RADAR SENSOR SYSTEM FOR MONITORING ELDERLY PEOPLE AT HOME

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Bru Catalán i Mor

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Thesis supervisor:

Dominique Schreurs

Mentor:

Oluwatosin Babarinde

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Abstract

Considering the aging society tendency that the whole world is experiencing, the percentage of elderly people will incrementally represent a larger share of the total population. Older adults are more prone to develop health problems. For them to be successfully treated, early detection is crucial. So as to facilitate this, monitoring them will make for a remarkable improvement.

A radar sensor which enables this possibility is what this thesis is about. Starting from an already developed project, several parts have been modified to make the system more efficient.

The contributions implemented in the practical work of the thesis are about the modification of the functioning of the system, adding a more secure way of storing the data by introducing a Raspberry Pi for such purposes. Moreover, a PIR sensor, which is used to detect movement, is also added to the structure providing several benefits to improve the performance of the whole system.

Last but not least, since this project affects the privacy of its users, an ethical discussion has been carried out to assure its viability.

Resum

Tenint en compte la tendència actual en la qual, arreu del món, les societats s'estan envellint, el percentatge de gent gran representarà cada cop una quota major respecte al total de la població. Les persones d'edat avançada són més proclius a desenvolupar problemes de salut. Per a ser tractats amb èxit, detectar prematurament una malaltia és crucial. Per facilitar això, monitoritzar el seu comportament suposaria una millora remarcable.

Un sensor de radar que possibilita aquest monitoratge és sobre el que tracta la tesi. Partint des de la base d'un projecte ja desenvolupat, diverses parts han estat modificades per a fer el sistema més eficient.

Les contribucions implementades a la part pràctica del treball de la tesi són sobre la modificació del funcionament del sistema, afegint-hi una manera més segura d'emmagatzemar les dades incorporant una Raspberry Pi per a aquestes finalitats. A més a més, un sensor PIR, que s'utilitza per a detectar moviment, ha estat afegit a l'estructura, oferint diversos beneficis per a millorar el rendiment del sistema en general.

Per últim, però no per això menys important, com que es tracta d'un projecte que afecta a la privacitat dels seus usuaris, una discussió sobre els aspectes ètics s'ha portat a terme per a assegurar la seva viabilitat.

Resumen

Teniendo en cuenta la tendencia actual en la que, en todo el mundo, las sociedades están envejeciendo, el porcentaje de personas mayores representará cada vez una cuota mayor respecto al total de la población. Las personas de edad avanzada son más proclives a desarrollar problemas de salud. Para ser tratados con éxito, detectar prematuramente una enfermedad es crucial. Para facilitar esto, monitorizar su comportamiento supondría una mejora notable.

Un sensor de radar que posibilita este monitorizaje es sobre lo que trata la tesis. Partiendo desde la base de un proyecto ya desarrollado, varias partes han sido modificadas para hacer el sistema más eficiente.

Las contribuciones implementadas en la parte práctica del trabajo de la tesis son sobre la modificación del funcionamiento del sistema, añadiendo una manera más segura de almacenar los datos incorporando una Raspberry Pi para estos fines. Además, un sensor PIR, que se utiliza para detectar movimiento, ha sido añadido a la estructura, ofreciendo varios beneficios para mejorar el rendimiento del sistema en general.

Por último, pero no por ello menos importante, como que se trata de un proyecto que afecta a la privacidad de sus usuarios, una discusión sobre los aspectos éticos se ha llevado a cabo para asegurar su viabilidad.

Samenvatting

Gezien de vergrijzing van de bevolking die de wereld aan het ervaren is, zal het percentage van oudere mensen stijgen t.o.v. de gehele bevolking. Oudere volwassenen zullen dan meer gezondsheidsproblemen ondervinden. Als deze mensen goed willen behandeld worden, is het vroegtijdig opmerken van deze problemen cruciaal. Voor dit te laten werken, zouden de mensen constant moeten onderzocht worden voor een opmerkelijke vooruitgang.

In deze thesis zal een radarsensor besproken worden die dit mogelijk maakt. Vertrekkend vanuit een al ontwikkeld project zijn enkele onderdelen ervan gewijzigd om een efficiënter systeem te maken.

De bijdragen die geïmplementeerd zijn in het praktische gedeelte van de thesis gaan over de wijzigingen van de functionaliteit van het systeem. Dit betreft het toevoegen van een veiligere manier van opslaan van gegevens door het introduceren van een 'Raspberry Pi' voor dat soort doeleinden. Bovendien wordt ook een 'PIR' sensor, die gebruikt wordt om beweging te detecteren, toegevoegd aan de structuur. Dit geeft verscheidene voordelen zodat de performantie van het hele systeem verbeterd wordt.

Tenslotte is er, aangezien dit project de privacy van de gebruikers betreft, een ethische discussie uitgevoerd om de haalbaarheid te verzekeren.

Acknowledgments

First of all, I would like to thank Prof. Dominique Schreurs for helping me with her advice during the development of this thesis and also for being attentive whenever I need anything. Also, special thanks to researcher Oluwatosin Babarinde for guiding me through the whole process, for creating an enjoyable work environment in the laboratory, for making sure I was learning while working and for motivating me. It was a pleasure working with both of them.

I would not have got to this point of finishing my degree without the support and encouragement of studying given by my parents. I am profoundly grateful for the education they have given me and the resultant mindset I have acquired.

To finish, I would also like to thank Belgium and specifically the city of Leuven and its KU Leuven University for being the perfect place for a student to live in while carrying out his degree because of its facilities and helpful manners towards students.

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List of abbreviations

PIR – Passive InfraRed

RF – Radio Frequency

TX – Transmitter

RX – Receiver

SIR – Signal-to-Interference Ratio

CW – Continuous Wave

UWB-IR - Ultra-Wideband Impulse Radio

SFCW - Stepped-Frequency Continuous Wave Radar

ADC – Analog to Digital Converter

LNA - Low Noise Amplifier

IQ – In-phase/Quadrature

PLL – Phase Locked Loop

VCO – Voltage Controlled Oscillator

GPIO – General Purpose Input/Output

SPI - Serial Peripheral Interface

USART - Universal synchronous and asynchronous receiver-transmitter

GND – Ground

CHAPTER 1

INTRODUCTION

1.1.-Aging Population

Societies in developed countries are affected by aging population. Today's percentage of people above the age of 65 is considerably high. In addition, several studies regarding this topic have projected that the share of this age group will only increase in the next years. This tendency is reflected in the following graphs. [Fig. 1.1, 1.2, 1.3, 1.4]. It can be seen that in Belgium, Catalonia and the European Union the percentage of people older than 65 years old is close to 20% at the moment but is expected to grow to more than 25% in no more than 15 years. Accordingly, the life expectancy of these societies is increasing every year. Going from today's ~82 years old to ~85 in the next years. Considering the whole world, we can see that both the percentage of people over 65 years old and the life expectancy is not as high as in the developed world, so many countries still do not have an aged population. As much as their population might not be considered old at the moment, the tendency in the world is also to increase those statistics. So, it may not be a problem now but it is going to be in the near future.

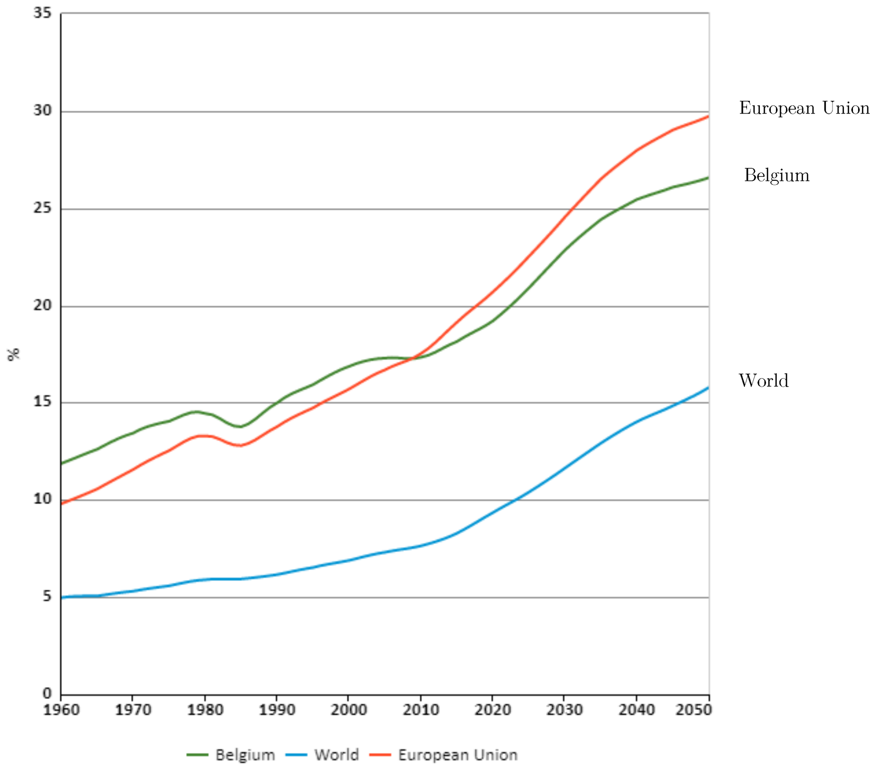

Figure 1.1. % of population over 65 years old in Belgium, the European Union and the whole world.

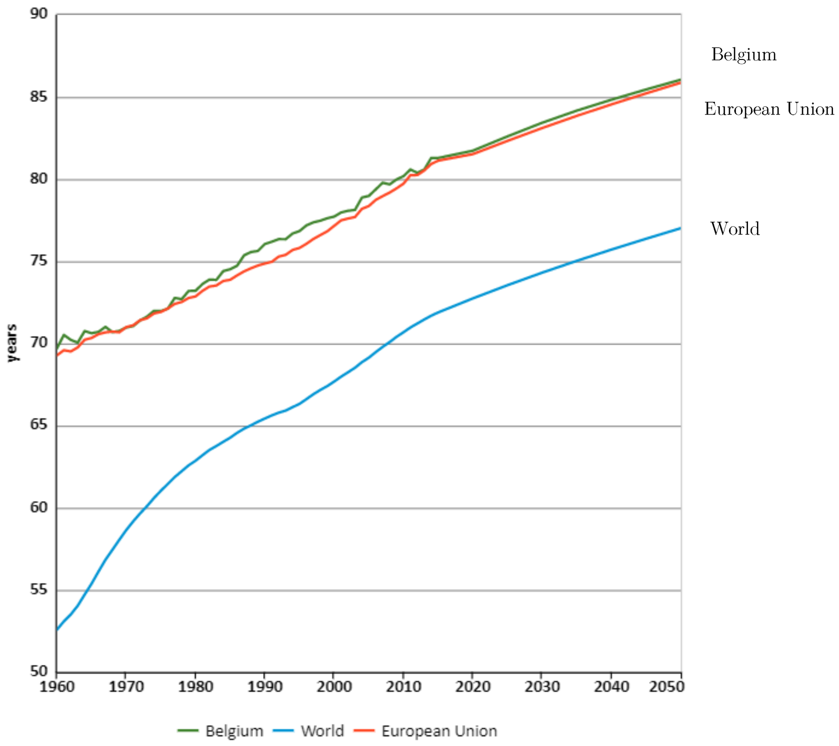

Figure 1.2- Life expectancy in Belgium, the European Union and the whole world.

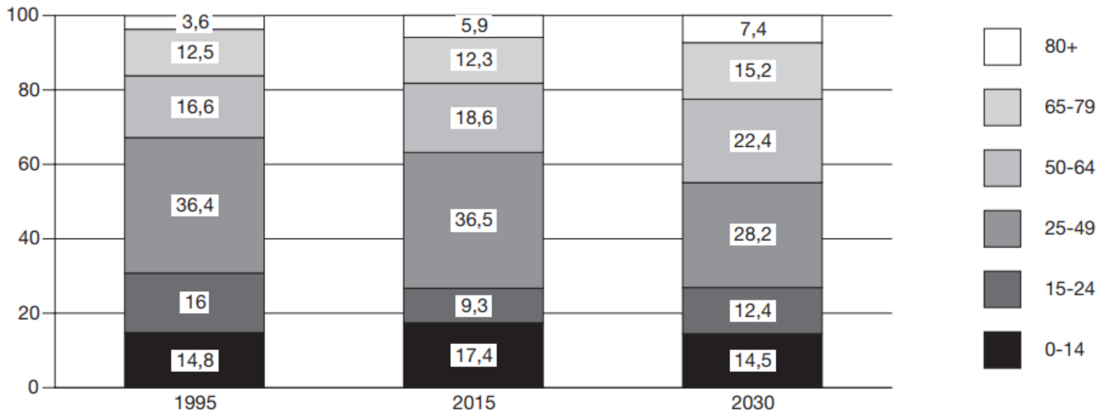

Figure 1.3- Age groups % in Catalonia in 1995, 2015 and the projection in 2030.

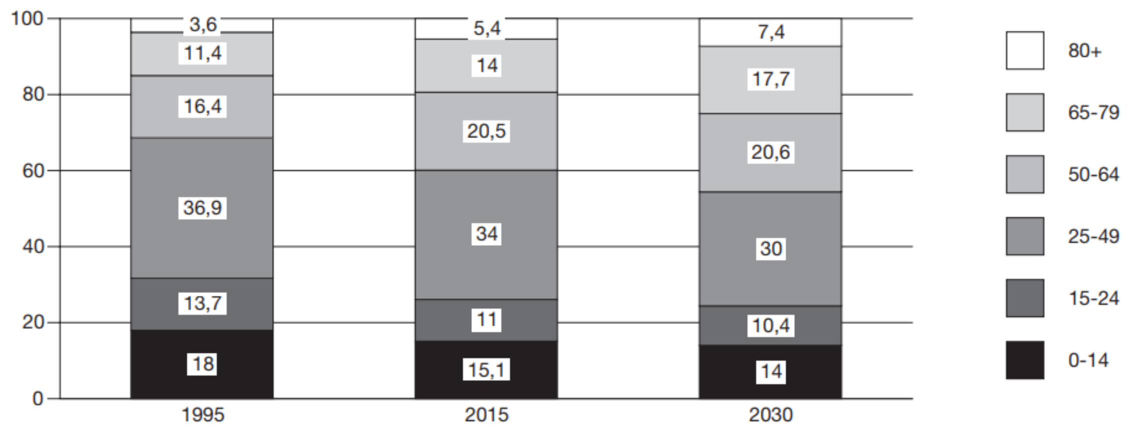

Figure 1.4- Age groups % in the European Union in 1995, 2015 and the projection in 2030.

1.2.-Healthcare

There are many health problems that are directly linked to old age. Elderly people are more prone to several health issues such as: lack of cognitive health, mental illnesses, chronic diseases (Heart disease, stroke, cancer, diabetes, etc.), physical injuries, sensory impairments (vision, hearing), etc.

For these health issues to be treated efficiently it is important to detect them as early as possible. Considering that nursing homes have limited places and also that some families cannot afford them for its expensive costs, plenty of older adults live at home. This creates a health risk, especially when the aged people live alone. Moreover, caregivers are normally family members or unspecialized workers without professional support that will not have the ability to detect early symptoms of a disease or will not be able to help the person in a dangerous situation. Furthermore, there is the problem of fall events. Research pointed out that 30% to 45% of people older than 60 years old fall at least once a year.

People who experience a fall event at home, and remain on the ground for an hour or more, may suffer from many medical complications, such as dehydration, internal bleeding and cooling. The delay in hospitalization increases mortality risk. Studies have shown that the longer the people lie on the floor, the poorer is the outcome of medical intervention. This is a risk that have elderly people who live alone at home and cannot ask for assistance after a fall occurs.

1.3.-Monitoring

Both for detecting falls and changes of behavior or changes in the speed of movements of the older adults that can be the symptom of a health issue, it is necessary some kind of monitorization of those people. Some systems already exist but they are either too invasive in people's privacy (camera systems) or they require user involvement which is not always reliable. Regarding the invasive systems, people usually will not be comfortable having cameras around their home as they want to preserve its privacy. Concerning the systems requiring user involvement, there are devices like wristwatches or necklaces with a button that should be pressed by the person in case of emergency or dangerous situations to trigger an alarm to a caregiver or physician. However, the main problem is that in those situations the person may no longer have the reflex to press this button or may no longer be able to do so. In addition, wearable sensors to monitor user's health constants and movements have some handicaps. This involves that people might forget to wear them or to activate them. Also, they work with batteries and if they go out of power, lots of data will be lost. Another inconvenience could be that people might not feel comfortable wearing those sensors, and for that reason, they could stop using them during some periods of time which will result in biased data.

Therefore, for the mentioned home situations, 'telesensing', or in other words contactless health monitoring, meaning without the need for actions by the person, would be the ideal solution. In this way, a person can freely carry out his/her activities while being monitored remotely detecting any dangerous situation or a change of behavior or change of speed in his movements that might be the symptom of a health issue.

1.4.-General idea of the project

This thesis is a continuation to the already developed 'Contactless Health Monitoring Sensors' [1], a project developed in ESAT's department TELEMIC of the university KU Leuven.

The radar sensor consists of a pair of antennas, a radar circuit board including a microprocessor, a raspberry pi, a power supply and a movement detector. The general idea of each component is the following. The radar circuit board will generate the radar waves that will be transmitted via an antenna to the moving person, and after reflecting on the person, the returned signal is received by the second antenna. If the excitation is a single-frequency radio-frequency (RF) signal, the person's speed can be measured using the Doppler effect. If the excitation is a stepped frequency RF signal, the distance between the person and the sensor can be determined. By having such three measurements, the location of the person can be known. The microprocessor will process the received signal and transform it to storable data. Then the raspberry pi is needed to collect these data and store them on the USB pen drive for the duration of the tests. The function of the power supply is to interface between the mains and the electronics, as to bias all the components with their proper voltage and current settings. Finally, the movement detector will be used to save memory capacity. It will detect whether a person is in the room and it will only activate the radar and the Raspberry Pi if there is someone present.

With at least three of these sensors installed in a room, we are able to know the exact position of the moving person and, in addition, we can measure his/her speed. Basically, we want to study if the movements of a person are normal. By looking at the data obtained over the whole period of time (>1 month) we can detect gradual changes in the behavior or a sudden change of speed of his/her displacements in the room being monitored. When that happens, it may indicate that the user is suffering from a health problem, including cognitive decline.

1.5.-Contributions in the development of the project

The contributions done in this thesis are the following. First of all, the work on the board as some changes have been made regarding the design of the whole system and the change of some components. Secondly, the discussion about the ethics and the consequent writing of them in the ethical application of the project. As it is a project that involves user's privacy, it must be stated that it does follow all the laws concerning the privacy of people at their home, also that everything is done in a secure way both for the security of the data obtained and the safety of the user's health. Last but not least, an improvement of the system adding a movement sensor in order to detect whether there is a person or not in the room so as to make the whole radar system more efficient.

CHAPTER 2

STATE OF THE ART

2.1.- Introduction

In this chapter some other applications already in the market are going to be explained briefly so as to put the reader in context of the available tools the monitor elderly at home. By knowing which tools are available nowadays, we can appreciate that there is nothing like the radar system developed in ESAT for monitoring elderly people and carry out studies to detect changes of behavior, changes in the speed of movements of the users or fall events. Afterwards, a technical approach to the theoretical background of the radar sensor will be exposed. The main equations and theorems formulated in the design of the system are explained as well as the reasoning behind them.

2.2.- Existing systems

In the ambit of monitoring elderly people at home, there exist some systems that help caregivers to be aware of the wellbeing of the older adults. These systems are less complex than the one that this thesis contributes to.Some examples of those already existing systems are the following.

A device that monitor the pills that an older adult has to intake during the day sends notifications to your smartphone about whether the older adult has taken or not the pill or if he has accidentally taken the wrong one.

Another system uses cameras placed around the house that allow the caregiver to check whenever he wants what is happening at user's home via a mobile app. This system can be good enough for checking on a person in a specific moment, but it does not store any data to carry out a study on the changes of behavior or changes of speed in a person. In addition, a fall event will not be detected unless the caregiver checks for himself the video transmitted by the camera. Moreover, this system is too intrusive for many people as they will not like the idea of being recorded all the time, lacking privacy at home.

There also exist systems that use movement sensors in specific places of the house, such as the fridge, the doors of each room, the living room and also temperature sensors in the kitchen. These sensors send a notification to the caregiver telling them things like: 'the fridge was opened', 'temperature in the kitchen raised to 25 degrees', 'front door was opened', 'no movement has been detected in the living room', etc. Using this system, the caregiver will be informed of the routine of the elderly person and will be able to stay aware if something does not go normally. As well as the other systems mentioned before, these systems lack the capacity of detecting changes in the speed of movement of the person, so it will not be useful for early detecting of health issues.

2.3.- Theoretical background

2.3.1- General Radar Equation

Radar, acronym for radio detection and ranging, is an electronic device used to transmit an electromagnetic signal to a target and to receive the reflected echo, on the basis of which the target's speed and absolute distance can be extracted.

It consists basically of a transmitter TX, a transmit antenna, a receiver RX, a receive antenna, and signal processing hardware and/or software. The transmitter generates a waveform T(t) that is emitted by the transmitting antenna. A portion of this signal is intercepted by the target and is reradiated in all directions. Part of this energy is reradiated back to the radar and collected by the received antenna. The receiver then compares the received signal R(t) with a copy of the transmitted signal T(t) and the signal processing unit analyzes how the returned signal has been altered by the target. More precisely, the time delay between the transmitted and received signals indicates the distance to the target, while the frequency shift of the received signal enables calculation of the target's speed.

A huge advantage of radio and microwave frequency radar systems is that they can go through objects that are opaque, so it allows the detection of objects that cannot be seen. Moreover, they guarantee both the optimal resolution and sensitivity to remotely monitor a human target in a home environment, thus representing the most suitable solution for applications like vital signs monitoring, fall detection, and tagless localization.

The radar performance depends on the signal coming into the receiver from the target and the strength of the interference signals. The ratio to measure this is the Signal-to-Interference Ratio, SIR. For better detection, it is important to maximize this ratio.

$$\mathrm{SIR} = \frac{P_r}{P_n + P_c + P_j} \qquad (2.1)$$

Where Pr is the received power reflected from the target, that is calculated this way:

First, Pd is the power density at a target, from a directive antenna with radiated power Pt and transmitted gain Gt, divided by the surface area of an imaginary sphere of radius R.

$$\mathrm{Pd} = \frac{P_t\ G_t}{4\pi R^2} \qquad (2.2)$$

Then the radar captures a portion of the echo power. The power density at a target is now affected by σ, the Radar Cross Section, which is a characteristic of a target and is determined by the physical size of the target, its shape, and the material from which the target is made. A_r is the effective capture area of the receiving antenna. Now the denominator is squared as it is taken into account that the wave goes to the target and then comes back to the antenna.

$$P_r = \frac{P_t G_t A_r \sigma}{(4\pi R^2)^2} \qquad (2.3)$$

The relation between antenna receiver gain and the effective area Ar is:

$$G = \frac{4\pi A}{\lambda^2} \qquad (2.4)$$

The received power can be expressed as:

$$P_r = \frac{P_t G_t G_r \lambda^2 \sigma}{(4\pi)^3 R^4 L_s} \qquad (2.5)$$

With Ls the total system loss term, defined as the sum of the transmit loss, the atmospheric loss, and the receiver loss.

Then Pn, the thermal noise power has a power spectral density that can be expressed as:

$$P_n = kT_0(F\text{-}1)B \qquad (2.6)$$

Where

k is Boltzmann's constant (1.38 x 10−23 Watt-sec/K);

T_0 is the standard temperature (290 K);

F is the noise figure of the receiver subsystem (unitless);

B is the instantaneous receiver bandwidth (Hz).

Then, Pc the clutter power spectral density is the reflected power in other objects that are not the target of the radar. In this case power reflected in the furniture of the room, insects or random objects might return an unwanted echo that will interfere in the radar system. It can be expressed as:

$$P_c = \frac{P_t G_t G_r \lambda^2 \sigma_c}{(4\pi)^3 R^4 L_s} \qquad (2.7)$$

Where σ_c is the clutter radar cross section.

Finally, Pj is the power of other interfering signals, known as noise jammer, can also come from sources of electromagnetic energy remote from the radar, such as communication signals, motors, and generators.

A vital characteristic of a radar is his sensitivity. It is expressed as the minimum SIR necessary for detection. For being detected, the reflected signal from the target must exceed the sum of the interfering signals by a considerable wide margin for the target to be detected with high probability.

$$S_i=(SIR)_{min} \qquad (2.8)$$

By combining equations 2.5 and 2.8, the maximum range of the radar con be calculated.

$$R_{max}=\left(\frac{P_t G_t G_r \lambda^2 \sigma}{(4\pi)^3 s_i L_s}\right)^{\frac{1}{4}} \qquad (2.9)$$

2.3.2.-Radar Architectures

Three radar architectures were studied to see which one was the most suitable one for this project. CW radar, UWB-IR (Ultra-Wideband Impulse Radio) radar and Stepped Frequency Continuous Wave (SFCW) radar.

2.3.2.1- Continuous Wave Radar

Continuous Wave radar, a.k.a. Doppler radar transmits a single-tone continuous-wave signal that is demodulated in the receiver after reflecting in the target. By the Doppler effect, a radio wave reflected at the moving target undergoes a frequency shift proportional to the surface velocity in the direction of the Poynting vector.

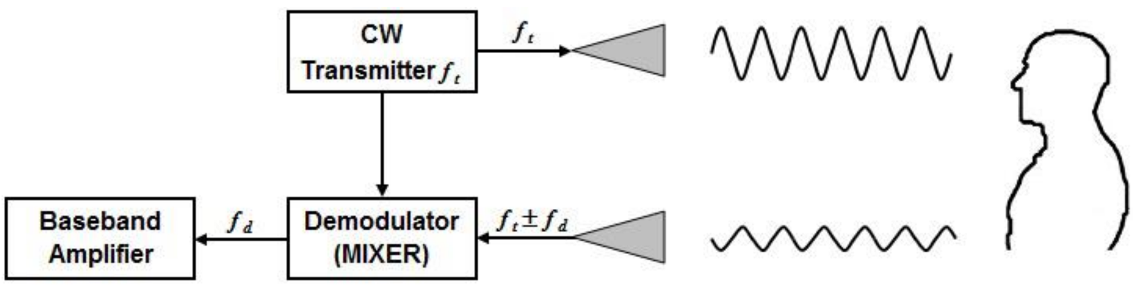

Figure 2.1.- CW schematic

If D is the distance from the radar to the target, the total number of wavelengths contained in the two-way path is $2D/\lambda$. Since one wavelength corresponds to an angular excursion of 2 radians, the total angular excursion - traveled by the electromagnetic wave is $4\pi D/\lambda$ radians. If the target is moving, D and the phase - are changing continuously. A change of ϕ with respect to time is equal to a frequency, such as the Doppler angular frequency ω_d is:

$$\omega_d=2\pi f_d=\frac{d\phi}{dt}=\frac{4\pi}{\lambda}\frac{dD}{dt}=\frac{4\pi v_t}{\lambda} \qquad (2.10)$$

Where fd is the doppler frequency shift and vt is the radial target speed. The doppler frequency shift is therefore

$$f_d=\frac{2v_t}{\lambda}=\frac{2v_t f_t}{c} \qquad (2.11)$$

With ft the radar transmitting frequency.

The CW architecture is really accurate with the measurement of the target's speed. It also has a simpler architecture. In addition, it does not require isolation between the transmitter and the receiver antennas as the crosstalk interference does not affect the system, neither cutter interferences coming from stationary objects like furniture. Both produce a DC baseband signal that can be easily filtered and do not affect the frequency shift. The main limitation of a CW radar is that it is not capable of detecting absolute distances.

2.3.2.2.- Ultra-Wide Impulse Radio Radar

This radar sends short, ultra-wideband electromagnetic pulses with a fixed pulse repetition frequency. The time delay between the transmission of the pulse and the reception of the echo is proportional to the distance between the target and the radar. This pulse sequence is reflected from the object and collected by the receiver. As the transmitted wave is reflected by a target, the PRF of the reflected wave is modulated by the target's movement, so this change can be used to monitor a person. However, as a downside, implementing this architecture is of high complexity.

2.3.2.3.- Stepped-Frequency Continuous Wave Radar

This radar transmits and receives a group of coherent CW pulses with a fixed increment of frequency(Δf) from pulse to pulse. For each pulse the frequency (constant) can be written as:

$$f_n = f_0 + (n - 1)\Delta f \qquad (2.12)$$

With f_0 being the starting carrier frequency.

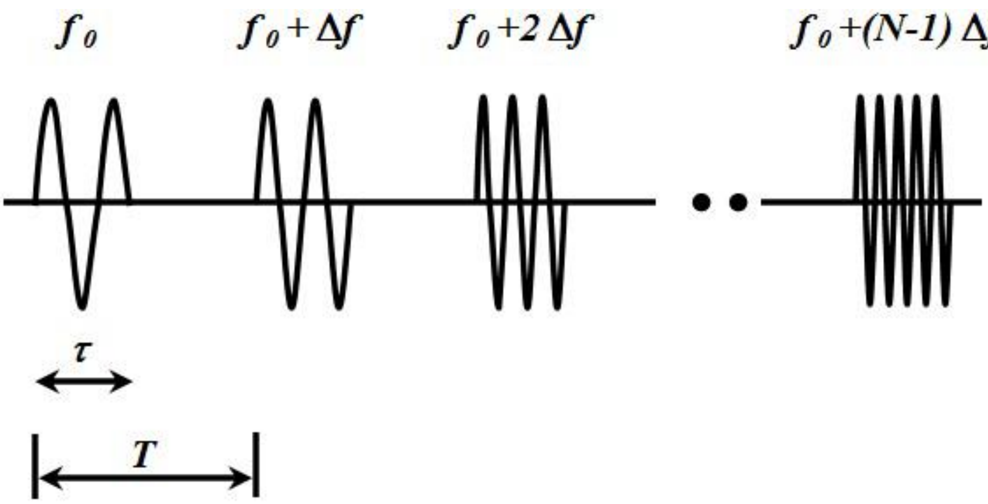

Figure 2.2.- Pulses of a SFCW

τ is the pulse width in seconds and T is the interval between pulses.

The total bandwidth of the signal is NΔf. However, since the frequency is constant within the individual pulse, its bandwidth is approximately equal to the inverse of the pulse width. These pulses have narrow bandwidths, thus making the instantaneous bandwidth of the radar narrow. This improves the radar's sensitivity which goes by the following formula:

$$\Delta R = \frac{c}{2B} \qquad (2.13)$$

With ΔR being the range resolution, c the speed of light and B the total bandwidth.

The main positive things of this architecture are the following. Unlike the CW Radar that can only determine the speed, SFCW can compute both the position and the speed of a target. UWB-IR can also do that but is much more complex to implement. Opposed to the UWB-IR architecture, the narrow instantaneous bandwidth combined with the large effective bandwidth (sequentially over many pulses) of the SFCW radar implies that the hardware requirements become less stringent. Lower-speed ADCs and lower level processors can be used. Moreover, the receiver bandwidth is smaller, resulting in lower noise bandwidth and higher signal-to-noise ratio. This also increases the radar sensitivity.

Compared to UWB-IR waveforms, frequency step waveforms require lower AD conversion sampling rates, low peak power sources, and slower computers to process smaller sets of data. In fact, to sample an UWB-IR pulse with good accuracy, at least ten sampling points per pulse need to be acquired while, with a SFCW radar, only one sample every time interval T, corresponding to each frequency, needs to be acquired. Another downgrade of the UWB-IR is that it is not capable of monitoring the speed of a target using the Doppler effect.

2.3.3.- Final radar design

After considering the previous architectures, the final system chosen for the radar was a hybrid approach consisting in a CW-based architecture where a CW waveform is alternated with a SFCW signal. The former does the monitoring of the target's speed while the latter is used to localize the target. As explained before, a SFCW can simultaneously detect both absolute distance and speed but in this case, determining the target's speed uninterruptedly is basic while we do not need to measure the target's position that often. Moreover, alternating the single tone with the SFCW waveform allows to increase the output power while still satisfying the European and FCC UWB Spectral Mask.

The CW waveform is a single frequency signal in the Industrial, Scientific and Medical (ISM) radio band of 5.8 GHz is employed to exploit the Doppler effect. This tone is alternated every two seconds by a stepped frequency waveform working in the UWB band, used to detect the target's absolute distance.

The latter consists of N = 40 coherent CW pulses whose frequencies are increased from pulse to pulse by a fixed increment f of 25 MHz. Each pulse is τ = 30 μs long, and the time interval between pulses is T = 100 μs. This results in a burst duration NT of 4 ms, while its total band NΔf is 1 GHz positioned between 6 and 7 GHz. This allows an unambiguous range of 6 m with a smallest resolution of 15 cm. The full waveform is 2.004 seconds and the signal power is 0 dBm. This solution allows satisfying the European and Federal Communications Commission (FCC) UWB mask requirements while simultaneously having sufficient transmit power to track a person in a typical room setting.

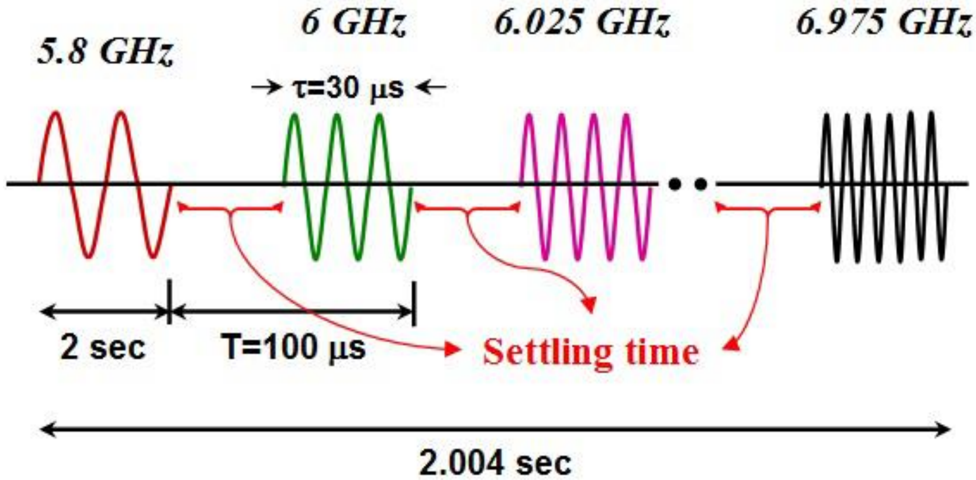

Figure 2.3.- Chosen values for the signal.

The interval in between CW pulses, defined as settling time in Fig. 2.3, is dimensioned to guarantee that a new frequency is correctly generated and ready to be transmitted.

Assuming a maximum target movement/falling speed of 2 m/s, the baseband signals containing speed information should be acquired at least with a sample period of about 6.5 ms. This value is defined considering the Nyquist theorem and eq. (2.11), where fISM is 5.8 GHz. Experimental evaluations on human volunteers have failed to demonstrate significant improvements even when the sample time is decreased below 7.2 ms. This indicates that the maximum speed produced by the subjects' movements is about 1.8 m/s, lower than the 2 m/s initial assumption. However, a sample rate of 4 ms has been chosen providing a sufficient margin to detect movements of humans with different weights.

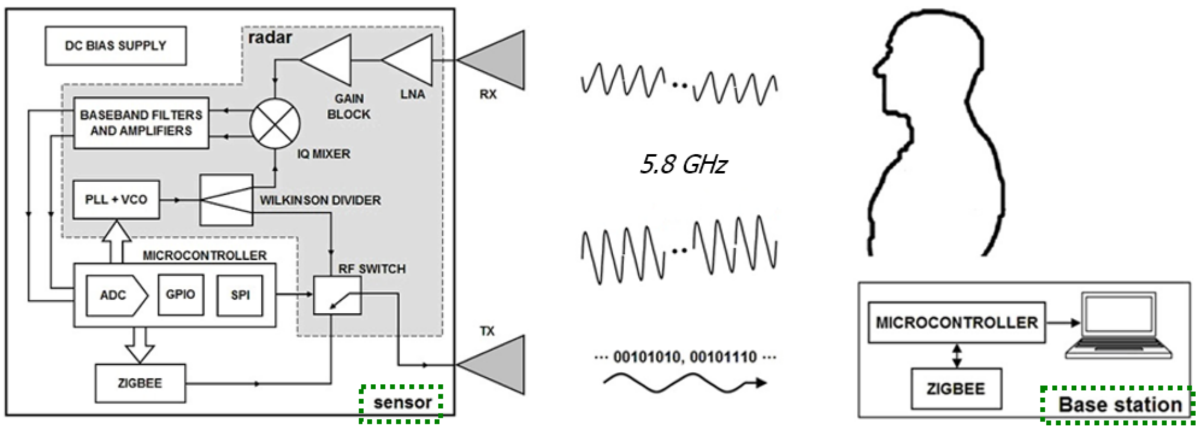

Figure 2.4.- Schematic of the old system.

This is the schematic of the old version of the system. The modified and improved new system will be explained in chapter 3. Each component of the schematic is responsible for the following applications.

First the RX antenna takes the reflected echo of the signal thrown at the target. Next, the LNA, the Low Noise Amplifier, removes noise and discards some frequencies, then the gain block is a multiplier that amplifies the received signal.

Afterwards, the signal goes to the IQ mixer were both the signal coming from the gain block and the one coming from the divider are convoluted and then an IQ modulation is performed. Two channels go out of it, the In-phase and the Quadrature components respectively. These two components go to a block where they go through a baseband filter to discard unwanted frequencies and noise, also amplifiers are used to strengthen the signal.

The PLL+VCO block is the oscillating circuit which generates two waveforms, the CW and the SFCW. A PLL is a control system that generates an output signal whose phase is related to the phase of an input signal.

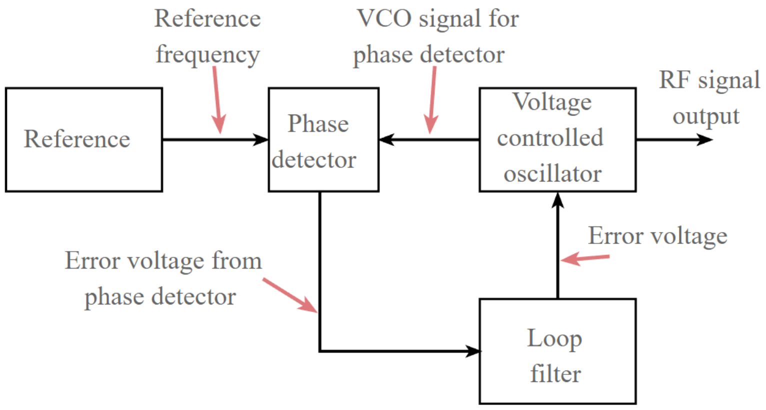

Figure 2.5.- Schematic of the functioning of a PLL.

The PLL used for the project is the HMC834LP6GE device. It is a low noise, wideband, Fractional-N PLL that features an integrated VCO operating in the IEEE C-band. It also integrates a Phase Detector (PD), a precision controlled charge pump, and a delta-sigma modulator. The device offers excellent phase noise and spectral performance across all frequencies, with high frequency resolution and ultra-low frequency step size.

The signal generated from that last block is divided in the Wilkinson divider, which distributes the received power into two completely isolated ways. One of them goes to the IQ mixer to perform the IQ modulation and the other one goes to the TX antenna to be emitted towards the room.

The microcontroller is connected to the PLL via a GPIO pin to configure the right frequency of the signal. Also in it, it happens the Analog to Digital Conversion which is basically sampling of the received signals I and Q. The microcontroller is connected to a Zigbee by the SPI (Serial Peripheral Interface) where the microcontroller is the Master (controls the Zigbee, sends data) and the Zigbee is the slave (passive receiver).

Finally, there is the RF switch that allows the TX antenna to transmit both the signal generated in the PLL block and also the wireless communication of the Zigbee to the base station where the data will be processed and analyzed.

2.4.- Conclusions

In this chapter, the description of the system has been exposed. First, it is shown that already existing systems are not comparable with the one we are working on. These other devices can be useful to some point but they are rather incomplete and inconsistent. That puts into perspective the whole range of completeness contributed to the topic of elderly people monitoring that this system has to offer.

After that, the functioning of the radar has been explained. Different parameters that should be taken into account when implementing a system of such characteristics are explained. Which aspects intervene in the maximization of the SIR are studied and developed to fully understand the general radar equation.

Later, the previous study that was done before the development of the radar is put into context. The main characteristics, positive and negative points of three alternatives are explained. Examining the three of them, the most suitable approach for the project was a mixture between CW and SFCW for successfully tracking accurately the speed of user's movement and also determine its position in the room.

The CW waveform is a single frequency signal in the Industrial, Scientific and Medical (ISM) radio band of 5.8 GHz is employed to exploit the Doppler effect. This tone is alternated every two seconds by a stepped frequency waveform working in the UWB band, used to detect the target's absolute distance. Specific values of the design are mentioned and reasoned.

Afterwards, how the signal is generated in the PLL and then its path trough each block of the board is explained. Techniques about substracting noise, amplifying, IQ modulation, ADC conversion are required. For the purpose of sending the data, the Zigbee connection method is used by employing the SPI standard.

It is of importance to mention that what is explained in this chapter is the state in which the system was prior to this semester's work and improvements. The system was fully operative then but, in order to polish some details for it to work in a more secure and efficient ways, some modifications have been applied. Those will be exposed in chapter's 3 and 5.

Although data analysis and its information treatment is one of the main parts of the radar sensor, it is not discussed in this thesis since this was unfortunately out of the scope of this thesis study. All the development of this part was carried out by another researcher who was working apart from us.

It should also be remarked that this chapter has only been a presentation of general characteristics of the radar sensor. More theory was applied in its development and also many other design parameters are needed but they are not explained since they are not really needed for this thesis.

To sum up, a general idea of how the radar works has been presented while giving insight in the functioning of it so as to understand the basics of it.

CHAPTER 3

BOARD IMPROVEMENTS

3.1.- Introduction

The previous design of the board, explained in the State of the Art chapter, presented some disadvantages that have been tried to improve by modifying some components of it.

The reason for these changes is mainly the Zigbee wireless communications system. It was unsecure as the information transmitted through it could be easily stolen due to its relatively uncomplicated access and thus user's privacy could not be assured. In addition, using the Zigbee technology introduced unnecessary complexness to the system due to possible interferences with the radar signal and the sharing of the TX antenna.

Another inconvenient of the previous whole system was the need for installing yet another device in a room, the base station, which was responsible for receiving the data sent by the Zigbee and storing it in a computer. Taking into account that for the system to be able to exactly locate a target, three radar sensors are needed, a fourth element installed in a room could be bothering to the user as it might take up too much space.

To improve those things, a Raspberry Pi will be included in the system, it will be placed inside the same box where the whole board is and it will replace the whole base station.

Linked to the previous, the SPI communication interface standard presents some limitations in the way that it works. The Master-Slave architecture that it implies, makes the microcontroller the master and the other element at which is connected must be the slave. In the case, the slave would be the Raspberry Pi but considering how it is designed, it can only take the role of the master so the SPI standard is not suitable now. It will be replaced with the USART standard.

Also, how to successfully save data in text files will be studied for it to be included in the Raspberry Pi software.

3.2.- Methodology

As explained in the Introduction, the Zigbee module along with the base station have been removed from the system [Fig 3.1] and they have been replaced with a Raspberry Pi placed inside the sensor's box.

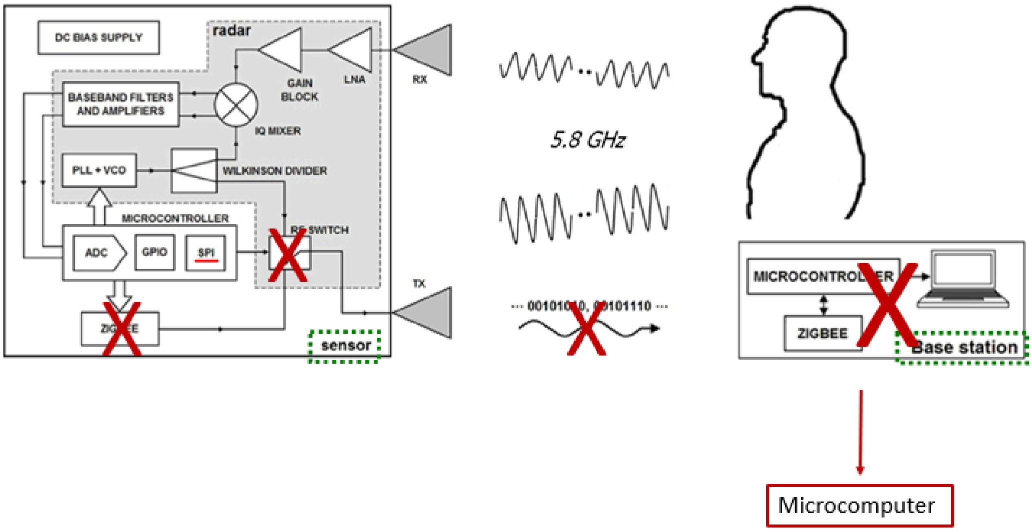

Figure 3.1.- Schematic showing the discarded components of the all system.

To carry out all these changes, a new software was needed for the sending of data.

During the process of developing the new code I had a supporting role and tried to enhance it by studying data formats compatibility and the storage of the data.

In the system, the data formats must be looked at carefully in order to know how is the data stored in every device and process it accordingly. When thinking about the ways of transmitting data from the microcontroller to the Raspberry Pi and then storing it in the USB pen drive, a research about data formats conversion was carried out. We studied several options about how to convert arrays from or to hexadecimal, decimal, binary, string and Ascii. They also had to include some code to work in a whole buffer which consists in an array of many of positions. This whole research was done in order to make all the devices compatible with each other.

Regarding the function of storing the data in a pen drive, the objective was to develop a function to store the data in a text file. The methodology carried out to accomplish that was to first look at different internet pages where code about doing this was explained and also studying some tutorials so as to clearly understand what was the reasoning besides every component of the code. Once this was accomplished, some testing was done. This is, starting with simpler codes performing easier tasks so as to make sure everything worked out well and a posteriori, evolve the code gradually so it performs all the tasks that are required.

3.3.- Results

After the modifications are done, the resulting schematic of the system is the following:

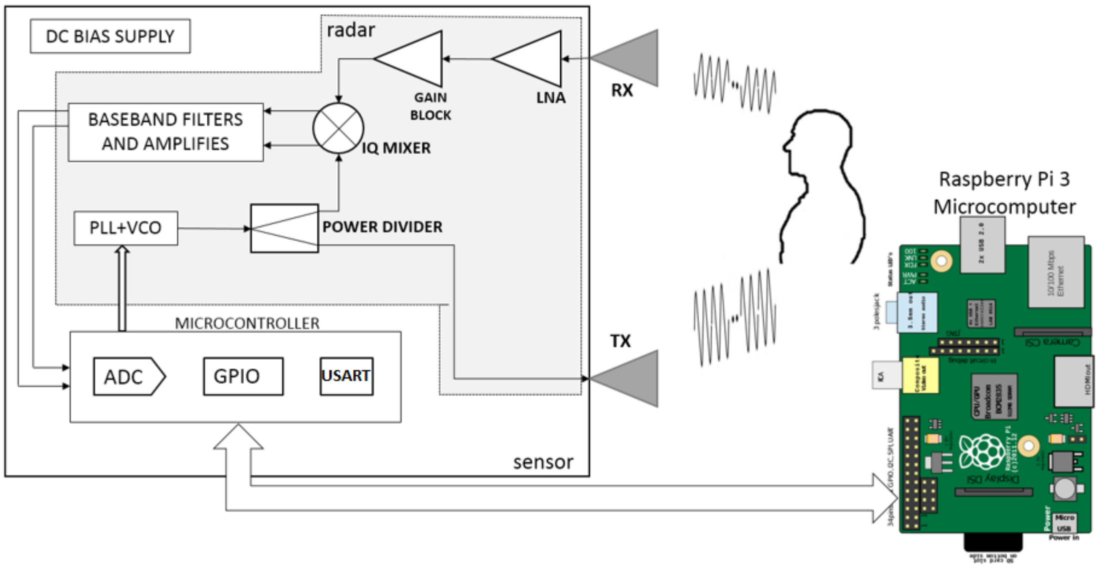

Figure 3.2.- Schematic of the final design of the system.

Now, there is no wireless communication to send the data. Instead, a microcomputer, in this case we use the Raspberry Pi 3, is connected to the board to perform the tasks about storing the data. Moreover, the Raspberry Pi is placed in the same box that contains the whole radar sensor, representing a save of inconvenience for the user. A USB pen drive connected to the Raspberry Pi will store the data, making it easily collectable from the microcomputer by researchers.

Also, instead of using the SPI interface standard, USART is implemented. Both the microcontroller and the Raspberry Pi support this standard and are compatible with it. The software for the transmission had to be changed.

In this case, the connection from the microcontroller to the Raspberry Pi is done by wires. This makes it barely impossible for anyone outside of the project team to access the data, assuring user's privacy. Also, data transmission will not interfere with the radar signal.

A function to store all the data sent by the microcontroller in a text file in the USB pen drive connected to the Raspberry Pi was developed. As the code is developed in the Raspberry Pi, the coding language used is C. Basically, what is in the code is file management functions.

First a file opener function is used. It opens a file in the mode that you declare, in this case we use the 'append' mode which will not overwrite any data but write after the last position occupied in the previous call to that file. Defining it in this mode is crucial because if it is defined in the ‘write’ mode, every time the system starts recording data, the file were the previous values were saved will be overwritten and information will be lost. Also, if the name defined in the in the function does not exist in the specified folder, a new file will automatically be created.Then, the most important function we use is ‘fprintf’ which is the necessary command to actually write data into a text file. Finally, it is important for the whole code to work properly that the file is closed using the ‘fclose’ function.

The general idea of the developed code is to read what is coming from the communication channel (using the USART standard), then putting it in a buffer, opening (or creating one if it does not exist yet) the file which stores data in append mode and then write all the information that is being received and finally close the file.

3.4.- Conclusions

Now, all the components have been successfully assembled, the modified software to send the data, switching from SPI to USART, fully works after all the work carried out in the laboratory by researcher Oluwatosin Babarinde along with my support.

Regarding the data conversion study that was done, finally it has not been implemented since there were no data format incompatibilities at the end. Nevertheless, it can be useful in the future if some modifications are done and there are problems of such characteristics.

Considering the data saving procedure, the developed code works properly for its purposes and is accomplishing the objectives that were needed for this part of the project.

CHAPTER 4

ETHICAL DISCUSSION

4.1.- Introduction

When developing a project of such characteristics, a question comes to mind: Is it ethical to monitor people so that we control what they are doing in their private homes? At first look, it might seem like it is a privacy invasion which is not ethical neither will anyone be comfortable with it. Dealing with these issues is a delicate topic. What should be done in this case is to make the system as less invasive as possible. It must be done in such a way that people do not loss any kind of privacy while using it and it has also to be explained in a way for them to understand that nobody will be spying on them or that it will not be known exactly what they are doing. Moreover, people who will have access to the data obtained by the radar sensors must be limited. This is, only researchers and medical professionals have to be able to consult or read the data. All these considerations must be properly explained for a project of this nature to be approved by the Medical Ethics Committee UZ KU Leuven.

Furthermore, there is a law regulation about people's privacy at their homes that must be followed. As stated before, the system should not be too invasive in people's privacy so as to fulfill the law obligations. In addition, working with electromagnetic waves requires a study about the power levels of the transmitted radiation to accomplish the regulation.

Another requirement for a project to be approved is that there is an evidence of it being useful or that it will suppose an improvement on the already existing similar systems. The properties of the project should be accurately explained, mentioning the benefits that will the users obtain from it.

After that, another basic prerequisite to get the approval for the system is that it can be considered safe. This includes user's safety, this is, there is no possibility of any old adult being harmed by the sensors installed in their home. Moreover, wireless waves used transmitted by the antennas must not have any influence on people's health.

Also, providing that the data cannot be stolen by anyone should be mentioned so as to explain the security of the collecting of the data and its storage.

How the documentation about the ethical discussion was redacted, its most important aspects and which was the methodology used to do it is what will be exposed in this chapter.

4.2.- Methodology

First of all, in order to write the document describing the radar sensor and its ethical discussion so as to get the project approved by the Medical Ethics Committee UZ KU Leuven, I had to first learn the correct style of writing for this type of documents. To do so, I was given an example which was the same required document that was written for other sensors also used to monitor constants of elderly people. In it, I could check the requirements of a document of this nature, so I did an exhaustive reading of it looking at every detail.

Secondly, I had a meeting with executive researcher at KU Leuven drs. Ine D'Haeseleer. In this meeting we discussed which aspects should be mentioned on the document. She gave me some insights about which things should we highlight the most to state that our project was ready to get the approval. Also, I had the opportunity to ask her questions to clear up my doubts. In that meeting we wrote down the first draft of the structure of the document including its most important specifications.

One thing we discussed in the meeting was that the language used in the writing must not be too technical. The reason besides that is that this paper, even taking into account that is about an engineering project, is meant to be sent to non-engineers. Is it because of that, that the writing must be understandable for professionals that are not able to understand the technical details of an engineering work. The conclusion was that we should discard specific details of the system and, in contrary, explain the main idea of the crucial features.

Afterwards, I also had a meeting with my supervisor, prof. Dominique Schreurs. We discussed the general structure of the document and she gave me advice on how to do it. In addition, she told me about multiple specifications of the radar sensor that I was not aware of and that must be explained in the addendum. She also explained to me the methodology of testing the radar system as testing is a really important part in the process of getting a project approved.

Once all the 'research' part was done, I was able to proceed to start writing the addendum for the radar system.

After the first version was written, it was revised by prof. Dominique Schreurs and then improved. Later, it was sent to drs. Ine D'Haeseleer for another revision as to polish every detail of it.

4.3.- Results

In this section, so as to present the results of the document about the ethical discussion, some fragments of it will be added.

As stated before, the most controversial aspect of the project is about user's privacy. To deal with it, the designed system preserves every user's privacy with a secure data management as well as not allowing anyone except from researchers to access it. All the data obtained from the radars as well as the user's information will be handled in a secure way. This involves coding the data so no one except from KU Leuven researchers can access it. Moreover, during the whole process of collecting the data, it will never be sent through any communication system. Instead, the data will be stored on an USB pen drive that will be removed manually from the radar by a KU Leuven researcher at the end of the on-site study. By working in such a way, we assure there will be nobody else who could access the data that is being recorded, assuring the privacy of the users.

Data will be archived in a secure KU Leuven database managed by the research team.

All data collected will only be used for the research described in this protocol. All data will be handled in concordance with the Belgian Privacy Act of December 8 2012, ("Wet van 8 december 2012 tot bescherming van de persoonlijke levenssfeer ten opzichte van de verwerking van persoonsgegevens, BS 18 maart 1993").

The collected data by the sensor data will be coded and stored in a secure database (SSL encryption on the traffic and SHA256 encryption on the data) to which only the principal investigator and his co-workers – the KU Leuven researchers – have access. Data will always be coded when it is further processed or communicated. The permission to record and analyze the data (cfr. the research objectives) and the use of the data for scientific purposes after the project, will be determined in a written informed consent. Moreover, participants will be informed that in no way this information will be used for a diagnose or a follow-up.

Data that contains contact information of participants is stored on a secure server in the Group T building located at another location than the data collected by the radar which will be stored in the ESAT department. A coded number – and not a name or other information that possibly could identify the person – is used as a reference. Only the researchers from Group T will have access to the participants' personal data and will be able to pair these to the sensor data.

The applicants of this proposal (Principal investigator Prof. Dr. Jos Tournoy, Prof. Dr. Dominique Schreurs, executive researcher ir. Oluwatosin Babarinde and executive researcher drs. Ine D'Haeseleer) guarantee to act in good faith and to adhere to all applicable laws and rulings as prescribed by the Belgian Privacy of December 8 2012, ("Wet van 8 december 2012 tot bescherming van de persoonlijke levenssfeer ten opzichte van de verwerking van persoonsgegevens, BS 18 maart 1993"), and in compliance with the declaration of Helsinki.

The other important aspect is about the radar itself is not harmful or bothering to users. Therefore, the whole system will be covered using a plastic box in which all the parts of the radar are placed, as to isolate the electrical parts from the user. In addition, the output power will satisfy the European and FCC UWB Spectral Mask and not be in any case harmful to users.

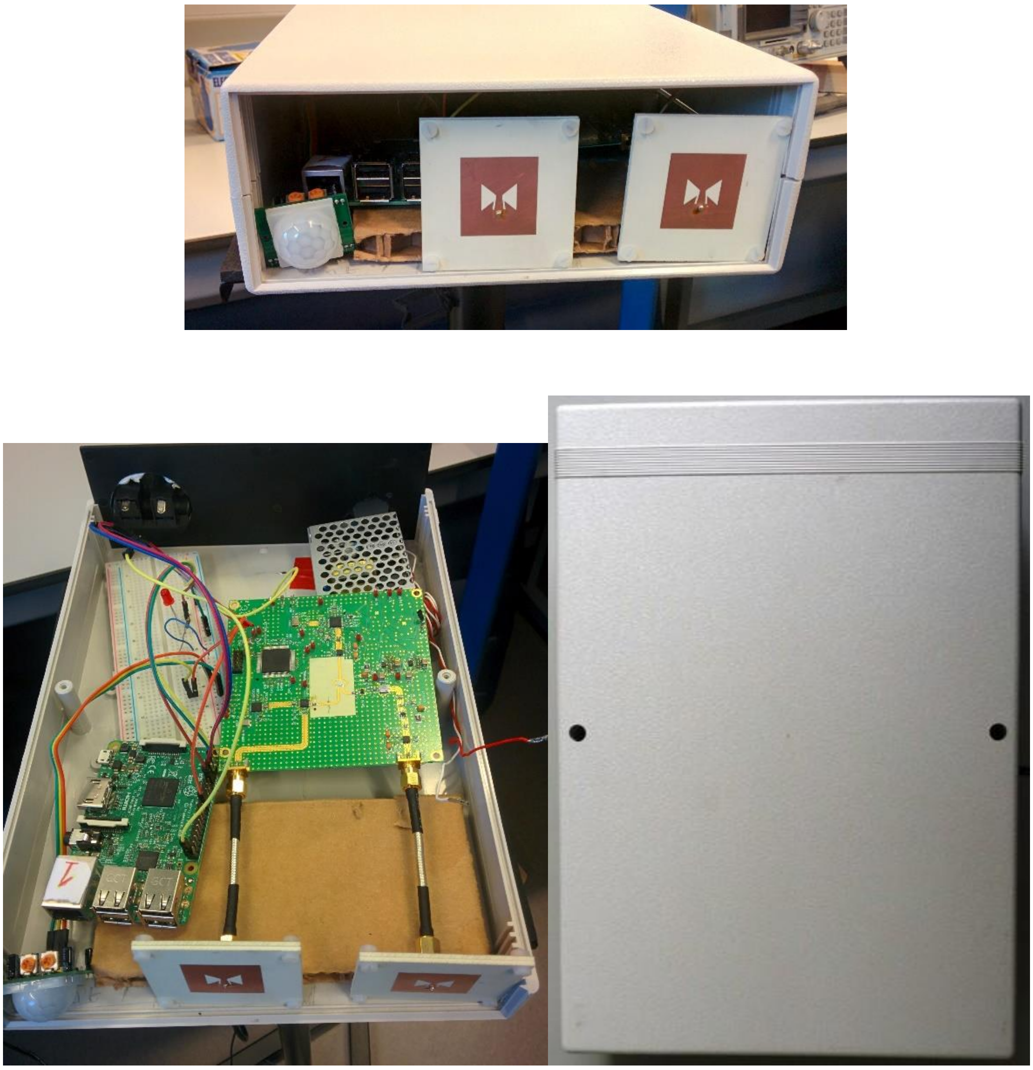

Figure 4.1.- Front view and top view of the box and a closed one.

Regarding the usefulness and improvements that the radar offers the following is stated. The handicap of using wearable sensors is that they need user involvement. This implies that people might forget to wear or activate them. Also, they work with batteries and if they go out of power, lots of data will be lost. Another inconvenience could be that people might not feel comfortable wearing those sensors, and for that reason, they could stop using them during some periods of time which will result in biased data. None of these problems apply to the radar.

The radar sensor is a context aware, environmental sensor that will work in an easier way. First of all, the sensors will be placed near the walls of the room. In addition, they do not need batteries as they will be powered through the mains, and thus people involved in the study will not have to do anything in order to make them work. Adopting this approach will prevent any of the possible losses of data stated in the previous paragraph.

One of the goals of the project is to be able to develop an efficient system with relatively low costs. Implementing the radar will not suppose additional costs other than the investment of its production as it doesn't need maintenance and data can be easily collected.

For the purpose of testing the radar system we will proceed to installing three sensors on three different walls so to have three coordinates in order to detect the exact position of a person. Using the developed technology, we will also be able to know the speed of a moving person. With that being known, we can study if that person moves normally or if she/he is having a change of behaviour after a period of time, e.g., movements slow down over time. The data obtained from the testing will be stored on a USB pen drive.

Figure 4.2.- Radar sensor placed in the stand near a wall.

Basically, we want to study if the movements of a person are normal. By looking at the data obtained over the whole period of time (7-10 days in the planned testing study, but >1 month in practical use) we can detect gradual changes in the behaviour or a sudden change of speed of his/her displacements in the room being monitored. When that happens, it may indicate that the user is suffering from a health problem, including cognitive decline.

All participants of the test will be recruited by KU Leuven researchers and/or in collaboration with InnovAGE. For the testing of other sensors related to healthcare of elderly people, 20-25 participants will have been selected for the first study according to a criterion of inclusion. For this add-on study, we will choose 5 of those 20-25 participants for the testing of the radar sensors.

A total of 2 hours is required at the user premises. The first intervention of about one hour is for the installation of three radar sensors in the user's living room, and the second intervention is for the dismantling of the radar sensors at the end of the study, combined with retrieving the USB pen drive with the data. These are the only time instances that the participants will need to invest in the study as all the testing will not affect their daily routine. The test will last for 7-10 days in order to have a big enough data set to be analysed.

RADAR TESTING	**TIME INVESTMENT**
Set-up of system	1 hour
Testing	7-10 days (not bothering to participant)
Dismantling of system	1 hour
Total	±2 hours

Table 4.1.- Amounts of times for the testing.

When participating in this study, users will be informed that the collected data will be used only for research purposes, namely to evaluate the use of radar sensors in realistic environments.

They will also be informed that their participation is voluntary and can be terminated at any time. We will also specify that the client is flawlessly liable for any damage incurred by the participant and/or its proprietors and which directly or indirectly relates to the experiment.

4.4.- Conclusions

Which things should the ethical discussion include, the methodology followed to accomplish a satisfactory result and the most important parts of it is what is explained in this chapter.

First, a brief explanation on every topic that is going to be discussed is done. Afterwards the whole process for me to be able to redact it in the required way so as for it to be approved by the Medical Ethics Committee UZ KU Leuven is mentioned. Lastly, fragments of the document are presented to illustrate all the previously mentioned ideas and to expose how has the whole work been done. Moreover, characteristics and details of the system are explained for the reader to get familiar with it.

To sum up, it has been exposed that the radar sensor system is not too intrusive in user's privacy, that it fulfils all the law requirements, its use is not bothering to users, that its use is secure in the way that it cannot be harmful for elderly people and about the security of the data collected and specifications of the testing study.

CHAPTER 5

PIR SENSOR

5.1.- Introduction

The previous version of the project, worked in a way that it was supposed to be continuously recording data. That, apart from being inefficient, required huge memory capacity. Considering that the microcontroller is constantly sending information, that the data is collected by researchers after at least a month and that data is stored in a USB pen drive with limited memory capacity, saving memory is a must.

When there is nobody in the room it does not make sense to store any data. In this case, the radar sensor will be detecting a steady environment and the values that the microcontroller will send to the Raspberry Pi will be pretty much constant apart from some deviations created by noise or different interferences.

Also, for the purpose of analysing the obtained data in order to detect the movements of the user, having large quantities of data which is not relevant will result in an inefficient data processing work. Extracting the information of the user's movement over a period of at least a month from the data stored requires plenty of computational effort. It should be taken into account that data from at least a month has to be processed so it can take a considerably large period of time.

Furthermore, having the system working all the time represents a substantial waste of energy. If there is nobody in the room where the study is taking place, shutting down the radar sensor will suppose a great saving of energy and will make the system more efficient in power consumption terms.

For the improvement of the whole system, the addition of a PIR sensor, which detects motion, to the radar device has been implemented. Its function is to detect whether there is or not a person at the room. It is pretty much low consuming so its addition will not represent barely any increment in power consumption.

Figure 5.1.- PIR Sensor.

A Passive InfraRed sensor works in the following way. It is made of a pyroelectric sensor that is able to detect infrared radiation. Everything emits some low-level radiation, and the hotter something is, the more radiation is emitted. The sensor in a motion detector is actually split in two halves. The reason for that is that we are looking to detect motion (change) not average IR levels. Along with the pyroelectric sensor there is a bit of supporting circuitry, resistors and capacitors [Fig 5.2].

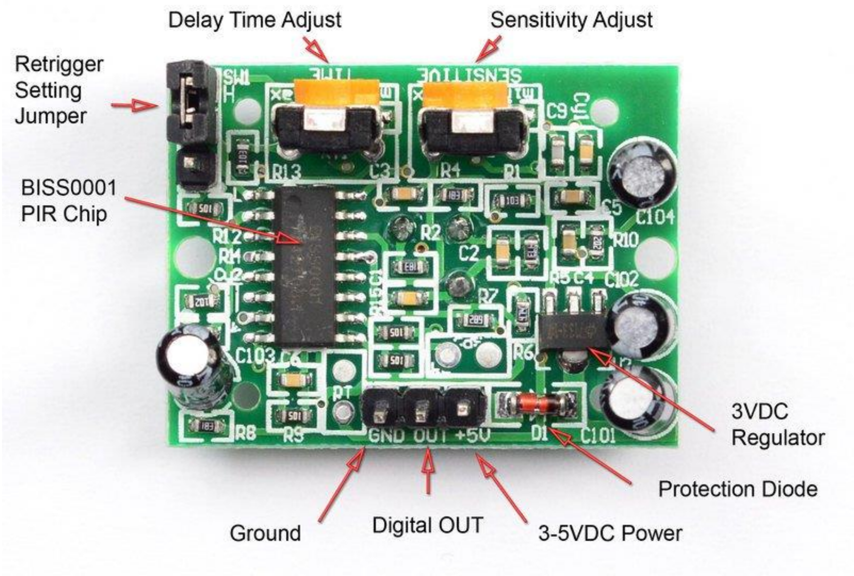

Figure 5.2.- Circuitry of the PIR sensor.

The two slots of pyroelectrical material can 'see' out past a range (basically the sensitivity of the sensor). When the sensor is idle, both slots detect the same amount of infrared radiation, the ambient amount radiated from the room or walls or outdoors. When a warm body like a human or animal passes by, it first intercepts one half of the PIR sensor, which causes a positive differential change between the two halves. When the warm body leaves the sensing area, the reverse happens, whereby the sensor generates a negative differential change. These change pulses are what is detected.

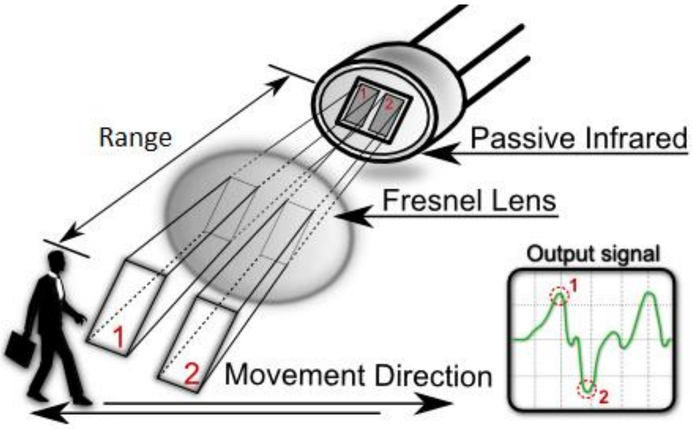

Figure 5.3.- Functioning of a PIR sensor.

The Fresnel lens condenses light, providing a larger range of IR to the sensor. Actually, we do not want two really big sensing-area rectangles, but rather a scattering of multiple small areas. So, what is done is splitting up the lens into multiple sections, each section of which is a Fresnel lens. The different faceting and sub-lenses create a range of detection areas, interleaved with each other. [Fig 5.5]

Figure 5.4.- Close up of the Fresnel lens.

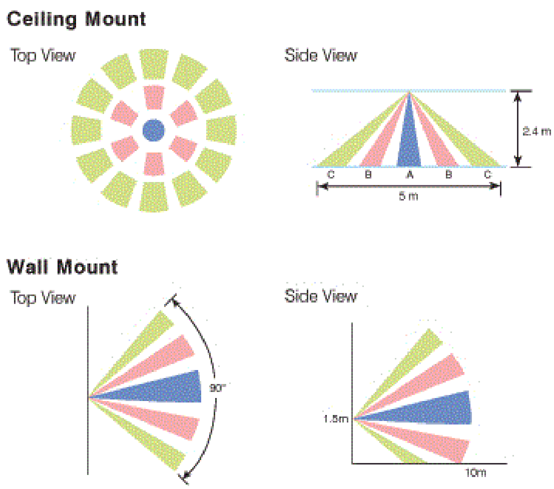

Figure 5.5.- Range of detecting areas.

The PIR sensor used has a 3-pin connection, power, ground and output signal. It requires to be supplied 5V to be powered and the expected voltage at the output when the PIR detects motion is of 3,3V.

Also, the PIR used is equipped with a pair of small trimpots. One is for regulating the sensitivity, this is, the range where it can detect movements and the other is for adjusting how much time will the output signal be 'high' when it detects motion.

The objective was to use the PIR to deactivate the storing of data whenever there is no one in the room. To achieve this, plenty of research and testing has been carried out and different approaches have been contemplated and discussed.

5.2.- Methodology

As it has been said in the previous paragraph, diverse approaches to the final solution have been studied and taken into consideration. A brief explanation of the procedure in each case will be developed in the following lines.

Before trying to add the PIR sensor to any part of the project, itself alone was tested in a separated board to make sure it was working well. It was connected as [Fig 5.6] shows.

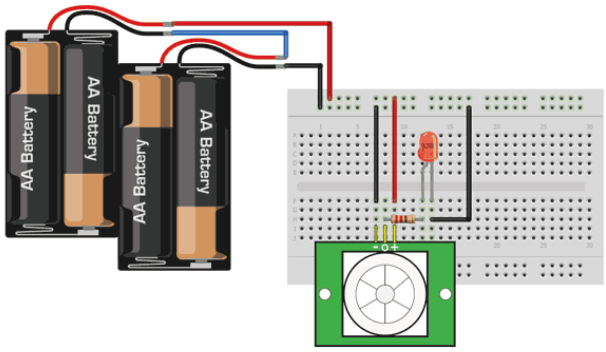

Figure 5.6.- Testing of the PIR with a led.

The board is powered at 5V and the output of the PIR goes through a resistance before the LED for current controlling purposes. When the sensor detects movement, the output will be high and 3,3V will come from it, thus lighting the LED for a determinate amount of time depending on the delay used. Once this is done we can proceed to try it on the projects boards.

At first, including the PIR sensor in the microcontroller board was the first way.

Considering that my knowledge of this microcontroller was null, an exhaustive study on its specifications, how does it work and its connections for every specific purpose had to be carried out. First, I read its datasheet [4] to know its functioning, specially the part about the General-Purpose Input/Output Controller (GPIO) as they are the pins that will be needed to connect external components.

With some awareness on the topic I proceeded to study some tutorials [5] in order to understand the functioning of the board more properly. With that and the background knowledge on programming microcontrollers learnt at university I was able to do a few tests on controlling the pins for lighting LEDs by stablishing a pin as 'high' or by controlling it with a button. For it to work, each pin's registers had to be accessed and modified accordingly. Another thing that needs mentioning is that I did not work directly in the microcontroller board of the project but instead I did program all the tests in the STK 600 testing board so as not to cause problems to the already designed program for the real radar board. That implied some differences like the number varying number of each pin that could be easily solved by checking specifications documents.

Figure 5.7.- STK 600 testing board.

The option of including the PIR sensor in the microcontroller board was discarded as it was thought it will be easier and more efficient to include it in the Raspberry Pi part.

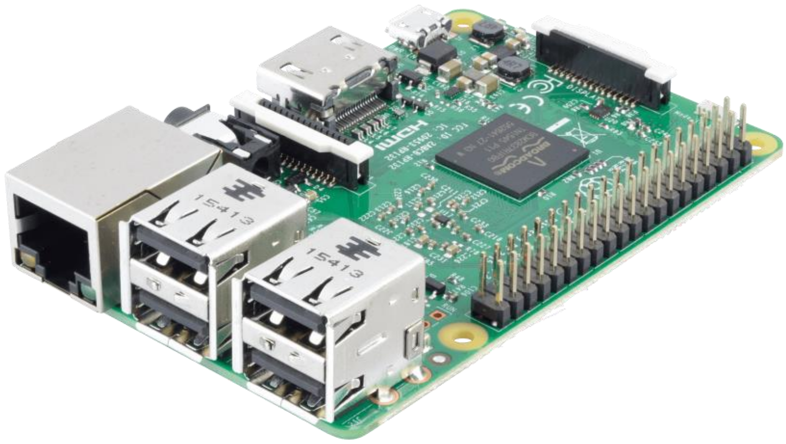

Figure 5.8.- Raspberry Pi 3.

A Raspberry Pi is a microcomputer which can perform like a normal computer in many procedures. As it can be seen in Fig 5.8, it consists of a small board with two columns of pins (different purposes for each pin), USB ports, HDMI port, ethernet connection and powering connection. Its small shape and wide range of possibilities offered makes it the perfect fit for the project.

That was the first time I had to work with a Raspberry Pi so again, considerable time was invested in learning its functioning.

Firstly, learning how to set it up and studying its commandments so as to use the Terminal. Then, getting used to the pins [Table 5.1] and understanding their different purposes.

wiringPi Pin	BCM GPIO	Name	Header	Name	BCM GPIO	wiringPi Pin
—	—	3.3v	1 | 2	5v	—	—
8	R1:0/R2:2	SDA	3 | 4	5v	—	—
9	R1:1/R2:3	SCL	5 | 6	0v	—	—
7	4	GPIO7	7 | 8	TxD	14	15
—	—	0v	9 | 10	RxD	15	16
0	17	GPIO0	11 | 12	GPIO1	18	1
2	R1:21/R2:27	GPIO2	13 | 14	0v	—	—
3	22	GPIO3	15 | 16	GPIO4	23	4
—	—	3.3v	17 | 18	GPIO5	24	5
12	10	MOSI	19 | 20	0v	—	—
13	9	MISO	21 | 22	GPIO6	25	6
14	11	SCLK	23 | 24	CE0	8	10
—	—	0v	25 | 26	CE1	7	11
wiringPi Pin	BCM GPIO	Name	Header	Name	BCM GPIO	wiringPi Pin

Table 5.1.- Raspberry Pi pins.

Each side has three columns. The outermost column, headed wiringPi Pin refers to the pin number in the wiring Pi code. The middle one, headed BCM GPIO refers to the pin number of the BCM2835 chip, and this is the pin number used when addressing the GPIO using the /sys/class/gpio interface. The innermost column, Name is the name of the function of the pin.

To start, programming directly to the terminal was what was done. Using Python, I was able to test different pins to control a LED. After this first testing stage, I proceeded to start with coding in C language. After considering different alternatives, using the 'wiringPi' library was the selected one. This library simplifies considerably working with the Raspberry Pi. Its main benefit comes with the use of GPIO pins.

Again, I studied a couple of tutorials to get used and get examples of how to proceed [10]. A program that included the PIR sensor was developed. In this case, the software is able to read whether the output signal coming from the PIR is 'high' (motion detected) or 'low' (motion not detected) and act accordingly. In the test, when the Raspberry Pi detects a 'high' value, it proceeds to put the pin where the LED is connected to 'high' too. By working in this manner, we can easily see if the developed code works correctly or not to be sure we are doing it in the proper way. After this is tried, adapting it to the system code is the next step, which will be explained in the next section.

5.3.- Results

After all the possibilities have been tested, implementing the PIR sensor connected to the Raspberry Pi was the alternative selected. The reasoning behind that is that it is in there where the data is stored and also the code in there is less complex compared to the one running in the microcontroller. So, including the functions to add the sensor will be simpler.

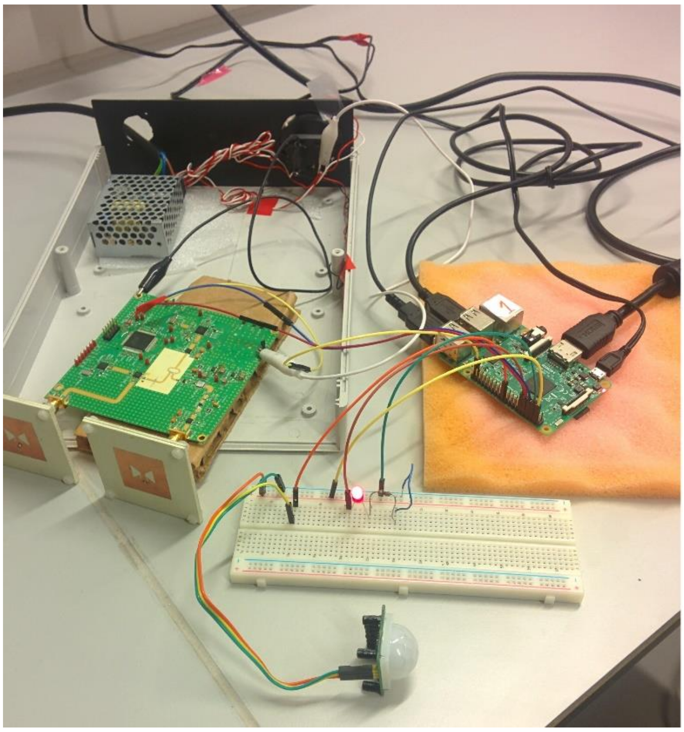

Figure 5.9.- Whole system.

In Fig 5.9 the whole Radar sensor is shown. It can be seen that the board containing the PIR is connected to the Raspberry Pi by 4 wires. Two are for powering it, 5V and GND (header 4 and 6 respectively), another one is connected to the output of the PIR and connected to a GPIO pin configured in read mode and the last one is connected from the LED (lighted in the picture), to a GPIO pin configured in write mode. Any GPIO could be used for these purposes if the software is changed accordingly.

Three wires connect the microcontroller board to the Raspberry Pi. One is for them to share the same GND, and the other two are for the USART transmission. One for transmitting and the other for receiving (headers 8 and 10 of the Raspberry Pi respectively).

The white wire connected to the microcontroller board comes from the power supply and powers the board supplying 5V.

The accomplished system works in the following way. The radar board is continuously sending data to the Raspberry Pi which receives it all but only stores it when the PIR sensor has detected movement, this is, a 'high' signal is read from the GPIO pin where the output of the PIR is connected. In addition, to make it clearer whether the data is being stored or discarded, the LED will be on or off, this is, the GPIO pin where the LED is connected will be put in 'high' mode when data is stored or in 'low' mode when it is discarded.

The amount of time that the output of the PIR is in state 'high' can be determined by adjusting the trimpot in the circuitry of the sensor. It has to be studied how much time should the Raspberry Pi keep on storing data after movement is detected. Since most of the systems will be installed in a living room, where users may sit in a sofa/chair without moving for a quite long period of time, it has to be calculated which is the better relation between maintaining it 'high' while storing data for too long (waste of memory, user might have left the room) or maintaining it 'high' for too few time (loss of information, user might still be in the room sitting in somewhere without moving).

5.4.- Conclusions

To sum up, with the addition of a PIR sensor, which can know whether there is a person or not in a room by detecting movements of warm bodies, we can decide whether we store the data that is being received or not. By doing this, we maximize the limited data capacity of the USB pen drive and also do not store any 'dummy' data that will difficult the analysing of it and make it heavier and more time consuming.

Different approaches on how to include it have been studied, either in the microcontroller or the Raspberry Pi, either using Python or C coding languages. Finally, it has been included on the Raspberry Pi while developing the software in C. Anyway, as the PIR is placed in a separated board, in the future it can be used for new purposes.

5.4.1.- Next steps

With what is done at the moment, the improvement is only made in what concerns the storage of data, but the sensor can be helpful in other ways.

Specially with power saving techniques, where the PIR could be used to stop the whole system when it does not detect anyone in the room. Turning the whole system on and off continuously will not be efficient as it needs some time to get fully operative after turning it on, specially the Raspberry Pi. But turning it off for large periods of time, as in the night, when users will probably be sleeping will allow to save plenty of power.

Also, if only the microcontroller board has to be turned off when the room is empty (Raspberry Pi takes more time to be turned on/off), a connection from the PIR board to the microcontroller board can be done just by adding some wires. If that is done, stopping to run the code in the microcontroller could be achieved and by doing this, saving all the power consumed by it and the whole signal generation (Antennas, PLL, VCO, microcontroller and losses in the circuitry).

CHAPTER 6

BUDGET

Component	Cost (€)
RF Adapters	95,56
RF Amplifier LNA	25,61
IQ Mixer	29,53
AT32UC3A1512 Microcontroller	12,13
Power Supply	6,75
Plastic box	14,87
Stand	20,8
Antenna cables	20,42
Raspberry Pi 3	39,97
Circuitry (cables, capacitors, resistences, connectors, etc)	200
TOTAL (€)	465,64

Table 6.1.-Costs of components.

Team member	Dedicated hours	€/h	Total salary (€)
Team leader	500	45	22500
Researcher engineer (data analysis)	750	30	22500
Researcher engineer (developer)	600	25	15000
Researcher engineer (Electronics)	1000	30	30000
Junior engineer	250	16	4000
Circuitry assembler	20	20	400
TOTAL (€)			94400

Table 6.2.-Salaries of team's members.

Regarding the components costs, the cost of the circuitry is an estimation while the others are exact.

An estimated 250 hours have been dedicated to the practical part of the project by me. The salary for a junior engineer in Belgium is in the range of 2500€/month and considering that the normal timetable consists of 8h/day during 5 days a week 4 weeks a month, 160 hours/month are computed. 2500€/160h = 15,6€/h → 16€/h.

The other members of the research team have been assigned a number of dedicated hours taking into consideration that the project started some years ago but also that people working on it are also working in other projects so they are not dedicating all their working hours on it.

Components costs are calculated for a single sensor and for the system to work properly, three of them are needed. This amounts for 465,64€*3sensors=1397€/system.

6.1.- Financial viability

Every new system will cost 1397€ plus the installation costs that will not be too high since the sensors can be easily installed and they do not require extra actions. An 80€/installation is assumed, for the installer labour effort and transport. Now the total cost is at 1477€ per system installed.

A viable business model could consist in selling the whole system and also providing the 'service' that it offers, this is, continuously monitor elderly people for a monthly payment.

Considering that nursing homes in Belgium cost around 1200€/month, the system could be sold at the range of 1200€-1500€ and then the monitoring could be charged at the range of 150-300€/month and still it would be way cheaper than a nursing home. Taking into account that the processing and analysing of data would be mostly automated, we can consider costs of 100€/month for each user monitoring (this will include detailed information given to the caregivers of each user, notifications of unusual situations, etc). To sum up, families or caregivers will be saving plenty of money by using this system instead of paying an elderly people residence home. In addition, each operating system contracted will suppose a monthly positive cash flow of around +100€ for the 'company' while the costs of building the sensors will be practically covered by the first payment of the users.

Furthermore, since it is a system that contributes to society taking care of elderly people, it could receive public funds as it can be regarded as a service to society. These public funds could make up for part of the costs of developing the system (basically the sum of the salaries of all the contributors) while the other costs can be recovered with the positive cash flow of around +100€/month that each operating system sold will generate.

CHAPTER 7

CONCLUSIONS

As to have an overall overview, after the work done, we now have a fully operating improved system with the following changed characteristics:

A base station is no longer required in the installation since its purposes are now performed by a Raspberry Pi included in the same box of the radar sensor. Related to this, the SPI standard has been replaced by the USART one to be able to communicate the microcontroller board to the Raspberry Pi. Moreover, data is stored in a text file in the USB connected to the Raspberry Pi. Additionally, not all the data received in the Raspberry Pi is stored. Only the information that is of relevance is saved while data about periods that are of no interest is discarded. This is, when the user is not present in the room where the monitoring is being carried out. A PIR sensor possibilities this functionality by determining if there is a person or not in the room with its motion detection capacity.

Benefits in the security of data transmission, storage capacity, data analysis complexity and inconveniences to users is what these changes contribute to the system.

Firstly, transmitting data directly to the Raspberry Pi instead of sending it to the base station using a Zigbee wireless connection makes for a more secure treatment of private data that should not be transmitted in a way that it can be accessed by others.

Secondly, discarding unnecessary data, helps reducing the needed storage capacity for the system while also improving the data analysis efficiency. With the improvement of not saving irrelevant data, processing all the data obtained will take less computational effort and, in addition, provide more accurate results since that irrelevant data would only bias the information about user behaviour which data includes.

Also, not needing to install a base station in user's room will make the project more user-friendly as it will barely take up any space of the room as the three required radar sensors will be placed in the walls or in the ceiling.

Moreover, the ethical discussion has had a satisfactory outcome. This system can be regarded as non-invasive when talking about user's privacy. Furthermore, this project is on compliance with laws defending privateness of people. The system can be considered as secure and non-bothering or, in any way, harmful for users.

7.1.- Next Steps

The system as of it is today is fully working and certainly useful for its objectives but it can still be improved.

As it is designed at the movement, data analysis is done a posteriori, when the collected data from a whole month is taken from the USB pen drive and analysed in the laboratory. This is appropriate for studying the behaviour of users to see if they are experiencing any signs of a health problem. However, this does not enable real-time monitoring. For example, a fall event can be determined when analysing the data in the laboratory but it cannot be detected at the same moment it occurs. Detecting it at the exact moment it happens so the person experiencing a fall can be helped instantly can be of huge importance in some cases. In order to do this, implementing the data analysis software in the Raspberry Pi would be a remarkable improvement as it will allow real-time monitoring and consequently users could be quickly assisted in case an emergency occurs.

Another thing the system could capitalize more on is the PIR sensor. At the moment it is only used to discard irrelevant data but it can also be used for power saving purposes. Since the PIR will be placed on its own board inside the box of the radar sensor, it will be feasible to connect it to the microcontroller and to develop a code to turn off the whole system whenever there is nobody in the room. This will allow power savings of around 40-50% considering that the user will not be in the same room more than half of the day so the system could be off for this amount of time.

PIR to microcontroller connection has already been tested and it is doable. It has not been implemented because further modifications in the general software must be done to implement the functionality of turning it off and on depending on if there is someone in the room.

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