Application of Energy Efficient Filtering for UWB Indoor Positioning

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***Abstract*—Nowadays indoor positioning systems (IPS) are quite an intriguing subject of research. Several positioning methods have been evaluated including wireless communications and inertial navigation systems. In particular, UWB systems, with improved stability and precision, that have been developed in recent years pose a good solution for IPS. Although UWB technology provides with great accuracy in Line-Of-Sight (LOS) conditions, it suffers in Non-Line-Of-Sight (NLOS) conditions. Accuracy is also degraded due to signal interference caused by the multipath effect. In this paper a UWB-based localization system is under test in order to evaluate the efficiency of the measurements. A set of position data was acquired in lab environment. Simple filters, in means of computational power, were applied, and the results are compared with the true path. The module deployed (for positioning) in this study is Decawave DWM1001.**

Keywords—Indoor positioning, Ultra-Wide Band (UWB), low power, localization method, positioning accuracy, TWR, Low pass Filter, Moving average Filter

I. Introduction

Building the era of IoT, the ability of indoor positioning has become an important need. Localization techniques that emerged for this task are making use of technologies like Inertial Navigation System, Magnetic Based, Sound Based, Optical Based and Radio Frequency (RF) Based [1],[2] and [3]. Radio Frequency Based is the most commonly used and includes FM, Cellular Networks, WIFI, Zigbee, Bluetooth, RFID and Ultra-Wide Band (UWB). UWB is a carrier free technology. UWB-based positioning has gained a lot of interest in the last years.

The accuracy in UWB-based systems is estimated in magnitude of centimeter. Even more the use of very short pulses for communication combined with the use of high bandwidth offers better multipath protection and penetration capacity [3]. Nevertheless, interference miscalculations still occur in a reduced manor and a lot of research concentrates on solving the effects of NLOS and multipath interference to increase accuracy. (It is challenging to find a solution for these effects.)

A significant part of the work towards positioning correction has been accomplished with data filtering. The majority of filtering techniques are complex and computational demanding though. Kalman Filters and extensions like extended, complex and unscented Kalman are proposed in [4] [5] [6] [7] [8]. Linear Bayesian Filtering is also examined in [9].

The data fusion with INS-IMU yields significant correction with extra hardware [10] [11] and is for future study of this work. Dai Peng et al. [12] studied in brief the NLOS effect on certain materials. Another approach to estimate the accuracy of the UWB systems examines different base station configurations in [13].

In this paper, a UWB-system for indoor localization is developed. The acquired measurements are processed with non-complicated algorithms to limit the need for computational power. These algorithms include a low pass filter, a moving average filter, and a custom algorithm to detain extreme deviations on the readings. The routes selected include 3 paths in an area covered by 4 anchors and 1 path with transitions through areas covered by 4, 2 and no anchors at all.

II. Theory of Operation

The premanufactured Decawave DWM1001 module was used. For the purposes of the research a semi-custom software was created, that made use of the provided software by Decawave.

A. Structure of the software

The designed software included the standard programming libraries of Decawave but the polling of anchors in certain time periods, data export over UART communication and the ability to export direct distance measurements from a selectable number of anchors were introduced. The default software by Decawave provides a position estimation by processing responses only from the 3 nearest anchors, for 2D positioning.

A tag is programmed to export via UART communication the distance response from 6 anchors. The time delay between each exported response of an anchor is 100ms so a total of 6 distances from the anchors is acquired in 600ms. The value on the number of anchors and the duration of the time delay is user defined. The anchor is programmed in default responder example software.

B. Localisation method

There are 4 main localization methods Angle of Arrival (AoA), Time of Arrival (ToA), Received Signal Strength Indicator (RSSI) and Radio-Frequency (RF) Fingerprinting. UWB implements a Two-Way-Ranging (TWR) version of ToA. As shown in Fig. 1 this method requires the tag to send a radio message to the anchor. Included in the message is the time of sending, t1. When the anchor receives the message time t2 of receival, is stored in the message. After internal operations the anchor saves time t3 on the initial message and responds and last time t4 is saved upon the reception of the message on the tag. The time of flight is estimated by equation:

$$ToF = \frac{(t_4 - t_1) - (t_3 - t_2)}{2} \tag{1}$$

The distance between Tag and Anchor can then be calculated by equation:

$$r = c * ToF \tag{2}$$

Where c denotes the speed of light.

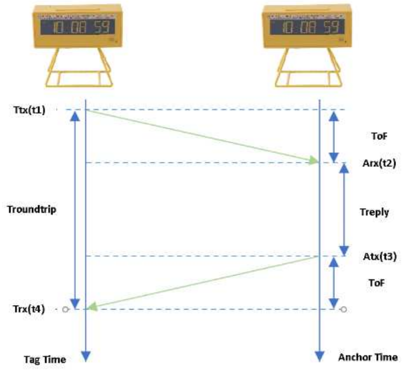

Fig. 1. TWR theory of operation

In 2D plane the coordinates for each Anchor will be A_i (x_i, y_i) and for the Tag (x, y). So, the Euclidian distance for each Anchor will be given by equation:

$$\begin{cases} r_1 = \sqrt{(x_1 - x)^2 + (y_1 - y)^2} \\ r_2 = \sqrt{(x_2 - x)^2 + (y_2 - y)^2} \\ \quad \cdot \\ \quad \cdot \\ \quad \cdot \\ r_i = \sqrt{(x_i - x)^2 + (y_i - y)^2} \end{cases} \tag{3}$$

Due to noise, there is no single solution, and the equation represents a system of non-linear equations and the solution of the position of the tag (x, y) is given with the use of least-square (LS) method.

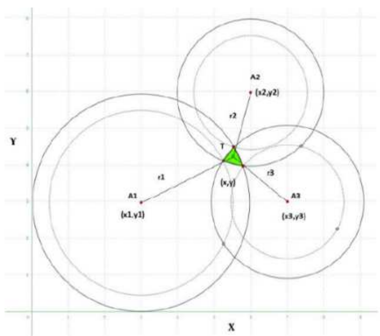

Fig. 2. Position estimation with trilateration in noisy environment

In this research a total of 6 distances for equivalent number of anchors were available for estimation. Two series of data are created. The first includes the position (x, y) of the tag by applicating the LS method to distances of 4 anchors and the second by applicating to distances regarding 6 anchors.

III. Positioning Experiments and Results

4 routes were tested, and the description of the different paths is as follows:

- Path 1 is straight-line connecting points A and B traveled forward and backward with a total length of 9m.
- Path 2 is a circular movement rectangle shaped with a total length of 10.8m.
- Path 3 contains 3 diagonal movements along the length of AB with a total length of 5.16m.
- Path 4 is the movement in Fig 3. Starting point is A and the path proceeds with the points: B, C, D, E, D, F, G and backwards. The total length of the path is 53.4m.

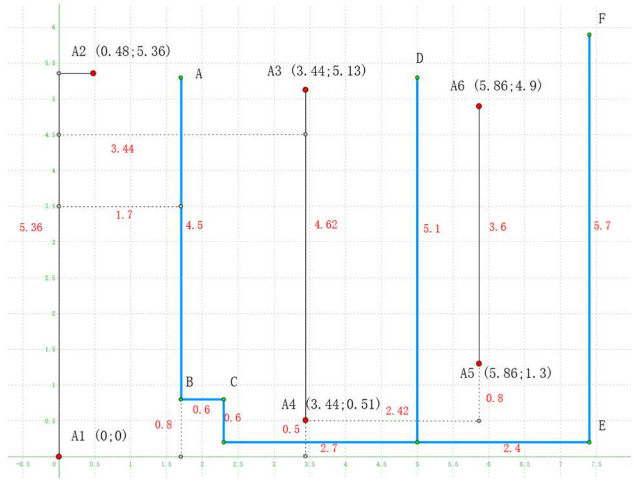

Fig. 3. Path 4 – Ground truth

A. *Paths 1, 2 and 3*

In Fig. 3, Fig. 4 and Fig. 5 actual path as well as raw and filtered data are displayed for Paths 1, 2 and 3. The filtering process was conducted on the (x, y) positions exported from the LS method with 4 Anchors.

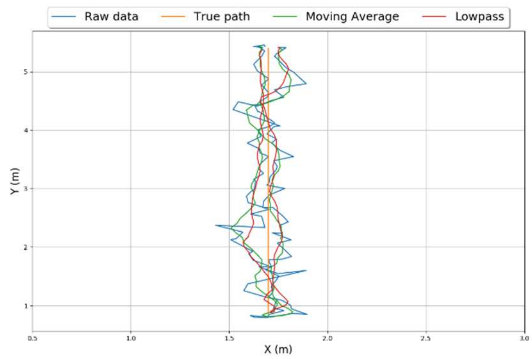

Fig. 4. Path 1 – 4 Anchors

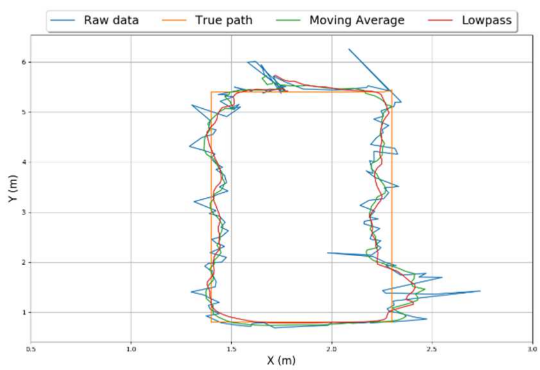

Fig. 5. Path 2 – 4 Anchors

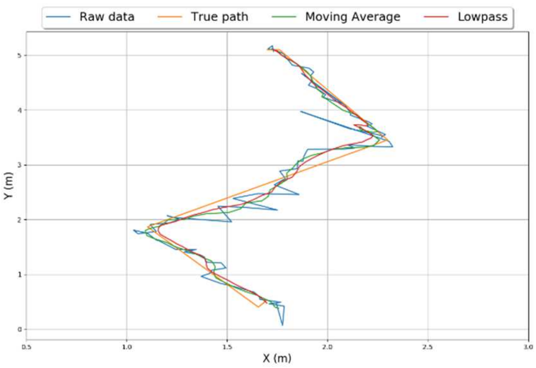

Fig. 6. Path 3–4 Anchors

In Fig. 6, Fig. 7 and Fig. 8 actual path as well as raw and filtered data are displayed for Paths 1, 2 and 3. The filtering process was conducted on the (x, y) positions exported from the LS method with 6 Anchors.

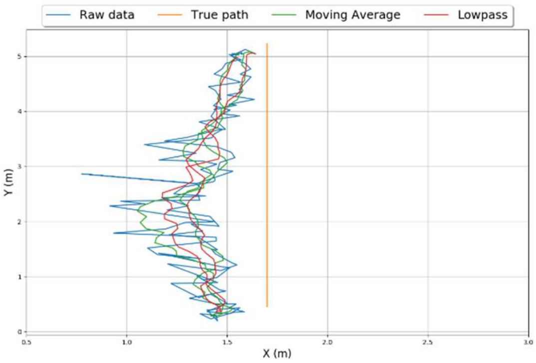

Fig. 7. Path 1– 6 Anchors

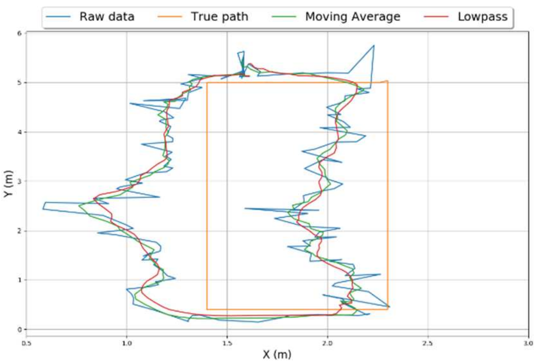

Fig. 8. Path 2– 6 Anchors

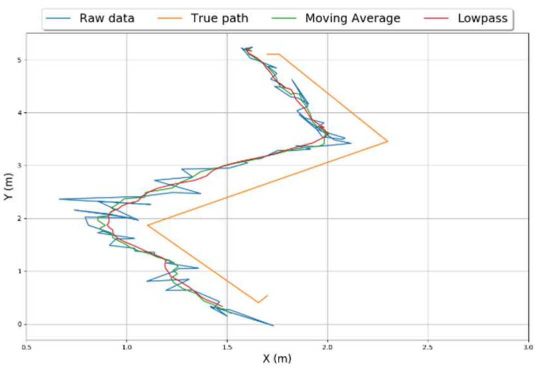

Fig. 9. Path 3 – 6 Anchors

Qualitatively it is revealed from Paths 1, 2 and 3 data analysis, increased accuracy is achieved when the data from 4 Anchors are processed for positioning. This makes perfect sense since from the map on Fig the 4 Anchors A1, A2, A3, A4 are in LOS condition and A5, A6 are in NLOS condition. Table 1 provides calculated Root Mean Square (RMS) error for Paths 1-3 and table 2 shows the percentage of filtering improvement on RMS error.

TABLE I. RMS error for paths 1-3

Path - Anchors	**RMS error (m)**		
	Raw data	*Moving average Filter*	*Low pass Filter*
1-4	0.18	0.17	0.15
2-4	0.24	0.21	0.19
3-4	0.15	0.10	0.09
1-6	0.38	0.37	0.36
2-6	0.40	0.37	0.36
3-6	0.31	0.30	0.28

TABLE II. Improvement Calculation on paths 1-3

Path- Anchors	**Accuracy Increase % Moving average Filter**	**Accuracy Increase % Low pass Filter**
1-4	4.92	12.79
2-4	14.61	20.21
3-4	31.44	40.76
1-6	3.83	6.61
2-6	5.34	8.64
3-6	1.57	10.01

B. Path 4

Path 4 because it is more complicated has been examined in the line segments A to B, D to E and F to G and backwards for RMS error calculation.

From Fig. 9, Fig. 10 and tables 3, 4, 5 and 6 it is revealed that the positioning is quite accurate while reading 4 sensors only for the area that has LOS conditions. Rest of the path contains a lot of noise. But while reading from 6 sensors and there is a reduced accuracy in the area with LOS conditions for the 4 sensors, the existence of the 2 extra Anchors offers some increased accuracy in the total Path.

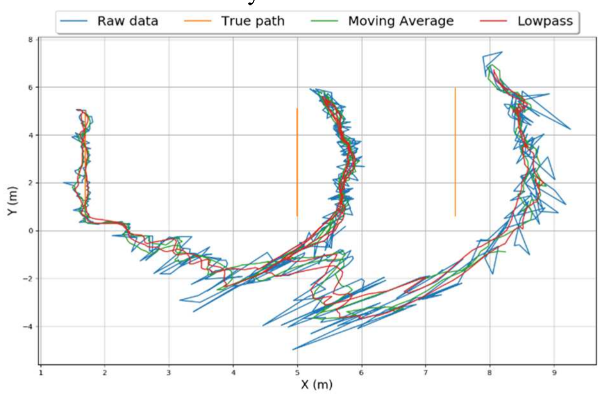

Fig. 10. Path 4– 4 anchors

TABLE III. RMS error for paths 4 – 4 anchors

Line Segment	RMS error		
	Raw data	*Moving average Filter*	*Low pass Filter*
A-B	0.12	0.10	0.11
D-E-D	0.88	0.88	0.87
F-G-F	1.34	1.26	1.28
D-E-D	0.86	0.83	0.85
B-A	0.16	0.15	0.13

TABLE IV. Improvement Calculation on path 4 – 4 Anchors

Line Segment	Accuracy Increase % Moving average Filter	Accuracy Increase % Low pass Filter
A-B	17.81	4.18
D-E-D	0.85	1.50
F-G-F	6.49	4.63
D-E-D	3.46	1.71
B-A	10.50	22.13

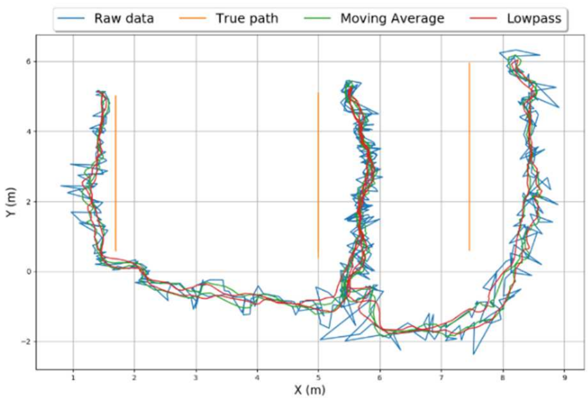

Fig. 11. Path 4– 6 anchors

TABLE V. RMS error for paths 4 – 6 anchors

Line Segment	RMS error		
	Raw data	*Moving average Filter*	*Low pass Filter*
A-B	0.39	0.37	0.37
D-E-D	0.82	0.81	0.81
F-G-F	1.08	1.06	1.07
D-E-D	0.79	0.78	0.78
B-A	0.33	0.32	0.32

TABLE VI. Improvement Calculation on paths 4 – 6 anchors

Line Segment	Accuracy Increase % Moving average Filter	Accuracy Increase % Low pass Filter
A-B	6.92	6.86
D-E-D	1.74	1.70
F-G-F	2.40	1.09
D-E-D	1.47	0.87
B-A	2.24	3.72

IV. Conclusion

In this paper different sets of UWB-based positioning measurements were acquired for different movement paths. Data were further processed with a moving average and a low pass filter, and the results were analyzed. The use of the filters offered a reduction in RMSE. Proposing the filtering of the data is implemented in the software of the microcontroller unit, that handles DW1000 module, it can provide positioning with increased accuracy and reduced power consumption.

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