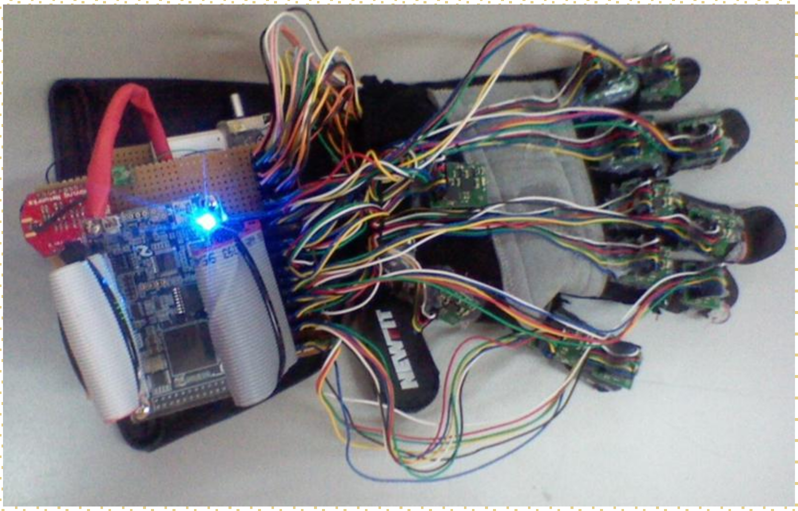

Pedro Miguel Baptista Machado

InerTouchHand

Master Dissertation

24 of September 2012

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Universidade de Coimbra

· U C ·

UNIVERSITY OF COIMBRA
Faculty of Science and Technology
Department of Electrical and Computer Engineering

Dissertation for the degree of Master of Science in Electrical and Computer Engineering

InerTouchHand

Pedro Miguel Baptista Machado

Jury:
President: Professor Doctor Rui Pedro Duarte Cortesão;
Supervisor: Professor Doctor Jorge Nuno de Almeida e Sousa Almada Lobo;
Member: Professor Doctor Paulo Jorge Carvalho Menezes.

Coimbra, 10 of September 2012

· U C ·

University of Coimbra

To my parents, sister and girlfriend.

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I want to thank my supervisor Prof. Doctor Jorge Nuno de Almeida e Sousa Almada Lobo for his guidance, patience and oportunity to do this dissertation. Also I like to thanks to Professor Doctor Jorge Manuel Miranda Dias for the oportunity that he gave me to work at Mobile Robotics Laboratory (MRL) in Institute of Systems and Robotics (ISR). Furthermore I like to thanks to Master Antonio Cunha for his guidance during the period that i worked as a Researcher at Laboratory for Automatic and Systems at Institute Pedro Nunes.
I cannot forget to thanks my co-supervisor Eng. Pedro Trindade that was always avialable to help me with master dissertation. Moreover, I want to thanks to all of my colleagues that worked with me in both Laboratories. Finally and not less important I want to thank my Taekwondo family for having taught me to have courtesy, integrity, perseverance, self-control and indomitable spirit.

Abstract

Humans are skilful users of their hands, using them to grasp and manipulate objects to complete daily tasks, and also to communicate with more or less explicit gestural and body language. While some specialised complex manipulation tasks are clearly recognised as complex, "simple" daily tasks that we take for granted are also very complex, and require learning staring when we are born, and can degrade in old age due to physical limitation. There has been a growing interest in this research field, trying to learn from the biology, as the emerging robotic sensing and actuation technologies enable the construction of better mechatronic systems.

Applications fields range from medicine to assisting living. However to understand hand movements and interactions, researchers require adequate sensing system, such as the use of glove based systems for data acquisition. Unfortunately most of this systems are either high cost solutions for laboratory use, and some low cost solutions are limited, and both tend to be cumbersome and hinder the natural hand movements.

In this dissertation we propose a system based on miniature inertial sensors, designated as InerTouchHand. The current prototype is glove based, but further miniaturisation can enable a lighter system in the future. It is a low cost solution that uses small MEMS sensors that retrieve orientation data from its magnetometers and accelerometers. A FPGA is used as a central processing unit to perform parallel data acquisition. The InerTouchHand prototype has the capability of generating vibro-tactile feed-back, speed charge, wireless communication, portability, cross-platform, fault tolerant and plug and play. The InerTouchHand system, fully developed in the scope of this dissertation, is presented, addressing some of the implementation choices, and results of initial tests with the working prototype are presented. InerTouchHand can be a good solution, not only to study human manipulations skills, but also for fields such as games industry, tele-robotics, rehabilitation and virtual in-

teraction.

Keywords: Accelerometer, vibrotactil, force feedback, glove, FPGA.

Declaration

The work in this master dissertation was developed in the MRL of ISR in Coimbra, Portugal. None of the parts of this dissertation was submitted elsewhere for any other degree or qualification. All the work that was not made by me it is referred in the text.

Contents

List of Acronyms

DoF Degrees of Freedom

ITH InerTouchHand

DIP Distal Interphalangeal

PIP Proximal Interphalangeal

MCP Metacarpophalangeal

TMCP Trapeziometacarpal

MIT Massachusetts Institute of Technology

FPGA Field-Programmable Gate Array

ROS Robotic Operating System

VHDL VHSIC Hardware Description Language

VHSIC Very High Speed Integrated Circuit

MRL Mobile Robotics Laboratory

ISR Institute of Systems and Robotics

EPM Electronic Power module

AM Actuators module

SM Sensors module

CM Concentrartor module

PWM Pulse Width Modulation

UART Universal Asynchronous Receiver-Transmitter

TCP **Transmission Communication Protocol**

ESD **Energy Storage Device**

XML **Extensible Markup Language**

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Chapter 1

Introduction

This chapter is used to give an introduction about this master dissertation.

1.1 Motivation

The human being uses hands to manipulate and move objects [2]. They use the ability to manipulate and move objects with hands to perform all kind of tasks. This faculty has been case of study by scientific community. Researchers seek knowledge through analysis of hand trajectories to grab objects and man-machine interaction for gesture recognition. This knowledge is then used to approximate the natural movements and mechanical movements in gestural interaction with social robots [3].
Furthermore with the evolution of fields like military, heavy industry, physiotherapy, medicine and sports. Solutions are required to give robots the capability to perform precision tasks like move-

ments recognition, assisted surgery, lesions recovery and even to high performance training.
Nowadays we are assisting to a change of mentalities. Regular keyboard and mouse are being replaced by other types of input hardware. For example in iPad (Figure 1.1-a) we use our fingers to touch the screen, Xbox (Figure 1.1-b) uses the Kinect to capture humman movements and submit it to a recognition or in Wii (Figure 1.1-c) that we use Wiimote to produce movement that is captured by the accelerometer and then converted into commands.

(a) Wii and Wiimote (b) Xbox and Kinect (c) Ipad

Figure 1.1: Wii, Xbox and iPad

However these solutions do not provide feedbacks similar to the stimulus that we receive when we interact with real objects.
Therefore in the last 30 years, several technologies where developed to assist researchers to proceed with their studies [1]. Those technologies are named as data glove based sytems that are basically gloves instrumented with sensors used to perform data acquisition. However all the above presented technologies have some liabilities since none fulfill the following requirements:

1. Good resolution;

2. Parallel data acquisition;

3. Low cost;

4. Force feedback;

5. Tilt compensation;

6. Wireless communication;

7. Capability to support a fast charge;

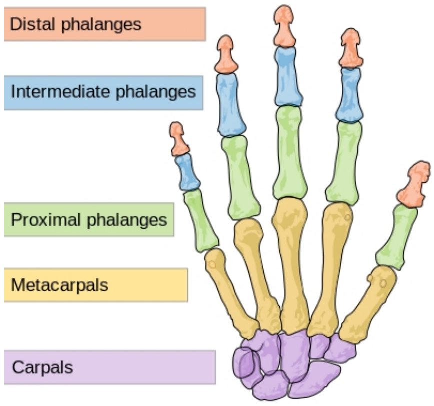
8. Plug and play - capable to add and remove sensors and actuators;

9. Fault tolerant - ITH system will continue to work even with sensors or actuators damaged;

10. Cross-platform.

Notice that a glove based system is defined as an array of electronic sensors to be used for hand data acquisition and processing [1]. Generally this array sensors is installed in cloth glove made of Lycra.

(a) Human hand parts



(b) Bones of the human hand

Figure 1.2: Human hand

In figure 1.2-a is depicted the human hand parts and in figure 1.2-b the bones of human hand.
Human hand is characterized for having Degrees of Freedom (DoF) to describe hand motions. During the execution of movements each finger joint has:

- 1 DoF for the Distal Interphalangeal (DIP) and Proximal Interphalangeal (PIP) (concetric/excentric);
- 2 DoF for the Metacarpophalangeal (MCP) (concetric/excentric, abduction/adduction);
- 3 DoF for the Trapeziometacarpal (TMCP) (allows thumb to rotate longitudinally);

1.2 Related work

This section is used to describe related worked developed by other Researchers teams.

1.2.1 Gloves

Since the goal of this dissertation is to develop a Vibro-tactile and for better understand the propose of ITH I will review some glove-based systems, presenting the advantages and disadvantages of each system.
According to [1] the most obvious design would be to place a sensor per DoF, however, over the years, there are some different gloves designs and configurations. In this chapter I will present most of these gloves.

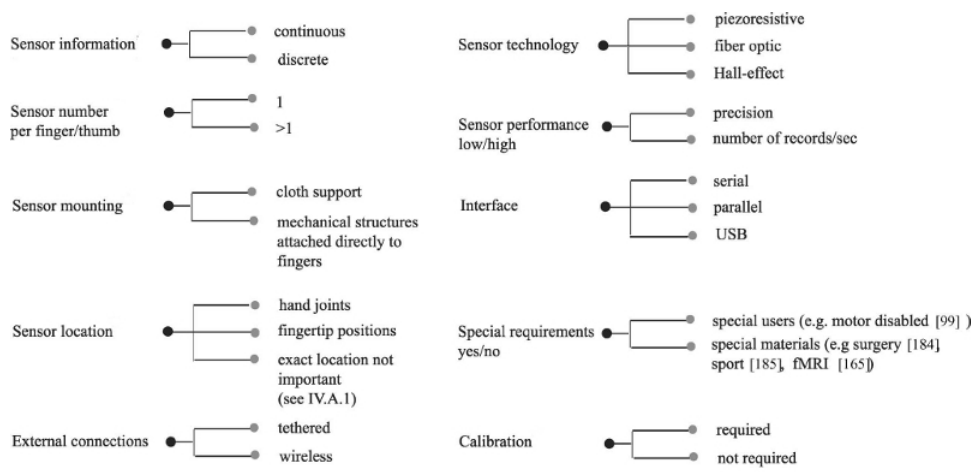


Figure 1.3: Gloves characteristics [1]

Figure 1.3 depicts most of gloves characteristics like sensor information, number per fingers/thumb, mounting, location, technol-

ogy, performance, interface, calibration and special requirements as reported in [1].

The first glove base system was developed during the 70s and since then several glove based systems have been proposed [1].

This glove based system protypes were developed at Massachusetts Institute of Technology (MIT) and were designated as MIT-LED and Digital Entry Data Glove.

In 1977 Thomas de Fanti and Daniel Sandin developed the Sayre glove prototype based in Rich Sayre proposal. This glove was made using light as source that is conducted throughout flexible tube, mounted along each finger, that as photocell to measure light variations. Early in the 80s MIT developed a new version that used a camera-based LED system to track body motion in real time processing.

Later in 1983, Gary Crimes developed and patented the Digital Entry Data Glove that had sensors installed on cloth to detect if thumb is touching any part of the hand or fingers, measure the thumbs joint flexion, hand tilt and the twisting/flexing of the forearm.

Zimmermam in 1982 developed a data glove using flexible plastic tubes and detectors installed on a cloth to capture joint angles. Late in 1987, Visual Programming Language Research, Inc. appeared with a new version using fiber optics. This new version came equipped with 5 to 15 sensors to measure flexion, abduction and adduction.

Nissho Electronics in 1995, developed and commercialized the Super Glove. This glove came with 10 to 16 sensors and used resistive

ink printed on boards sewn on the glove cloth [1]. In 2002 Super Glove was updated for Power Glove.
When we analyze this type of gloves we notice that all of them share the same goals that are:

1. Measure finger joint bending;
2. Uses cloth for supporting sensors;
3. Meant to be a general-purpose devices.

With scientific evolution new solutions are being projected and tested. Starting in fingernails a glove developed by MIT that uses photodiodes mounted on the fingernails to detect variations of nails coloration due to touching, bending, extension and shear.
George Washington University proposed a solution based in accelerometers mounted in five rings. However the first version had an issue associated with the constant breaking of wires.
A second version was developed with sensors installed in a leather glove. Moreover, Howard and Howard has a watch-size wireless device, a five-pixel LED scanner/receiver sensor array and accelerometers to detect additional motions. In 2007 the Superior Institute of Sant'Anna, Italy presented PERCRO a data glove with vibrotactile feedback.
PERCRO is characterized by a low cost, robust construction and no need of previous calibration. This glove uses goniometric sensors, and was developed as a device to perform the regular human gesture activities [4]. The University Tun Hussein Onn Malaysia proposes Smart Glove that uses flex sensors and flexi force sensors

to detect finger flexion and measure the pressure force between body and external surfaces [5].
E-Glove is a glove based system that uses accelerometer to track 6 types of forearm and wrist motions [6]. SOKA University presented a Wearable Sensitive Glove with hetero-core fiber-optic sensors to analyze sensitivity, stability, and reproducibility due to a single-mode propagation scheme [7].

1.2.2 Distributed sensors Network

A distributed sensors network is a group of sensors with a communications infrastructure intended to collect data at diverse locations.
Distributed sensor networks are used to provide important information such fields as forecasting, security, environmental monitoring [8] and human behavior. In this master dissertation the focus will be human behavior.
In the past years there has been intensive research to develop fixed accelerometers in the calculus of angular motion, to substitute the use of gyroscopes. Normally fixed accelerometers are selected instead of rotating accelerometers since fixed accelerometers configurations have a simple setup.
However fixed accelerometers do not give an explicit expression for angular velocity leading to sign indeterminacy problem [9].
Inertial Measurement Modules generate signals that after a double integration process origin position information[10]. Recently, appeared a new approach for using a large number of rotating ac-

celerometers. However in [9] is proposed a method to extract the angular velocity with less number of rotating accelerometers and without approximations.

Some investigation was made about feet movements where inertial sensors where mounted on the foot. Through velocities update techniques is possible to lower double integration error [10]. Furthermore, in [11] is proposed a method to estimate position from a limited number of sensors without knowing the localization of all sensors available.

1.3 Our Work

Some investigation about grasping and reach to grasp has been made at MRL in ISR [2], [3], [12].

As refereed above there are some work made in the development of glove based systems. However it is important to have more flexible tools to perform data acquisition and to generate force feedback.

In this dissertation is proposed a non intrusive sensors. These sensors are 3 axial accelerometers that included a magnetometer to perform tilt compensation. These sensors provide angle, pitch and roll information.

Since gesture is a sign language, ITH glove based system may be used in gesture recognition.

Gesture language may be static and/or dynamic. If the gesture is recognized then it will generate knowledge that can be used in the human-machine communication. Moreover, this knowledge may be used in the development of Portuguese sign language.

Vibro-tactile feedback will help in the communication, since the human body react to stimulus. This stimulus may be used to pass information that for many reasons cannot be sent by other way[12].

1.4 Overview of dissertation

In this Master dissertation it is proposed a data glove based system that has the following features:

- Uses compensated compass tilt sensors to get accelerometer and magnetometer to receive the yaw, pitch and roll like depicted in figure 1.4;

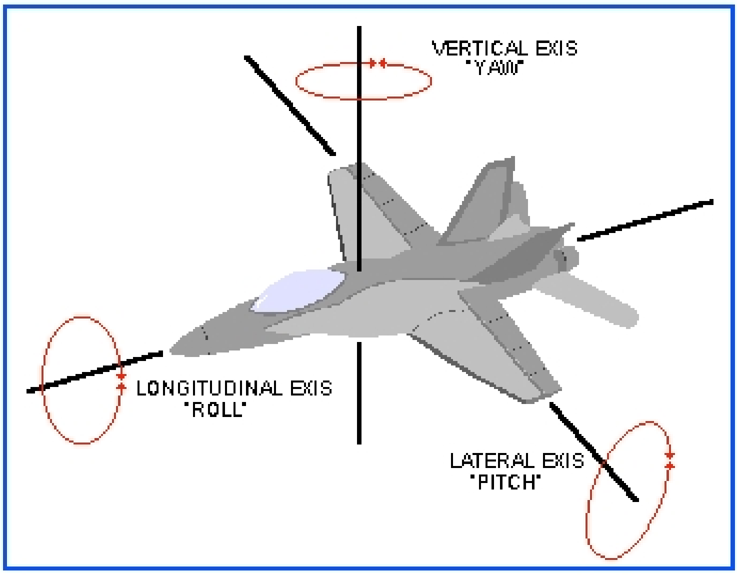


Figure 1.4: Yaw, Pitch and Roll

- Uses vibration motors to give force feedback;

- **Wireless module to allow communication with wireless devices;**
- **LiFePO4 batteries to allow speed charge and avoid explosions due to short circuits;**
- **Parallel data acquisition;**
- **Modular system that allow to add/or remove sensors and/or actuators.**
- **Fault tolerant avoiding to stop working if one sensor and/or actuator stops working;**
- **Cross-platform solution.**

In Background chapter it will be presented goals of ITH glove based system. Then in Our Implementation chapter it will be presented all the work made during the implementation period.
Then in Results chapter it will be discussed the results of ITH system. Finally, conclusions and future work will be presented in last chapter.

Chapter 2

Background

ITH glove based system will give contribution in data acquisition in environments outside laboratories. Since ITH is a Wireless device and can easily be used in industrial, office and home environments. Moreover since it is a low cost solution, ITH may be used for more people, allowing those persons to take advantage of ITH glove based system.

Since ITH is a modular system that can be used to perform other type of tasks.

If any sensor or actuator suffer any damage it will be easy to replace it since the system is modular.

ITH may be used for human machine interaction since it is possible to interact with virtual objects. Once the user can receive force feedback every time that he touches in a virtual object.

In fields like rehabilitation the glove may be used to evaluate the evolution or degradation of movements produced by the human hand.

Blind persons may use ITH to interact with applications since they can receive force feedback.
Gamers may use ITH glove based system to have new experiences while are playing.
Finally and not less important ITH may be used in investigation as a tool to understand hand poses.

Chapter 3

Our Implementation

3.1 ITH prototype design

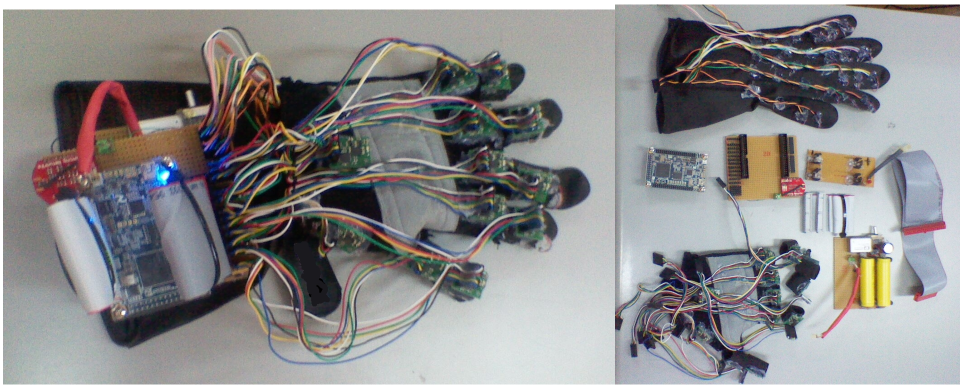
In this section are detailed all modules used in the design of ITH glove system. ITH glove is composed by the following modules:

- **Concentrator - All the other modules are all wired connected to concentrator.**
- **Wifly[1] - This module is used to perform wireless communication;**
- **Electronic Power module (EPM) - Used to feed the ITH glove system;**
- **Sensors module (SM) - 12 CMPS10 Tilt Compensated Compass sensors [2];**

[1] https://www.sparkfun.com/products/10822

[2] http://www.robot-electronics.co.uk/htm/cmps10doc.htm

- **Actuators module (AM) - 14 Vibration motor [3];**
- **FPGA[4] - Is used as main processing unit.**



(a) ITH integrated system (b) ITH modules

Figure 3.1: ITH modules

Figure 3.1-a depicts the integrated system and Figure 3.1-b depicts separated modules.

It is important to refer that all the modules will be required for transmit and receive information from the FPGA.
In this project was used a DE0 nano FPGA as showed in figure 3.2.

[3] https://catalog.precisionmicrodrives.com/order-parts/product/310-103-10mm-vibration-motor-2-7mm-type

[4] http://www.terasic.com.tw/cgi-bin/page/archive.pl?No=593

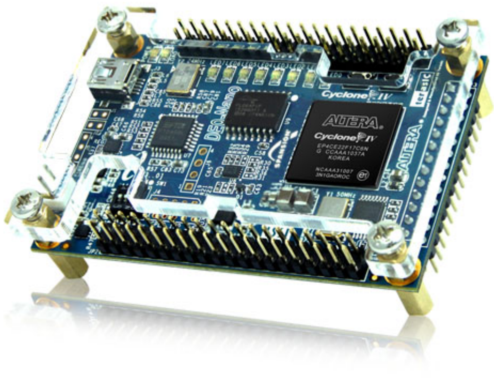


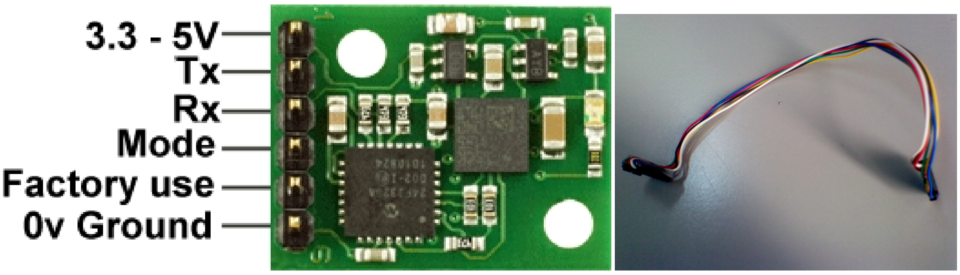
Figure 3.2: FPGA DE0 nano

3.1.1 Concentrator

CM has the main goal of centralize all the wired connections from AM, SM, FPGA and EPM.
Moreover CM was designed to receive signals from the FPGA that sends a Pulse Width Modulation (PWM) signal to a Darlington Array that convert the signal in a power signal.
This power signal is then sent to the selected Vibration Motor.

3.1.1.1 CMPS10 sensors

CMPS10 sensors are characterized for being Tilt Compensated Compass. In this project are used to aquire accelerometer and magnetometer raw data. Data from CMPS10 is used to get the angle, pitch and roll.
Connections from the concentrator to CMPS10 sensors were made according to manufacturer instructions.



(a) CMPS10 serial configuration (b) Connection cable

Figure 3.3: Sensor and connection cable

Figure 3.3-a depicts CMPS10 serial configuration and figure 3.3-b shows the cable used to connect the sensor to CM. Moreover, CMPS10 sensors were installed according to figure 3.4 Layout.

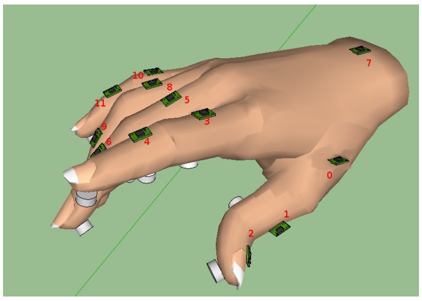


Figure 3.4: Hand sensors layout

The first step was producing cables to connect each sensor to AM. Cables were manufactured according to table 3.1.

Table 3.1: Wire colors correspondence

Pin Number	Description	Conductor colour
1	+3.3V	White
2	Tx	Black
3	Rx	Red
4	Mode	Green
5	Factory use (not connected)	Yellow
6	Ground	Blue

Once the connection cables were manufactured it was possible to connect the 12 CMPS10 sensors into CM. In CM the sensors are connected to a FPGA 40 pin headers 0 that is designated as GPIO_0.

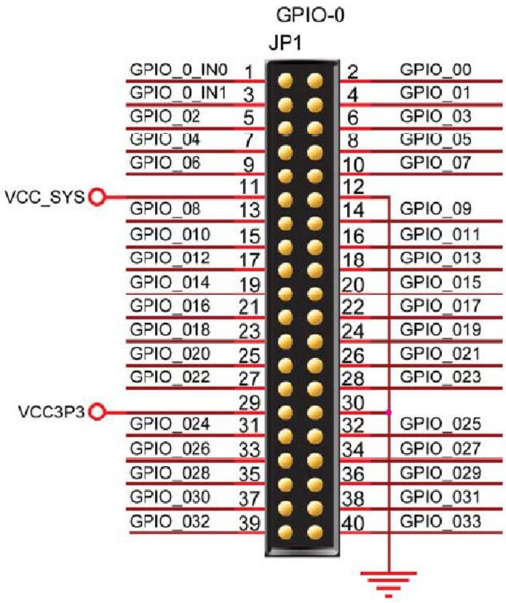
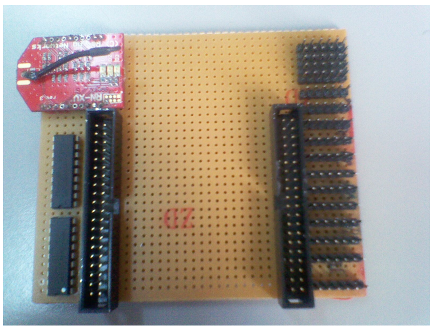
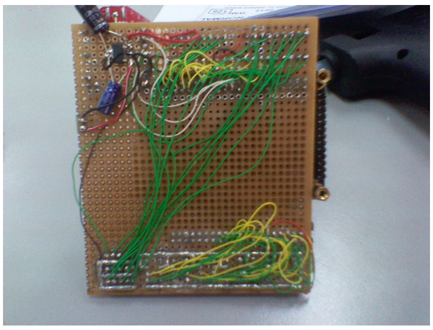


Figure 3.5: FPGA Pin arrangement of the GPIO_0 expansion headers

Figure 3.5 shows a FPGA pin arrangement of the GPIO_0 40 pin expansion headers.
The concentrator has also a power converter electronics to convert 5Vdc in 3.3Vdc used by Wifly module.



(a) Concentrator Top view



(b) Concentrator Bottom view

Figure 3.6: Concentrator top and lower views

Figure 3.6 shows the CM views.

Sensors CMPS10 were connected to the FPGA like is listed in table 3.2.

Table 3.2: FPGA conection to CMPS10 sensors

Sensor	PIN	Description	Colour	Signal name	FPGA Pin
All	1	+3.3V	White	VCC3P3	3.3V
	4	Mode	Green	GND	Ground
	5	Factory use	Yellow	N.A.	N.C.
	6	Ground	Blue	GND	Ground
0	2	Tx	Black	GPIO_033	PIN_B12
	3	Rx	Red	GPIO_032	PIN_D12
1	2	Tx	Black	GPIO_031	PIN_D11
	3	Rx	Red	GPIO_030	PIN_A12
2	2	Tx	Black	GPIO_029	PIN_B11
	3	Rx	Red	GPIO_028	PIN_C11
3	2	Tx	Black	GPIO_027	PIN_E10
	3	Rx	Red	GPIO_026	PIN_E11
4	2	Tx	Black	GPIO_025	PIN_D9
	3	Rx	Red	GPIO_024	PIN_C9
5	2	Tx	Black	GPIO_023	PIN_E9
	3	Rx	Red	GPIO_022	PIN_F9
6	2	Tx	Black	GPIO_021	PIN_F8
	3	Rx	Red	GPIO_020	PIN_E8
7	2	Tx	Black	GPIO_019	PIN_D8
	3	Rx	Red	GPIO_018	PIN_E7
8	2	Tx	Black	GPIO_017	PIN_E6
	3	Rx	Red	GPIO_016	PIN_C8

Table 3.2: FPGA conection to CMPS10 sensors

Sensor	PIN	Description	Colour	Signal name	FPGA Pin
9	2	Tx	Black	GPIO_015	PIN_C6
	3	Rx	Red	GPIO_014	PIN_A7
10	2	Tx	Black	GPIO_013	PIN_D6
	3	Rx	Red	GPIO_012	PIN_B7
11	2	Tx	Black	GPIO_011	PIN_A6
	3	Rx	Red	GPIO_010	PIN_B6

3.1.1.2 Vibration motor

Like described in Introduction, ITH is capable to give force feedback due to the use of Vibration Motors or actuators. The selected vibration motrs were 310-103 10mm Vibration Motor [5].
Since the FPGA is used to processing unit, it was required that actuators were connected to GPIO_1 also designated as FPGA 40 pin expansion headers.
However since the FPGA will send PWM signals it was necessary to add 2 Darlinghton Arrays to convert the PWM into a proportional power signal.

[5] https://catalog.precisionmicrodrives.com/order-parts/product/310-103-10mm-vibration-motor-2-7mm-type

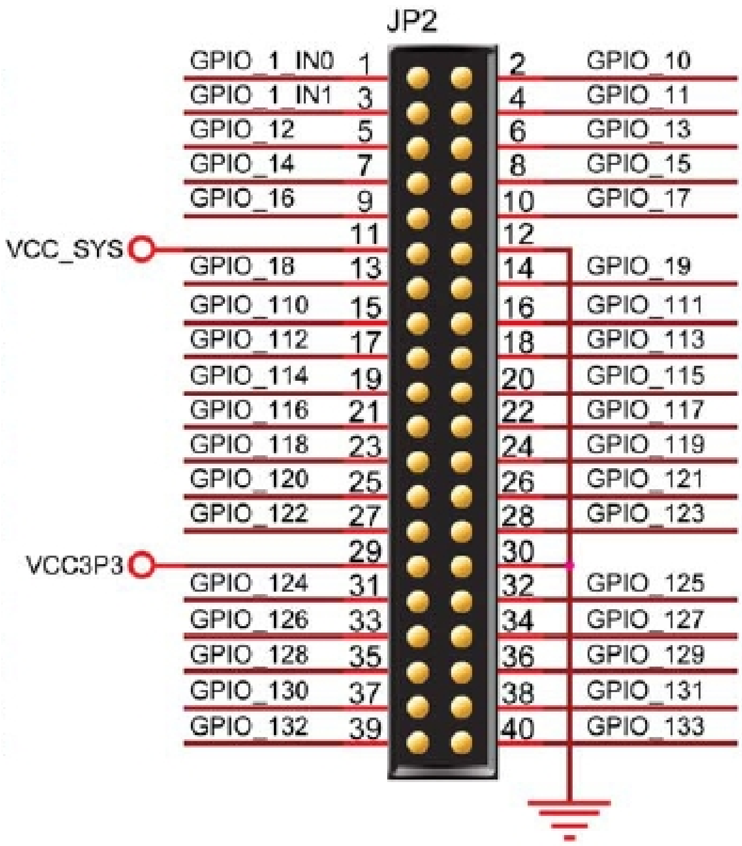


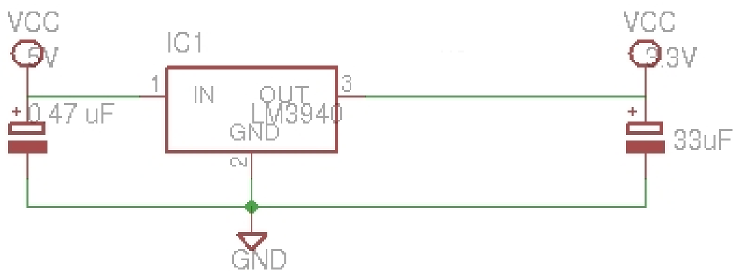
Figure 3.7: FPGA Pin arrangement of the GPIO_1 expansion headers

Figure 3.7 shows a FPGA pin arrangement of the GPIO_1 40 pin expansion headers.
The actuators (Vibration Motors) were connected to FPGA 40 pin expansion header GPIO_1 througout the circuit in figure 3.8-b.

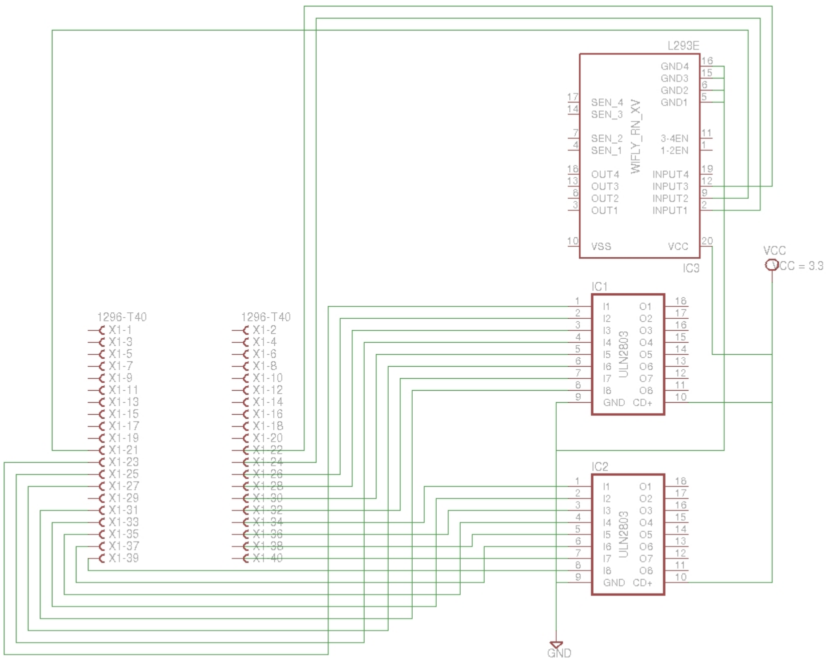
3.1.1.3 Wifly module

EPM feed the system with 5Vdc, however the actuators and Wifly module only work with 3.3Vdc. Since it is required 3.3Vdc, the CM has a energy converter.

the concentrator is feeded with 5Vdc that are then converted in 3.3Vdc. This conversion is possible because a linear converter is used to convert the energy.
Figure 3.8-a shows the electric schematic for the power conversion scheme.



(a) Power conversion scheme

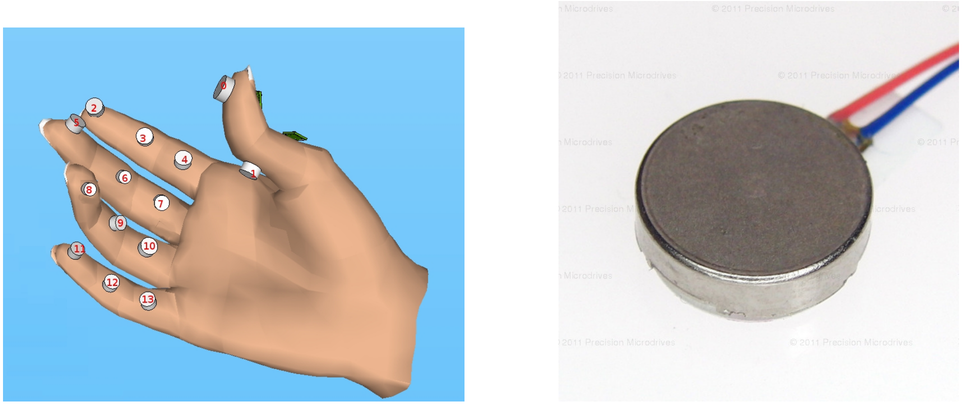


(b) Concentrator electric scheme for actuators wire connection

Figure 3.8: Actuators layout and electric scheme

Actuators were grouped by each finger meaning that there are 5 cables connecting to CM like depicted in figure Figure 3.9-a.

Figure 3.9-b show the used actuator.



(a) Actuators installation layout

(b) Vibration Motor or actuator

Figure 3.9: Power converter and actuator

Actuators were connected to FPGA like is listed in table 3.3.

Table 3.3: FPGA conection to Actuators

Actuator	Signal name	FPGA Pin
0	GPIO_133	PIN_J14
1	GPIO_132	PIN_J13
2	GPIO_131	PIN_K15
3	GPIO_130	PIN_J16
4	GPIO_129	PIN_L13
5	GPIO_128	PIN_M10
6	GPIO_126	PIN_L14
7	GPIO_125	PIN_P14
8	GPIO_124	PIN_N15
9	GPIO_123	PIN_N16
10	GPIO_122	PIN_R14

Table 3.3: FPGA conection to Actuators

Actuator	Signal name	FPGA Pin
11	GPIO_121	PIN_P16
12	GPIO_120	PIN_P15
13	GPIO_119	PIN_L15

Since one of the main goals was use wireless communication between the ITH and Wireless devices. To fulfill this goal a wifly RN-XV-GS module was installed in the CM.
This wireless device has the advantage to replicate data received throughout Universal Asynchronous Receiver-Transmitter (UART) into the wireless using Transmission Communication Protocol (TCP) packets.
Wifly RN-XV-GS module, showed in figure 3.10 was connected like depicted in figure 3.8-b.

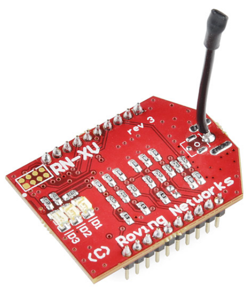


Figure 3.10: Wifly module that was installed in the CM

Wifly RN-XV-GS module was connected to FPGA like presented in table 3.4.

Table 3.4: FPGA connection to wifly module

Wifly PIN	Description	Signal name	FPGA Pin
1	+3.3V	VCC3P3	3.3V
2	UART_TX	GPIO_118	PIN_R16
3	UART_RX	GPIO_117	PIN_K16
8	GPIO9	GPIO_116	PIN_L16
10	GND	GND	GND

3.1.2 Energy Storage Device

Energy Storage Device (ESD) was developed to feed up the ITH. Moreover, the ESD was developed using 2 LiFePO4 cells connected in series configuration.
LiFePO4, reference APR18650M1-A, have the following characteristics:

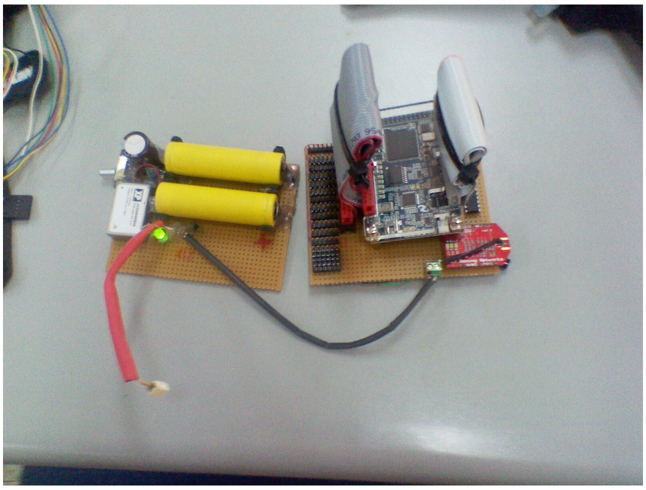
- Nominal voltage: 3.3V;
- Nominal capacity: 1.1Ah;
- Power: Over 1850 W/kg and 4400 W/L;
- Safety: Excellent abuse tolerance and environmentally friendly;
- Speed charge: Up to 5C;
- Lifetime: Over 1000 cycles;
- Tolerance of short circuit without the explosion risk;

- **Weight: Heavier then regular Li-Ion cells;**

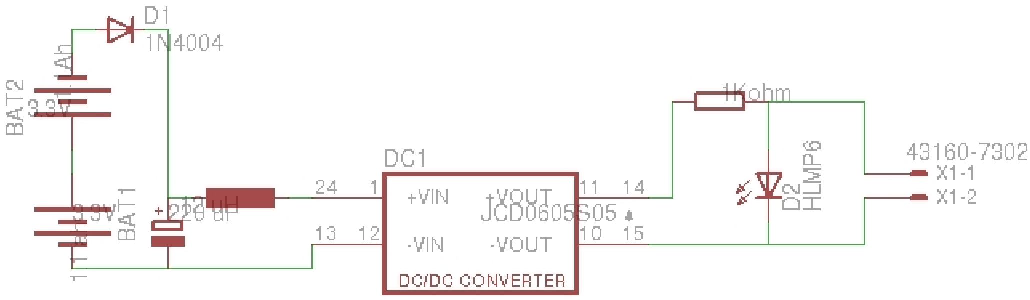
Figure 3.11 show a reference LiFePO4 APR18650M1-A cell;

Figure 3.11: LiFePO4 APR18650M1-A cell

The development of ESD was made according to circuit of 3.12-b resulting in figure 3.12-a.



(a) ESD connected to concentrator



(b) ESD scheme

Figure 3.12: power supply design

A power charger was also developed since it was necessary to perform quick charge. Figure 3.13 shows a power charger capable to suply 4,3V at 4A.

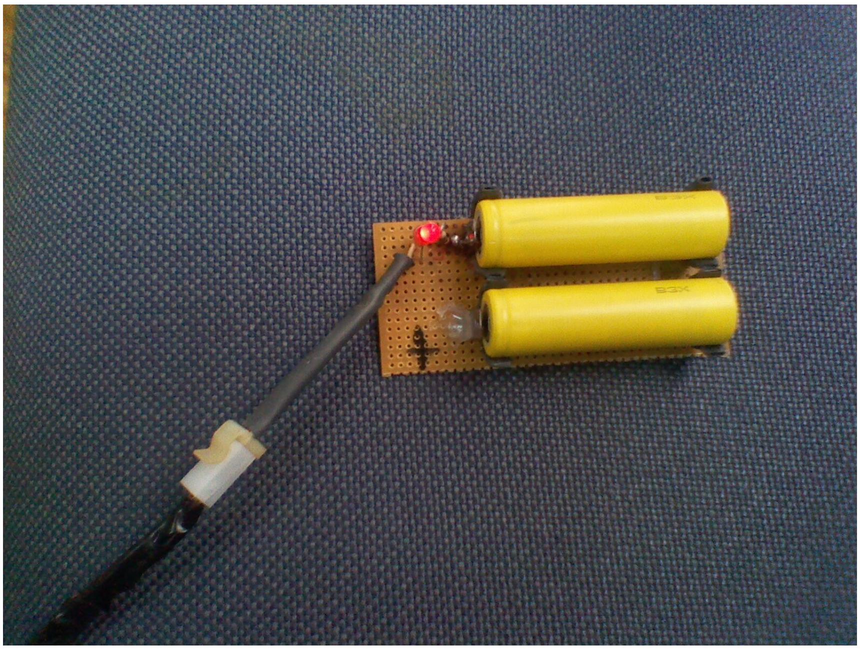


Figure 3.13: Power charger

3.2 System Requirements

3.2.1 System minimal requirements

1. **Operating System: Windows Xp or Ubuntu 12.04;**
2. **Programming Platform: Altera Quartus 12.0;**
3. **Programming Language: VHDL;**
4. **Equipment: Asus Eee PC 1005PE, 2Gb of RAM;**

3.3 Configurations

3.3.1 Wifly Module configurations

In order to establish a new connection to Wifly module it is required to access the network configuration and select "Wifly-GSX-a0".

Then, select the network properties and configure manually the Ipv4 configuration.

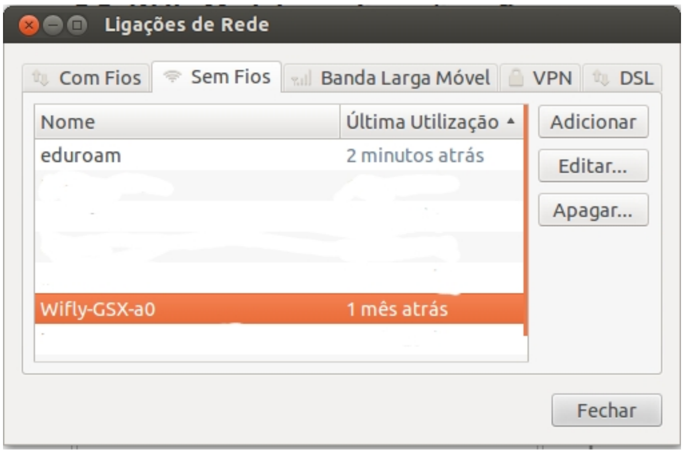
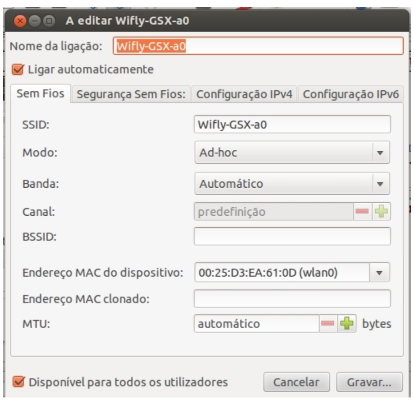
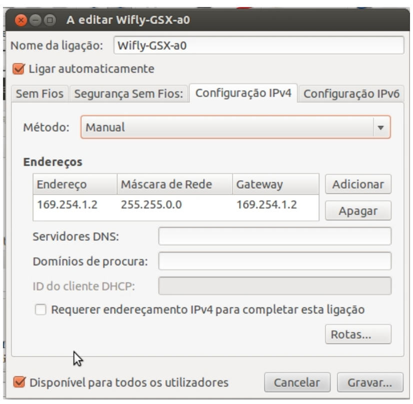


Figure 3.14: Edit network definitions



(a) Network properties



(b) Edit Ipv4 definitions

Figure 3.15: Network configurations

1. Select the Wifly-GSX-a0 network, as shown in figure 3.14;

2. Edit the connection Wifly-GSX-a0, as showed in figure 3.15-a;

3. Select Ipv4 configuration, as shown in figure 3.15-b and manually enter the following configurations: Method: Manual;

   - IP: 192.254.1.2;
   - Sub-mask: 255.255.0.0;
   - Gateway: 169.254.1.2;

After the Wireless connection is established with Wifly module we must open a telnet console and enter the following command:

```
$ telnet 169.254.1.1 2000
```

If the connection is established with success the module will reply with the stream *HELLO*. After we had received the reply we must send the following command:

```
$ $$$
```

When the command $$$ is send the Wifly module will enter in configuration mode. To change the ip address we have to send the following command:

```
$ set ip address 169.254.1.1
```

To turn off the DHCP server we have to send:

```
$ set ip dhcp 0
```

To configure the Gateway we have to send:

```
$ set ip gateway 169.254.1.2
```

To select the TCP protocol:

```
$ set ip protocol 2
```

The port configuration will be made with the following instruction:

```
$ set ip localport 60000
```

Change the UART baud rate is made by sending:

```
$ set uart baud 115200
```

Save the configuration

```
$ save
```

Reboot the module with the new configurations

```
$ reboot
```

To reset the module to factory defaults it is required to follow the steps:

1. **Press Key0;**
2. **LED0 will blink**
3. **Refresh the connection to the wifly module and proceed acording to the procedures mentioned above.**

3.4 Communication protocol

To communicate with ITH system it was required to develop a communication protocol to grant communication between the system and any wireless device (e.g. notebook, iPad, PDA, Smartphone). This section will describe the communication protocol.

3.4.1 Packet types

In the communication between a device and the ITH it will be used configuration and command packets.

3.4.1.1 Configuration packet

Configuration packets are sent whenever the user wants to change the number of sensors or actuators. By default there are 12 sensors and 14 actuators.
Each packet has the following configuration:

Table 3.5: Configuration Packet

C	S	S	S	A	A	A
1	b0	...	b11	b12	...	b22

If the configurations are changed with success the system will send FF0000000000000FF. Otherwise, if there is any error the system will send FFFFFFFFFFFFFFFFF (17 bytes with value F).

3.4.1.2 Command Packet

Command packets will have the following configuration:

Table 3.6: Command Packet

C	Sel	S/A	S/A	S/A	M	M	M
1	b0	b1	...	b15	b16	...	b22

In command packets the field C will have the logic value of 0.
Field Sel will have the logic value of 0 if the user wants to send a command to be interpreted by the sensors or the logic will be 1 if the user wants to sent a command to be interpreted by the actuators.
Field S/A is used to select the sensors or actuators to send the command. Finally the field M is used to send the command.
Sensors configuration packet has the following configuration:

Table 3.7: Sensors Command Packet

C	Sel	S	S	S	M	M	M
1	0	b2	...	b15	b16	...	b23

Notice that b2 and b3 are reserved for statistic proposes. If we want to estimate the response time of each sensor then b3 is set with the logic value 1. Table 3.8 lists options that can be sent to CMPS10 sensors.

Table 3.8: Sensors Mode meaning

Name	M	M	M	M	M	M	M	M
Bit	b16	b17	b18	b19	b20	b21	b22	b23
Com	Ver	Angle 8b	Angle 16b	Pitch	Roll	Mag	Accel	All
Status	Not impl	Not impl	Not impl	Not impl	Not impl	Impl	Impl	Impl

Since the cmps 10 are used to get the Magnetic and Accelerometer raw data, when the Mode is 0xE0 or 01110000 then the commands 0x21, 0x22 and 0x23 are sent to the selected cmps10 sensors. If the mode has any other value the system will return the error byte with the value 0xFFFFFFFFFFFFFFFF. If the mode is 0xE0 then the ITH will reply with 17 bytes from each sensor like described in table 3.9.

Table 3.9: Sensors reply

B1	B2..B7	B8..B13	B14..B17
Sensor ID	Magnetic Raw Data	Accel Raw Data	Angle, Pitch and Roll
id 1B	X 2B, Y 2B, Z 2B	X 2B, Y 2B, Z 2B	Angle 2B, Pitch 1B, Roll 1B

Reply format it is detailed in table 3.10.

Table 3.10: Reply format

Magnetic Raw Data	Xhigh Xlow signed	Yhigh Ylow signed	Zhigh Zlow signed
Accel Raw Data	Xhigh Xlow signed	Yhigh Ylow signed	Zhigh Zlow signed
All	Angle 0..3600	pitch -85..+85	roll -85..+85

For calculate the CMPS10 transmission time (since the FPGA 0 gives the order until the FPGA receives the all data) is required to send the first 4 bits with the value 0x4. Example 0x4FFFE0 in this case we are asking the transmission time for all sensors. Reply will be 0xAFFXXXXXXXXXXXXX, where X may assume values from 0 up to F. Each sensor will have 10 bits of information to send its transmission time.
Actuators packet is similar to sensors packet with the difference that the 2 bits resered for transmission time are used for 2 actuators and the b1 has value 1. Actuators configuration packet has the following configuration:

Table 3.11: Actuators Command Packet

C	Sel	A	A	A	M	M	M
1	1	b2	...	b15	b16	...	b23

The field mode can assume the following hexadecimal values:

Table 3.12: Sensors Mode meaning

Name	M	M	M	M	M	M	M	M
Bit	b16	b17	b18	b19	b20	b21	b22	b23
Meaning	P100%	P75%	P50%	P25%	T1000ms	T750ms	T500ms	T250s

Example: we will send the 0xF2FF22 (75% of Power during 750ms) to all actuators or 0x12013 (100% of Power during 500ms) to actuator 2.

3.5 VHDL components

In this section it will be detailed all the components used to develop ITH firmware. Figure 3.16 diagram show the components used in FPGA firmware.

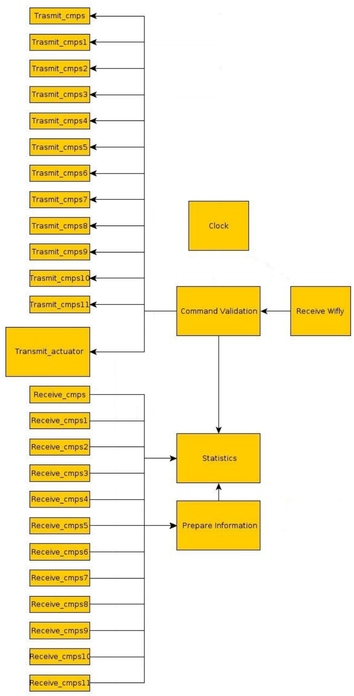


Figure 3.16: VHDL components

All VHDL programming was made using Altera Quartus II version V12 as depicted in figure 3.17.

Figure 3.17: Altera Quartus II V12

3.5.1 Clock

Clock is used to to generate 4 distinct clocks that are:

- 9.6 Khz - Transmit information for CMPS10 sensors and to actuators;
- 19.2 Khz - Receive information from CMPS10 sensors and to calculate transmission time;
- 115.2 Khz - Transmit information to Wifly module;
- 230.4 Khz - Receive information from Wifly module and to command validation.

These clocks are all obtained from 5 Mhz FPGA internal clock;

3.5.2 Receive wifly

This component receives commands sent from Wifly module throughout GPIO_118 FPGA pin. Works in a frequency 2 times higher

then transmission frequency.
System sends 5 Bytes, however this module remove the ¡CR¿ and ¡LF¿ and send the 3 bytes to component command validation.

3.5.3 Command validation

After the information is received, the first 3 Byts are analyzed and after this analysis the command is validated. If the command is not recognized then the component will activate the error flag.
When the command is recognized, the component activate the transmission flags and send the 3 commands to transmission_cmps, transmission_actuators and statistics components. This component is one of the more important components since it has the responsibility to synchronize with other components working at 9.6 Khz.

3.5.4 Transmit CMPS

Transmit CMPS component has the responsibility to send the information for the CMPS10 sensor. Each sensor has one of this components. Once like as described above, the protocol uses one hot methodology. Meaning that each bit represents one sensor and if a sensor is selected then the logic value will be 1.
Since it is possible to define the specific sensors that we want to select it was necessary to add one component per sensor. When the component receives the signal to read the command, the component will inspect the selected sensors and if the sensor was selected then the component will transmit the command.

3.5.5 Transmit Actuators

Like Transmit CMPS component, Transmit actuators works using the same principle. However in this component it is implemented a PWM that will generate a signal during a specific period.
The diference between the two components is that we only need one component to perform all the work. PWM signal is only sent to actuators that had been previous selected.

3.5.6 Prepare Information

This component receives information from receive_cmps, statistics and command validation components. All the information is acquired in parallel and then is packed using 1 start bit, 8 data bits, no parity and 2 stop bits.
After the information is all packed is sent to transmit_wifly component at 115.2Khz. This component has buffers to store data sent by other components and then uses a random algorithm to pack and send data.

3.5.7 Statistic

Statistic component starts one internal counter when data is sent to CMPS10 sensors and save the counter value when ready signal is received. The maximum time is 530ms and if the signal takes more time it will be assumed that was 530ms.

Transmission time is a selective process since it only gives the time from selected sensors.

3.5.8 Transmit Wifly

Transmit wifly will receive the information from prepare information component and will send it throughout GPIO_117 FPGA pin that is connected to Wifly UART receive. Transmission frequency will be 115.2Khz.

3.5.9 Application

To communicate with ITH is used two scripts in Matlab. Basically it was developed one TCP client and server. TCP serve is used to receive incoming connections from Wifly module and TCP client to send data commands to Wifly module. Data is received and then stored in a Extensible Markup Language (XML) file to be used by other application.

Chapter 4

Results

4.1 Tests

During the development of this master dissertation it was used the spiral model. By using this model it was possible to design, implement, test and anlyse in each phase of the project.
Figrure 4.1 represents the spiral model.

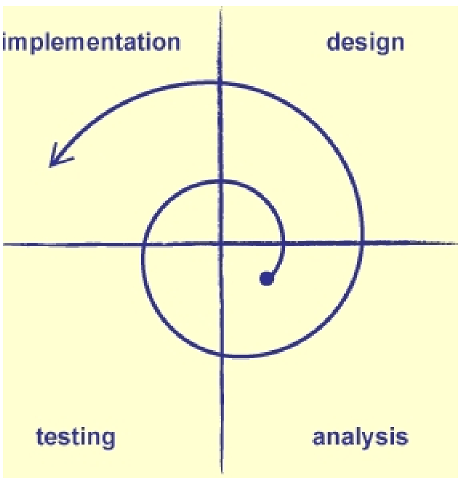


Figure 4.1: Spiral model

4.1.1 Hardware development

During the semester it was developed 4 main parts that were:

- CMPS10 Sensors glove;
- CM;
- ESD;
- Actuators glove layer.

4.1.1.1 CMPS10 sensors glove

During the development of this first glove there were made conductivity tests, ny using a multimeter to test conductivity. During this tests some short and open circuits were detected and corrected.
Moreover when the glove was tested it was identified that some sensors were misplaced. All misplaced sensors were removed and the placed in the right position.
This task was made during 4 weeks, since it was required to make 11 cables, adapt the glove and install sensors.

4.1.1.2 Concentrator Module

Developing CM had been the most dificult task because it was required to install the connecting terminals for sensors and actuators. Moreover it was required to connect all the terminals to FPGA 40 pin expansion headers, install 2 darlinghton arrays, Wifly module

and power conversor.
After everything was installed it was required to perform all the conductivity tests. During the conductivity tests seberal open and short circuits were detected and corrected.

4.1.1.3 Energy storage Device

ESD and its power charger was developed in 2 weeks. This module was also tested with a multimeter to detect open and short circuits. Like before all identified problems were corrected.
To test the integrity of this module I had connected the module to FPGA and performed a few complete cycles of charge and discharge.

4.1.1.4 Actuators glove

Like before the actuators glove was developed and tested. After the Vibration Motors were installed was necessary to develop calbes. Actuators were gruped by finger, giving a total of 5 connecting cables. Since there are 2 gloves the system may be used with only one of that gloves or used with both gloves. This glove was tested to detect open and short circuits. In this case none problem was found.

4.1.1.5 Firmware

During the Hardware and firmware development were made integration tests to check if the modules were correct. During this

tests it was used one osciloscope to view the signals that were send and received.

Thank to the osciloscope were detected errors associated with the transmit and receive frequencies. Moreover it was detected that in first versions were expected 12 bits instead of 11 bits.

Infinite or incomplete cycles, in the firmware. were also detected and corrected.

Unfourtanly detecting code faults was show to be the most difficult task once the code has thousands of lines and was difficult to detect and correct all errors.

For that reason, and to help in debug process we had used the Altera DE2.

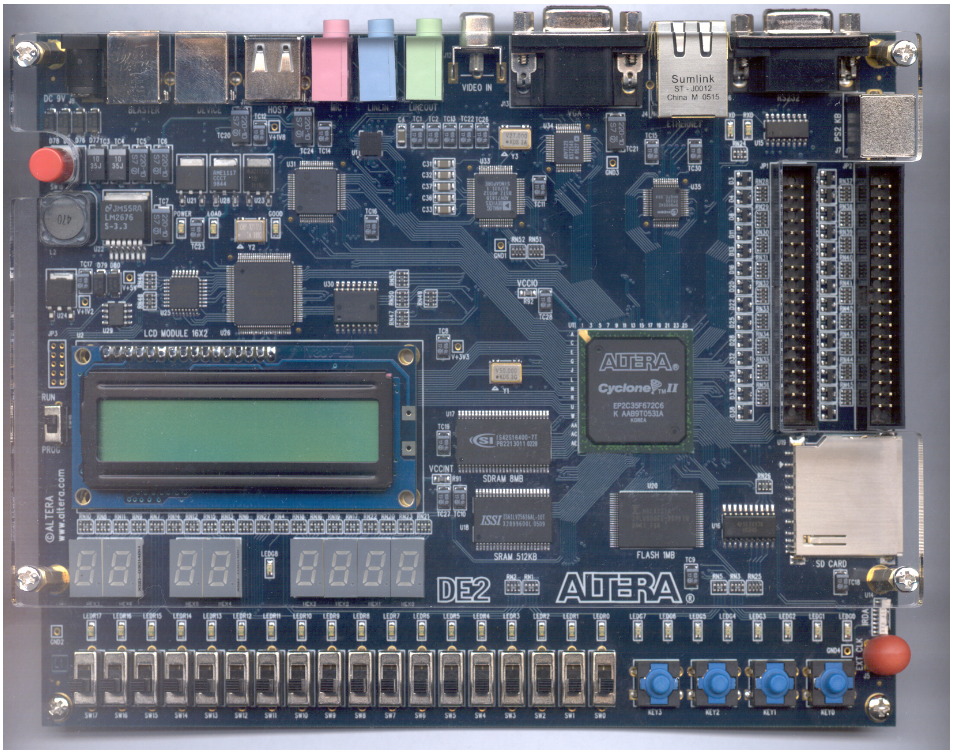


Figure 4.2: Altera DE2

Figure 4.2 shows Alter DE2 board.
With the use of Altera DE2, it was possible to use 7 segments digital display, 18 red leds, 9 green leds and RS-232 communication. The use of Altera DE2 board was an excellent strategy because it was easy to detect and correct firmware errors.

4.1.1.6 Software

For testing the comunication with other devices we had developed a python source to send and receive data throughout the RS-232 communication.
After the Software were working without errors my Co-orientator Eng. Pedro Trindade hada developed had developed a 3D cube in Blender [1] that moves according to the angle, pitch and roll sent by ITH.

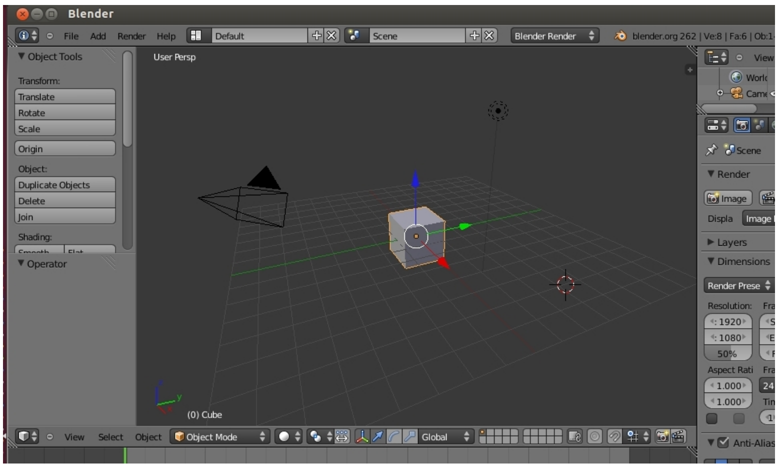


Figure 4.3: Cube in Blender

Figure 4.3 show the cube in Blender.

[1] http://www.blender.org/

Chapter 5

Conclusions and Future work

5.1 Conclusions

During this Master dissertation I had encontered several difficulties that lead me to develop strategies to deal and solve those issues. After the tests that were conducted ITH proved to be a good choice since has:

- **Good resolution;**
- **Parallel data acquisition;**
- **Low cost solution;**
- **Force feedback;**
- **Tilt compensation;**
- **Wireless communication;**
- **Capability to support a fast charge;**

- Plug and play - capable to add and remove sensors and actuators;
- Fault tolerant - ITH system will continue to work even with sensors or actuators damaged;
- Cross-platform.

Moreover to understand the ITH accuracy we have tested reply times and obtained the graph of Figure 5.1.

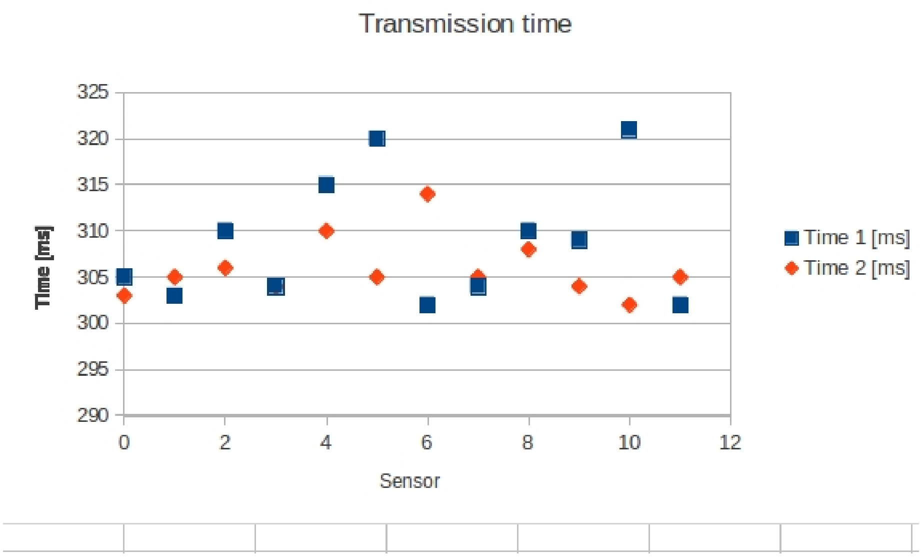


Figure 5.1: Dispersion graph

In the graph Time 2 occurred 1 minute after Time 1. And if we analyse the times we will conclude that the system has a good fidelity.
Moreover during the test period some sensors were disconected and connected. Like was espected the system continuos to work. When the sensor was removed ITH only send the information of the other sensors that were working. But after we connect the

sensor we will receive the expected values
The success is due to parallel data aquisition and to the algorithm implemented in prepareinformation component.
Intermedial, thumbsṕroximal and distal phalanges sensors were installed in a finger holder. This situation is quite interesting because we can easialy use those sensors in other configuration to perform other type of tasls.

5.2 Future Work

Several work was made during this master dissertation however ther are much more work to do.
It is necessary to perform the following tasks:

- **More stress tests to evaluete ITH performance;**
- **Prepare a driver for Robotic Operating System (ROS) integration;**
- **Develop and miniaturize the CM and ESD**
- **Use cables strong and thin;**
- **develop more interesting frontend aplications.**
- **develop a right hand glove;**

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