Implementation of Two Indoor Localization Algorithms on an FPGA

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***Abstract*—Although the Global Positioning System (GPS) is very accurate for outdoor positioning operations, it is generally unsteady for indoor operations. To handle this situation, variety of systems have been developed and Radio Frequency Identification (RFID) technology is generally preferred in these implementations. In this project, it is aimed to obtain localization information of people inside a building by using RFID tags. For this purpose, Received Signal Strength Indicator (RSSI) values are used to have a distance estimate. To implement localization algorithms, some mathematical operations need to be performed and Field Programmable Gate Arrays (FPGA) have been used to realize these operations.**

Same RFID transciever devices have been used as both readers and tags. RFM23B module has been selected as RFID transciever and this device has been used in control of a microcontroller. A microcontroller is necessary to drive and modify the operation modes of the transciever and Arduino modules are used for this purpose.

In localization process, the tags transmit their identity (ID) value to the reader. When the reader obtains the radio signal, RSSI value is calculated by related analog equipments of the RFID module and this value converted to a 8-bit binary format to be processed by digital components. This RSSI value is used for a distance estimation and stored with related tag ID. Using the distance values from different tags the localization algorithm calculates the position of the reader. Finally, the results are sent to main frame and printed out to a screen.

I. Introduction

Localization of objects and people is one of the key aspects for security, safety and service applications in today's technology. Although this field of study emerged a while ago, it is still actively researched [2]. For outdoor localization applications, GPS technology is quite sufficient to locate people or objects. However it is not able to work out for indoor localization applications. The main reason is that GPS technology requires direct "line of sight" which means that between the satellite and the target there should not be any obstacles such as trees, walls, buildings etc [5]. Also for localization with GPS, it is required that at least 4 different satellites should participate in the operation and this condition increases the cost. Therefore, lots of new methods have been proposed for indoor localization and they all require a wireless technology for implementation. Radio Frequency Identification (RFID) and Bluetooth are the most widely used wireless technologies through low cost and accurate operation performances. Considering all these factors mentioned above, RFID wireless technology has been chosen to realize this indoor localization system.

Trilateration has been selected as localization algorithm and it has been preferred to realize two dimensional (2D) localization in this study. First, the algorithm has been implemented on C++ via Visual Studio and then it is implemented on Field Programmable Gate Array (FPGA) using Microblaze. Microblaze is virtual microprocessor that can realized on FPGA device and the programs written with C or C++ can be run on the device. Finally, some parts of the algorithm has been implemented as hardware using Verilog HDL language. The designed hardware module has been then operated under the control of Microblaze processor.

II. Background Information

A. Radio Frequency Identification

RFID is a rapidly growing technology that uses wireless antennas to identify objects from a distance without requiring line of sight or physical contact. The success rates in capturing real time information accurately from both moving and stationary objects has contributed to be today's widely-used wireless technology [4].

A typical RFID system is mainly composed of two parts that are a tag and a receiver. The tags radiates radio waves with their antennas and the reader receives these radio waves. Depending on the application, different types of tags can be used such as active, semi-active and passive. Active tags are connected a power supplies and can operate continually. On the other hand, passive and semi-active tags are normally in sleep mode and started to operate with the coming wave energy from reader. In this project, active RFID tags have been used and same RFID transceiver module has been used for both the reader and the tag. Also communication between the tags and the reader has been performed at 433 MHz.

B. Received Signal Strength Indicator

Received Signal Strength Indicator (RSSI) is the strength of power which is measured at the receiver antenna. RSSI value depends on transmitter power and the distance between transmitter and receiver antennas. There is an exponential dependency between RSSI and distance instead of linear one. Thus, calculation of the distance value from related RSSI value is a rather complex process. The formula that explains this relationship is shown below [1].

$$P_{RX} = P_{TX} * G_{TX} * G_{RX} \left(\frac{\lambda}{4\pi d} \right)^2 \tag{1}$$

Where, P_{TX} = Transmission power of sender, P_{RX} = Remaining power of wave at receiver, G_{TX} = Gain of transmitter, G_{RX} = Gain of receiver, λ = Wavelength, d = Distance between sender and receiver.

C. RFM23B Module

To realize the communication between the tags and the reader, RFM23B module generated by HOPERF Electronics company has been used. Through its transceiver property, same module has been used for both RFID tag and RFID reader.

For accurate connection with a microcontroller and an antenna, this module is printed on a board and necessary pin connections are attached as shown in Fig. 1.

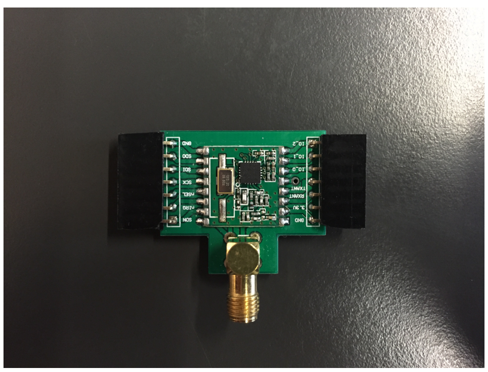

Fig. 1. Soldered RFM23B on board

III. LOCALIZATION ALGORITHM

Localization is a set of mathematical operations to obtain the position information of an object or a person. For this project, it has been decided to realize trilateration algorithm for indoor localization. The term trilateration refers to process of determining locations by measurements of distance using some geometrical figures such as circles, spheres and triangles.

A. 2D Trilateration Algorithm

Two dimensional trilateration algorithm is a localization method which uses circle geometry in a plane. Therefore, the algorithm performs through the geometrical formulas of circles. There are at least three reference points and corresponding distance values are required for 2D localization [3]. Reference points indicate the tags on the wall and distance values are obtained from related RSSI values. Number of required circles is determined according to resulting possible solutions. When only one distance value of a tag is considered, this corresponds to infinite possible solutions around the tag with same distances. In other words, possible solutions corresponds a circle as shown in Fig. 2.

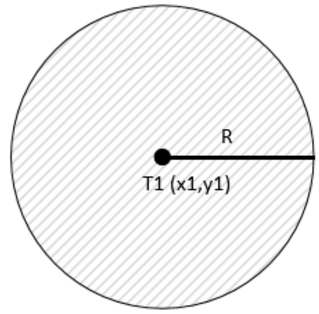

Fig. 2. Infinite solutions with one tag

x_1 and y_1 are coordinates of tags in x axis and y axis respectively. Taking second tag into account, decreases the number of possible locations from infinite to two. Obviously the reason is that two circles intersect each other at two points as shown in Fig. 3.

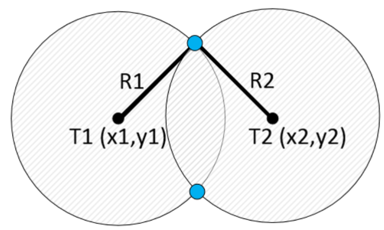

Fig. 3. Two possible solutions with two tag

There is not a unique solution obtained yet and that is why the third tag is necessary. After the third tag is participate in the operation the unique solution is obtain as shown in Fig. 4.

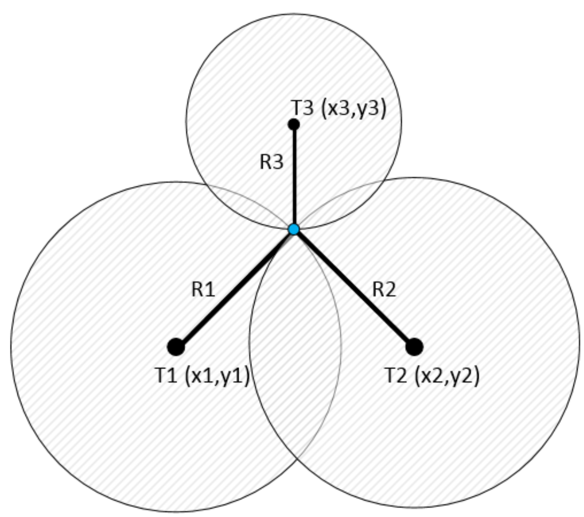

Fig. 4. The unique solution with three tags

Localization operation proceeds on the circle equations according to Cartesian coordinates which is shown in Fig. 5.

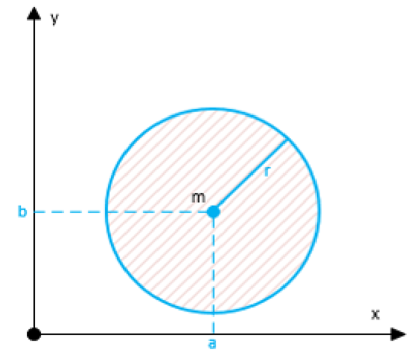

Fig. 5. Geometry of a circle

$$(x-a)^2+(y-b)^2=r^2 \tag{2}$$

When considering all three tags with respect to the position of the reader following equations obtained.

$$\begin{aligned}(x-x_1)^2+(y-y_1)^2 &= r_1^2\\(x-x_2)^2+(y-y_2)^2 &= r_2^2\\(x-x_3)^2+(y-y_3)^2 &= r_3^2\end{aligned}$$

In the equations, x_1, x_2, x_3, y_1, y_2, y_3 indicate coordinates of tags and $r1$, $r2$, $r3$ indicate distance values between the reader and related tags. x and y are the coordinates of the reader which are wanted be determined. After proceeding exponential operations of parenthesis, the equations are obtained as below.

$$\begin{aligned}x^2-2x(x_1)+x_1^2+y^2-2y(y_1)+y_1^2 &= r_1^2\\x^2-2x(x_2)+x_2^2+y^2-2y(y_2)+y_2^2 &= r_2^2\\x^2-2x(x_3)+x_3^2+y^2-2y(y_3)+y_3^2 &= r_3^2\end{aligned}$$

The problem in these equations is squares of x and y, because it prevents calculation of x and y with linear analysis such as Gaussian elimination. It is serious problem in terms of realization conditions and it is simpler to realize with linear equation solvers. In this project, Gaussian elimination method is used to solve the linear equations. Therefore, to get rid of squares of x and y, the equations are subtracted from each other sequentially and related results are obtained as below.

$$\begin{aligned}2x(-x_1+x_2)+2y(-y_1+y_2)+x_1^2+y_1^2-x_2^2-y_2^2 &= r_1^2-r_2^2\\2x(-x_1+x_3)+2y(-y_1+y_3)+x_1^2+y_1^2-x_3^2-y_3^2 &= r_1^2-r_3^2\\2x(-x_2+x_3)+2y(-y_2+y_3)+x_2^2+y_2^2-x_3^2-y_3^2 &= r_2^2-r_3^2\end{aligned}$$

As seen, three linear equations with unknown x and y values are obtained while all other parameters are known. By using linear equation solver x and y values are easily calculated and Gaussian elimination method has realized and used in this study.

IV. Implementation of Localization Algorithm

At least three tags are necessary to participate in localization operation to obtain the unique solution in two dimension. It is presumed that the locations of tags are known. The reader makes a distance estimation according to the RSSI. It is 8-bit unsigned number and a distance-RSSI table is used to obtain the distance between the tag and the reader. Same operation is performed between the reader and different three tags at three time. When three different distance information is acquired, the localization algorithm starts to obtain position information. This algorithm is composed of three parts which are shown in Fig. 6.

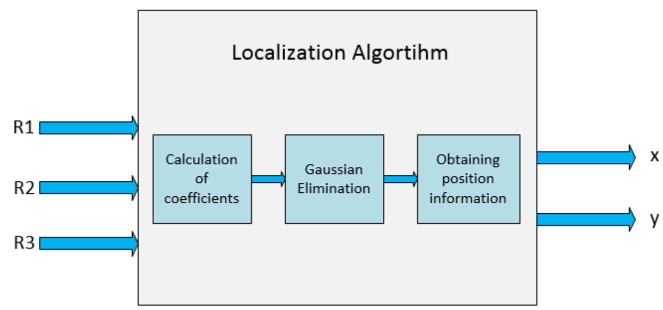

Fig. 6. Basic operations of localization algorithm

First, the algorithm has been realized and tested on Visual Studio. After ensuring that the algorithm operates properly, it has been implemented on Microblaze to perform localization operation on FPGA device. Finally, first part of the algorithm which is calculation of coefficients has been designed as hardware. Microblaze processor operates with this hardware module properly and hardware-software design has been checked.

A. Realization on General Purpose Processor

In this part, the algorithm has been realized with C++ on Visual Studio. This is purely software design for ensuring that the 2D trilateration algorithm operates properly. First, related three circle equations are formed according to obtained three distance values. Then to get rid of squares of x and y, the equations are subtracted from each other as explained in previous section. After that, three first order equations are left and x and y values could be obtained using a linear equation solver. Gaussian Elimination method has been preferred to be used and the coefficients in the equations have been assigned to a two dimensional array to perform Gaussian Elimination.

Although all possible combinations after subtraction requires a 3×3 two dimensional array, working with 2×3 size matrix is enough to obtain the solution. Therefore, just first two equations have been used in the algorithm. After the Gaussian Elimination is performed x and y values are obtained which means that the location of the reader is determined. The pseudocode of this algorithm is shown in Fig. 7.

After the program has been written via C++, it has been tested with some virtual position and distance values. For

```
Initialize r1, r2, r3 to distance values
Initialize x1, y1 to position of tag1
Initialize x2, y2 to position of tag2
Initialize x3, y3 to position of tag3
Declare a 2D double array k
Set k[0][0] to (2 * x2) − (2 * x1)
Set k[0][1] to (2 * y2) − (2 * y1)
Set k[0][2] to (r1)^2 − (r2)^2 − (x1)^2 − (y1)^2 + (x2)^2 + (y2)^2
Set k[1][0] to (2 * x3) − (2 * x1)
Set k[1][1] to (2 * y3) − (2 * y1)
Set k[1][2] to (r1)^2 − (r3)^2 − (x1)^2 − (y1)^2 + (x3)^2 + (y3)^2
If k[0][0] is 0 and k[1][0] is not 0
    For i = 0 to i = 2 do
        Temp = k[1][i]
        k[1][i] = k[0][i]
        k[0][i] = Temp
    end for
end if
Else if k[0][0] is 0 and k[1][0] is 0
    Print "First column is 0 and the unique solution cannot be obt
end if
For i = 0 to i = 1
    Temp = (k[i][0])/(k[0][0])
    For t = 0 to t = 2
        k[i][t] = (k[i][t]) − temp * (k[0][t])
    end for
end for
y = (k[1][2])/(k[1][1])
x = ((k[0][2]) − (k[0][1]) * y)/(k[0][0])
```

Fig. 7. The pseudocode of the algorithm

example, according to an origin point x and y values of the reader and the tags are considered as (6,6), (1,1), (11,2), (6,-3) respectively. According to these positions, the distance values between the reader and the tags should be measured as 7.07107, 9 and 6.40312 in meters. As stated before it is presumed that the tag positions are known and using these distance values the reader is located as shown in Fig. 8.

As seen, the position of the reader has been obtained as equal to its real position. The precision of result could be increased with using more precise distance values and this precision is enough in terms of meters.

B. Software Realization on Microblaze

General-purpose processors might be inadequate for speed performance or project costs. Also some drawbacks are able to emerge during implementation period. Considering these reasons, the localization algorithm has been realized on Microblaze to operate on FPGA device. First, it has been implemented purely with software and performed on Microblaze which is a virtual processor realized on FPGA.

When position of the reader is determined, the results are sent to computer via UART and printed on screen. To test the design same virtual position and distance values in previous section have been used and the results are obtained as shown

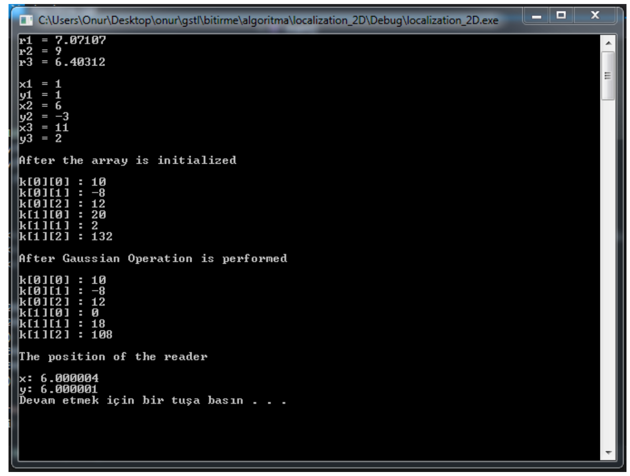

Fig. 8. Localization results on general purpose processor

in Fig. 9.The obtained results from Microblaze is shown in the window at the bottom-right corner.

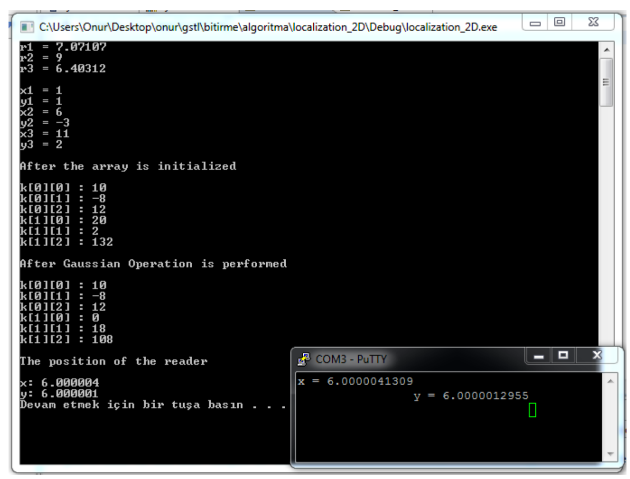

Fig. 9. Localization results on both Microblaze and computer

C. Hardware/Software Codesign on Microblaze

In this part, it is aimed to implement the localization algorithm completely in hardware using Verilog. However, after certain parts of the algorithm has been designed as hardware, the communication between processor and additional hardware module could not perform properly. Although the hardware operates properly and calculate related coefficients accurately, after the results are transmitted to processor, the values obtained incorrectly. Due to this failure, first part of the algorithm which calculates coefficients to initialize the two dimensional array has been designed as hardware.After these coefficients are calculated on hardware module, they are sent back to processor and rest of the algorithm is performed in Microblaze and localization operation is completed. The graphical view of the system is shown in Fig. 10 and the added hardware module is indicated in an orange circle.

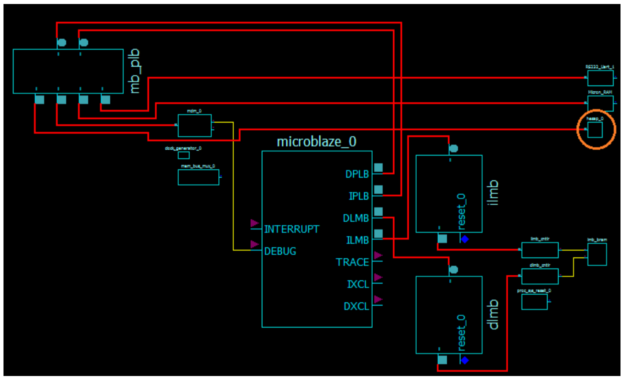

Fig. 10. Microblaze structure with user defined hardware module

Hardware module has been designed in ISE tool via Verilog. The block schematic of this module which shows its inputs and outputs is shown Fig. 11.This is a 9-input 6-output hardware module that the inputs are connected to 32-bit registers which holds distance and position values. Similarly six outputs are connected to 32-bit registers to initialize two dimensional array. coef-calculator block is mainly composed of three components which are 32-bit adder, subtractor and multiplier modules.All three blocks have two 32-bit input and one 32-bit output.

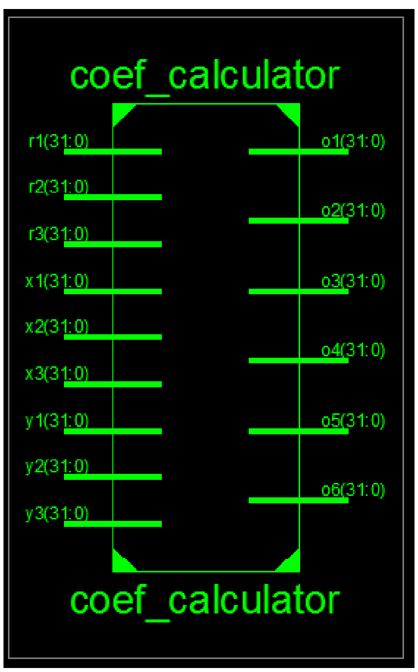

Fig. 11. coef-calculator module

V. Conclusions

The algorithm is aimed to be designed as completely hardware and operate in conjunction with Microblaze processor. However this system can not be implemented due to some problems of data transmission between Microblaze processor and user-defined hardware module. For tansmission data between Microblaze and user-defined hardware module, there are some write and read functions that are supplied by Xilinx. These functions are defined to operate with integer values and do not allow user to work with floating numbers. Performing mathematical operations with floating numbers is necessary to obtain exact position information of the reader. Due to this problem, floating numbers could not be sent to hardware module, because only exponential part of floating numbers are able to be transmitted. Although some modifications were made in library functions to transmit floating numbers to hardware module implemented systems did not operate properly and generated false positioning results. Therefore only first part of the algorithm which calculates necessary coefficients was designed as hardware and only integer values are inserted into this module. After hardware module finishes its operation, sends the related coefficients to Microblaze and localization is completed with C++. This situation cause some deviations in localization results but the position of the reader can still be obtained very similar to real one. Finally, results were printed on a screen by designing a simple graphical interface program through C# and performance of each design observed.

If the floating number transmission problem can be resolved, the whole trilateration algorithm can easily implemented on hardware and operate with Microblaze which means exact position information of the reader can be obtained with hardware module.

References

[1] S. J. Halder, J. Park, and W. Kim. Adaptive filtering for indoor localization using zigbee rssi and lqi measurement. July 2011.
[2] A. Loeffler and H. Gerhaeuser. Localizing with passive UHF RFID tags using wideband signals. In *Proceedings of the Microwaves, Communications, Antennas and Electronic Sysytems (COMCAS)*, pages 1–6, 2011.
[3] O.S. Oguejiofor, A.N. Aniedu, H.C. Ejiofor, and A.U. Okolibe. Trilateration based localization algorithm for wireless sensor network. *International Journal of Science and Modern Engineering (IJISME)*, 1, 2013.
[4] L. Sandip. *RFID Sourcebook*. IBM Press, USA, 2005.
[5] T. Sanpechuda and L. Kovavisaruch. A review of RFID localization: Applications and techniques. In *Proceedings of the 5th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON)*, pages 769 – 772. IEEE, 14-17 May 2008.