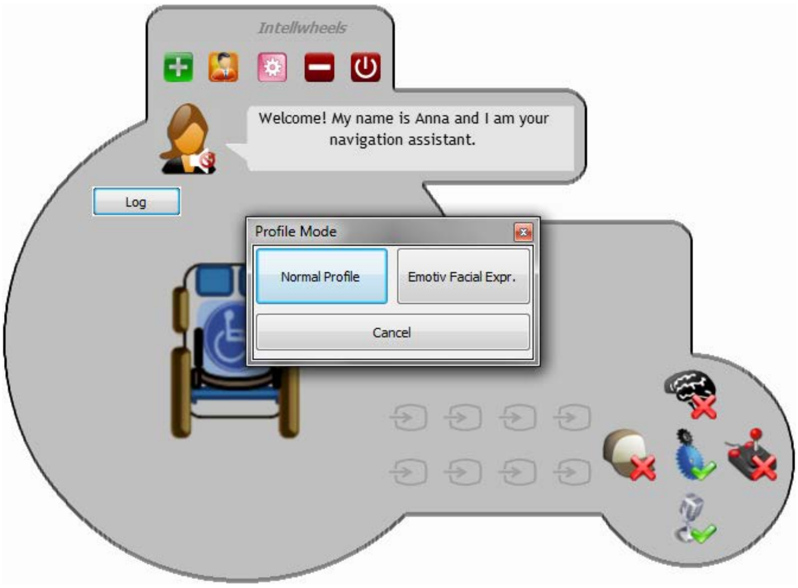


Figure 4.5: *IntellWheels*' User Profiler.

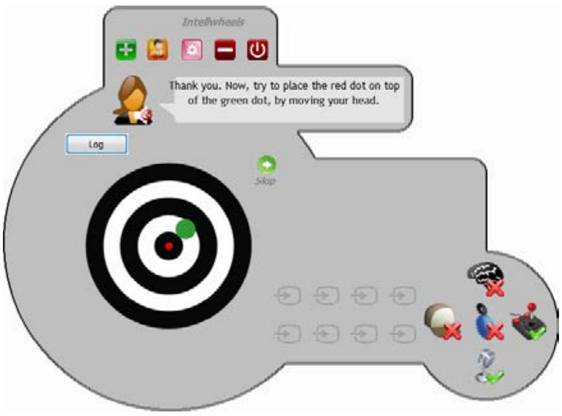
4.5.1 Input Devices

For each input, a test was devised with the objective of classifying the users ability to perform certain actions with the input device in an ascending difficulty.
For the USB joystick there were two tests, so that the prowess regarding the two input methods the USB joystick provides, "autonomous" and "manual", could be measured. For the "autonomous" method, the user was asked to perform a series of sequences with an increased number of buttons to press (Figure 4.6). As for the "manual" mode, the user was asked to fully move a small circle into the middle of a larger one that would diminish size and location along the test. This same test was performed with the Wiimote, as seen on Figure 4.7, as the input method is the same, but the locations of the bigger circles were different from the USB joystick ones.
Regarding the Microphone, the test consisted of asking the user to repeat several words that could later be associated to high-level commands (Figure 4.8).
For the BCI, the user was asked to mirror expressions enacted in front of him (examples in Figure 4.9). During this, the external application which serves as bridge between the BCI input device and the Multimodal Interface was measuring the percentage of recognition of said expressions (an example of such a file is present in Table 4.3) as well as the contact quality of all fourteen sensor pads and their EEG raw data to file.

(a) USB Joystick Button's Proficiency Test 1 - BTN1, BTN2

(b) USB Joystick Button's Proficiency Test 3- BTN6, BTN1, BTN7, BTN4 and BTN2

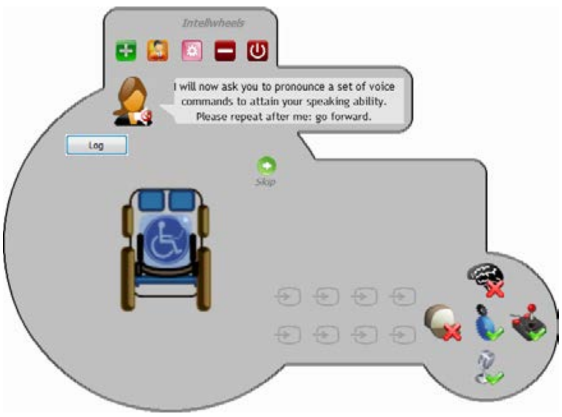
Figure 4.6: USB Joystick Button's Proficiency Test.



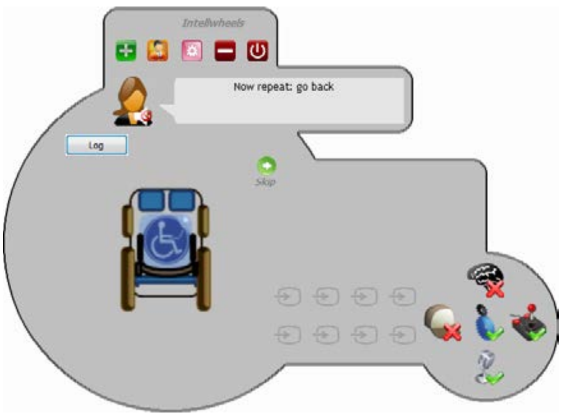
(a) Wiimote's Proficiency Test 1

(b) Wiimote's Proficiency Test 3

Figure 4.7: Wiimote's Proficiency Test.



(a) Microphone's Proficiency Test 1 - "Go Forward"



(b) Microphone's Proficiency Test 5 - "Go Back"

Figure 4.8: Microphone's Proficiency Test.

(a) BCI's Expression Mirror - Right Blink

(b) BCI's Expression Mirror - Right Smirk

(c) BCI's Expression Mirror - Clench Teeth

(d) BCI's Expression Mirror - Furrow Brows

Figure 4.9: BCI's Expression Mirror.

Table 4.3: Percentage of Recognition of Mirrored Expressions.

Timestamp	**CURRENT**	**Blink Right**	**Blink Left**	**Blink**	**Raise Eyebrows**	**Furrow Brows**	**Smile**	**Clench**	**Smirk Left**	**Smirk Right**
400.83	Smirk Left	FALSE	FALSE	FALSE	0	0	0	0	28.764	0
400.86	Smirk Left	FALSE	FALSE	FALSE	0	0	0	0	28.764	0
400.89	Smirk Left	TRUE	FALSE	FALSE	0	0	0	0	28.764	0
400.95	Smirk Left	TRUE	FALSE	FALSE	0	0	0	0	21.066	0
401.08	Smirk Left	TRUE	FALSE	FALSE	0	0	0	0	18.918	0
401.2	Smirk Left	TRUE	FALSE	FALSE	0	0	0	0	16.505	0
401.23	Smirk Left	FALSE	FALSE	FALSE	0	0	0	0	16.505	0
401.33	Smirk Left	FALSE	FALSE	FALSE	0	11.804	0	0	0	0
401.36	Smirk Left	FALSE	FALSE	FALSE	0	11.804	0	0	0	0
401.46	Smirk Left	FALSE	FALSE	FALSE	0	15.550	0	0	0	0
401.58	Smirk Left	FALSE	FALSE	FALSE	0	0	0	0	0	0
401.84	Smirk Left	FALSE	FALSE	FALSE	0	0	0	0	39.302	0
401.86	Smirk Left	FALSE	FALSE	FALSE	0	0	0	0	39.302	0
401.95	Smirk Left	FALSE	FALSE	FALSE	0	0	0	0	0	0
402.2	Smirk Left	FALSE	FALSE	FALSE	0	0	0	0	20.494	0
402.34	Smirk Left	FALSE	FALSE	FALSE	0	0	0	0	24.659	0
402.36	Smirk Left	FALSE	FALSE	FALSE	0	0	0	0	24.659	0
402.45	Smirk Left	FALSE	FALSE	FALSE	0	0	0	0	22.711	0
402.58	Smirk Left	FALSE	FALSE	FALSE	0	0	0	0	13.591	0
402.71	Smirk Left	FALSE	FALSE	FALSE	0	0	0	0	11.929	0
402.84	Smirk Left	FALSE	FALSE	FALSE	0	0	0	0	11.721	0
402.86	Smirk Left	FALSE	FALSE	FALSE	0	0	0	0	11.721	0
402.96	Smirk Left	FALSE	FALSE	FALSE	0	0	0	0	10.284	0

4.5.2 Simulator

The second part of the test consisted of allowing the user to control the *IntellWheels* chair in a simulated environment, namely a circuit in a recreation of the Association of Cerebral Palsy of Porto, depicted in Figure 4.10, marked in red.
The scenarios created were different and with a gradual degree of difficulty. Several variables were introduced to provide higher immersiveness and realism, such as: different lighting conditions; obstacles that could be in a building like a hospital or public institution, ramps and narrow corridors.
The map was divided into three parts. The first part is characterized by having simple and large corridors without any kind of obstacles. The second part has narrow corridors, ramps and obstacles. The last part involved a circuit entering in three rooms with different kinds of illumination and noise.

The user was asked to perform the circuit six times, one for each input device the *IntellWheels* chair offers and a last one without restriction about the input device to use, allowing the user to experiment with the multimodal interface.

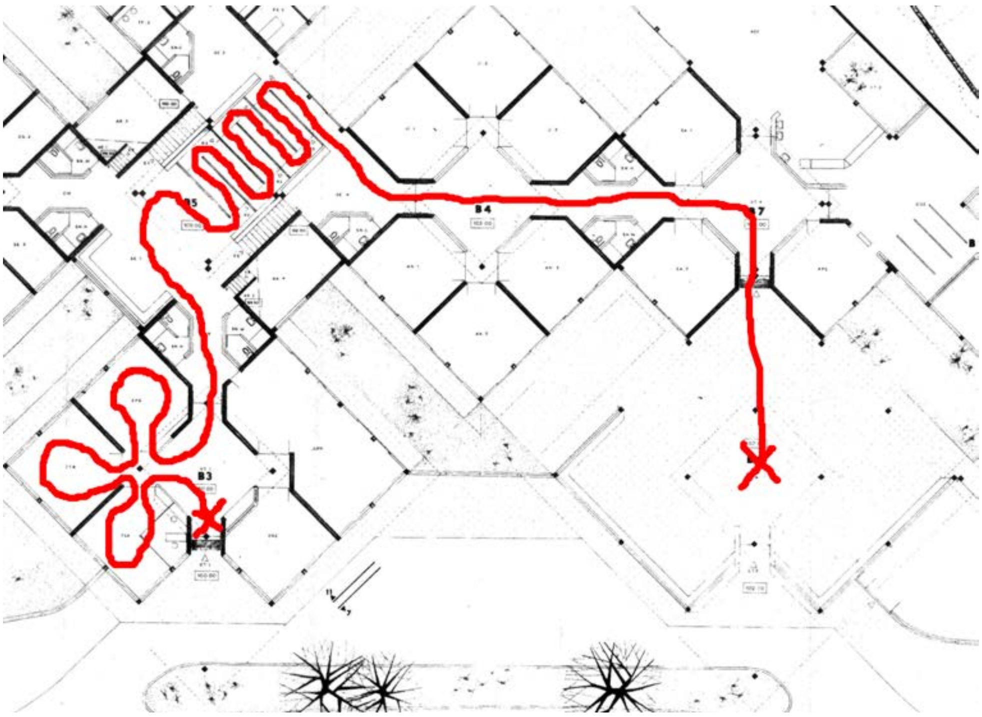


Figure 4.10: Association of Cerebral Palsy of Porto circuit marked in red.

During this driving session in the Simulator, values regarding the coordinates of the virtual IW were captured, as well as all other sensor data available.

4.6 Questionnaire

After each session of testing the users were invited to fill out a questionnaire (available in appendix A.2).
The questionnaire was divided in five parts:

- **Demographical Data** - Several questions about age, gender, height, weight, motor or cognitive constrains, the level of education and experience with videogames, gamepads and joysticks;

- **System Usability Scale (SUS) [Bro96] and Safety** - The SUS is a scale of usability where a final score is obtained from questions made in a Likert scale. The SUS scale score varies from 0 to 100 and if the value is near 100 it means that the individual considered the instrument extremely effective, efficient and satisfactory. Some questions regarding the sense of safety were also asked;

- **Utilization of the Input Devices** - Questions about the level of satisfaction with the different input devices of the *IntellWheels* chair and several open questions about the user's opinion where asked;

- **Multimodal Interface** - Questions regarding the information given by the Multimodal Interface where asked;

- **Frustration and Fatigue** - For each input device of the *IntellWheels* chair, questions were asked about the feeling of frustration, fatigue, boredom, concentration of the users and difficulty using the device.

These questions allow to have a more precise feedback from the users, besides the performance of driving the IW.

4.7 Summary

A description of the work done during this dissertation was described in this chapter.
The implementation of the data acquisition system is explained and the synchronisation mechanism exposed. Examples are given regarding the type of data collecting files originating from the acquisition system. Also, a presentation of the tests carried out was offered.

Chapter 5

Experiments and Results

In the following chapter, the results obtained from the tests described in section 4.5 are displayed and discussed.
Two type of tests were performed, an input device proficiency assessment and a "hands-on" *IntellWheels* navigation session on the simulator for each input device and an extra one without restriction about the input device to use, allowing the user to experiment with the Multimodal Interface.
A questionnaire was filled after every session by the users, this matter is addressed in section 5.2.3. The consent form and questionnaire used are available in Appendix A. During the trials, failures or abnormalities that were encountered while using the data acquisition system were fixed. Fine-tuning was also performed on the *IntellWheels* platform, in order to increase the sense of realism of the Simulator, according to the feedback received on the questionnaire. It is important to refer that these experiments and results are a way of proving that the data acquisition system functions correctly and it is very useful to track the required transformations and adaptations of the *IntellWheels* platform.

5.1 Data Acquisition System

The experiments were divided in two cases. The first was to test the data capturing system for the user profiler. Figure 5.1 shows an exemplification of all the data that can be acquired.

In Figure 5.2 can be observed the possible data that can be acquired from one example test performed in the Simulator.

5.2 Users' Trials

The results presented in this section were gathered from three long trials per user, with a total of 2 users, a male and a female, both of 24 years of age.

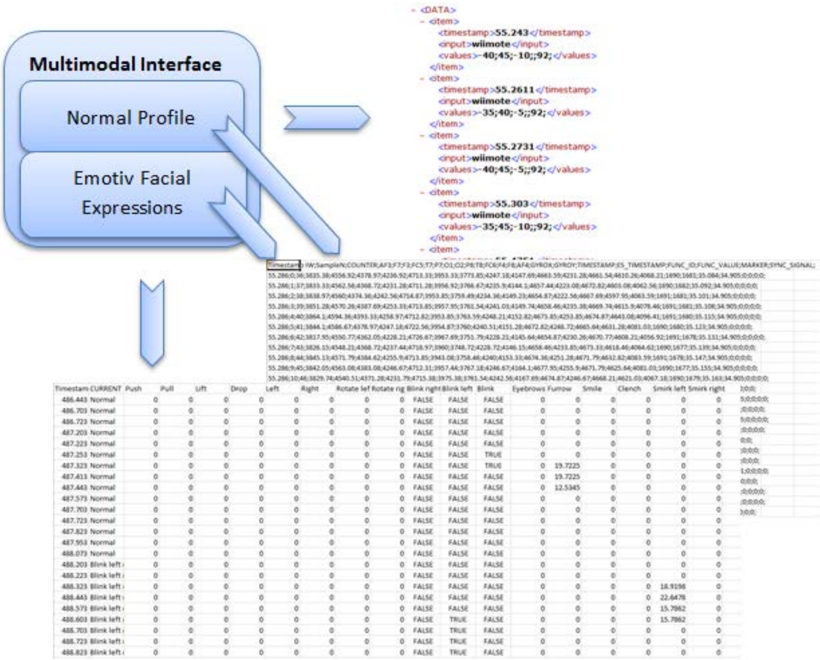


Figure 5.1: Data that can be Acquired During the User Profiling.

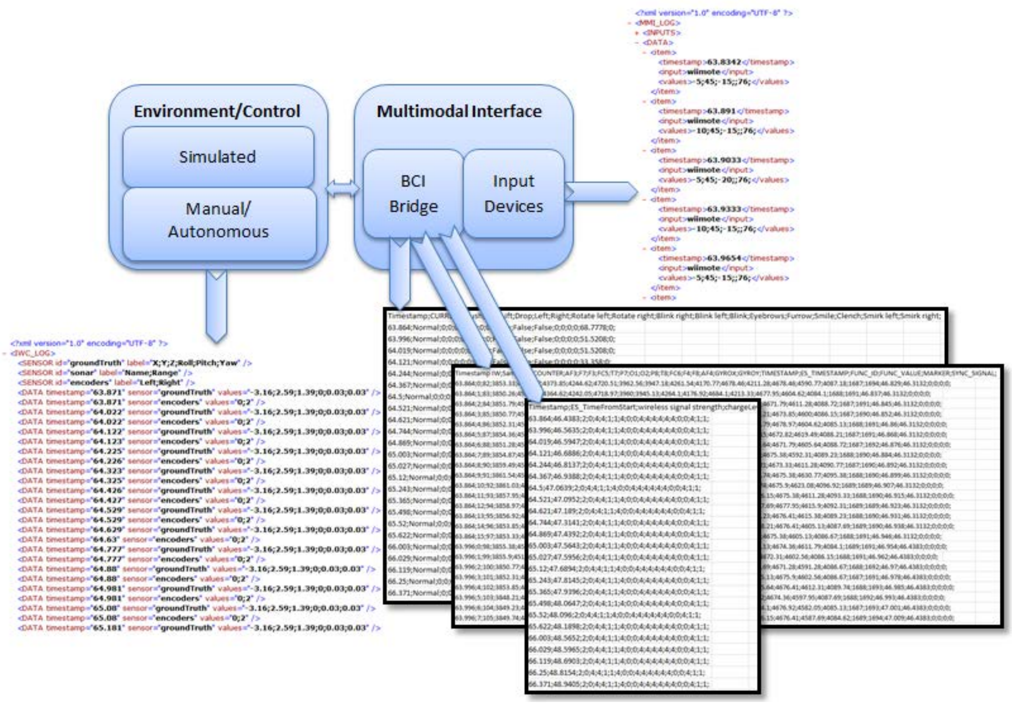


Figure 5.2: Data that can be Acquired During a Trial on the Simulator.

To interpret the results with a critical point of view, the characterization of the users' experience with videogames, gamepads and joysticks was done. The responses of the users can be observed in Table 5.1.

Table 5.1: Users' Characterization.

User	Frequency of Play per Week	Frequency of Use of Commands (Wiimote, gamepad)	Frequency of Use of Joystick
1	Always	Always	Always
2	Always	Rarely	Rarely

The two users have different experience with videogames, gamepads and joysticks. The first user always plays weekly and has experience in using the kind of commands that are used to command the *IntellWheels* chair. The second user has less experience with the devices although the frequency of weekly play is high.

As stated above, two type of tests were done. On the following subsections are displayed some of the results acquired from the first batch of tests.

5.2.1 Input Devices

The first test consisted of performing different tasks for each input modality. It served to measure the user's ability for each device available on the *IntellWheels* chair.

USB Joystick

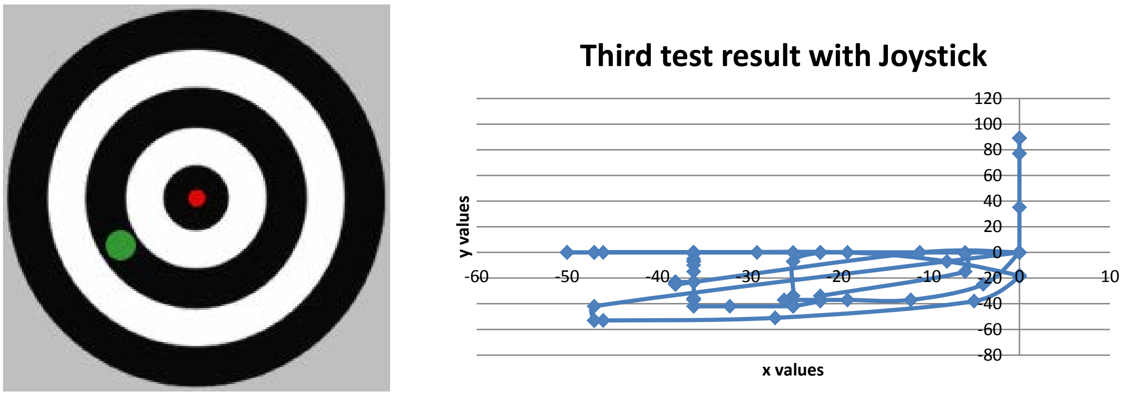
The users were first asked to mimic a sequence of buttons, with increasing difficulty for each round. The number of buttons they were asked to press also increased on each round.
On Table 5.2 the results for the first session are shown (time is displayed in seconds).

Table 5.2: First USB Joystick Session Results - Button Pressing.

	Seq. 1		**Seq. 2**		**Seq. 3**		**Seq. 4**	
User	Time	N Errors	Time	N Errors	Time	N Errors	Time	N Errors
1	3,635	0	4,430	0	7,426	0	11,232	0
2	15,834	2	3,432	0	4,742	0	8,861	0

The time and number of errors can be saved for later analysis.

Next, the users were told to move a small circle into the middle of a larger one, that would diminish its size and change location on each round, using the analog stick.
Since the coordinates of the joystick are saved, it is possible to create a graphical representation. This allows to have information about the difficulty of the user in performing this kind of task. In Figure 5.3 is shown such a graphic representation of one of the users' movements with the analog stick during the first session. On Table 5.3 the time of execution (in seconds) is displayed for the first session of the two users.



(a) Requested Position.

(b) Graphic representation of one user movements.

Figure 5.3: First USB Joystick Session Results - Analog Stick.

Table 5.3: First USB Joystick Session Time (seconds) - Analog Stick.

User	Round 1	Round 2	Round 3
1	12,355	3,682	11,357
2	9,797	6,614	10,421

Wiimote

Similarly to the second USB joystick test, the users were told to move a small circle into the middle of a larger one, that would also diminish its size and change location on each round, using head movements.

On Table 5.4 the time of execution (in seconds) is displayed for the first session of the two users.

Table 5.4: First Wiimote Session Time (seconds).

User	Round 1	Round 2	Round 3
1	26,582	17,347	30,015
2	16,973	12,355	48,236

Microphone

The users were asked to say specific combinations of words to measure the percentage of recognition.

On Table 5.5 the results from the first session are shown.

Table 5.5: First Microphone Session Results.

	Words						
User	"Go Forward"	"Go Back"	"Turn Right"	"Turn Left"	"Right Spin"	"Left Spin"	"Stop"
1	82,306	94,945	94,828	94,500	94,242	92,916	95,128
2	93,021	94,456	94,085	93,393	94,808	94,707	94,913

Information about the percentage of recognition is recorded and also if the system was able to recognize what was said, comparing the percentage of recognition to a defined threshold.

Brain-Computer Interface

The trial sessions with the Brain-Computer Interface (BCI) served to acknowledge that the recognition values of the facial expressions mimicked by the user are highly dependent on the correct placement of the neuroheadset and also the moist of the sensors, as the recognition percentage for each specific expression varied throughout the trials.
As can be observed in Figure 5.6, in the next section, by changing the standard commands for facial expressions previously defined, to expressions that the user can reach with a higher degree of confidence can make all the difference.

Regarding the raw values read from the sensors, a graphical representation can be created. Figure 5.4 provides a visual perspective of the EEG captured data of the first user during the input device assessment. In an analogous matter, this data can also be recorded when the user is performing the task of driving the *IntellWheels* chair.

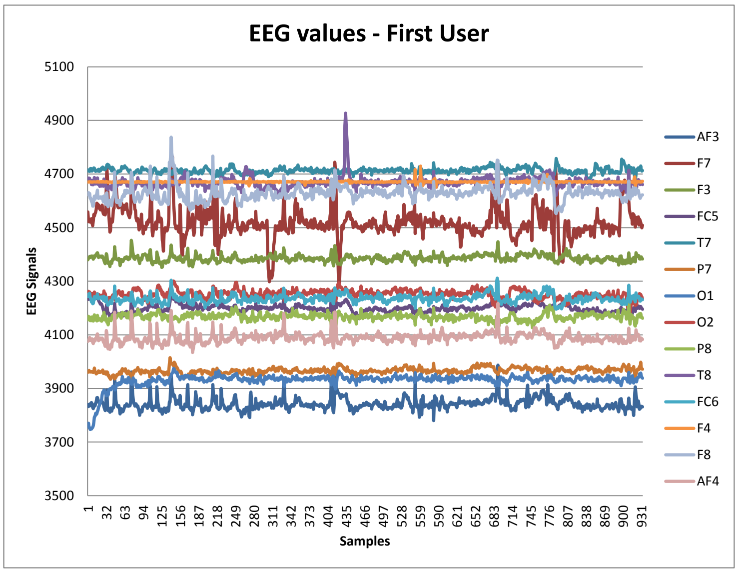
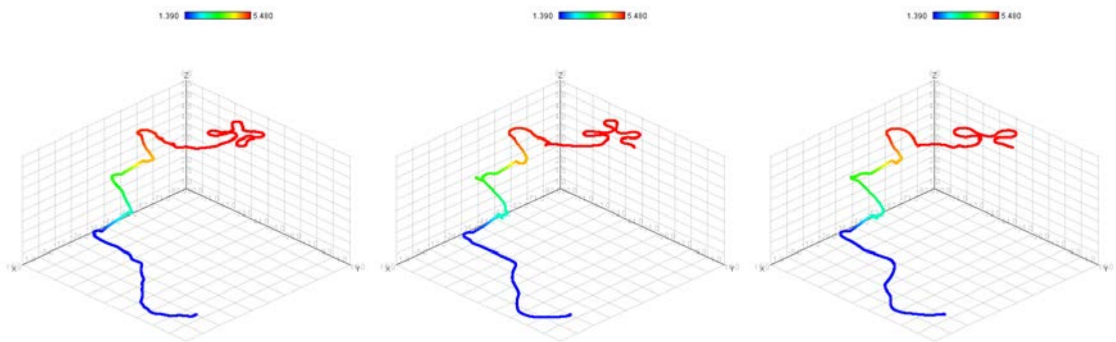


Figure 5.4: Graphic Representation of Captured EEG Data.

5.2.2 Navigation Session on the Simulator

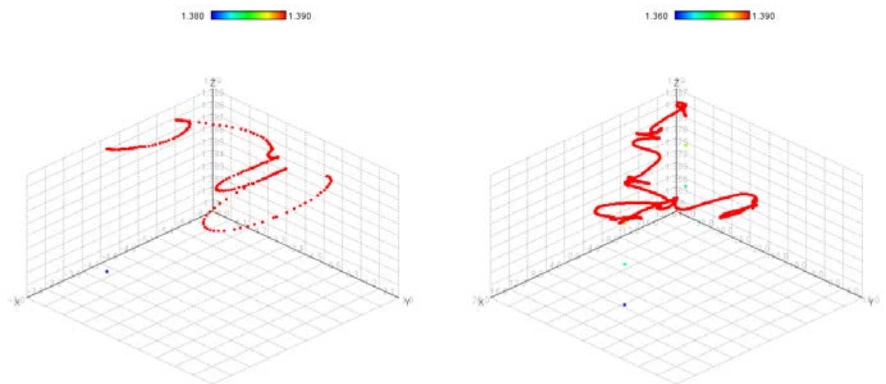
The collected data from the Simulator allows plotting the circuits afterwards the experiment. It is a way of analysing the behaviour of the users using different input devices.

As an example, in Figure 5.5 are represented the three Wiimote navigation sessions by one of the users.
Also, in Figure 5.6 is shown the difference of using the default facial expressions' orders association or defining a user specific association of facial expressions to be used with the BCI. The image on the left was created from data captured using the standard facial expressions association and the image on the right was created using data from a session where the association was redefined according to the user.



(a) Session 1. (b) Session 2. (c) Session 3.

Figure 5.5: Wiimote Navigation Sessions By One of the Users.



(a) Default Facial Expressions' Commands Association. (b) User Specific Facial Expressions' Commands Association.

Figure 5.6: Default Facial Expressions' Commands Association Versus a User Specific One.

The images represent the location of the chair in three dimensional space, during the session.

5.2.3 Questionnaire

Taking into account the responses given by the users, changes to the platform were performed in order to improve the usability of the system and eliminate bugs after each trial.

On the following sections are represented the responses given by the users, regarding the several topics of the questionnaire: usability, safety, satisfaction level of the input devices, interaction with the Multimodal Interface and fatigue and frustration level regarding the input devices.

Usability

As mentioned in the previous chapter, a System Usability Scale (SUS) was applied in the questionnaire. Table 5.6 shows a variation of the opinion in terms of usability. The reasons for these results are mainly the enthusiasm or novelty factor that disappears after the first trial, and changes to the system, that one user considers as an improvement while the other does not.

Table 5.6: Score of the SUS For Each User After Each Trial.

User	Trial 1	Trial 2	Trial 3
1	82,5	90	85
2	72,5	47,5	50

It is interesting to notice that the user that had more experience with videogames, gamepads and joysticks shows a better opinion in terms of usability.

Safety

The users were asked about the feelings of safety, about the control of driving the *IntellWheels* chair, if it was easy to drive in narrow spaces and if it was necessary lots of attention to drive it. The results of these questions revealed an overall feeling of some constraints in driving the *IntellWheels* chair. In fact, as was mentioned previously, the response of the users allowed to have more information about the system and several improvements were applied during the three trials.

Satisfaction Level Regarding the Input Devices

The satisfaction level of the different ways of controlling the *IntellWheels* chair was also inquired. The best results regarding the satisfaction level were obtained by the wiimote and the joystick's button mode. As can be observed in Table 5.7 the preference order confirms this fact. Another interesting remark that we can make is that for the different users, the preferred command can also be different.

The level of satisfaction with the input devices generally increased during the trials. As can be observed in Table 5.8 regarding the satisfaction level using the joystick in "high-level" mode, and the voice commands, in Table 5.9.

From observing the responses, one can comprehend that controlling an IW on the Simulator is hard, and the level of satisfaction with the input devices was generally increased during the trials.

Table 5.7: Order of preference of the Input Devices by Trial.

	Order of Preference		
	Trial 1	Trial 2	Trial 3
User 1	Wiimote Joystick (Analog) Microphone Joystick (Buttons) BCI	Wiimote Microphone Joystick (Buttons) Joystick (Analog) BCI	Wiimote Microphone Joystick (Buttons) Joystick (Analog) BCI
User 2	Wiimote Joystick (Analog) Joystick (Buttons) - -	Joystick (Buttons) Joystick (Analog) Wiimote BCI Microphone	Joystick (Buttons) Joystick (Analog) BCI Wiimote Microphone

Table 5.8: Satisfaction Level Regarding the USB Joystick in "High-Level" Mode.

User	Trial 1	Trial 2	Trial 3
1	Displeased	Indifferent	Pleased
2	Strongly Displeased	Pleased	Extremely Pleased

Table 5.9: Satisfaction Level Regarding the Microphone.

User	Trial 1	Trial 2	Trial 3
1	Indifferent	Pleased	Extremely Pleased
2	-	Strongly Displeased	Displeased

Fatigue and Frustration Level Regarding the Input Devices

The feeling of weariness and the sensitivity of users when they are doing the experiments are very important aspects to take into account. If a device is more exhausting than another, it is important to know and provide alternatives at long term.

The results obtained about the fatigue and frustration levels regarding the several input devices are shown in Tables 5.10 to 5.16.

It is perceptive that an innovation/novelty factor was present during the first trial of the tests.

5.3 Summary

As seen throughout this chapter, the data acquisition system is functioning correctly. Also, the changes made to the several parts of the platform could not have been proved as successful, as they did not lead to an improvement of the usability of the *IntellWheels* chair according to the carried out tests.

The information given by the Multimodal Interface aided the users throughout the duration of the

trials, even though some adjustments need to occur in order to be able to display both the Simulator and the Multimodal Interface in a comfortable viewing manner.
After this longitudinal case study analysis, it should be considered important to perform more tests with different users in the future. It was demonstrated the importance of this data acquisition system to improve the *IntellWheels* platform and this system should be considered for user profiling and environment modelling.

Table 5.10: Fatigue and Frustration - I Felt Tired After the Trial.

	BCI			Wiimote			Microphone			Analog Joystick			Gamepad		
User	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
1	Strongly Disagree	Strongly Agree	Agree	Strongly Disagree	Strongly Disagree	Strongly Disagree	Agree	Strongly Disagree	Strongly Disagree	Strongly Disagree	Indifferent	Indifferent	Strongly Disagree	Strongly Disagree	Strongly Disagree
2	Strongly Disagree	Strongly Disagree	Strongly Disagree	Strongly Disagree	Strongly Disagree	Strongly Disagree	-	Agree	Agree	Strongly Disagree	Strongly Disagree	Strongly Disagree	Strongly Disagree	Strongly Disagree	Strongly Disagree

Table 5.11: Fatigue and Frustration - I Felt Frustrated After the Trial.

	BCI			Wiimote			Microphone			Analog Joystick			Gamepad		
User	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
1	Disagree	Strongly Agree	Agree	Strongly Disagree	Strongly Disagree	Strongly Disagree	Agree	Strongly Disagree	Strongly Disagree	Agree	Disagree	Strongly Disagree	Strongly Agree	Disagree	Strongly Disagree
2	Agree	Agree	Indifferent	Strongly Disagree	Disagree	Disagree	-	Strongly Agree	Indifferent	Strongly Agree	Disagree	Indifferent	Strongly Agree	Strongly Disagree	Strongly Disagree

Table 5.12: Fatigue and Frustration - I Felt Bored During the Trial.

	BCI			Wiimote			Microphone			Analog Joystick			Gamepad		
User	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
1	Strongly Disagree	Agree	Indifferent	Strongly Disagree	Strongly Disagree	Strongly Disagree	Disagree	Disagree	Strongly Disagree	Strongly Disagree	Disagree	Strongly Disagree	Agree	Strongly Disagree	Strongly Disagree
2	Disagree	Agree	Indifferent	Strongly Disagree	Strongly Disagree	Strongly Disagree	-	Agree	Strongly Agree	Agree	Disagree	Strongly Disagree	Strongly Agree	Strongly Disagree	Strongly Disagree

Table 5.13: Fatigue and Frustration - Thinking About the Actions is Tiresome.

	BCI			Wiimote			Microphone			Analog Joystick			Gamepad		
User	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
1	Strongly Disagree	Agree	Strongly Agree	Strongly Disagree	Strongly Disagree	Strongly Disagree	Disagree	Strongly Disagree	Strongly Disagree	Disagree	Disagree	Strongly Disagree	Disagree	Strongly Disagree	Strongly Disagree
2	-	Strongly Disagree	Strongly Disagree	Strongly Disagree	Strongly Disagree	Strongly Disagree	-	Strongly Disagree	Strongly Disagree	Strongly Disagree	Strongly Disagree	Strongly Disagree	Strongly Disagree	Strongly Disagree	Strongly Disagree

Table 5.14: Fatigue and Frustration - Doing the Actions is Tiresome.

	BCI			Wiimote			Microphone			Analog Joystick			Gamepad		
User	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
1	Strongly Disagree	Agree	Strongly Agree	Strongly Disagree	Strongly Disagree	Strongly Disagree	Agree	Strongly Disagree	Strongly Disagree	Disagree	Strongly Disagree	Strongly Disagree	Disagree	Strongly Disagree	Strongly Disagree
2	Disagree	Strongly Disagree	Strongly Disagree	Strongly Disagree	Strongly Disagree	Strongly Disagree	-	Strongly Disagree	Strongly Disagree	Strongly Disagree	Strongly Disagree	Strongly Disagree	Strongly Disagree	Strongly Disagree	Strongly Disagree

Table 5.15: Fatigue and Frustration - A Lot of Concentration is Required to Think About the Actions.

	BCI			Wiimote			Microphone			Analog Joystick			Gamepad		
User	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
1	Strongly Disagree	Agree	Strongly Agree	Strongly Disagree	Strongly Disagree	Strongly Disagree	Indifferent	Strongly Disagree	Strongly Disagree	Strongly Disagree	Strongly Disagree	Strongly Disagree	Indifferent	Strongly Disagree	Strongly Disagree
2	-	Strongly Disagree	Strongly Disagree	Strongly Disagree	Strongly Disagree	Strongly Disagree	-	Strongly Disagree	Strongly Disagree	Strongly Disagree	Strongly Disagree	Strongly Disagree	Strongly Disagree	Strongly Disagree	Strongly Disagree

Table 5.16: Fatigue and Frustration - A Lot of Concentration is Required to Do the Actions.

	BCI			Wiimote			Microphone			Analog Joystick			Gamepad		
User	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
1	Disagree	Agree	Strongly Agree	Strongly Disagree	Strongly Disagree	Strongly Disagree	Indifferent	Strongly Disagree	Strongly Disagree	Indifferent	Strongly Disagree	Strongly Disagree	Indifferent	Strongly Disagree	Strongly Disagree
2	Strongly Disagree	Strongly Disagree	Strongly Disagree	Strongly Disagree	Strongly Disagree	Strongly Disagree	-	Strongly Disagree	Strongly Disagree	Strongly Disagree	Strongly Disagree	Strongly Disagree	Strongly Disagree	Strongly Disagree	Strongly Disagree

Chapter 6

Conclusions and Future Work

Conclusions

This document offers a definition of what is an intelligent wheelchair, together with a retrospective of relevant prototypes and also a small note on current portuguese projects and other input devices that could be implemented in intelligent wheelchairs, for persons with severe mobility difficulties. From examining several intelligent wheelchairs in development and already in production, one comes to the conclusion that the number of those that make use of a multimodal interface is very reduced.

Following this brief introduction to the subject, the *IntellWheels* platform was exposed, detailing its input devices and sensors used, as well as a view on its multi-agent system architecture. The applications that make part of the platform were also presented: the Control application, that handles the connection of the *IntellWheels* to the selected world (real, augmented reality or virtual), the Simulator, that allows to test new configurations and algorithms implemented in the *IntellWheels* in a cheap and safe manner, and the Multimodal Interface, that allows to command the *IntellWheels* using a mixture of different input devices, according to choices of the user

To further develop the possible analysis and personalisation of the *IntellWheels* chair, a data acquisition system was implemented in the platform. Its details were presented and information regarding the various data available to collect and ways of collecting was offered. A user profiler was also implemented in order to test the capturing system, and tests were carried out to validate the acquisition system.

The data acquisition system enables easy and more complete experimental test conduction. A complete set of experiments was performed in order to show that the system is fully functional and will enable flexible and more extensive experiments. In these experiments all data gathering, conversion and storing procedures worked as expected. Simple data analysis was also performed on the data gathered showing that it will enable in a very easy way to conduct complete and more elaborated tests in the future. Thus, the original objectives were completely fulfilled and the construction of new related modules will also be possible using the work developed as a basis.

Future Work

Now that a data acquisition system is implemented in the *IntellWheels* platform, advanced data analysis techniques can be applied, relating to both user profiling and algorithm testing.
With a functioning data acquisition system and a user profiler already in place, an environment profiler could be implemented, so that in conjunction with the user profile, the safest input device available for the situation could be suggested by the platform.
Another piece of software that could be developed relates to the data extracted from the Simulator: it is now possible to create an application that allows to "playback" user sessions, as the coordinates of the chair in the map are stored, as well as the input commands from the user to the Multimodal Interface.
Another application that could be of use is one that filters the collected data according to the input device used, or regarding a specific sensor.

Appendix A

Material Used During the Tests

TERMO DE CONSENTIMENTO INFORMADO

Declaração de consentimento informado

Conforme alei 67/98 de 26 de Outubro e a "Declaração de Helsínquia" da Associação Médica Mundial (Helsínquia 1964; Tóquio 1975; Veneza 1983; Hong Kong 1989; Somerset West 1996, Edimburgo 2000; Washington 2002, Tóquio 2004, Seul 2008)

Designação do Estudo: IntellWheels - Cadeira de Rodas Inteligente com Interface Multi-Modal Flexível

Eu, ____abaixo-assinado fui informado que o Estudo de Investigação acima mencionado se destina a obter dados sobre o desempenho na condução de uma cadeira de rodas inteligente (CRI) recorrendo a uma interface multimodal. Esta interface permite conduzir a CRI utilizando diversos inputs, tais como: movimentos de cabeça, comandos de voz, através de uma *brain computer interface*, *gamepad* e *joystick*.

Sei que neste estudo está prevista a realização de testes num simulador e preenchimento de um questionário tendo-me sido explicado em que consistem e quais os seus possíveis efeitos.

Foi-me garantido que todos os dados relativos à identificação dos Participantes neste estudo são confidenciais e que será mantido o anonimato.

Sei que posso recusar-me a participar ou interromper a qualquer momento a participação no estudo, sem nenhum tipo de penalização por este facto.

Compreendi a informação que me foi dada, tive oportunidade de fazer perguntas e as minhas dúvidas foram esclarecidas.

Aceito participar de livre vontade no estudo acima mencionado.

Também autorizo a divulgação dos resultados obtidos no meio científico, garantindo o anonimato.

Data	Assinatura
___/___/_____	____

Nome do Investigador Principal e Contacto: Luís Paulo Reis (lpreis@fe.up.pt)

Figure A.1: Consent Form.

Questionário I

Questionário – Usabilidade da Cadeira de Rodas Inteligente (CRI) (Simulador)

Através deste questionário pretende-se obter informações sobre a utilização da Cadeira de Rodas Inteligente (IntellWheels). A recolha destes dados permitirá que intervenções futuras na plataforma melhorem as condições de utilização. Os dados fornecidos serão tratados de forma agregada bem como será mantida a confidencialidade. Agradecemos a disponibilidade e a colaboração de todos.

1. Identificação do Utilizador.

1.1. Idade: _____________ 1.2. Sexo: Feminino ☐ Masculino ☐

1.3. Peso (em kg): ____________ 1.4. Altura (cm): _____________

1.5. Apresenta alguma dificuldade motora? Sim ☐ Não ☐

1.5.1 Se sim qual(ais)? _________________________________

1.6. Apresenta alguma dificuldade cognitivas? Sim ☐ Não ☐

1.6.1 Se sim qual(ais)? _________________________________

1.7. Indique o seu caso:

1.7.1. Destro? Sim ☐ Não ☐ 1.7.2. Daltónico? Sim ☐ Não ☐

1.8. Assinale o seu nível de escolaridade (ou que frequenta):

1º Ciclo		Bacharelato	
2º Ciclo		Licenciatura	
3º Ciclo		Mestrado	
Secundário		Doutoramento	

1.9. Qual a frequência de utilização de Jogos de Vídeo?
Instruções: Cada opção de resposta expressa uma atitude numa escala de 1 a 5, onde:
1 = Nunca, 2 = Raramente, 3 = Às vezes, 4 = Muitas vezes, 5 = Sempre
Para cada questão deve tentar comparar a sua opinião com cada uma das opções de resposta, marcando com um x na opção mais exacta.

	1	2	3	4	5
1.9.1. Costumo jogar jogos de vídeo.					
1.9.2. Costumo utilizar comandos de jogos de vídeo (tipo wii, playstation).					
1.9.3. Costumo utilizar o joystick.					

2. Fez a sessão de *Profiling*? Sim ☐ Não ☐

3. Usabilidade e Segurança da Cadeira de Rodas Inteligente (Simulador).

Instruções: Cada opção de resposta expressa uma atitude numa escala de 1 a 5, onde:
1 = Discordo totalmente, 2 = Discordo, 3 = Indiferente, 4 = Concordo, 5 = Concordo totalmente

1 de 5

Figure A.2: Questionnaire Page 1.

Questionário I

Para cada questão deve tentar comparar a sua opinião com cada uma das opções de resposta, marcando com um x na opção mais exacta.

Tradução da Escala SUS ***(System Usability Scale)***	1	2	3	4	5
3.1. Penso que gostaria de utilizar a CRI com frequência.					
3.2. Achei que a CRI é desnecessariamente complexa.					
3.3. Penso que a CRI é de fácil utilização.					
3.4. Penso que iria necessitar de apoio de um técnico para ser capaz de utilizar a CRI em pleno.					
3.5. Penso que as diversas funções da CRI foram bem integradas.					
3.6. Penso que a CRI tem muitas incoerências.					
3.7. Penso que a maioria dos utilizadores aprenderia facilmente a utilizar a CRI.					
3.8. Penso que a CRI é muito complicada de utilizar.					
3.9. Senti-me confiante na utilização da CRI.					
3.10. Penso que ainda necessitaria de aprender muitas funcionalidades da CRI.					
Segurança	1	2	3	4	5
3.11. Senti-me seguro na condução da CRI.					
3.12. Senti que tive controlo da CRI.					
3.13. É fácil conduzir a CRI em espaços estreitos.					
3.14. Conduzir a CRI não necessita muita atenção.					

4. Utilização dos Meios de Controlo da Cadeira de Rodas Inteligente (Simulador). Instruções: Cada opção de resposta expressa o nível de satisfação numa escala de 1 a 5, onde: 1 = Muito Insatisfeito, 2 = Insatisfeito, 3 = Indiferente, 4 = Satisfeito, 5 = Muito Satisfeito Para cada questão deve tentar comparar a sua opinião com cada uma das opções de resposta, marcando com um x na opção mais exacta.

4.1. Indique o **nível de satisfação relativamente ao tipo de controlo da CRI**.	1	2	3	4	5
4.1.1. Utilização do joystick no modo manual.					
4.1.2. Utilização do gamepad (modo de alto nível).					
4.1.3. Utilização dos comandos de voz.					
4.1.4. Utilização dos movimentos de cabeça.					
4.1.5. Utilização da Brain Computer Interface (BCI).					

2 de 5

Figure A.3: Questionnaire Page 2.

Questionário I

4.1.6. Utilização de modo integrada de todos os comandos.					

4.2. Indique quais as falhas/incoerências que encontrou durante a realização da experiência com CRI:

4.3. Indique quais as principais dificuldades que sentiu durante a realização da experiência com CRI:

4.4. Indique possíveis alterações de melhoria do Simulador:

5. Interface Multimodal.
Instruções: Cada opção de resposta expressa o nível de satisfação numa escala de 1 a 5, onde:
1 = Discordo totalmente, 2 = Discordo, 3 = Indiferente, 4 = Concordo, 5 = Concordo totalmente
Para cada questão deve tentar comparar a sua opinião com cada uma das opções de resposta, marcando com um x na opção mais exacta.

	1	2	3	4	5
5.1. A Interface Multimodal facilitou a informação sobre o tipo de comandos que estava a utilizar.					
5.2. A Interface Multimodal ajudou na criação de sequências de comando.					

5.3. Indique possíveis alterações de melhoria da Interface Multimodal:

6. Fadiga e Frustração.
Instruções: Cada opção de resposta expressa uma atitude numa escala de 1 a 5, onde:
1 = Discordo totalmente, 2 = Discordo, 3 = Indiferente, 4 = Concordo, 5 = Concordo totalmente
Para cada questão deve tentar comparar a sua opinião com cada uma das opções de resposta, marcando com um x na opção mais exacta.

6.1. Fadiga/Frustração da **BCI**	1	2	3	4	5
6.1.1. Senti-me fatigado depois da experiência com a BCI.					
6.1.2. Senti-me frustrado com a experiência da BCI					
6.1.3. Senti-me aborrecido com a experiência da BCI.					

3 de 5

Figure A.4: Questionnaire Page 3.

Questionário I

6.1.4. Pensar nas acções é cansativo.					
6.1.5. Fazer as acções é cansativo.					
6.1.6. É preciso muita concentração para pensar nas acções.					
6.1.7. É preciso muita concentração para fazer as acções.					
6.2. Fadiga/Frustração dos **Movimentos de Cabeça**	1	2	3	4	5
6.2.1. Senti-me fatigado depois da experiência.					
6.2.2. Senti-me frustrado com a experiência					
6.2.3. Senti-me aborrecido com a experiência.					
6.2.4. Pensar nas acções é cansativo.					
6.2.5. Fazer as acções é cansativo.					
6.2.6. É preciso muita concentração para pensar nas acções.					
6.2.7. É preciso muita concentração para fazer as acções.					
6.3. Fadiga/Frustração dos **Comandos de Voz**	1	2	3	4	5
6.3.1. Senti-me fatigado depois da experiência.					
6.3.2. Senti-me frustrado com a experiência					
6.3.3. Senti-me aborrecido com a experiência.					
6.3.4. Pensar nas acções é cansativo.					
6.3.5. Fazer as acções é cansativo.					
6.3.6. É preciso muita concentração para pensar nas acções.					
6.3.7. É preciso muita concentração para fazer as acções.					
6.4. Fadiga/Frustração do **Joystick**	1	2	3	4	5
6.4.1. Senti-me fatigado depois da experiência.					
6.4.2. Senti-me frustrado com a experiência					
6.4.3. Senti-me aborrecido com a experiência.					
6.4.4. Pensar nas acções é cansativo.					
6.4.5. Fazer as acções é cansativo.					
6.4.6. É preciso muita concentração para pensar nas acções.					
6.4.7. É preciso muita concentração para fazer as acções.					
6.5. Fadiga/Frustração do **Gamepad**	1	2	3	4	5
6.5.1. Senti-me fatigado depois da experiência.					
6.5.2. Senti-me frustrado com a experiência					

4 de 5

Figure A.5: Questionnaire Page 4.

Questionário I

6.5.3. Senti-me aborrecido com a experiência.					
6.5.4. Pensar nas acções é cansativo.					
6.5.5. Fazer as acções é cansativo.					
6.5.6. É preciso muita concentração para pensar nas acções.					
6.5.7. É preciso muita concentração para fazer as acções.					

6.8. Indique por ordem crescente de dificuldade (1 – Mais Fácil até 5 – Mais Difícil) o tipo de comando utilizado:

☐ Comandos de voz ☐ Movimentos de cabeça ☐ Joystick (modo manual)

☐ Brain Computer Interface ☐ Gamepad (modo alto nível)

6.9. Indique por ordem crescente de preferência (1 – Gosto Pouco até 5 – Gosto Muito) o tipo de comando utilizado:

☐ Comandos de voz ☐ Movimentos de cabeça ☐ Joystick (modo manual)

☐ Brain Computer Interface ☐ Gamepad (modo alto nível)

5 de 5

Figure A.6: Questionnaire Page 5.

Material Used During the Tests

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