Indoor localization System for elder people

Lambert Sellés, Mathew

Abstract— Locating people or objects outdoors is relatively simple nowadays, with a simple GPS receiver a high precision can be acquired, taking into account the total surface, and it's cheap but when trying to do so indoors walls, frames and interferences take place and the method is not reliable anymore. The existing localization models are applicable to this field of study, the technology is available and few solutions are cheap and simple to implement. The models that fit to the needs have been analysed as the possible technological alternatives available to make the system viable, economic and profitable and it has been choosed to develop the system using radiofrequency and a localization model based on the calculation of centroids with fixed receivers at known positions and low power mobile senders. To test and make measurements in order to deduce if the system is viable, a prototype has been developed using and Arduino board acting as a fixed receiver and a garage remote-control as a sender. To conclude an estimation of the material costs is done.

Index Terms—Indoor localization, locating people in buildings, profitable and low-cost indoor localization system, radiofrequency 433MHz, localization model based on centroids, localization with Arduino.

Resumen— Localizar personas u objetos en exteriores resulta relativamente sencillo en la actualidad, con un receptor GPS sencillo se alcanza una precisión alta, teniendo en cuenta la superficie total, y es económico pero al intentar hacer lo mismo en el interior de un edificio entran en juego paredes, armazones e interferencias y este método resulta ineficaz. Los modelos de localización existentes son aplicables a este campo, la tecnología está disponible y hay pocas soluciones que resulten económicas y sencillas de implementar. Han sido analizados los modelos que se ajustan a las necesidades y las posibles alternativas tecnológicas disponibles para proponer un sistema viable, económico y rentable y se ha elegido desarrollar el sistema usando un modelo de localización mediante radiofrecuencia y usando un modelo basado en el cálculo de centroides con receptores fijos en posiciones conocidas y emisores móviles de baja potencia. Para realizar pruebas y mediciones, con el fin de deducir si el sistema resultaría viable se ha realizado un prototipo con una placa Arduino actuando como receptor fijo y un mando a distancia del tipo de puerta de garaje como emisor. Para concluir se realiza una estimación de coste del material.

Palabras clave— Localización en interiores, localización de personas en edificios, sistema de localización en interiores rentable y de bajo coste, radiofrecuencia 433MHz, modelo de localización basado en centroides, localización con Arduino.

---

1 INTRODUCTION

ELDERLY people, living in nursing homes, which have a decent degree of mobility have always to be controlled and announce their movements in order to get located in case of emergency. Nurses, sons, and residents have been interviewed in order to determine the goals to achieve.

Nurses insist that the existent systems are really expensive [1] and need a lot of infrastructure (a locating arch around each door), of course, they would like to give more freedom to the elderly, but freedom implies loss of security. Residents argument that they need a bit of freedom and they understand the danger that it implies, on the other side they wouldn't like to be located with cm precision because it involves almost a violation of privacy. Of course familiars want their beloved to be as secure as possible.

The people interviewed converge in a point, knowing the area where the resident is would be sufficient, understanding area as a delimited zone of the residence normally implying a pair of rooms and the living rooms; a section of the rooms floor. The goal could be established as finding an affordable indoor localization system in order to offer the patients a greater degree of freedom and maintain the safety levels.

We will review existing locating method and technologies, analyze a particular method and technology, setup the required devices, measure and analyze the results and prove the technical viability of an indoor localization system using low cost and low infrastructure elements.

The system should be affordable, simple, technologically viable and profitable.

- *E-mail address: mathew.ls@outlook.com*
- *Expertise: Enginyeria de Computadors.*
- *Project totured by: Lluís Ribas (Microelectrònica I Sistemes Electrónics)*
- *Course 2013/14*

2 Localization systems

There is a large range of combinations between multiple technologies and techniques used nowadays to locate people or objects in indoor environments featuring a huge interval of possibilities for every variable analyzed. Models, or techniques, include Time of Flight measuring and trilateration, near receiver, pass-by message, etc…; each of them can be implemented with different technologies like Radio Frequency (as Bluetooth, Wi-Fi, Zig Bee or plain RF), light pulses (including Infrared), sound or lasers.

The locating systems can be naturally sorted by the localization model used, by the technology but also by the precision achieved, that can range from less than 1cm to a whole room, by the power usage or by the need of new infrastructure. A review of the system by models will be done.

2.1 Time of Flight

The vast majority of localization systems are based on time of flight measuring, the distance from a moving object to a fixed known position is calculated measuring the time taken by the electromagnetic wave to do a round trip between the two devices [2][3][4] and [5]. Using two fixed receivers the moving object can be triangulated in two dimensions (see Fig. 2) using the Pythagorean Theorem (see Fig. 4), increasing the number of fixed receivers increases the precision.

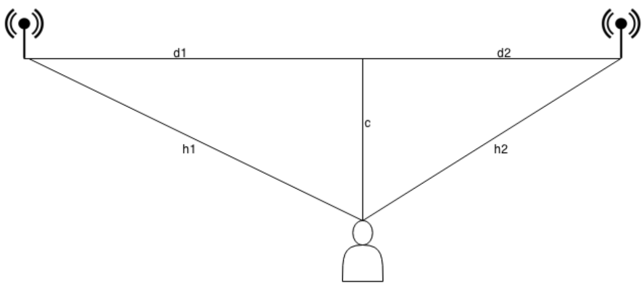

Fig. 2. Position calculation based on the time of flight

$$d_1^2 + c = h_1^2 \ , d_2^2 + c = h_2^2$$

Fig. 4. Pythagorean Theorem applied to calculate each distance.

This model can be implemented using multiple RF technologies, as Bluetooth, Wi-Fi, and ZigBee as well as light and sound technologies.

The main advantage of this model is the great precision of the localization, but there is a big drawback, there must be a big infrastructure in order to achieve that precision, this means having multiple receivers in every room.

2.2 Near receiver

This less precise but simpler localization model lies on knowing which receiver is near the moving object, in order to determine a fixed diameter determined by the signal coverage, around the receiver. (see Fig. 1)

This model can be exploited using electromagnetic waves (such as RF systems) [5][6] and [7] but also using pressure waves (such as sound and ultrasounds [7][8] and [9]). The strength of the model is the simple infrastructure needed; therefore the achieved accuracy is much lower.

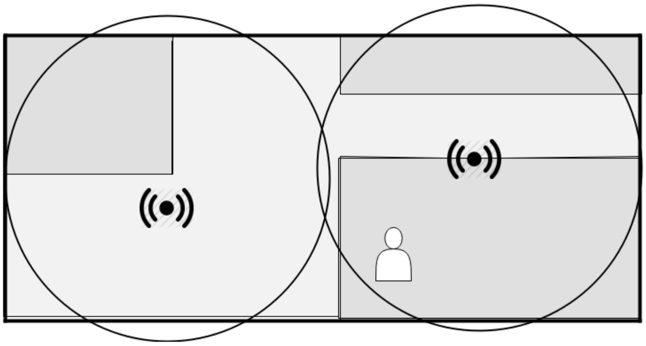

Fig. 1. Position calculation based on the nearest receiver. A floor plan with three rooms, two receiver and a person can be observed.

2.3 Center of masses

An alternative localization method is the one based on the center of masses. It increases the accuracy of the 'near receiver' method but keeping simple and low cost infrastructure. [10][11][12][13].

In order to determine the position of the object, we calculate the center of masses of the polygon formed by the receivers that got the message from the sender.

On the figure (see Fig. 3) a simulation of a system using this localization model can be seen. Note that the physical measures are not realistic.[14]

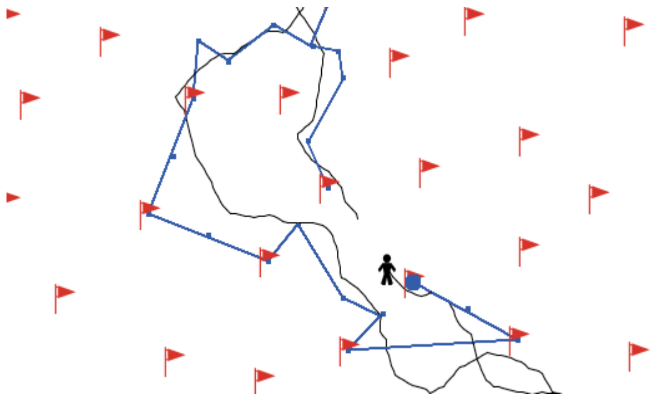

Fig. 3. Simulation of a center of masses localization system. The flags are the receivers, the black line is a random path that simulates someone walking randomly across the plane, and the thicker blue line is the estimated path.

2.4 Weighted center of masses

The previous method can be enhanced using weighted centers of masses, this means that the nearest beacons have more power when calculating the center than the ones that are farther.

This can be accomplished measuring the power of the reception, calculating the time of flight, or calculating the time difference between regular pulses.

3 Technologies

In order to apply one or another model we need to establish a communication between the receiver and the moving object, there are multiple technologies that can help to achieve the goal.

The chosen solution should be inexpensive and easy to implement.

3.1 Infrared and light pulses

This technology consists of communicating with light pulses. This can be done easily but has a big drawback, it depends on line of sight, if the receiver can't see the sender it won't receive the message.

3.2 Sound

Air pressure waves can also be used to transmit a short message but this technology is only suitable for non-noisy environments, the line of sight requirement is not so narrow as for the light pulses and it depends on the power of the emitter.

3.3 Radio Frequency

Using electromagnetic waves is a bit more complex than previous studied technologies, buy the main advantages are that it has less interferences [15][16][17] and [18], and better coverage, so it can travel better and as sound, without line of sight. This can be implemented using different RF technologies.

4 Model and Technology to analyze

The proposed system has to meet some strong requirements implied by the use case.

Pricing will be the most limiting requirement, as the system needs to be very affordable, and the need of new infrastructure installation needs to be minimized.

Power availability is limited, as the locating element has to be as small as possible and should run on a battery for at least one month.

The needed accuracy of the system should be around a pair of meters. The looseness of this last requirement is what allows us to choose a specific set of technique and technology.

The center of masses technique along with simple radio frequency technology, using LD433, will be used for the system. This ensemble permits us to meet the battery life, low-cost infrastructure, lack of line of sight and great coverage.

The solution will be based on hardware commodities based on Do It Yourself. It will consist on an Arduino board receiving the messages and a garage-door remote acting as a sender.

To improve the accuracy of the center of masses the beacons should be weighted, with the chosen technology the only way of achieving this is measuring the time difference between regularly sent pulses, the precision of the measurements should be at least 3ns to achieve a localization precision of 1m, this is because the delta time must be multiplied by the speed of light. The tests done where unsuccessful, as the precision of the measurements done is 100us. Exact details can be read on Appendix 1.

5 Characterization

The resulting system should be able to locate people inside a building, and to be as precise as possible, this precision factor relies primarily on the amount of locating elements distributed across the locating plane.

In order to calculate the position of the person the system calculates the center of masses (centroid) of the polygon created by the union of the receivers that got the signal from the sender, in the case that a polygon can't be calculated, the position is determined by the middle point of the two receivers, or the position of the only receiver that got the signal. This demonstrates that the number of receivers that get the signal is very important to determine the precision of the system, as we described, with one or two receivers getting the signal lowers the precision.

On the figure (see Fig. 5) we can see an example of a simulation [14]. The flags are the receivers, the black line is a random path that simulates someone walking randomly across the plane, and the thicker blue line is the estimated path, created by the union of the calculated centroids. It can be observed that the estimated path can be suitable for an approximate location, this simulation uses a real floor plan.

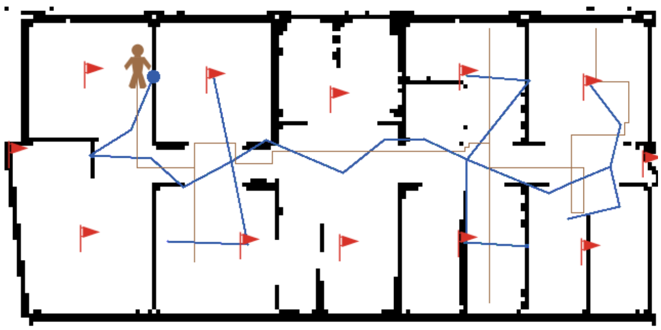

Fig. 5. Localization by centroids. The thin brown line is the real path. Blue and thicker line is the simulated path, resulting of the union of the detected positions.

With the purpose of characterizing the signal used on the project an analysis of the signal reach have been done. In two words we can see that the signal can't pass over the firewalls, difficulty over the brick walls and the plaster wall blocks around 20% of the signal. The best length of the antenna for the project would be 1cm. These results have been summarized (see Fig. 6).

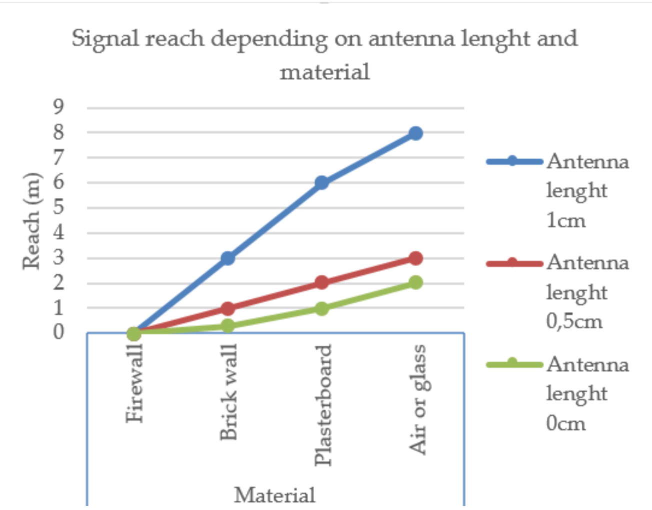

Fig. 6. Signal reach analysis. The ideal signal reach would be stronger on the brick and plasterboard walls in order to have a similar coverage.

In order to increase the accuracy of the estimated position two procedures can be followed (not exclusive):

- Find the best position of the receivers in order to get the best coverage with less devices. This can be accomplished by analyzing the position of the receivers on the plane, and distributing them according some rules. Per example putting a receiver in the center of a room will limit its coverage to that room, but setting it by the wall, will increase the coverage to the nearby room.
- Add a trilateration method to calculate the position. This could be accomplished on the following scenario: If we set the senders to emit at a regular period, the receivers can detect an increment or decrement of the period, this would mean that the object has moved, farther or nearer, knowing the period difference the difference of distance can be calculated, and therefore, weighed center of masses method can be used.

5.1 Interacting elements

The system uses two types of devices to accomplish the localizations. One is the 'located' or sender device that every person that needs to be located should wear, the second is the beacons, or receivers, the last are fixed at some position. In order to display the results and configure new people there is a computer. As the names indicate, the element that will be located sends a message to the receiver beacon.

The sender (see Fig. 8) consists of a simple device capable of sending LD433 messages periodically, using very low power. To accommodate to the needs, a simple 433MHz remote, like the ones used for garage doors, will be used. This device offers us the requirements at low price. One modification has to be done although, this devices don't emit regularly so a timer needs to be added to the remote-control to send the messages every period. There are several approaches to accomplish this:

- NE555 timer: Connecting a 555 timer in an astable configuration to the remote's button in order to simulate a push is a reliable solution.
- Resistor-Capacitor charging circuit: this is a simple solution that can also be used in order to simulate the button push. Less material is needed to build it and it's smaller than the 555 timer solution. It can fit easily in every remote control.
- Clock circuit: This last solution is more expensive and precise that the previous ones. This level of high precision is not needed for the sender.

The receiver (See Fig. 7) will be prototyped using the single-board microcontroller Arduino Mega 2560 equipped with a 433MHz receiver module and a Wi-Fi communicating module or 'shield'. This device will act as a transceiver, its goal is to receive the message sent by the remote-controls and send it to the central computer using the Wi-Fi module.

Fig. 7. Arduino Mega 2560 attached with a 433MHz receiver acting as the fixed receiver element.

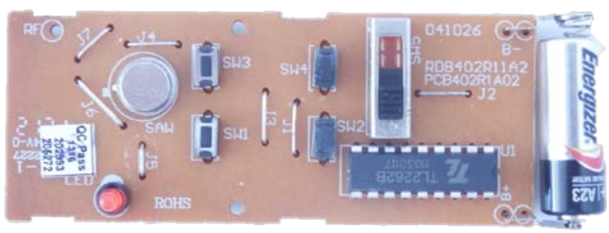

Fig. 8. 433MHz remote control acting as sender and located

The receiver's program (see Fig. 9), consisting of three blocks, is simple. The first part is charged of including the necessary code to work with the LD433 module, the second part configures the communications with the computer and enables the receiver, this two are only done once when powering-up the board. The last part repeats always, it receives the code from the receiver module if it's ready, and sends it to the central host by the emulated serial port.

6 Measures and Results

TO prove the viability of the system the results of the measures done have to be analyzed.

```
//++++++ FIRST BLOCK ++++++
long unsigned int received = 0;
//Declare RF reciever
int interrupt_rf = 0;
#include <RCSwitch.h>
RCSwitch reciever = RCSwitch();
//++++++ SECOND BLOCK ++++++
void setup() {
  //Enable serial comm with PC
  Serial.begin(9600);
  //Enable reciever
  reciever.enableReceive(interrupt_rf);
}
//++++++ REPEATING BLOCK ++++++
void loop() {
  if (reciever.available()) {
    recieved = reciever.getReceivedValue();
    if (recieved != 0) Serial.println( recieved );
    reciever.resetAvailable();
  }
}
```

Fig. 10. Code used to receive the message from the remote-control and transmit back to the central host. Divided in three blocks: Including code, Set-up and Repetition.

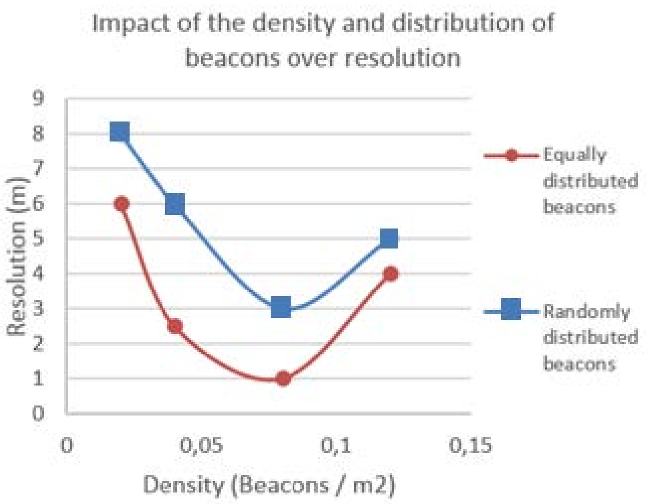

Fig. 9. Analysis of the impact of the number of beacons and distribution over achieved resolution

The number of beacons and the distribution of these ones impact directly with the obtained resolution. If the number of beacons is low, the number of receivers that communicate with the sender is only one or two, this implies that the resolution is low. On the other hand, if the number of beacons increases too much, too many receivers communicate with the sender and the calculated position is not any more accurate, this leads to an inefficient system. The results can be seen on the figure below (see Fig. 10).

A resolution of 2.5m would be enough to locate people inside a building and determine if they are in a room or in another, this can be accomplished installing beacons with a density of 0.04 beacons/m^2 (12 beacons for 300m^2).

7 Viability and Cost Analysis

Few similar systems compete in the market, this could mean that the projects are normally not viable, or too expensive to introduce. For starters the target of this kind of system is not very large, it could be used also to track other moving objects rather than persons to make it more profitable.

7.1 Cost analysis

It's important to note that the analysis of costs will not be targeted for analyzing the price, this should include gains and other variables that would made the product profitable for the company.

ELEMENTS FOR EACH RECEIVER	COST
ARDUINO MEGA 2560 BOARD	50.00€
WIFI SHIELD	75.00€
433MHZ RECEIVER MODULE	10.00€
AC/DC TRANSFORMER	10.00€
TOTAL	145.00€

ELEMENTS FOR EACH SENDER	COST
433MHZ REMOTE	15.00€
ELEMENTS FOR MODIFICATION	5.00€
TOTAL	20.00€

To estimate the cost of the materials for a real situation we count 12 receivers for a 300 m^2 floor, and 50 senders, one for each person, this data were extracted from a real nursing home.

QTY	ITEM	COST
12	BEACONS	1740.00€
50	SENDERS	1000.00€
	TOTAL	2740.00€

It's important to remember that one of the goals is that the system is affordable, and therefore, the cost of the material are low. With the analysis above it can be seen that this point is accomplished, the cost of hardware commodities for locating 50 persons would be around 55€/person.

7.2 Viability analysis

The achieved solution for the project is affordable, technologically simple, should be easily profitable, and exploits hardware elements that are already consolidated.

The project seems to be viable for commercialization.

8 Conclusion

Indoor localization systems require an infrastructure installation and depending of the precision needed this can be costly. Using mature hardware to communicate low power senders with fixed receivers, and calculating the estimated position with a centroids model is a low-cost solution that can be profitable in order to locate with a high precision.

Even that there are errors on the determined position, the system can be used to locate and track moving objects. With the used hardware the weighted centroids method can't be used but it could be done with different hardware.

The described system could be used not only to locate persons but also objects as robots and stocks in sheds and animals in farms. The central host of the system is not described in this article, this one should communicate with each receiver using a wired or wireless link depending on the size of the building, it would consist on a program receiving messages from the receivers that have senders nearby, and calculating the position using the described model.

ACKNOWLEDGMENTS

Special thanks to the project tutor Lluís Ribas who has always been interested and made this article possible.
Thanks to F. Lambert, nurse at the elderly residence "Résidence des Chênes" who has indicated real life situations and comments of families.
My Father who has always pushed me into solving myself the problems and raised concerns about hardware.

BIBLIOGRAPHY

[1] GrupoNeat, "Localización indoor". [Online]. Available: http://www.gruponeat.com/index.php?ids=906&lang=es. [Accessed: 12-Mar-2014].

[2] S. A. Mitilineos, D. M. Kyriazanos, *et al*, "Indoor Localization with wireless sensor networks", *Progress In Elecrtomagnetics Reseach*, Vol. 109, vol. 109, no. June. 2010, pp. 441–474.

[3] J. Paul A. Denning, "ZigBee-based Indoor Positioning System with Intelligent Assistive Technology for Alzheimer's Patients," *California State Science fair Project Summary*, 2013, p. Ap2/13.

[4] H. Noguchi, H. Fukada, and T. Mori, "Object and Human Localization with ZigBee-Based Sensor Devices in a Living Environment," *INTECH open science*, 2013, pp. 223 – 244.

[5] R. Jarvis, A. Mason, *et al*, "Indoor Positioning System", *Louisiana State University*, 2011.

[6] M. Deseada, G. Pascual, "Indoor Location Systems based on zigbee networks", *Mikkeli University of Applied Sciences,* 2012.

[7] C. Detweiler, "Passive Mobile Robot Localization within a Fixed Beacon Field", *Massachusetts Institute of Technology,* 2006.

[8] R. W. Morin, "A novel localization System for experimental autonomous underwater vehicles", *Worcester Polytecnic Institute,* 2010.

[9] M. Peca, "Ultrasonic Localization of Mobile Robot Using," in in EUROBOT 2009, CCIS 82, Springer-Verlag Berlin Heidelberg, Ed. 2010, pp. 116–130.

[10] D. J. Blumenthal, Ralf Grossmann, Frank Golatowski, "Weighted Centroid Localization in Zigbee-based Sensor Networks," Intelligent Signal Processing, 2007. WISP 2007. IEEE International Symposium, 2007.

[11] Sukhyun Yun, Jaehun Lee, *et al* "Centroid Localization Method in Wireless Sensor Networks using TSK Fuzzy Modeling," *Yonsei University*.

[12] Z. Zhiliang, G. Jingmin, "Corrected Range Weighted Centroid Localization Algorithm Based on RSSI for WSN," in in Proceedings of the 2011, International Conference on Informatics, Cybernetics, and Computer Engineering (ICCE2011) November 19–20, 2011, Melbourne, Australia, vol. 111, L. Jiang, Ed. Berlin, Heidelberg: Springer Berlin Heidelberg, 2012.

[13] P. Paolo, P. Luigi, and P. Dario, "Accuracy of RSS-based Centroid Localization Algorithms in Indoor Environment," University of Trento, 2011.

[14] L. Ribas, "Netlogo centroid model simulation." Personal communication, 2014.

[15] C. Ó Conaire, K. Fogarty, et al, "User localisation using visual sensing and RF signal strength" Workshop on Applications, Systems, and Algorithms for Image Sensing, 04-Nov-2008.

[16] N. Kassem, A. E. Kosba, and M. Youssef, "RF-Based Vehicle Detection and Speed Estimation," in 2012 IEEE 75th Vehicular Technology Conference (VTC Spring), 2012, pp. 1–5.

[17] H. G. Schantz, "On the origins of RF-based location," in 2011 IEEE Topical Conference on Wireless Sensors and Sensor Networks, 2011, pp. 21–24.

[18] P. Bahl and V. N. Padmanabhan, "RADAR: An In-Building RF-based User Location and Tracking System.", *Microsoft Research*.

APENDIX

A1. USING PERIODICAL PULSES IN ORDER TO MEASURE DELTA TIMES.

In order to locate a person, the remote controller used in the project must send at a regular period, in order to accomplish this a small microcontroller has been used to regularly "push" the button of the remote. For sending one command the microcontroller must close the circuit for 30ms, below this time the remote doesn't send any command, and over 35ms two commands are sent even that the second is not correctly encoded. Over 55ms two signals are sent.

Calculating the position of the sender: To calculate the estimated position of the sender, the receivers that get the signal, send the code of the receiver to the host, and this one is charged of calculating the position. This is done by calculating the centroid (or center of masses) of the polygon formed by the receivers that received the signals.

Measuring period between two pulses: With the purpose of applying a new location calculation method based on trilateration that knows the distance between the sender and the receivers the time between two pulses (sent at a regular interval) had to be measured and be very precise. To do so a simple counter on the receiver calculates the time with a microsecond precision between both signals. This led to discard this new calculation technique, as the time measured varied as much as 10ms in some occasions (with a mean of 3.7ms). A second test was made with an Arduino and a RF emitter to plan a second technique, this time the variations were two orders smaller (between 50us and 200us, 65us mean fluctuation) but still too big.

The results obtained on the testing for the calculation of the period difference, and therefore the trilateration, have not been successful. The remote control used as sender was not acting as expected, the period was fluctuating as much as 10ms, this could be due to the design of the remote control, which doesn't need so much precision, the receiver module, or interferences. Alternatively a test has been done with another Arduino and a sender module, decreasing period fluctuation, but still remaining between 50us and 200us. This values can seem small, but in order to calculate the difference of period, the fluctuation should be as small as 3ns which equivalent to 0.9m (Speed of Light = 299.792.458m/s = 0,299.792.458m/ns. 0,299.792.458m/ns * 3ns = 0.90m)