EASYID

A WIRELESS SENSOR PACKAGE TO MEASURE HUMAN INTERACTION FEATURES

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THESIS

Master of Science Thesis

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Science is a wonderful thing
if one does not have to earn one's living at it.

Albert Einstein

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SUMMARY

Extensive researches have been developed for the last few decades, to better understand the roles of human behaviors during social events. Non-verbal behavioural cues as postures, body movement are of high neccessay to be captured during social interactions for those studies. Instead of using self-reports method, the fast, objective and long lasting automated sensing technique is used.

This thesis proposes a low-cost and small size customized data acquisition sensor badge, called Easy ID, which is especially designed for the Vision Lab Group in TU Delft for their on body data capture during social events. Easy ID is designed based on an open source platform, which provides enough spaces for future upgrade and extension. The innovate infrared communication algorithm and the open source software created to drive the circuits in this thesis can be shared with other similar implementations. Instead of using C/C++ language, this work uses python to enhance the code readability for our clients and realize a high-level programming method to drive hardware. To overcome the delays while modulating the transistors, a 555 oscillator is adapted, for a 38kHz carrier frequency. The performance of Easy ID's identification is evaluated under both static and dynamic scenarios. With the infrared communication modules, the Easy ID can detect any facing another Easy ID with a range of 120 degrees opening angle and 3.5 meters distance. The sampling frequency of motion capture is typically 20Hz with 9 DoFs inertial sensors. A highly accurate global time stamp can be stored combined with the data from sensors as data logs.

ACKNOWLEDGEMENTS

This thesis is submitted for the degree of Master of Science at the Delft University of Technology. This work is to the best of my knowledge original, except where references are made to the previous work.

Time flies. It has been roughly eleven months since I have started this thesis project. The completion of this project is approaching. At this moment, I would like to express my thanks for those who have helped and guided me through the progress of this project.

Please let me acknowledge at the start my appreciation of Dr.ir. Andre Bossche, my direct supervisor, who introduced me to this thesis work that activated the magnets of curiosity, knowledge, and wisdom in me. His patience, enthusiasm, and immense knowledge have pushed me forward. It is him, where I got the base of Integrated Sensors and this knowledge will benefit my future academic life, including the project I am undertaking now. And my special thanks to Prof. Dr.Wouter Serdijn and Prof. Dr.Paddy French, for their lectures in wearable medical sensors and devices. In their classes, they always present the material in a clear and logical sequence and demonstrate an expert knowledge in Implantable Devices as well as Biomedical Sensors. And the continuous unlimited sources provided from TU Delft is what keeps inspiring me during the project, especially when I am facing with problems that I couldn't solve according to what I had learned.

More specifically in the context of circuit design and manufacturing, I would like to thank Jeroen Bastemeijer who helped put forward the project by offering me with abundant information in hardware, software design and especially for soldering electronic components. As a biomedical engineering student who has little background in software, I would not be able to finish the codes with specialized theories and detailed data collection without him. My thanks are to his expertise, knowledge, and patience.

What I know through the whole project, is not only advances myself in electronics design for wearable sensors but provides me with collections of amazing views held by my colleague in EI Lab, Zu-yao Chang who helped me a lot with soldering the MEMS sensor, Douwe van Willigen who shared his experiences in PCB layout with me, and Laura Cabrera who kept concerning the process of the project and provided valuable feedbacks, which encouraged me the passionate about the project. The interesting and stimulation discussions I shared with them are precious. And I enjoyed the time working together with them.

At last, I would like to say thank you to my parents, my boyfriend Hongjia Wu and my best female friend Yaxi Peng. Their encourages, love and support have fueled me with confidence.

1

INTRODUCTION

A spate of extensive studies involved in social interactions was developed in the past few years. Non-verbal behavioural cues as postures, body movement are of high neccessay to be captured during social interactions for those studies. Instead of using self-reports method, the fast, objective and long lasting automated sensing technique is used. In this chapter, first a brief introduction of the thesis background is given, as well as the importancy of automated sensing social behaviors. Then, the motivation of this thesis is followed by comparing state of the art sensor packages. The contribution of the thesis is listed in a general description. Improvements in more details will be shown in the follwing chapters. Finally, this chapter outlines the structure of the follwing chapters.

Social interaction can be defined as a simple or complex event in which a certain agent performs some social actions addressed at another agent that is actually or virtually present [1], which can be understood as human behaviors to express certain self-regulated human attitude, as beliefs, evaluations, social emotions etc. Even currently, people heavily rely on email, telephone, and virtual communication platforms as Facebook; human sciences (psychology, anthropology, sociology, etc.) have shown how social interactions dominate our perception of the world and shape our daily behavior [2]. Therefore, a spate of extensive studies involved in social interactions was developed in the past few years.

And how can we measure social interactions?

There are a spate of social signals that can be used for the study on human-human interaction. The **social signal** is the communicative or informative signal that provides information about social interactions. Instead of detecting verbal social signals using microphone, non-verbal behavioral cues as posture should be taken as a more important aspect of social aspect [2]. Becuase several decades of human sciences have shown that we are surprisingly effective at understanding social signals underlying the rich variety of nonverbal behaviours displayed by people around us [3]. And this make it possible to automatically measure social signals through sensors.

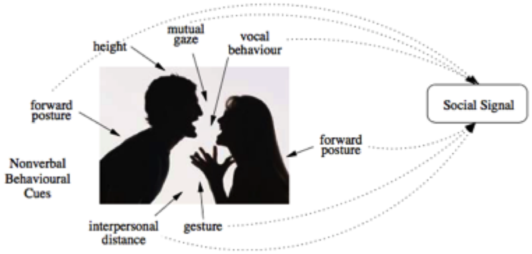

Figure 1.1: Nonverbal behavioural cues and social signals (Lepri B, Staiano J, Rigato G, et al., 2012)

Instead of using self-reports and recall surveys which have difficulties in recalling activities in the past, are subjective, and are impossible for long-term measurement, we use automated sensing techniques. The rapid development of sensors and signal processing technology has made it possible to capture social interaction features on human through sensor badge during face-to-face conversations [4, 5]. As **wearables** become more and more integrated into our daily life it provides the opportunity to use appropriate sensors to capture information about how groups of people interact over periods of weeks, months and even years [6]. They can precisely detect a range of events and can be precise, responsive and permanently operational [7]. Especially, the small size and lightweight Microelectromechanical systems (MEMS) sensor can enable reliable data captured from humans in a fast and unobtrusive way. This makes it accessible to use the wearable sensor packages, that are uniquely designed to collect motion and identification data from people wearing them and answer epistemological questions on human behavior in a data-driven manner, which provide prescriptive guidelines for persuading humans to undertake certain actions in real-world social scenarios.

1.1. MOTIVATION

THIS thesis is motivated by the research focusing on devising models to automatically interpret face-to-face human social behavior using wearable sensors in the Vision Lab Group TU Delft.[1] The wearable sensors can automatically capture human behavior during social events as meetings, the data will be used to synchronize with video cameras observation of people wearing the devices, which helps the researchers gain better understanding user roles in those meetings. Most of the state-of-the-art wearable sensor packages are able to measure human social behaviors in a fast and unobtrusive way, however, they are specially designed for one certain project, which is not convenient to use the packages for other researches or even the extension of that project. This may cause **missing some major variables** as well as **unnecessary data collection** that leads to extra power consumption. For example, the Sociometer designed by MIT Media Lab has a microphone on board which is not necessary for the research in Vision Lab, but do not have any gyroscope, which is important in defining the movement of users. Meanwhile, **open source platform** based sensor package can be adaptable during the future development and research work, which is more flexible. Considering the fast speed development of sensors and signal processing technology, open source platform can be upgraded and manufactured easily in the long term.

The study goal of the thesis is to design a low-cost and small size customized data acquisition sensor badge, which is especially designed for a certain client and meet all the requirements, but also provides enough spaces for future upgrade and extension.

The sensor badge should have motion sensors to capture human behavior related to their body movement; should detect and recognize any facing device with the same configuration; and should store all data in a full synchronized fashion, with the global time stamp as a reference. The device must be small and light and be able to run for at least a day on the same battery while storing all sensor data as it records. The devices will be operated as part of a network with many nodes.

1.2. CONTRIBUTION

THIS thesis presents a low-cost and small size customized sensor package, EasyID, based on an open source platform. The wearables can collect high accurate real-time human motion data and identification (ID) data of anyone wearing them, which can scale up to a large dense scenario.

The contribution of the thesis is listed:

1. **Customized PCB** Easy ID consists of an open source platform and a add-on Printed circuit board (PCB) with infrared communication module (transmitter, receiver) for ID detection, a MEMS 9 DoFs inertial sensor for human motion sensing, a real time clock for accurate time stamp, two indicators, and one push button for user interfaces to establish a real-time data collection sensor package at a high level of sensitivity.

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[1] Computer Vision Lab is a part of the Pattern Recognition & Bioinformatics Group in TU Delft, which develop new techniques for the automatic analysis of images and videos.

2. **Open source platform** Easy ID is designed on an open source platform RASPBERRY PI 3 MODEL B and the add-on board is accessible by RASPBERRY PI 2 MODEL B, RASPBERRY PI MODEL B+, and all RASPBERRY PI 1 MODEL. It can be easily upgraded, manufactured, which enables the possible extension of the sensor package.

3. **Python Programming** To control the Easy ID, a high-level programming language, python is used, which emphasizes code readability. Compared to C/C++ language, python is slower, which causes the problem while modulating infrared transmitters. A hardware solution is designed to solve the problem through a 555 oscillator. At the same time, the innovate infrared coomunication algorithm and the open source software created to drive the circuits in this thesis can be shared with other similar implementations.

4. **Low cost and small size** The overall cost of the manufactrued Easy ID is 64 Euros. The dimension of Easy ID is 85 × 56 × 25mm.

1.3. OUTLINE

THE rest of this thesis is organized as follows: related works and design instruction are provided in Chapter 2. The hardware and electronics design of Easy ID is provided in Chapter 3. Details of the software design and system archetecture are given in Chapter 4, followed by the experimental evaluation of Easy ID presented in Chapter 5. Finally, conclusions and future work are summarized in Chapter 6.

2

BACKGROUND AND RELATED WORK

Easy ID is such a wearable sensor package that automatically measures human interaction features. It is an adaption of the Hoarder board, a wearable data acquisition board, and functions as data recording during human face-to-face conversations. Data collection through wearables can be lower in price and more reliable than using human-delivered questionnaires, because a sensor-based approach is free from recall failures and personal interpretation bias of surveys, and does not involve coextensive human coders/observers. In general, sensor package that measures social behaviors is fast becoming ubiquitous with their implementation in wearable sensors. This chapter will explain what is sensor badge, and what makes a fully functional sensor badge for collecting human face-to-face interaction data. Related works will be described according to the time of the researches. And the related theoretical background, motion sensing, and proximity sensing will be described after the related works. Through the comparison and analysis of previous work, the design instruction of EasyID will also be listed at the end of this chapter.

2.1. BACKGROUND

SENSOR badges capable of detecting face-to-face interactions, conversations, body movement, and proximity to others, have been developed recently to capture individual and collective patterns of human behavior. This can be correlated with those individual (group) performances as well as the effects of the face-to-face communication. The ability to discover face-to-face communication networks automatically allows scientists and researchers to gather interaction data from larger groups of people.

The design of the sociometric badges was motivated by the fact that a large number of organizations already require employees to wear RFID name tags that identify them and grant them access to several locations and resources. These traditional RFID name tags are usually worn around the users' neck or clipped to their clothing. With the development of microelectronics, it is now possible to augment RFID badges with more sensors and computational power that allow measuring human behavior without requiring any additional effort on the user's side. By capturing individual and collective patterns of human social interaction with sociometer, it is possible to identify users' personality as well as their particular interesting during social events.

In the following subsections, several major measurements and their theoretical background will be explained one by one. Including motion capture, proximity sensing including infrared communication method.

2.2. RELATED WORK

IN this section, available wearable sensor systems that are used as social interaction data acquisition will be described, and their basic hardware and software configurations will be given as well.

Choudhury and Pentland [6] initiated behavior analysis using wearable sensors by developing the Sociometer in 2002, which were worn by participants to record various aspects of their behavior. The board has an IR transceiver, a microphone, two accelerometers, on-board storage, and its own power supply. The wearable stores the data locally on a 256MB compact flash card and is powered by four AAA batteries. The range of de-

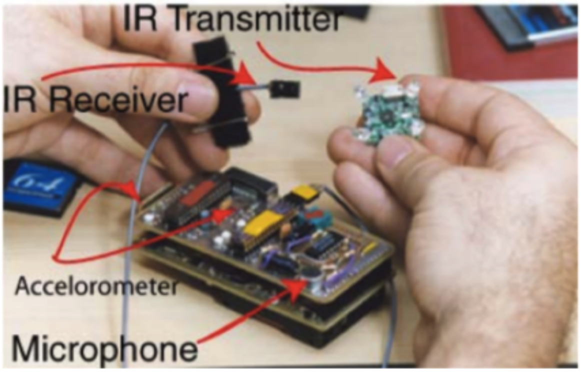

Figure 2.1: Sociometer (Choudhury T K., 2002)

tection is approximately six feet, which is adequate for picking up face-to-face communication [6]. One of the limitations is that it can only detect two people when they are involved in social interaction.

The sociometer (Figure 2.1) records the following information for each individual:

1. Information about people nearby (sampling rate 17Hz – sensor IR)
2. Speech information (8KHz - microphone)
3. Motion information (50Hz - accelerometer)

Similarly, one early sensor platform was developed in 2002 at Massachusetts Institute of Technology (MIT) (Figure 2.2, application see Figure 2.3, which is the data acquisition system for user-interface implementation, including exploring heart rate, breathing, temperature, and skin conductance changes in different situations [8]. The whole system includes a data-collection system consisted of a PIC 16C711 microcontroller, an FM radio-transmitter module, and a power supply circuitry with a 9V battery. The microcontroller provided four 8-bit analog-to-digital converter inputs, additional output pins to control optional LEDs or other components, and processing capabilities to assemble and send data packets over the RF link using a serial protocol [8]. The receiver module was connected to the serial port of a PC or other device, and the data were broadcast continuously in packets consisting of a predefined header byte, four samples from each analog input, and a check-sum byte.

Another badge platform developed at MIT for facilitating interaction in large groups of people was the UbER-badge [9]. (Figure 2.4) An UbER-badge measures 8.25 x 10.5 cm and weighs 0.1 kg with all four AAA batteries installed. At an average current of about 100 mA, badges last for roughly 15 hours of continuous use. The badge is equipped both with an IR communication channel to support face-to-face and local communication, and an RF communication channel to support larger distance and wider bandwidth communication. The IR system consists of a composite IR LED with a 17-degree spread, and an IR receiver with integrated demodulator, photodiode, and a Cygnal C8051F301 processor, which acts as a dedicated IR communication controller to buffer incoming and outgoing

Figure 2.2: HHD prototype (Gerasimov V,2002)

Figure 2.3: HHD application (Gerasimov V,2002)

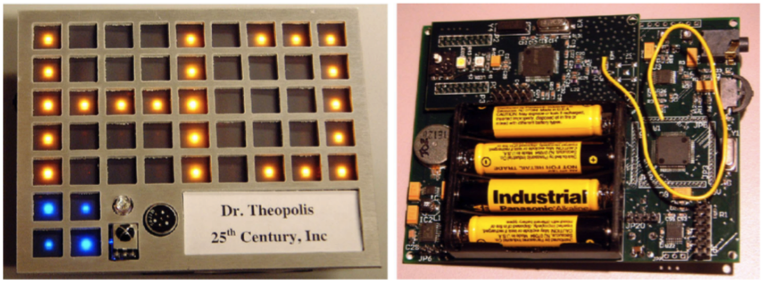

Figure 2.4: UBeR-Badge 1.0

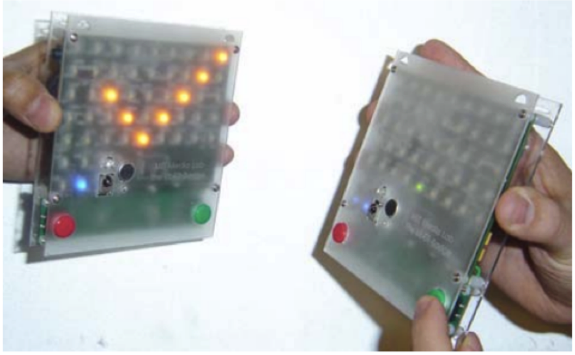

Figure 2.5: UBeR-Badge 2.0

IR messages. A slightly quicker version of the Sony-IR protocol is used on the badges, with the IR modulated at 40kHz. The badge's IR communication is sensitive up to 3 meters.

An improvement of the UBeR-Badge has been claimed in 2010 [10]. A complete UBeR-badge (including frosted plastic faceplate) measures 11 x 9 x 12 cm and weighs about 170 g with all four AAA batteries installed. At an average current of about 100 mA, badges last for roughly 15 hours of continuous use (Figure 2.5). The improvement is basically the display. The badge is equipped with an IR channel (875 nm modulated at 38 kHz) to support face-to-face and local communication. Badges can notice each other via the IR channel up to 3 meters and across large angles (e.g., 60). And the badge also supports an RF section to support higher bandwidth, non-line-of-sight communication across larger distances with a range of 100 meters.

Sociometric badge 2.0 and 3.0 are two advanced one compared to [6]. The front view of the sociometric badge 3.0 is shown in 2.6 2.7. The badge 3.0 has a three-axis MEMS accelerometer (Analog Devices, ADXL330) is used to detect when a person is moving. An IR transceiver module (Vishay, TFDU4300) is used to detect when two people are facing each other. A bridged-output audio power amplifier (Analog Devices, SSM2211) drives an electromagnetic speaker on the badge to play back messages and reminders. The main processing unit is an ARM microcontroller (Atmel, AT91SAM7S256). A 2.4-GHz

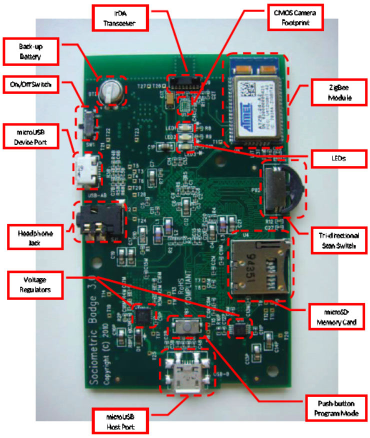

Figure 2.6: Sociometric badge 3.0 Circuit Design (Olguín-Olguín D, 2010)

Figure 2.7: Sociometric badge 3.0 Prototype (Olguín-Olguín D, 2010)

wireless transceiver (Chipcon, CC2500) and a class 2.0 Bluetooth module (BlueRadios, BR-46AR) have been incorporated for enabling wireless communications with fixed base stations and other Bluetooth-enabled devices. A microSD memory card socket has been included for storing data when the user is out of range of a fixed point or when the badge is used as a self-contained sensor package. The badge is powered by a 950-mAh lithium-polymer battery that is rechargeable through USB. In addition, data can also be transferred through the USB port. The dimensions of the badge inside the plastic enclosure are 4.5 × 10 × 2 cm, and the total weight including the battery is 110 g.

More recent works of wearable sensor package towards the ultra portable badge, that monitor body motion, and the social interaction. The arrival on the market of major players like Apple, Google and Microsoft popularized smartwatches and smartglasses and facilitated the development and widespread adoption of sensing applications (e.g. with Android Wear), opening doors in many areas including sport and personal monitoring.

Compared to the above proposed work, this thesis has following improvement:

1. **Open source platform** Easy ID is designed on an open source platform Raspberry Pi module B+ vision 3 and can also be accessed by all Raspberry module A and B. And this can be easily upgraded, manufactured and enable the possible extension on the sensor package.

2. **Python Programming** To control the Easy ID, a high-level programming language, Python is used, which emphasizes code readability. And the open source software created in this thesis can be shared with other similar implementations.

3. **Faster Signal Processing** Easy ID has a 1.2GHz Broadcom BCM2837 64bit CPU with a 1GB RAM compared to a 400 MHz previous work in 2011. This enables a faster signal processing during data collection.

4. **Larger Data Storage** Easy ID has a micro SD card slot, which can insert up to 128GB SD card for loading your operating system and storing data.

5. **Larger Detection Range** The ID detection can sense facing devices with the same configuration up to 3 meters away. And the maximal viewing angle of the device is 120 degrees.

6. **Low cost and small size** The overall cost of the manufactured Easy ID is 64 Euros. The dimension of Easy ID is 85 × 56 × 25mm.

7. **Larger Dense Scale** Easy ID can scale up to 256 devices with 8-bits data transition. There are sufficent spaces for future upgrades, which can easily be scaled up to 2084 devices with the current hardware configuration.

2.3. SENSORS

2.3.1. MOTION SENSORS

IT is possible to recognize meaningful expressions of emotions as talking, gesturing and laughing through the monitoring and analyzing of body motions. [11–14] Motion capture (mocap) is the process of recording the body motion of objects or people, which can be obtained by the inertial navigation system (INS).[1] INSs were first developed for rockets in the Second World War. In the decade that has followed, a wider range of application is realized, from airplanes or the automotive industry to smart phones or even running shoes with the development of new technology, with the benefits from MEMS technology. MEMS technology (Microelectromechanical systems) offers rugged,

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[1] INS is defined as a navigation aid that uses motion sensors (accelerometers) and rotation sensors (Gyroscopes) to continuously calculate the position, orientation, and velocity of a moving object without the need for external references.

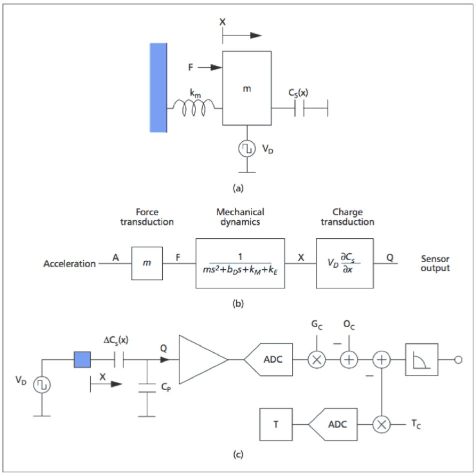

Figure 2.8: Accelerometer

low cost, small and lightweight inertial sensors relative to the other available technologies.

Microelectromechanical systems (MEMS) systems rely on miniaturized electromechanical elements for their operations. Three main input source used in most research is inertial sensor, and namely **accelerometer**, **gyroscope** and **electromagnetic**. They can be used individually to capture human motion, however, the need of the combination of them is growing. How each of them functions individually and in a system will be given. Accelerometers use a comparatively simple system to drive the MEMS, whereas gyroscopes require significant complexity to maintain self-oscillation and regulate the mechanical amplitude of the drive motion.

One of the main advantages of accelerometers is their relatively lower error rates as compared to other motion sensors: their bias errors can be estimated more easily than gyroscopes. However, its measurements are sensitive to dynamics which are not related to the motion that are aims to detect, for example the involuntary vibrations of a human body. Therefore, such dynamics need to be reconciled or smoothed during the features extraction. The effect of the sampling rate of an accelerometer on recognition accuracy was evaluated by Maurer et al [15] and it was found that there is no significant gain for having sampling frequency higher than 20 Hz.

Rotation measurements from gyroscopes are necessary to discriminate between motion modes whose acceleration measurements may seem almost identical, e.g., between a stationary platform at zero velocity and a platform moving at constant velocity. The main drawback of gyroscopes is that they tend to have high error rates: they usually have higher drift errors and higher run-to-run bias errors than accelerometers. Such errors can be estimated and partially removed by combining it with a magnetometer [16].

2.3.2. PROXIMITY SENSOR

PROXIMITY sensing can be defined as the detection of nearby objects presence without any physical contact. Proximity sensing can be achieved either directly by sensing proximity, or indirectly by inferring their absolute positions [17]. The Table 2.1 lists the most common methods to detect proximity. The electromagnetic gradient is usually subdivided into different spectrums according to their energy, namely radio waves, microwaves, infrared, (visible) light, ultraviolet, X-, and gamma radiation. Among all interfaces to measure distance (approaching distance) between tow nodes, Radio Frequency (Bluetooth, Wifi, etc) and infrared radiant are low cost and most used to measure distances. At the same time, infrared can be used to measure face-to-face conversation features with the line-of-sight.

Table 2.1. List of proximity sensing mechanisms

Type		Theorem	Limitation
Electrical sensors	Inductive [18]	Change of the electromagnetic field generated by coil,target converted into analogue output	Requires metal coil, Small measurement range, Range depends on sensor Low conductivity
	Capacitive [19]	Two conductive plates with minimal supporting electronics to detect the obstacles	Ambiguous data, quickly decaying resolution and exposure to external influences
Optical sensors	Infrared [20]	The reflections of the light sending out can be detected by photodiode	Complex and expensive, Unstable with environmental changes
	Visible		Dark color and non-matte surfaces not be sensed
Acoustic sensors	Sonar [20]	Ultrasonic energy can be transmitted and then received	Vulnerable to noise,Expensive to maintain,Flat surfaces hard to detect
	Ultrasonic		
Microwaves	Radar	Transmit a short pulse detect the reflection via microwaves[21]	Complex and expensive, Doppler effect, Noisy output [22]
	Laser	Transmitted and reflected microwaves[21]	Doppler effect, Large power supply
Radio Frequency	Bluetooth WiFi	Signal strenth can be used to measure distance	Biased measurement around RF cellular towers

INFRARED band of the electromagnet corresponds to 430THz to 300GHz and a wavelength of 980nm. The propagation of light waves in this band can be used for a communication system (for transmission and reception) of data. Infrared (IR) communications is based on technology which is similar to the remote control devices such as TV and entertainment remote controls used in most homes today. IR offers a convenient, inexpensive and reliable connection between two portable devices or between a portable device and a fixed device. Unlike radio-frequency (RF) wireless links, IR wireless cannot pass through walls, line-of-sight mode. Therefore, IR communications or control is generally not possible between different rooms in a house, or between different houses in a neighborhood (unless they have facing windows). This might seem like a disadvantage, but IR wireless is more private than RF wireless.

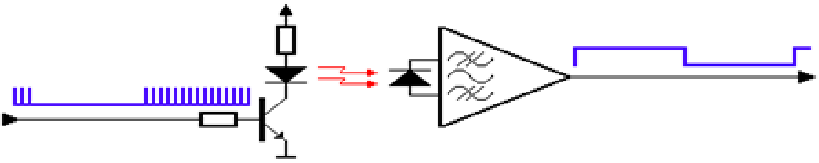

Figure 2.9: Infrared Communication

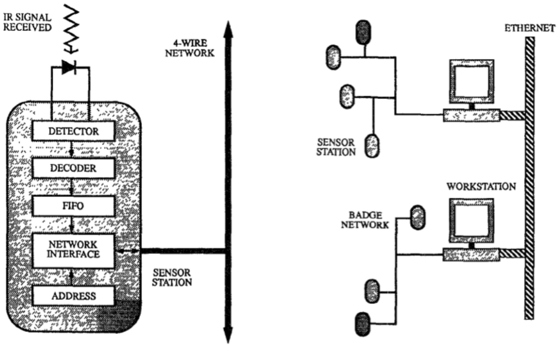

Figure 2.10: Badge sensor

The transmitter of an IR LED inside its circuit, which emits infrared light for every electric pulse given to it. This pulse is generated as a button on the remote is pressed, thus completing the circuit, providing bias to the LED.The LED on being biased emits light of the wavelength of 940nm as a series of pulses, corresponding to the button pressed. However since along with the IR LED many other sources of infrared light such as us human beings, light bulbs, sun, etc, the transmitted information can be interfered. A solution to this problem is by modulation. The transmitted signal is typically modulated with a carrier frequency of 38 KHz (or any other frequency between 36 to 46 KHz). The IR LED is made to oscillate at this frequency for the time duration of the pulse. The information or the light signals are pulse width modulated and are contained in the 38 KHz frequency.

The receiver consists of a photodetector which develops an output electrical signal as light is incident on it. The output of the detector is filtered using a narrow band filter that discards all the frequencies below or above the carrier frequency (38 KHz in this case). The filtered output is then given to the suitable device like a Microcontroller or a Microprocessor which controls devices like a PC or a Robot. The output from the filters can also be connected to the Oscilloscope to read the pulses.

As early as 1992 [23], the Active Badge 2.10 was developed as the earliest active infrared-based system, consisting of a cellular proximity system. Each person wears a small infrared badge which emits a globally unique identifier one-tenth a second every 15 seconds to the ceiling central nodes for estimation of badge's location. Pulse-width modulated infrared signals are used for communication between badge and sensor. Since then, the infrared communinication has been used for the proximity and location sensing beween nodes.

3

EASY ID: HARDWARE DESIGN

While a spate of researches on the design of sensor packages has shown fast and accurate human features capture, the up-to-date wearable sensors together with single board computers can offer faster and more reliable human data collection methods. In this chapter, the customized sensor package – EasyID will be introduced from the system requirements to the hardware configurations. Circuit design and selection of components will be described individually. This chapter contains the contents of the selection of open source platform, which performs as the power driver and microcontroller for the whole device. At the same time, the choice of major components as motion sensors and infrared transceiver and their designed circuits are shown together with the reasons of selection. The block diagram of hardware design will be given. Finally, the sensor package is manufactured as a PCB. PCB layout is given as the end of this chapter.

3.1. SYSTEM REQUIREMENT

ACCORDING to the previous chapter, several design instructions were already given based on the literature review. In this section, a general description of the functional and non-functional requirements will be given. For more detailed information, the list of full requirements is attached in the appendix.

Overall, the sensor package should be able to measure body motion data (acceleration, orientation and velocity), detect any facing devices with the same configurations and recognize their IDs. In the meantime,it should be able to store all the data in a fully synchronized fashion, using a global time-stamp as a reference. For the motion capture module, The acceleretion of the users should be measured with a range of ±2g at a resolution of 0.1g and a maximum deviation of ±0.1g; the linear velocity of the users should be measured with a range of $\pm 10m/s$ at a resolution of $0.1m/s$ and a maximum deviation of $\pm 0.1m/s$; and the angular velocity of the users should be measured with a range of $\pm 90°/s$ at a resolution of $\pm 1°/s$ and a maximum deviation of $\pm 5°/s$. At the same time, the sampling frequency of the motion data should be at least 20Hz. For the face-to-face detection modules, the detection range should be 3 meters, and the data rate should be at least once per second. Sufficient I/O capabilities (>10) should be left open for hardware extension. And the total weight of the device (including the battery and the enclosure) should not be too large. A small size of the device is necessary for the user's comfort. The whole system, when scaled to a large dense crowded scenario, at least 32 devices should be able to configured.

3.2. SINGLE-BOARD COMPUTER

SENSOR badges are small in size and light in weight, which requires high performance sensors as well as a small and cheap microprocessor. Operation with a single-board computer (SBC) is such a flexible platform that offers a fast multitasking capacity with a high level of automation [24]. Among all SBC, ARM is the leading in microprocessor technology aiming at designing a wide range of multi-functional, power-efficient, low-cost, convenient size and high-performance microprocessors. Because of its unique features and interfacing options, ARM technology is currently used in a large number of development board as well as wearable devices and handheld gadgets. Currently, there are 121 ARM based single-board computers with different ARM architectures. Based on the requirements of the wearable sensor packages, we selected some common Linux oper-

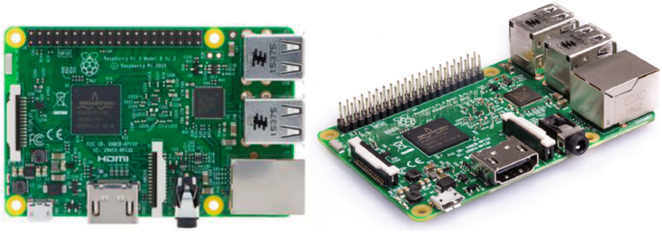

Figure 3.1: Top View and Side View of Raspberry Pi 3 Model B (RaspberryPi, 2016)

ating boards with low cost and small size characteristics and gave a comparison among them. Linux operation system is a collabration of free and open-source software. With Linux, free and open-source software development and distribution is possible, which benefits the extension and upgrade of Easy ID. Among those selected Linux based ARM SBC [25], we chose Raspberry Pi 3 Model B [26] (Figure 3.1) as the microcontroller and development platform for Easy ID. The reasons are following: (See comparision in the Appendix)

1. Fast processor and large storage capacity
2. Large user community and entensive software available.
3. Relatively small size, low cost with low power comsuption.
4. On board 802.11n wireless and Bluetooth 4.1 modules enable proximity sensing with a range of 5 meters.

3.3. ID DETECTION MODULE

The identification (ID) recognition module of EasyID will be described in this section. According to the previous literature review, for the ID detection module, we use infrared communication, which is composed of two parts: infrared receiver and the infrared transmitter. We start with the selection of the components, followed by their circuits and their layout when implemented on the PCB.

3.3.1. RECEIVER

Infrared receivers are selected based on the carrier frequency, application, maximum and minimum irradiance, and opening angle. According to the requirements, the receiver should see signals from a wide (180°) range. The carrier frequency is typically 38kHz. To find the target receiver among those remote control ones, because they are low in cost, small in size and best match the situation we are facing. Three main considerations of the receiver are power consumption, receiving distance and receiving angles. Then the receiver with lowest minimum irradiance (defined as power consumed per unit area [27]) and highest angle of half transmission is the best candidate. Because the sensing distance is defined as the square root of the division between receiver minimum irradiance and transmitter radiant intensity (Figure 3.2).

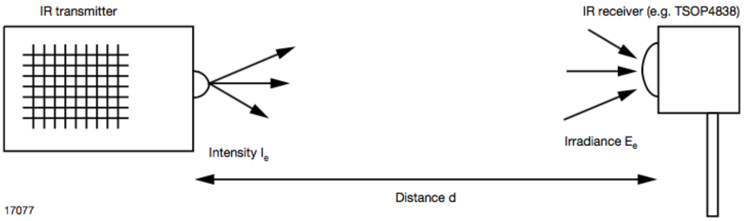

Figure 3.2: Relevant Values for IR Transmission Distance

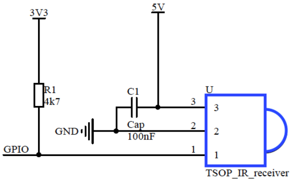

Figure 3.3: TSOP34838 Module

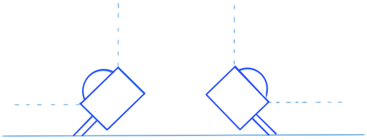

Figure 3.4: Infrared Receiver Electrical Connection

TSOP34838 is such an infrared receiver with lowest minimum irradiance among all 45 degrees angle of half transmission 38kHz modules. With 45 degrees angle of half transmission, two receivers should be sufficient. Meanwhile, two receivers can give us received ID information with two sensing zones. The electrical connection is shown in Figure 3.3. The three pins are Data out, ground and power respectively. A decoupling capacitor C is used to stabilise the power. And a pull-up resister is 4.7kΩ.

Since the largest possible half transmission angle is 45 degrees, two infrared receivers are sufficient to cover the full range of 180 degrees. When they are embedded in the PCB, they should be bent into 45 degrees to the board, and then rest on the chest of the user. With two infrared receivers connected to two different GPIO pins (4, 18 GPIO.BCM [1]), their received data can be stored separately which helps better to derive facing angles of the "talking devices".

3.3.2. TRANSMITTER

For the infrared transmitter, we need to select the feasible LED and a stable oscillator for 38kHz carrier frequency. For 38kHz carrier frequency, we select TLC555 over NE555 because:

1. It is functionally interchangeable with NE555.
2. It has a higher input impedance, which allows a smaller timing capacitors to be used. As a result, more accurate time delays and oscillations are possible.
3. The power consumption of TCL555 is low across the full range of power-supply voltage.
4. The package of TCL555 is SOIC8, which is one-fourth of the NE555 package.

The TLC555 application circuit can be seen in Figure 3.6. The 555 timer is capable of being used in astable and monostable circuits. In an astable circuit, the output voltage alternates between VCC and 0 volts, with the introduction of a resistor RB. By selecting values for RA, RB, and C we can determine the period/frequency and the duty cycle. To establish a 38kHz carrier frequency, theoretically a $10nF$ capacitor, a $1.4k\Omega$ resister,

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[1] referring to the pins by the "Broadcom SOC channel" number

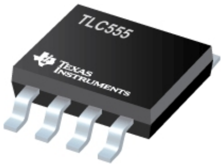


Figure 3.5: TCL555 Module

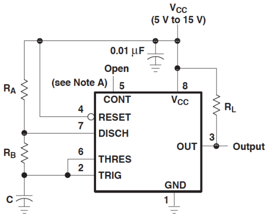


Figure 3.6: 555 Circuit for Astable Operation

and a 1.2$k\Omega$ resistor will do a duty cycle of 60%. However, in reality, the circuit tends to show a deviations in osilation frequency, with a capacitor tolerance (1%). By putting a 8.1 – 9.1$k\Omega$ in parallel with the 1.2$k\Omega$ resistor, the carrier frequency can be set back to 38kHz.

When selecting the infrared transmitter, it is important to understand what makes a large infrared transmission distance. The maximum possible transmission distance of an IR remote control system (receiver and transmitter) depends on various parameters but is mainly dependent on the radiant intensity (the radiant flux emitted per unit solid angle) of the emitter (Ie) and the sensitivity of the receiver (Ee min.). Figure 3.2 explains how to calculate transmission ranges in the simplest case assuming a quadratic relationship between the distance d and the irradiance of the receiver Ee. Given emitter intensity Ie, the maximum distance is calculated as:

$$d_{\max} = \sqrt{\frac{I_e}{\mathrm{E}_{e\min}}}$$

A larger emitter intensity is what makes a better IR LED for infrared communication. Meanwhile, a wide transmitter angle can enable a wide sening range during infrared detection. The typical intensity values of selected through hole emitters are listed in Table 4.2. We can see from the table that, the radiant intensity increases with decreasing of emission angle.

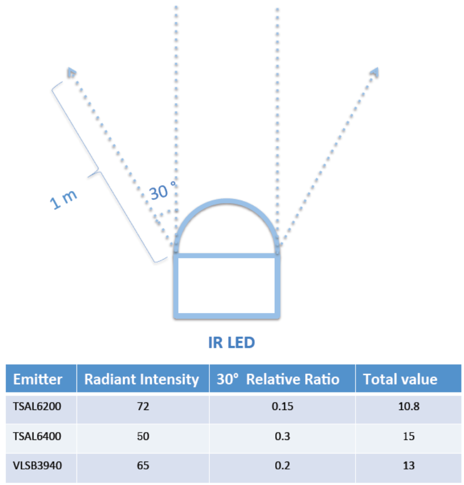
Table 3.1. Emitters for TSOP Receiver Modules

Emitter	Package Diameter	Wavelength (nm)	Radiant Flux $I_f = 100mA(mW)typ.$	Radiant Intensity $I_f = 100mA(mW)typ.$	Emission Angle	Remarks
TSAL6100	5 mm	940	35	130	± 10°	T-1¾
TSAL6200	5 mm	940	35	60	± 17°	T-1¾
TSAL6200	5 mm	940	35	40	± 25°	T-1¾
TSAL6400	5 mm	940	35	60	± 17°	T-1¾
VSLB3940	3 mm	940	40	65	± 22°	T-1

***All IR emitting diodes shown in Table 1 are suitable for use with the Vishay IR receivers for standard remote control applications (38kHz).**

The selection of infrared Led 3.7is to compare the calculated radiant intensity at the same sensing point, same sensing distance and sensing viewing angle. The viewing angle is 30° and the sensing distance is 1 meter. We calculate the relative radiant intensity according to the relationship between the angular displacement and radiant intensity for a certain fix angle 30 degrees. And also the radiant intensity based on the distance in between the tranmitter and the receiver.

In practice, the relationship between irradiance and transmission distance does not exactly follow a quadratic curve. In most cases, the actual distance and angle is smaller



Emitter	Radiant Intensity	30° Relative Ratio	Total value
TSAL6200	72	0.15	10.8
TSAL6400	50	0.3	15
VLSB3940	65	0.2	13

Figure 3.7: LED Selection Criteria

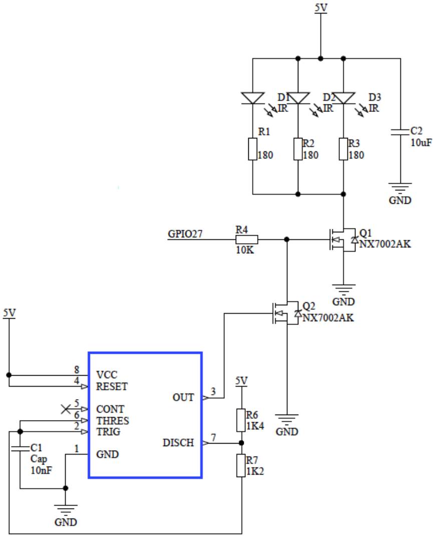


Figure 3.8: Infrared Transmitter Schematic

then calculated bt the exoression. At the same time, when an opaque window or light pipe is used between the receiver and the emitter, the actual transmission distance will be reduced.

The electrical connection of the infrared transmitter is shown in Figure 3.8. There are three IR LEDs in parallel, together covering a full angle of approximately 180 degrees. Each of them connected to a resistor. The current flow through each of them is set to

10mA, which is sufficient for a detection range of 3 meters for the receivers. According to the datasheet of the IR LEDs, we calculate the voltage difference with the forward current and forward voltage relationship. The Vbe voltage gives us R1,R2,R3 value, which is 360Ω. The switches MOSFET Q1 and Q2 together control the pulses and spaces of the IR transmission through GPIO control by the Raspberry Pi. When the osilator gives no signal to the circuit, the Q2 is switched off, which allows GPIO controls the LEDs. The 555 keeps giving modulated signals with 38kHz, this makes sure LED blinks with a constant 38kHz. If GPIO is High, the Q1 is on, the current directly flows to the ground, so that the LEDs are ON.

3.4. MOTION DETECTION MODULE

MEMS (Microelectromechanical systems) rely on miniaturized electromechanical elements for their operations. Three main types of electronic positional sensors, used for capturing human body movements, are accelerometer, gyroscope and electromagnetic. They can be used individually to capture human motion, however, the needs of the combination of them are growing. They together contribute to the 9 DoFs wearable inertial motion sensors. After looking into several MEMS inertial motion sensors from different providers as NXP, Analogue Device, InvenSense, Bosch, and STMicroelectronics, we selected available boards with overall good performances and low price and small size. With excellent sensing performance and fully integration, **LSM9DS1** has been selected as the most common used IMU (Inertial Measurement Unit) for human motion capture. The performace of LSM9DS1 is approximately the same with LSMLDS1, but has an extra 3 Dofs compass measurement. One advantage of LSM9DS1 is that, it is integrated on the Sensehat [2]. which has been used to measure human motion on Raspberry Pi.

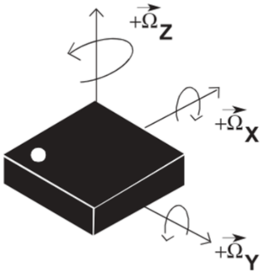


Figure 3.9: LSM9DS1 sensor

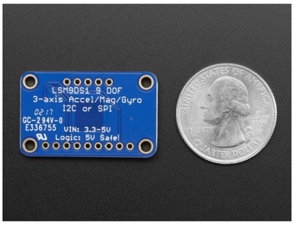


Figure 3.10: PCB Example of LSM9DS1

The chip (Figure 3.9) and PCB (3.10) are shown. LSM9DS1 is a handful IC that meastures three key properties of movement - acceleration, angular velocity, and heading. The LSM9DS1 measures body's acceleretion in gees. The minimum range of 9DS1 accelerometer capacity is ±2g, and can be scaled up to ±16g. The sensitivity of the accelerometer is ranging from 0.06mg - 0.7mg based on their measurement range. And the gyroscope can measure angular velocity in DPS (degree per second) with a maximal

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[2] Sensehat: An add-on board for Raspberry Pi, made especially for the Astro Pi mission

range up to 2000dps. The sensitivity is 8.75 - 70 mdps. And finally the nagnetometer, has a range of ±400 - ±1600, measures the power and the direction of magnetic fields.

Table 3.2. Comparison of MEMS inertial sensors

Specifications	STMicroelectronics LSM6DS33	STMicroelectronics LSM9DS1	Bosch BNO055	InvenSense 9255	NXP FXOS8700CQ FXOS8700CQ	iMAR iµIMU -01/iµVRU-01
Release date	Oct 2015	Sep 2014	Aug 2015	Sep 2014	Mar 2016	Apr 2014
Price	11.96$	6.4$	12.06$	7.22$	1.25$	N/A
Package	LGA 16s	LGA 24	LGA 28	QFN 24	QFN 16	20
Interface	I²C(400 kHz)/SPI	I²C	I²C (100-400kHz)	I²C/SPI(1MHz) (400kHz)	I²C	RS232/RS422/ INS/GNS(200Hz)
Resolution	14/16-bit	16-bit	14/16-bit	16-bit	14/16-bit	16-bit
No. Sensors*	3A 3G 1T	3A 3M 3G 1T	3A 3M 3G 1T	3A 3M 3G 1T	3A 3M 1T	3A 3M 3G 1T
Acc Range(g)	±2/±4/±8/±16	±2/±4/±8/±16	±2/±4/±8/±16	±2/±4/±8/±16	±2/±4/±8	±4 /±16
Gyro Range (dps)	±125/±245/±500 /±1000/±2000	±125/±245/±500 /±1000/±2000	±125/±245/±500 /±1000/±2000	±125/±245/±500 /±1000/±2000	N/A	±250/±500/ ±1000/±2000
Mag Range(μT)	N/A	±400/±800/ ±1200/±1600	±1200	±4800	±1200	±400-±1200
Acc Sensitivity (mg/LSB)	0.061 - 0.732	0.061 - 0.732	1	0.061- 0.48	0.024 -0.976	0.1mg
Gyro Sensitivity (mdps/LSB)	4.375 - 70	8.75 -70	62.5	7.634 – 60.9	N/A	N/A
Mag Sensitivity ($\mu T/LSB$)	N/A	0.014- 0.058	0.3	0.6	0.1	3
Zero level offset accuracy	±10 dps ±40 mg	±30 dp ±90 mg	±3 dps ±80 mg	±5 dps ±80 mg	±10 dps ±30 mg	N/A N/A
Acc rate noise Density($\mu/\sqrt{Hz}$)	90	N/A	150	300	99-126	1000
Gyro rate noise Density($mdps/\sqrt{Hz}$)	7	N/A	14	10	N/A	15
Non-linearity	N/A	N/A	1%	±0.1%	±0.5%	±0.5%
Output datarate(Hz)	13- 6664 13- 1666	N/A N/A	8- 1000 12- 523	4-4000 4- 8000	1.563-800 N/A	200-1000 200 -1000
Signal processing	8kbyte dynamic data batching	N/A	Programmable low pass filter			N/A
Power@3.3V	1.8mA	4.6mA	13.6mA	3.3mA	35-440 µA	<1W@7V

***(A: accelerometer, G: gyros, T: temperature, M: magnetometer, P: pressure)**

The IMU electrical conncetion circuit is described in 3.11. As we can see in the Figure, there are four decoupling capacitors in between the power and the ground. According to the datasheet [28] Power supply decoupling capacitors (C6, C12, C8 = 100 nF ceramic, C11 = 10 µF Al) should be placed as near as possible to the supply pin of the device (common design practice). Capacitor C7 (100 nF) should be a capacitor with low ESR (Equivalent Series resistance) value and should be placed as near as possible to the C1 pin [28]. Pin 21 must connect to GND with the ceramic capacitor with 10 nF (±10%), 16 V. A pull-up resister R9 is connected to the accelerometer and gyroscope data enable.

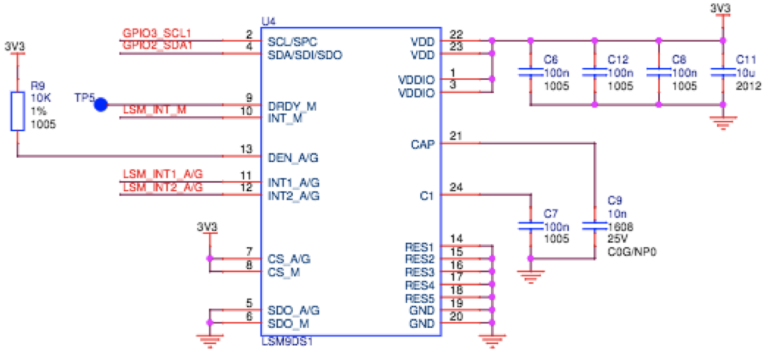

Figure 3.11: LSM9DS1 electrical connections (Sensehat shemetic)

Figure 3.12: RTC

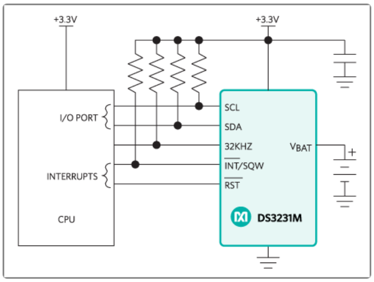

Figure 3.13: RTC Electrical Connection

The LSM9DS1 is connected to two I2C pins on Pi. The I2C embedded inside the LSM9DS1 behaves like a slave device and the I2C protocol must be adhered to. In the I2C of the accelerometer and gyroscope sensor, after the start condition (ST) a slave address is sent, once a slave acknowledge (SAK) has been returned, an 8-bit sub-address (SUB) is transmitted.

3.5. MISCELLANEOUS

The DS3231M is a low-cost, extremely accurate, I2C realtime clock (RTC). The device incorporates a battery input and maintains accurate timekeeping when main power to the device is interrupted. The integration of the microelectromechanical systems (MEMS) resonator enhances the long-term accuracy of the device and reduces the piece-part count in a manufacturing line. The DS3231M is available in the same footprint as the popular DS3231 RTC. The battery is a general small package type CR1220, which can provide power for RTC for at least 10 years.

One push button is connected to one GPIO to control the power on and off the board. Two indicators can be used to show any information for setting up of the device. A 3 pins connector is useful when another expansion board is sacked on, to provide the 3.3V source; 5 V source; and the ground. All of them can be easily controlled by Raspberry Pi.

3.6. HARDWARE ARCHITECTURE

THE overall hardware architecture block diagram is shown in Figure 3.14.

1. **CPU** Quad Core 1.2GHz Broadcom BCM2837 64bit CPU.
2. **Memory** 1GB RAM ; Removable microSD memory card (up to 128 GB).
3. **Sensors** MEMS 9-axis IMU (to capture body movement); IR transceiver/receiver (face-to-face interaction detection); BCM43438 wireless LAN and Bluetooth Low Energy (BLE) (wireless data transfer and proximity detection).
4. **Interface** 4×USB 2.0; 10/100mb Ethernet; 26 GPIO pins.
5. **Miscellaneous** 2 LEDs (charging status indicator); 1 push button; Real time clock with a 12 mm coin cell baterry; Rechargable power bank.

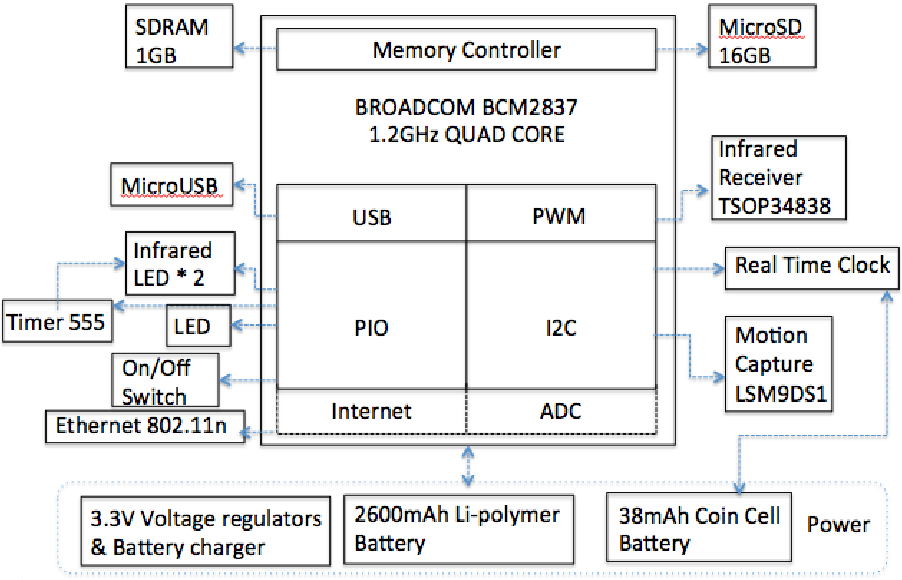

Figure 3.14: Hardware Architecture Block Diagram

3.7. PCB LAYOUT

WITH PCB, the environmental effects are minimized, which provide stable and fast modulated infrared signal.The all in one design provide ultra small board size with all functional components working properly.

The PCB Design of EasyID sensor board was designed with Altium. We take advantage of both sides space, which can minimize the board size. For the location of the components, we first consider the position of the receivers and the transmitters. Then we fix them and try to put the rest according to their schematics. After laying out all components, we start routing. To avoid the collision of routing, we first design the longest one, then a shorter one and leave the shortest and ground to the end. Testing the short circuit is important before finishing the routing. The schematic of the add-on board is attached in the appendix. And the PCB layout is described in 3.15.

Overall, the dimesion of the add-on board is 26.50 × 56.75 mm with 2 layers. With the open source platform, Easy ID can be 85 × 56 × 25mm with a plastic enclosure. There are 26 GPIO pins avaiable on board. And the prototype is weighted 50g. The total price of the Easy ID is 64 euros.

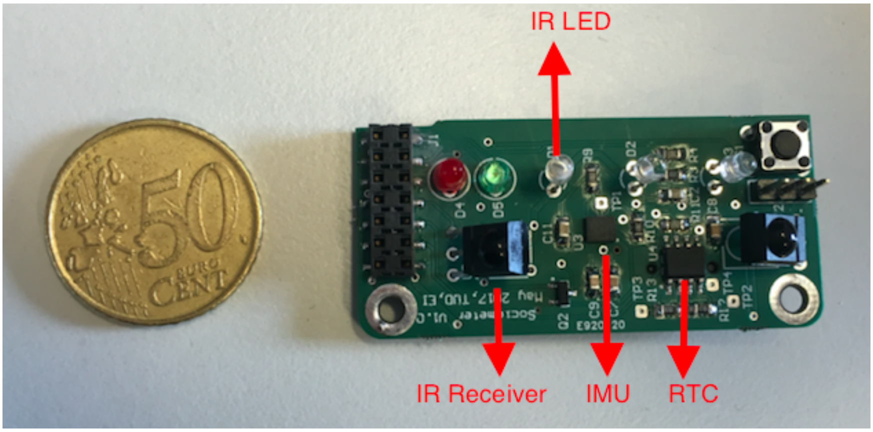

Figure 3.15: Add-on board Front View

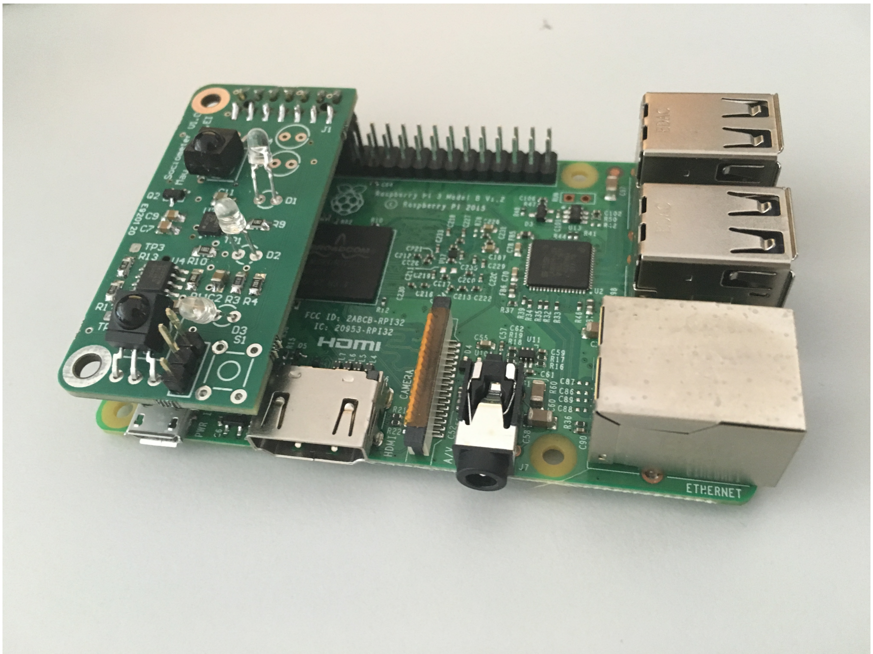

Figure 3.16: Easy ID prototype

4

EASY ID: SOFTWARE DESIGN

Based on the hardware circuit design, the software configuration is given. According to the selection on SBC as well as the motion sensors and their circuit design, the operating system and its software development can be determined. Basic software set up is implemented in this project, for the ID recognition, inertial sensor readout, and data storage. The chapter starts with the system architecture, and followed by each hardware control, especially the algorithm involved in infrared communication for identification detection. Finally, full synchronized data storage will be described at the end.

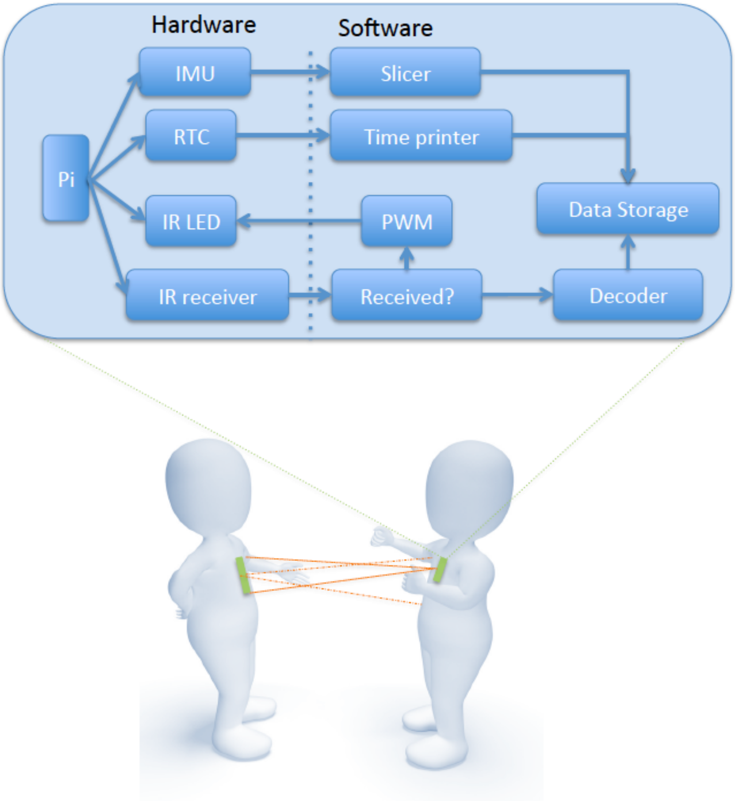

Figure 4.1: System Overview

4.1. SYSTEM ARCHITECTURE

The architecture overview of the EasyID is shown in the figure 4.1. The EasyID is mainly composed of three main functional components, namely IR transmitter, receiver; IMU; and RTC. Each of them is driven by Raspberry Pi through the GPIO control. When the infrared receiver receives any infrared singals with the same hardware and software configuration, the decoding process is triggered on. Together with the high accurate global time stamp provided by the real time clock (RTC), the IDs and human movement information can be stored into a micro SD card in the device. If the receiver doesn't receive anything for one second, the infrared transmitter starts to send its own ID to others. Data captured through 9 DoFs inertial measurement unit (IMU) is forwarded before storing into the file, according to their data source (acceleremetor, gyroscope and compass).

4.2. ID RECOGNITION

Figure 4.2 describes the system architecture for the identification (ID) recognition modules. This section will start with the modulation of the infrared transmitter and

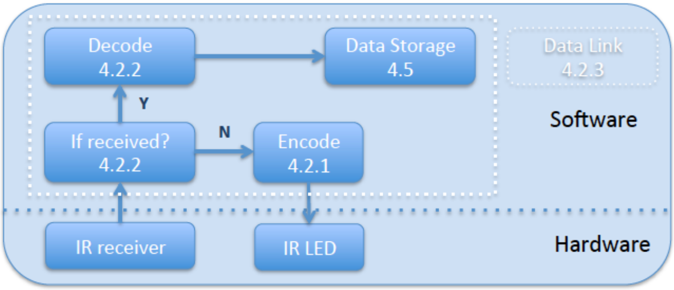

Figure 4.2: Software Architecture for ID Recognition

then describe the demodulation of the infrared receiver. A low pass filter is implemented in this software system.

4.2.1. ENCODING

As we can see from the previous chapter, one way to eliminate the noise and interference of ambient infrared sources is signal modulation. The transmitted signal is modulated using a carrier frequency of 38 kHz, because it is a common carrier frequency and suitable for our goal. The IR (infrared) LED is made to oscillate at this frequency for the time duration of the pulse. The information or the light signals are pulse width modulated and are contained in the 38 kHz frequency. There are two ways to modulate infrared LEDs at 38kHz, one is using the single board computer to drive PWM (Pulse Width Modulation), and the other one is an oscillator. For 38kHz modulation, we use 555 oscillators instead of the software package in Linux called LIRC (Linux Infrared Remote Control), becuase:

The LIRC package doesn't provide enough software development space for users. And the 38kHz oscillation is outside the range. The square wave shows sharp angles continuously when we were trying with the LIRC package. The timer in Raspberry Pi (and all signal board computers) is not accurate enough to make sure an accurate pulse length, as I stated in the previous chapter. The pulse length is what distinguish the logical 1 form 0, so we can not sacrifice the accurate pulse with the privilege of using software packages.Meanwhile, the only disadvantage of using hardware would be power dissipation and take up an extra physical space. The TCL555 oscillator can already provide low power solution (< 750mW) with small physical size (5*6 mm), the price to pay is low.

With a certain carrier frequency, logical 1s and 0s are encoded by pulsing (turning the LED on and off) at 38 kHz for a particular amount of time, pausing a particular amount, pulsing, pausing, etc. until the full signal has been sent. There are already some existing protocols that can be used to realize infrared communication between nodes, which are compared in chapter 2. We design a new protocol (see Figure 4.3), for identification detection among devices with the same configuration. Using existing protocols can cause noises such as commands from infrared remote controllers. The leading pulse is a 3.6ms

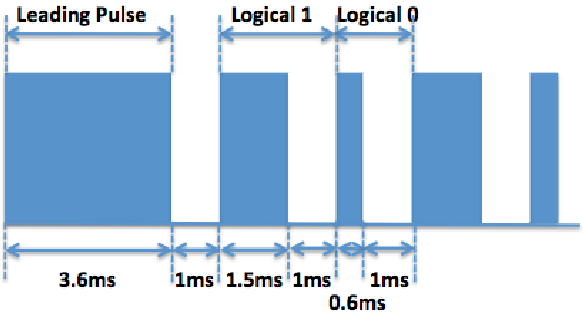

Figure 4.3: PWM modulation for transmitter

pulse with a 1 ms space, the logical "1" is 1.5ms with a 1 ms space and finally the logical "0" is 0.6ms with a 1ms space. The characteristics of the transmission protocol is listed as below.

1. Pulse width modulation
2. 38kHz carrier frequency
3. Bit time is 2.5ms or 1.6ms
4. 8 bit address

The design of the IR protocol is inspired by the NEC protocol, which is using pulse width modulation. Among all common Vishy infrared receiver suppurt protocol as RC5/RC6 code, Sony code, Sharp code and NEC code, we chose NEC becuase it is simple, 38kHz and use pulse width modulation. The total length of the binary string is 8 bits, can be scaled up to 255 devices. The logical 1 was designed as three times larger than the logical 0 (1.5ms to 0.5 ms), which makes the diffrences between 1s and 0s large and the totally time small. The space is twice larger than pulses in logical 0. But the 0.5ms pulse length was not stable becuase of the inaccurate python package time.sleep, the lowest possbile value is 0.6ms according to my test results. So we keep the rest as it should be and make the pulse length in logical 0 a bit longer. The code scheme of the encoding part is simple, we use a python package RPi.GPIO control on a Raspberry Pi. The GPIO.HIGH can be pulse and GPIO.LOW is defined as spaces in between two pulses. With designed pulse length, the code can be determined. (See the codes in Appendix)

4.2.2. DECODING

With the same configuration, the decoding of the infrared receiver, read out the pulse length and translates them into binary strings.

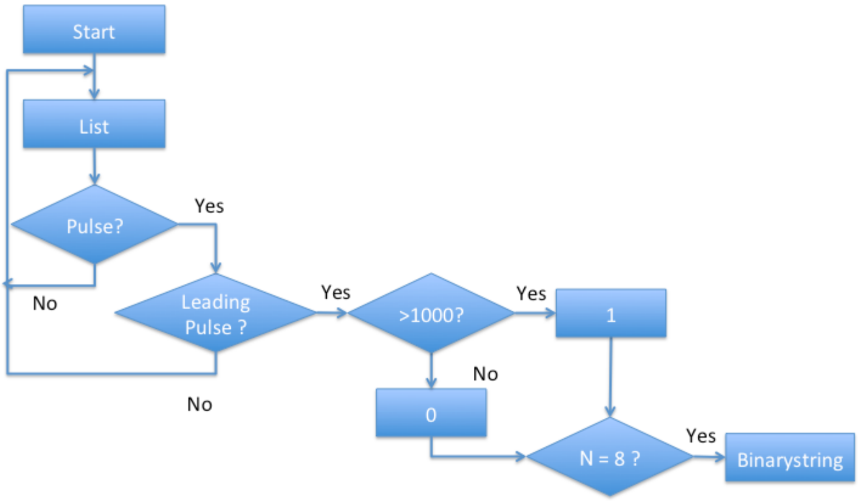

Figure 4.4: Decoding flow chart

The whole program can be divided into parts, namely: read out raw data, transfer into binary strings, and calculate the ID number. And it is better to seperate the three parts during coding, because it is faster and can reduce a lot of errors. After reading out the raw data, then starts with the decoding program can reduce the error rate of program up to 1.67 times, but the speed of sampling time is the same.

Reading out the raw data: Pin 18 and pin 4 (BCM) are used for capturing signal change during the reception. The decoding section does not require a PWM designed GPIO pins as input, so the extension space for future software and hardware development is large. The pulse, space and their time in between can be captured through RPi.GPIO package and datetime package. All raw data can be stored into a list called "command" 4 times per second, for later translations and calculation of the signals. During the raw data reading out, a simple low pass filter is implemented to filter out high-frequency noises signal. Meanwhile, the sampling frequency is defined as a variable, which can be changed according to scale scenario.

Translation into binary strings: The most difficult part for decoding is to translate the raw data into binary strings. Figure 4.4 explains how the program goes. The program starts with a decision if a pulse is received, if true, then it is decided if this pulse is the leading pulse (3.6 ms)? If yes, the bit value is determined as logical 1 or logical 0, if no, we go back to the top to read the raw data again. When we reach up to 8 bits data, the program produce of binary string, which marks the end of the program. The pulse length difference can be used to sperate leading pulse, logical 1 and logical 0. To make sure an exactly eight bits address is decoded, a counter variable is defined. The preamble variable is defined to capture the beginning of the infrared signals.

Calculation of ID number: the calculation from binary string into ID number requires a function, which is $Binarystrings =$ if the binary string is [0,1,0,1,0,1,0,1], the

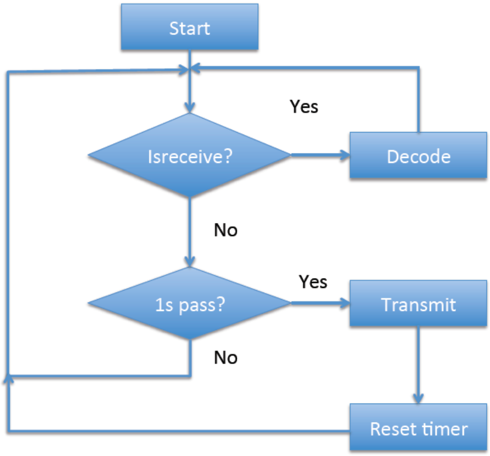

Figure 4.5: ID Recognition Flow Chart

ID equals to 85.

4.2.3. DATA LINK

While the encoding and decoding of the infrared nodes can make a full functioning physical layer configuration, several problems can happen during infrared communication between two nodes or among three nodes. The first one is that the device keeps receiving its own ID. The second one occurs when two nodes or more transmit their ID simultaneously, the collision happens, which causes higher error rates. An algorithms was designed to solve the above problems.

The algorithm is shown in Figure 4.5, which aims at separating the transmitting and receiving channels. If the receiver doesn't receive anything from other devices, the timer starts. If one second passes, then start to transmit. During that one second, the receiver should keep listening. This protocol ensures that the transmission and reception of infrared signals are two channels, which eliminates the chance of seeing itself as well as of interfacing with transmissions from other devices.

Isreceive is a function of deciding if the decoding part should be activated. Instead of reading out a series of infrared pulses and spaces, this function only read and determine if there is a transfer from space to pulse (or the other way around). If yes, the decoder can be activated. With this function, decoding and encoding can speed up to 3 times than without.

Because the designed PCB board has two infrared receivers to cover a full angle of 180 degrees, it is important to control two receivers respectively. The timer is used to check the time passed if the receiver doesn't receive anything. Only if neither receiver A nor receiver B receives anything, the timer can check if a second transmission delay has passed. The software configuration of both receivers is the same, but they can't be on the

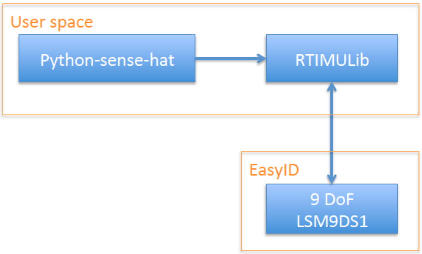

Figure 4.6: IMU software overview

same channel. They should run in parallel, without interrupting each other.

4.3. MOTION SENSOR

An overview of the connection with software and hardware for motion capture part can be seen in Figure 4.6. The RTIMULib is a C++ and python library that makes it easy to use 9-dof and 10-dof IMUs with embedded Linux systems (especially for Raspberry Pi). By default, RTIMULib will try to discover 9DoFs sensor on the I2C bus. If the I2C bus is occupied, the sensor will be detected. Especially, this software package provides magnetometer calibration, which stays in the file RTIMULibCal. Especially, the Kalmen filter is availabe in this library. For changning the scale of the sensors, the

Python file $sensehat.py$ in python 2.7 can be adjusted and adapted as the user space for MEMS sensor of the EasyID. The amended the codes are availabe in the Appendix. In the library, it provides the access to IMU sensor (LSM9DS1), with functions of initialisation the IMU, return the raw data from the IMU (accelemetor, gyroscope and compass respectively).

Python file mems.py is a program made in this project to print out the required data with the function given by $sensehat.py$ in python 2.7. The sampling frequency is set up to 20Hz, which is a variable that can be changed during later development.

The data from the three main parts of the IMU is captured in sequence, with the time stamp and together, they will be stored into the file.

4.4. SYNCHRONIZATION

DataData synchronizaion is realised through the on board real time clock. The real time clock (RTC) use I2C bus, and setting up the module requires the support for RTC through adding a device tree overlay. ($adddtoverlay = i2c-rtc, ds3231intheconfigurationfile$) The command that we used to capture and print out the current time is from the python package time in python 2.7.

4.5. DATA STORAGE

All ID information together with their time frame can be stored into files. With a certain function $orig_stdout = sys.stdoutf = file('mems.csv','w')sys.stdout =$

$fs.stdout = orig_stdout$ All printed data with global time stamp can be stored into a csv (Comma-Separated Values) format, which is stored into the SD Card and can be easily copy out of the open source paltform later on.

5

EASY ID: EVALUATION

After the hardware and software design of Easy ID, it is essential to validate all the functional components as well as the whole system. This chapter presents the performance evaluation of the EasyID badge. The EasyID system performance can be evaluated both with each module separately and with the whole sensor package. This section starts with the evaluation of the ID detection module, followed by the motion sensing module. The battery life of the Easy ID is tested with two different types of rechargeable power bank. Communication among three devices is recorded. Finally, it will show how Easy ID badge is going to be implemented on the human body.

The system performance of Easy ID is validated first with respective to the ID detection, and qunbsequently the motion sensor is tested to see if the data collection and storage is working properly. Finally, the practical Easy ID implementation is described at the end.

5.1. ID DETECTION MODULE

The experimental setup for evaluation the ID detection is shown in Figure 5.1. In this section, the evaluation is designed to see the performance of ID detection between nodes in different cases. Two Easy ID devices are facing each other, with different distances in between, or a different opening angels. Both of them can be controlled by a personal PC, which connected to the same local network, via a router. We only discuss the infrared communication between two devices in this section. Both of the devices can be receiver node and transmitter node.

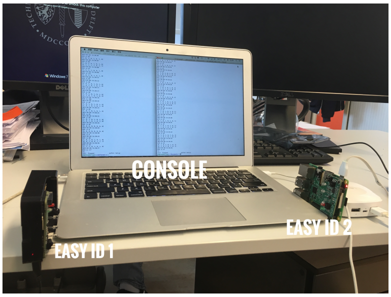

Figure 5.1: Experimental setup for ID detection

Figure 5.2: Enviromental Factors (Shuttered windows, Lights off)

5.1.1. STATIC SCENARIO

The performance of Easy ID's ID detection is first evaluated under static scenarios, i.e., fixed enviromental factors, as shown in Figure 5.2. More specically, the room is Room HB 15.160, the room ceiling lights are kept off and the windows are closed.

Data quality versus distance: Data quality is defined as the possibility of the correct ID detection during a certain period of time. Since there are two symmetrical devices, the average values of the two devices' data quality are calculated. The Data Quality of Easy ID is tested by varying the distance between two devices. The distance is defined as the perdendicular distance between them. The two devices are directly facing to each other, free from the impact of incidence and irradiation angles. The experiment is designed as this, we put one device fixed at one point, and move the other one with a constant speed (100mm/s). For each plot, the experiment lasts for 5 seconds. In this way, the distance in between the two devices is increasing with the response to time. Easy ID reports the instantaneous ID detection every 0.05 second (20Hz). The data in recorded file called distance1.csv, distance2.csv and distance3.csv stored on the SD card and then copied to be analyzed. Through 5.3, we can see that Easy ID maintains its peak ID Detection rate at up to 2.5 m. After this distance, it starts to drop and then drops dramatically because the received signal strength is not sufficient for the receiver to decode the signal.

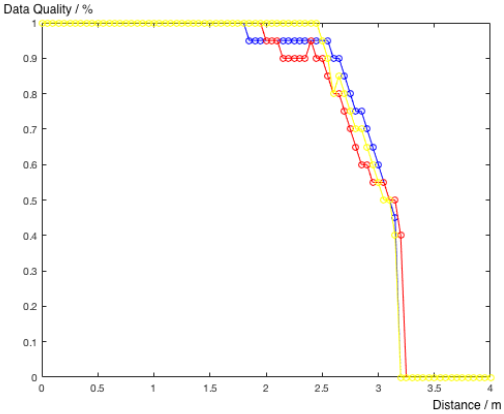

Figure 5.3: Data Quality versus Distance

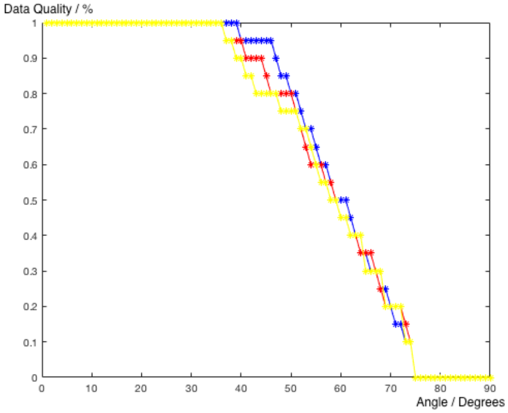

Figure 5.4: Data Quality versus Angle

Data quality versus angle: The performance of Easy ID is also measured while varying the incidence angle from LED to the photodiode. The dependent variable is again data quality, but independent variable is irradiation angles. During the experiments, the perpendicular distance (1 m) from LED to the photodiode is constant, with the variation of incidence angle. The data recorded as one node fixed at a certain point, the other one moving with a constant speed of 5 degrees per second. The sampling rate of the test is 20Hz. From the results, we can observe that the data quality starts to drop from 40 degrees.(Figure 5.4) The reasons why the data quality drops not that dramatically could be three LEDs can compromise each other and the overlap angles can reduce the speed of decreasing data quality.

Comparision with other carrier frequency: The maximum sensing distance of the 38kHz carrier frequency and the 36kHz carrier frequency is different. Figure 5.5 is the screanshot of oscilloscope with 38kHz modulated transmitted signal. With 36kHz carrier frequency, the maximum possible range is 0.6 meters. With 38kHz frequency, the maximum possible distance can reach up to 3.3 meters. With a 38kHz infrared receiver, a 38kHz modulated transmitter ensures the receiver receives maximal signals. Only 40% responsivity from a 38kHz infrared receiver with a 36kHz modulated infrared signal sending.

Comparision with different LEDs: Three LED modules are selected to be quantified and compared according to their behaviors during the experiments, namely VLSB3940 and the TSAL6200. The procedure of the experiments is same with the Data quality versus distance and angle ones. The maximum sensing range is measured that with 95% data quality during the signal communication. The experimental results do not perfectly match the Datasheets. There is a trade-off between the sensing distance and the opening angles. The IR LEDs can be easily soldered to the board as well as be removed from it. The selection of LEDs should be based on the implementation. And the test results have shown biases from the datasheets [29]. VLSB3940 has advantages as largest opening angles, and the physical size is small, can be selected for the crowded dense scenario. But the 5 mm IR LEDs can enable a longer sensing distance, suitable for large scale scenario.

Table 5.1. Comparison with Three Infrared LEDs

	VLSB3940 3mm	TSAL6200 5mm	TSAL6400 5mm
Maximum distance (meters)	2.1	3.3	3.5
Maximum angle (degrees)	160	100	120

5.1.2. DYNAMIC SCENARIO

This section presents the system performance of Easy ID under the dynamic scenario. Important factors could be the change of ambient light, remote controller and the change of room layout.

Ambient light: The change of ambient light may be a potential factor, that infulences the infrared communication, and causes problems while ID detection. The change of

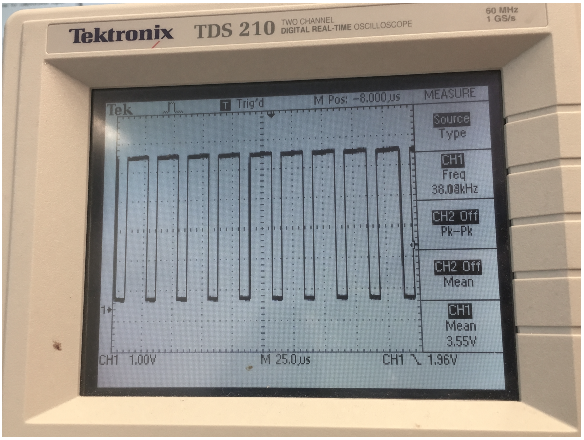

Figure 5.5: The Snapshot of the Transmitted Signals without Encoding

Figure 5.6: Shuttered Window

Figure 5.7: Meeting room

Figure 5.8: Cafeteria

ambient light during research could be a shuttered or unshuttered window with the ceiling lights on or off.

External remote controller: An external remote controller can effect the possibility of sensing correct ID if the receiver senses the signals for the remote controller. The remote controller selected in this experiment is a controller for a projector in the meeting room. The remote controller blinks once every five seconds towards the receiving photodiode. Results of the data quality are analyzed to see the effect of a remote controller.

Different rooms: Change of room layout may cause the reflection of infrared and change the infrared radiance during the studies. Since the most two common real venues are restaurants or theaters, instead of placing the devices only at EWI [1] HB 15.160, where the most of the experiments are done, different rooms are selected to mimic different scenarios will occor during the real life implementation of the devices. One is a meeting room HB 15.114, which mimics the situation in theaters (Figure 5.7) and the other one is at the cafeteria at EWI (Figure 5.8), for the situation in restaurant.

Scenario 1 is the control group, with a shuttered window, an off ceiling light and no interruption. Scenario 2 is the case when the window is shuttered but ceiling light on. Scenario 3 is when the window is unshuttered with an off ceiling light. Scenario 4 is a blinking remote controller scenario. During Scenario 5, we move the devices to the

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[1] Building 36,Faculty of Electrical Engineering, Mathematics and Computer Science (EEMCS) of TU Delft

meeting room. Scenario 6 is when the devices are in the restaurant at EWI. With a constant distance of 0.5 meters between two devices. the devices are directly facing each other. The data quality is calculated with the number of correct ID detection divided by the surrounding total detection (moving average).

From the table 4.1, we can see ceiling light do not effect a lot (2%) to the infrared communication between two devices. However, an open window can introduce a spate of noise, which cause difficulty for photodiode to distinguish the infrared signal from noise. For future research, it is strongly recommended to do the experiments without the effects of sunlight. A remote controller can effect the quality of the infrared connection. The reason why meeting room (theater scenario) has a relatively high data transmission accuracy is it is relative dark to the restaurant and do not have that many reflections according to the layout.

Table 5.2. Dynamic Scenario Experiments

	Discription	1 min	5 min	10 min	Average
Senario 1	Control group	98.6%	95.5%	96.7%	96.9%
Senario 2	Ceiling light on	96.2%	92.1%	96.0%	94.8%
Senario 3	Window opened	56.3%	58.9%	58.0%	57.7%
Senario 4	Remote controller blinked	65.5%	60.1%	60.2%	61.9%
Senario 5	Meeting room Fig 5.7	88.2%	81.1%	81.7%	83.6%
Senario 6	Restaurant Fig 5.8	76.0%	75.2%	60.9%	70.7%

5.2. Motion Detection Module

During the experiments to validate the motion sensing module, data is colllected with moving devices or stable ones. All experiments are repeated three times to eliminate the measurement errors. And the calculated averages of the variables are plotted.

5.2.1. Zero Level

Zero level motion detection quantifies the variation of the sensor when there is no input. If the device is motionless it feels about 1g of acceleration at the z axis. For most low-cost inertial navigation applications, the only aiding source that can be used to limit the velocity errors (and thus reduce the position error divergence rate) is the zero-velocity updates. The box plots are ploted to better indicate the variability of the measured variables. Figure 5.9 5.10 5.11 describe the variation with zero motion on the accelerometers. Each axis is repeated three times. The recording time is 1min per test. The sampling rate is 20Hz. According to the figures, all three axes of acceleration are free of offsets. The datasheet [28] has indecated that the zero level linear acceleration is 90mg for a 8g measurement range, however, the raw data is only recorded as 100mg resolution. So the offest is not recogized during the experiments.

The gyroscope, we can refers to Figure 5.12 5.13 5.14, which show the offsets from the gyroscope measurements. The offsets for three axes are ranging from. For a ±2000dps measurement range, the zero gauss level is claimed ±30 dps (degrees per second). Woth zero movement, the derivation is ranging from 0.05dps - 0.15dps for a 245dps range.

5.2.2. MOVING OBJECTS

To evaluate the motion sensor sensitivity to the physical change, a constant velocity was applied to the device to see if the motion sensor can capture the changes. Figure 5.16 is the moving the device with a constant angular speed. Figure 5.17 shows the device reponsive to a moving with a constant and known acceleration. Figure 5.17 From Figure 5.16 and Figure 5.17 we can see the measured data don't perfectly match the expected one, because of the following reasons:

1. The speed is not constant. It is hard to move the device with a constant speed only by hands. The sensor is of high sensitivity, a little shaking during the movement can cause unexpected values. The limitation of the experimental instruments is lacking an automatic moving machine.

2. Noises. The sensitive IMU is easy to capture any noises from environment and occasion during experiments.

Before real life implementation of Easy ID, good calibration with the more advanced experimental setup is desired. And the calibration on the human body is necessary, to understand the factors that determine the variations.

5.2.3. RELIABILITY

The reliability test is designed as the records of acceleration, angular velocity, the orientation and navigation before all the measurement and after. The time in between is 1.5 hours. And the there are 43 tests in between. The variation of the average is 0.4% - 1.7%, which is calculated the average of the measured variables (accelerations, angular velocities, and orientations). The reliability test is important to define how stable the IMU and motion capture can be with the change of time and the operations on the devices. Small variations can be understood as a time constant data capture during measurements and later researches. The calculation can be seen in Appendix.

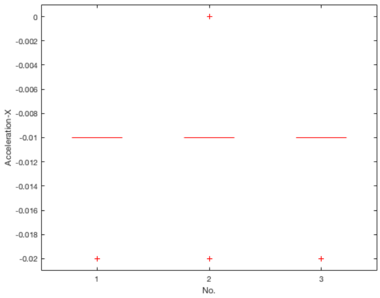

Figure 5.9: Box Plot of x Axis Acceleration

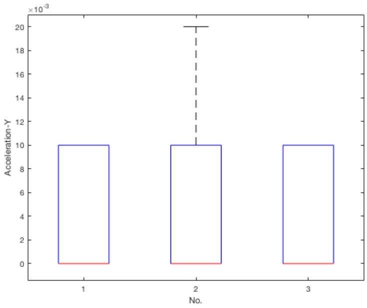

Figure 5.10: Box Plot of y Axis Acceleration

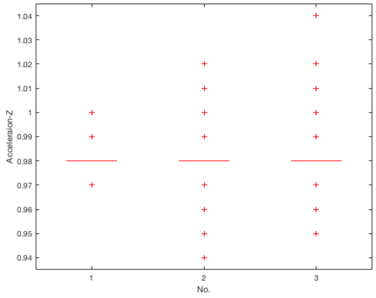

Figure 5.11: Box Plot of z Axis Acceleration

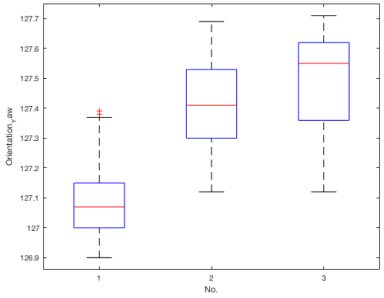

Figure 5.12: Box Plot of Angular Velocity with Yaw Axis

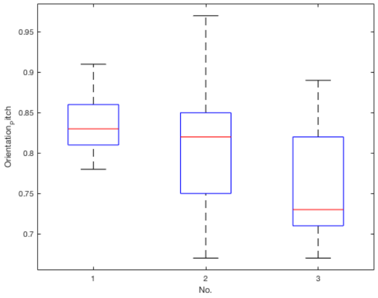

Figure 5.13: Box Plot of Angular Velocity with Pitch Axis

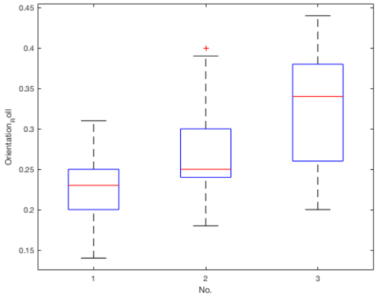

Figure 5.14: Box Plot of Angular Velocity with Roll Axis

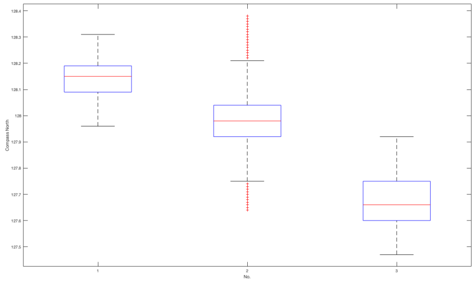

Figure 5.15: Box plot of the compass measurement

5.3. SENSER BADGE

After testing the main modules one by one, experiments are done to validate the sensor badge as a device and prototype and indicate the behaviors during the real life experiments.

Battery Life: The experiment is aimed at testing the battery life of the EasyID. Two available power banks are randomly selected. Figure 5.20. The larger one is the Lepow

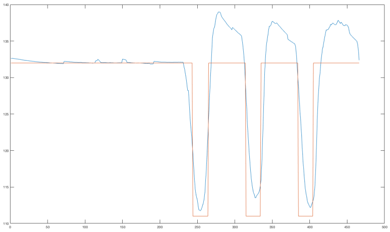

Figure 5.16: Gyroscope Measurements vs Standard

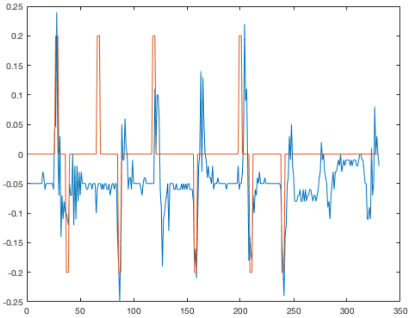

Figure 5.17: Accelerometer Measurements vs Standard

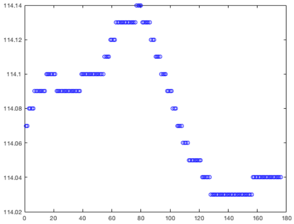

Figure 5.18: Compass Measurements Easy ID

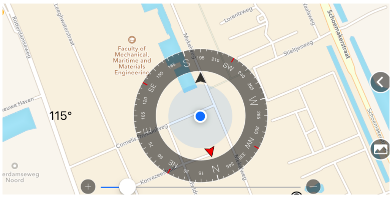

Figure 5.19: Compass Measurements Iphone 6s

Moonstone with a capacity of 6000 mAh, the smaller one is Lab31 with 2200mAh capacity. For the small one, it has a dimension of 25× 27× 88 mm and weights only 110 gram. With Lab31 power bank, the Easy ID can be powered for approximately 9 hours. With Lepow, the Easy ID can be powered up to 12 hours with all functional components working.

Three Devices: Communication among three devices is possible with the designed software and algorithm. By changing the waiting time in between the time where the receiver cannot receiving anything and signal sends, three Easy ID sensor packages can recognize them with the same local network. Figure 5.21 indicates the experimental

Figure 5.20: Lepow Moonstone vs Lab31

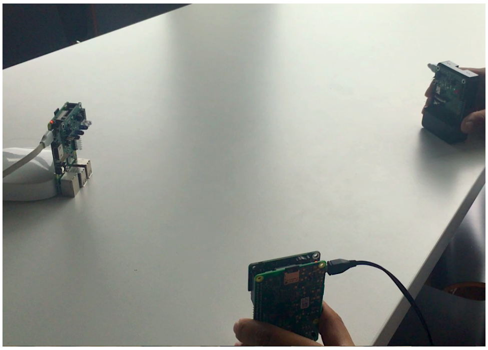

Figure 5.21: Three Easy ID

setup. The distance is no longer defined as the perpendicular distance anymore. But the central point distance. The average distance in between the devices is 0.5 meters and the viewing angle is approximately 60 degrees. The experiments are operated in the restaurant because it has a wider space to arrange three devices at the same table. The data quality for three devices is 57.2% (Easy ID 1 address 129), 61.8% (Easy ID 2 address 139) and 69.3% (Easy ID 3 address 149). The wait time of the three devices is set as 0.5s (Easy ID 3), 0.6s (Easy ID 2), 0.7s (Easy ID 1). A shorter waiting time (Easy ID 3) can recognize a correct data from others. However, the wait time cannot be too short, otherwise, the data quality will decrease.

Easy ID on the body: Figure 5.22 shows the Easy ID as a badge. With a rechargeable battery and a strip. On-body tests were deducted to test if the Easy ID can work properly on the human body. The Easy ID is hanging on the chest of the user, with the infrared LEDs and receivers facing to the front. The ID detection data and motion sensing data

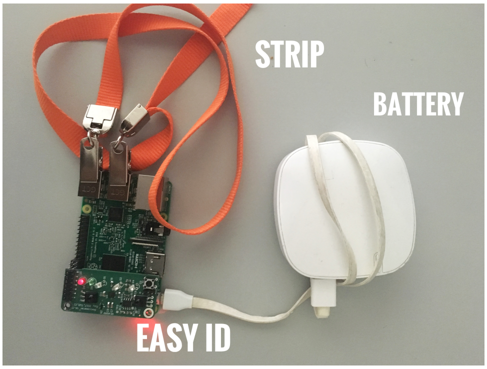

Figure 5.22: Wearable Easy ID

can be printed and stored as logs. Figure 5.23 indicates the on-body tests. The participants are facing to each other. Then one of the participants is turning around, which causes ID information disappears on the other Easy ID's user interface. Then, he turns back to the participant, and the signal comes back. Then both participants walk towards to each other and do a handshake. We notice some changes on the IMU logs during the movements of participants. The recorded data includes handshake, detection of ID, re-detection of ID and moving body with a global time stamp.

Figure 5.23: Wearable Easy ID on body

6

CONCLUSION

The design of an open source platform based sensor badge is important for future research on social behavior through automatically capturing human behavior during social events. This thesis proposed a low-cost and small size customized data acquisition and storage sensor badge called Easy ID that provides enough spaces for future upgrade and extension. Its key modules include i) motion sensor; ii) infrared transmitter; and iii) infrared receiver. Easy ID is based on the low cost and small sized open source platform Raspberry Pi, with a fast processor, large memory and the on-board Bluetooth 4.1. The motion sensor is LSM9DS1 from STMicroelectronics, the infrared receivers and transmitters are 38kHz modulated ones. The 38khz carrier frequency is generated through a low-power CMOS integrated circuit TCL555. The real time clock is a highly accurate DS3231M from Maxim Integrated. Experimental results have validated the stable and real-time data collection of Easy ID. The sensing angle of the Easy ID is 120 degrees and the sensing distance 3.5 meters with a 95% of the accuracy of successful ID detection. The motion sensor can be scaled up to 16g, and the sampling rate is set typically to 20Hz. The maximum sampling frequency is 20kHz. The Easy ID is weighted 48g and the dimension is 85 × 56 × 25mm. The total price includes the raspberry pi is 64 euros.

1. **Customized PCB** Easy ID consists of an open source platform and a add-on Printed circuit board (PCB) with infrared communication module (transmitter, receiver) for ID detection, a MEMS 9 DoFs inertial sensor for human motion sensing, a real time clock for accurate time stamp, two indicators, and one push button for user interfaces to establish a real-time data collection sensor package at a high level of sensitivity.

2. **Open source platform** Easy ID is designed on an open source platform RASPBERRY PI 3 MODEL B and the add-on board is accessible by RASPBERRY PI 2 MODEL B, RASPBERRY PI MODEL B+, and all RASPBERRY PI 1 MODEL. It can be easily upgraded, manufactured, which enables the possible extension of the sensor package.

3. **Python Programming** To control the Easy ID, a high-level programming language, python is used, which emphasizes code readability. Compared to C/C++ language, python is slower, which causes the problem while modulating infrared transmitters. A hardware solution is designed to solve the problem through a 555 oscillator. At the same time, the open source software created to drive the circuits in this thesis can be shared with other similar implementations.

4. **Low cost and small size** The overall cost of the manufactrued Easy ID is 64 Euros. The dimension of Easy ID is 85 × 56 × 25mm.

The proof-of-concept of wearable sensor badge has been presented and validated in this thesis. For the future work, I plan to extend its functionalities from two directions: i) Bluetooth. Current Easy ID can detect any facing device with the same hardware and software configuration. An improvement of the Easy ID is to sense nearby devices using radio- frequency based techniques, such as the BLE, which is already on the Raspberry Pi 3. And with Bluetooth, it is possible to enable the communication between devices; ii) Enclosure. To protect the Easy ID from damage during the experiments in the future, it is recommended to design a suitable enclosure for the Easy ID, for the wearibility of users.

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APPENDIX

Full Requirements

- `Functional requirement:`

1. The device shall measure body motion data (acceleration, orientation and velocity).
2. The device shall detect any facing or nearby devices with the same configurations.
3. The device shall recognize the IDs detected devices.
4. The device shall be able to store all the data in a fully synchronized fashion, using a global time-stamp as reference.

- `Non-functional requirement:`

1. The device must have the capacity to scale to dense crowded scenarios.
2. The device should be easy for users to carry. (Maximum: 200g in weight and 100*100*50mm for dimension)
3. The device should be initially low cost. (Each<100 USD) 9.The device should require minimal maintenance.
4. The start up time of the device when powering should be less than 30 seconds.

5. The accelerometers of the users should be able to be measured. (Minimum: a range of ±2g at a resolution of 0.1g and a maximum deviation of ±0.1g).
6. The linear velocity of the users should be able to be measured. (Minimum: a range of ±10m/s at a resolution of 0.1m/s and a maximum deviation of ±0.1m/s).
7. The angle velocity of the users should be able to be measured. (Minimum: a range of ±90°/s at a resolution of ±1°/s and a maximum deviation of ±5°/s.
8. The configuration capabilities of measurement would be provided using software.
9. The sampling rate of body motion data should be higher than 20 Hz.
10. The device should be able to detect another device within a range of 3 meters.
11. The device should recognize the IDs of nearby (50-300cm) devices.

12. The device should be able to store all the data in a fully synchronized fashion, using a global time-stamp as reference.
13. The global time-stamp should be accessed at a resolution of 0.1s and maximum deviation of ±0.1s.
14. The storage capacity of the device must be large enough to storage all the sensing data in a working day. (2GB)
15. The data must be able to be downloaded form the devices at the end of a recording.
16. The wireless device must be able to run for 6-8 hours on the same battery.
17. The device should have low power consumptions with the maximum 1W.
18. The device should be able to stay functioning at the temperature range from 0-40 °C.
19. The lifetime of the device should be longer than one year.
20. Sufficient I/O capabilities (>10) should be left open for hardware extension.
21. Serial peripheral interfaces as I2C and SPI should be left open on boards for the potential measurement of bio signals.
22. The device should provide means for programming and debugging the software.
23. The device needs to be evaluated in a system configuration of at least 32 devices.
24. The device should be able to robust to mechanical shock. (2g)
25. The device must not cause any severe damage to itself.
26. The device must not cause any health issues to users around it.
27. A third-party device should not read the device.

The Selection of Open Source Platform

Comparison of Raspberry pi, BeagleBone, OLinuXino, Orange pi and ODROID

Name	**RASPBERRY PI 3 MODEL B**	**RASPBERRY PI 2 MODEL B**	**BeagleBone Black**	**BeagleBone Green**	**BeagleBone Green Wireless**
Size	86 x 56 x 17mm		86 x 53 x 4.5 mm		
Weight	1.6 oz		1.4 oz		
Architecture	64/32-bit ARMv8	32-bit ARMv7	32-bit ARMv7-A		
SoC	Broadcom BCM2836		Texas Instruments AM3359 (AM335x)		
CPU	1.2GHz 64-bit quad-core ARM® Cortex®-A7	900 MHz 32-bit quad-core ARM® Cortex®-A7	1 GHz 32-Bit Sitara™ ARM® Cortex®-A8		
Processor Speed	1.2GHz	900 MHz	1GHz		
Clock speed (Max.)	400 MHz	250 MHz	606MHz	800MHz	
Cache	16KB of L1 and 512KB shared L2	16KB of L1 and 256 KB shared L2	32KB of L1 Instruction & 32KB of Data Cache		
SDRAM	1GB LPDDR2		512MB DDR3	512MB DDR3	512MB DDR3-1866
EEPROM	N/A		4KB	4KB	
GPU	Broadcom VideoCore IV		PowerVR SGX530		
Power consumption*	800 mA @ 5V		210 – 460 mA @ 5V	210 – 460 mA @ 5V	Low power mode (ELP)
I/O	40 GPIO		65 (digital) + 7 (analogue)	65 (digital) + 7 (analogue) + 2x Grove connectors*	
USB 2.0	4		1+1 (Standard A host port + mini B device port)		4 +1 (Micro USB)
Video out	HDMI, composite video		MicroHDMI, cape add-ons	Via HDMI Cape only	
Audio out	Multi-Channel HD Audio over HDMI, Analog Stereo from 3.5mm Headphone Jack		MicroHDMI, cape add-ons	Via A2DP	
Low-level peripherals	17× GPIO, UART, I2C, 2x SPI		4x UART, 8x PWM, LCD, GPMC, MMC1, MMC2, 7 AIN(1.8V MAX), 4 Timers, 4 Serial Ports, CAN0, EHRPWM(0,2),XDMA Interrupt, Power button, Expansion	8x PWM, I2C and UART GPIO(69 max), LCD, GPMC, MMC1, MMC2, 7 AIN(1.8V MAX), 4 Timers, 4 Serial Ports, CAN0, EHRPWM(0,2),XDMA Interrupt, Power button, Expansion	
On Board Internet	10/100mb Ethernet 802.11n wireless, Bluetooth 4.1	10/100mb Ethernet	10/100mb Ethernet		10/100mb Ethernet 802.11n wireless, Bluetooth 4.1
Real time Clock	RTC modules possible		N/A		
On-board storage	Micro SD card slot		8-bit eMMC (Rev B: 2 GB, ReV C: 4 GB); microSD card slot		
Storage capacity	64GB	32GB	4GB (provided) 64GB		
Power source	2 sources MicroUSB or GPIO header 5V1, 2.5A		4 sources USB port on a PC; A 5VDC 1A power supply; USB connector; Expansion connectors	3 sources A USB port on a PC A power supply with a USB connector; Expansion connectors	
Price	$35	$32	$55	$39	$45

Name	**A13-OLinuXino-WIFI**	**A10-OLinuXino-LIME-4GB**	**Orange Pi Plus2**	**ODROID-C2**	**ODROID-XU4**
Size	100 x 85 x 17 mm	84x 60 x 17 mm	108 x 60 x 17 mm	85x 56 x 17 mm	98 x 74 x 29 mm Including cooling
Weight	1.4 oz	1.4 oz	1.4 oz	1.4 oz	
Architecture	32-bit ARMv7-A	32-bit ARMv7-A	32-bit ARMv7-A	64-bit ARMv8-A	ARMv7
SoC	Allwinner A13	Allwinner A10	Allwinner H3	Amlogic S905	Samsung Exynos5 Octa
CPU	1GHz 32-bit ARM® Cortex® -A8	1GHz 32-bit ARM® Cortex® -A8	1.2GHz 64-bit Quad-core ARM® Cortex® -A7	2GHz 64-bit Quad-core ARM® Cortex® - A53	2Ghz Quad - ARM® Cortex® -A15 and 1.3GHz Quad -Cortex®-A7
Processor Speed	1GHz		1.2GHz	2GHz	2GHz
Clock speed (Up to)	553MHz	553MHz	696MHz	333MHz	933MHz
SDRAM	512MB DDR3		1GB DDR3	2 GB DDR3	2GB LPDDR3
EEPROM	N/A	2 KB	N/A	N/A	N/A
GPU	ARM Mali400		ARM Mali400 Supports OpenGL ES 2.0	3 x ARM Mali450	Mali-T628 MP6
Power consumption	Stand by: 380 mA @ 6V [23]	Stand by: 210 mA @ 5V	1 A @ 5V	350 – 880 mA @ 5V	600mA @ 5V
I/O	74 GPIO UEXT connector*	160 GPIO	40 GPIO (Ground)	40 (digital) + 7	60 GPIO
USB 2.0	3 + 1 USB hosts, (3 available for users 1 for WIFI)	2 + 1 (USB-OTG)	4 + 1	4 +1	1+ 2x USB3.0
Video out	VGA (800 x 600 resolution) LCD interface	HDMI	HDMI, Integrated CVBS	HDMI 2.0 4K/60 Hz	HDMI
Audio out	3.5 mm Jack; HDMI	3.5 mm Jack; HDMI	3.5 mm Jack; HDMI	HDMI/ I2S	I2S
Low-level peripherals	3x I2C; 2x UARTs; LCD	3x I2C; 2x UARTs; LCD	UART, compatible with Raspberry Pi B+	I2C; PWM; UART; 1-Wire ADC	UART; I2C; ADC; I2S
On Board Internet	WIFI RTL8188CU 802.11n 150Mbit (Not included)	10/100/1000M Ethernet, WIFI RTL8189ETV, IEEE 802.11 b/g/n	10/100/1000M Ethernet, WIFI RTL8189ETV, IEEE 802.11 b/g/n	10/100/1000M Ethernet	USB IEEE 802.11b/g/n 1T1R WLAN with Antenna
Real time clock	On board	N/A	RTC modules possible	N/A	
On-board storage	4GB NAND flash; microSD card slot	4GB NAND flash; (Not included) microSD card slot	8GB eMMC Flash TF card (Max. 64GB) / MMC card slot, up to 2T on 2.5 SATA disk	8GB eMMC Flash; microSD card slot	eMMC 5.0 HS4000 Flash Storage; MicroSD Card Slot
Storage capacity	4GB	8GB	64GB	32GB	32GB
Power source	3 sources 6-16VDC input power supply (Noise immune design); 1 USB OTG; Battery option and connector	4 sources 5VDC input power supply (Noise immune design) 1 USB OTG; Battery option and connector SATA Connector	2 Sources DC input USB	2 sources 5VDC input power supply; 1 USB OTG;	2 Sources DC input; USB
Operating system	Linux	Linux	Kali Linux Arch Linux	Linux (might not stable)	Linux
Price	$49	$39	$39	$40	$74

*UEXT is a board to board connector connecter, which supports three serial communication interfaces - I2C, SPI and RS232. There is also 3.3V line and GND. It is a great way to expand the features of the development boards you already have. The customer can choose which new feature he wants to expand.
*Grove connector: UART and I2C connectors for SeeedStudio Grove modules
*Power consumption depends on the tasks on board. Most of the values in this table are at idle, which make the minimal limits. And the maximal power consumption still needs experiments.

The Schematic of the Add-on Board

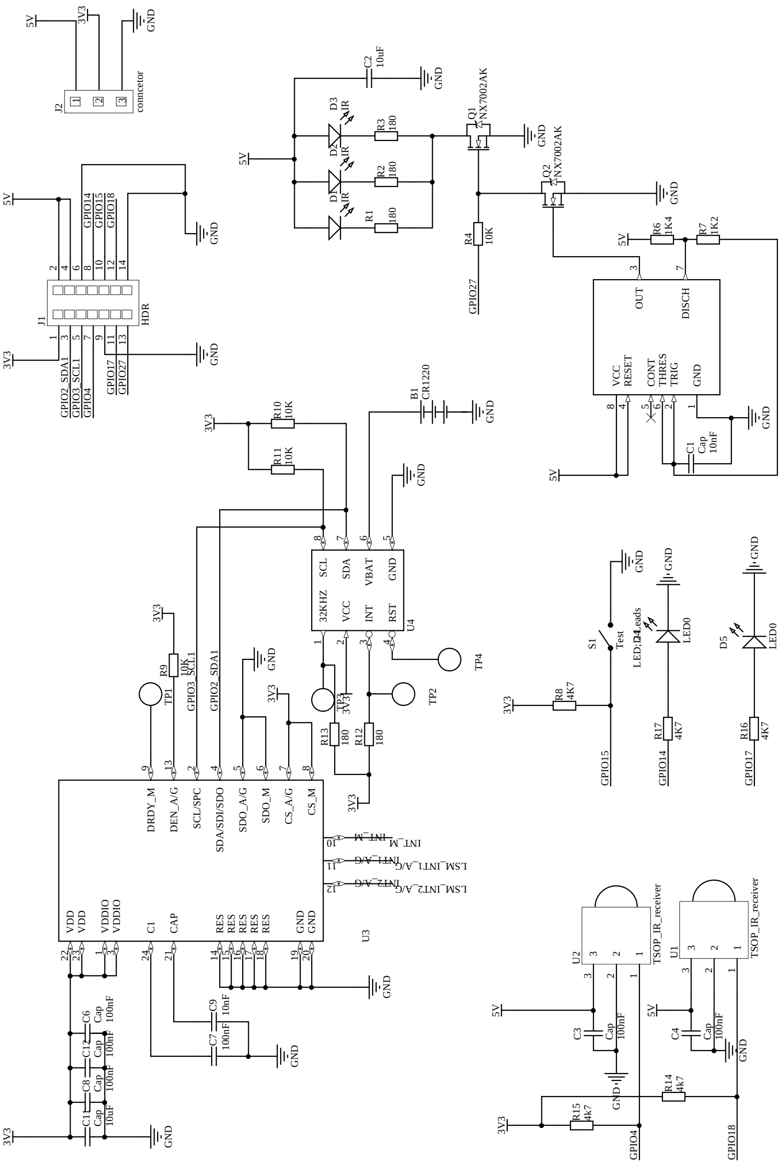

Figure 1: Relevant Values for IR Transmission Distance

Easy ID Demo

The demo video of this project is available here:
https://www.dropbox.com/sh/3qus0i5qm6lquw7/AAC0X7y28MnIIH1$_{n}u_{V}P7P-a?dl=0$.
For a better viewing experience, please download it and then watch it offline.