

Localino T-shirt: The Real-time Indoor Localization in Ambient Assisted Living Applications

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ABSTRACT

In the last decade, smart textiles have become very popular as a concept and have found use in many applications, such as military, electronics, automotive, and medical ones. In the medical area, smart textiles research is focused more on biomonitoring, telemedicine, rehabilitation, sport medicine or home healthcare systems.

In this research, the development and localization accuracy measurements of a smart T-shirt are presented, which will be used by elderly people for indoor localization in ambient assisted living applications. The proposed smart T-shirt and the work presented is considered to be applicable in cases of elderly, toddlers or even adults in indoor environments where their continuous real-time localization is critical.

This smart T-shirt integrates a localization sensor, namely the Localino sensor, together with a solar panel for energy harvesting when the user is moving outdoors, as well as a battery/power bank that is both connected to the solar panel and the Localino sensor for charging and power supply respectively.

Moreover, a mock-up house was deployed, where the Localino platform anchors were deployed at strategic points within the house area. Localino sensor nodes were installed in all the house rooms, from which we obtained the localization accuracy measurements.

Furthermore, the localization accuracy was also measured for a selected number of mobile user scenarios, in order to assess the platform accuracy in both static and mobile user cases.

Details about the implementation of the T-shirt, the selection and integration of the electronics parts, and the mock-up house, as well as about the localization accuracy measurements results are presented in the paper.

KEYWORDS

Indoor localization, wearable localization sensors, smart T-shirt, RTLS

INTRODUCTION

Albania is a developing country with population over 3 million. According to INSTAT available data, the 2009 population of elderly people in Albania (65 years or older) is 10 % and is expected to be 15 % of the total population in 2030. Based on this data, it can be projected that the total population of the people aged 60+ will increase by more than a hundred percent [1].

Living as an elderly person has its own difficulties. Being old reduces cognitive functions and this situation may put the elderly in emergency situations needing help in unforeseen ways. Family members and healthcare professionals need to know the real condition of the elderly and location information might be a key factor for providing health-care in a critical situation [2].

Different groups have worked on the study issues associated with the implementation of a real-time WiFi localization system for an indoor environment [3-4].

Heng *et. al.* [3] has studied the issues associated with the implementation of a real-time WiFi localization system for an indoor environment. In this system they have used smart antennas to receive signal strength from a mobile target (access point) and send the signal strength information to a data processing station. Moreover, Chelseer *et. al.* [5] has demonstrated bTracked, a field deployable tracking system for mobile BLE device bearers using BLE beacon signals. His group exploited in particular not only range estimations but also the pose of the BLE device bearer for tracking. Furthermore, Wang *et.al.* [2] has done a review of the state-of-the-art wearable technologies that can be used for elderly care. He has categorized these technologies into three types: indoor positioning, activity recognition and real time vital sign monitoring.

Lopez *et. al.* [4] has worked on the application of e-textiles which allows monitoring different physiological parameters and tracking the location of a group of patients within hospital environments.

In this context, it is proposed to develop the means for providing seamless, unobtrusive localization information of elderly people (as well as toddlers or even adults that may require so), and a means to do so is in the form of a wearable platform.

We propose a smart T-shirt that is able to detect the location and movement of its user and communicate with a centralized localization platform for the monitoring and triggering of further action. The T-shirt is considered to be applicable in cases of elderly or toddlers in indoor environments for which a continuous real-time localization is critical. Application examples may include localization of elderly people that live alone or in pension houses and need monitoring by their family or medical staff; localization of toddlers for supervision and monitoring purposes; or localization in general for recreation or security purposes. In the future, the proposed T-shirt platform is intended to be integrated with a GPS sensor and a host unit for seamless localization handoff in both indoor and outdoor environments, as well as an optional tactile actuator sub-system for providing feedback to visually impaired people.

The proposed T-shirt integrates a localization sensor, namely the Localino sensor that is part of an open-source localization platform. The Localino sensor is used together with a solar panel for energy harvesting when the user is moving outdoors, as well as a battery/power bank that is both connected to the solar panel and the Localino sensor for charging and power supply respectively. It was implemented using cotton fabric and is designed in order to host all the electronic parts needed for the proposed application. An energy harvesting solar panel module is located at the back of the T-shirt while the power supply and the Localino sensor are hosted in small pockets at the front. Cabling and electronics parts interconnections are concealed within the T-shirt fabric in order to assure comfort and ease of use from the user's point of view.

Furthermore, a mock-up house was deployed within the premises of the University of West Attica, including a mock-up living room, kitchen, bedrooms and bathroom. The Localino platform anchors were deployed at strategic points within the house area and accuracy measurements were obtained using the Localino sensor in all the house rooms. Moreover, the localization accuracy was also measured for a selected number of mobile user scenarios, in order to assess the platform accuracy in both static and mobile user cases.

Details about the implementation of the T-shirt, the selection and integration of the electronics parts, and the mock-up house, as well as about the localization accuracy measurements results are presented in the following sections of this paper.

SYSTEM OVERVIEW AND THE MOCK-UP HOUSE

The Localino localization platform is dependent upon the measurement of the time-of-flight of the ultrashort pulses that are broadcasted by a number of fixed anchor points and are received by tags that are attached to the person or object that is to be located. As such, and knowing the speed of light, it is straightforward to calculate the range of each tag from the specified anchors and then use standard triangulation or trilateration techniques in order to calculate the position of the tag in the space. With a minimum of three anchors a localization service may be provided in a flat two-dimensional space while three-dimensional localization requires at least four anchors [6].

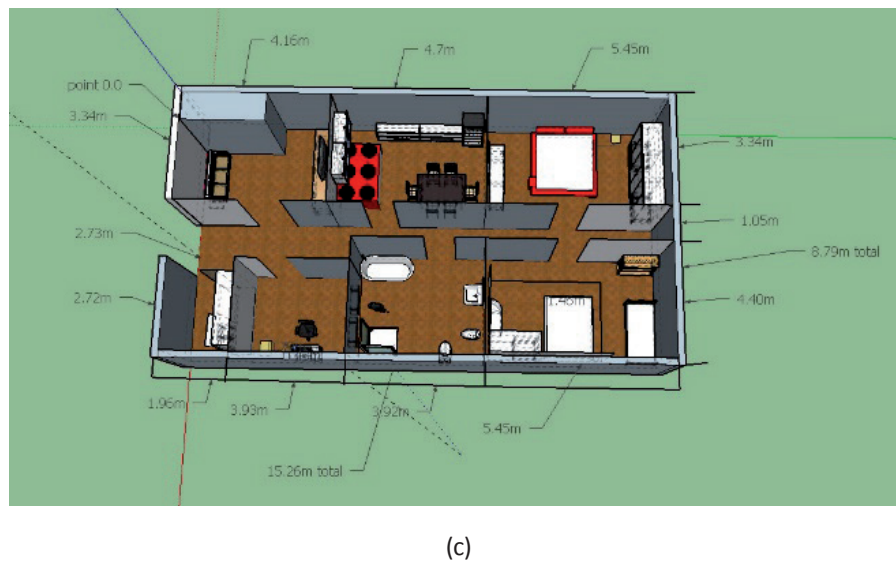
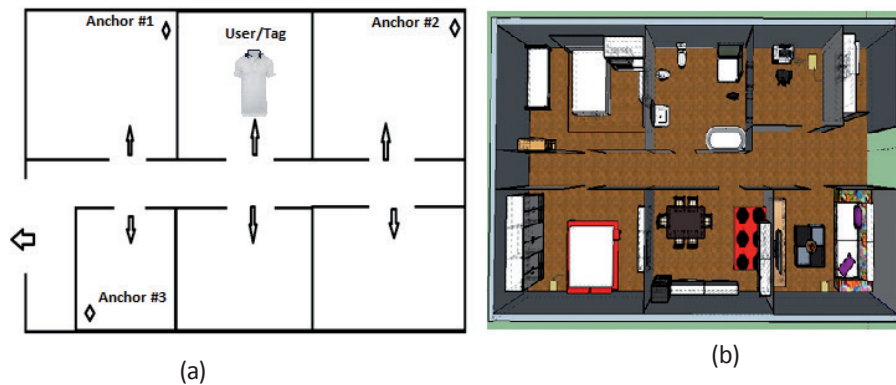


Figure 1: (a) The mock-up house layout with anchor locations (b) 3D representation of the mock-up house (c) The dimensions of the mock-up house (d) Photo of the mock-up house

Furthermore, a mock-up house was implemented within the premises of the University of West Attica, in order to resemble the interior of an actual living space. A general overview of the proposed localization application platform together with a layout of the mock-up house is displayed in Figure 1 (a). Three Localino anchors are placed in fixed positions that are known to the Localino server, while the mobile tag is attached to the user's T-shirt. There is also a localization server that is part of the Localino platform and is hosted in a standard laptop, as well as a WiFi standard router that interconnects the server and the Localino anchors. A 3D layout of the house implemented with the Sketch 2014 Suite is displayed in Figure 1 (b) and its dimensions are displayed in Figure 1 (c). Also, a photo of the mock-up house on the 2nd floor of the Department of Electrical and Electronics Engineering of the University is displayed in Figure 1 (d).

RTLS AND PERIPHERAL PARTS

1. RTLS

Real-Time Localization Systems (RTLS) are generally used in indoor and/or confined areas, such as buildings and do not provide global coverage like GPS. RTLS tags are affixed to mobile items to be tracked or managed. RTLS reference points, which can be either transmitters or receivers, are placed throughout a building to provide the desired tag coverage. In most cases, the more RTLS reference points installed, the better the location accuracy, until the technology limitations are reached [7].

Nowadays, there exists a wide range of RTLS solutions offered on the market. Most of them are closed, proprietary systems that usually come with restrictions in usability, deployment and billing. In some cases, intervention in the localization procedure is allowed through a dedicated API (Application Programming Interference), but with strong limitations.

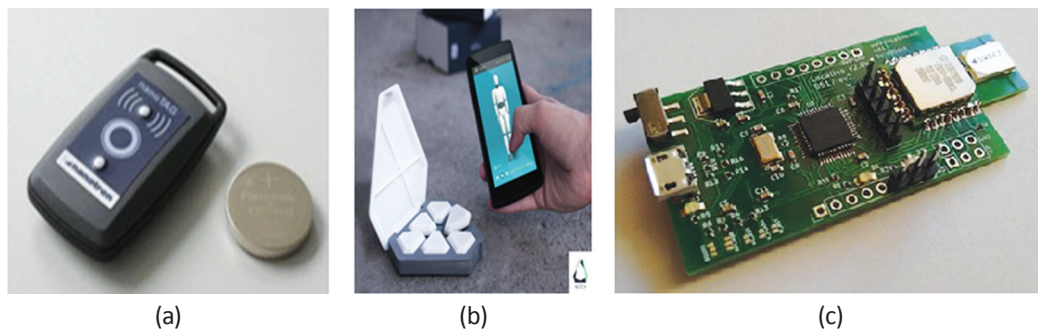


Figure 2: (a) Nanotron (b) Notch and (c) Localino RTLS tags

During our research, we investigated various market-available RTLS solutions; currently, there exists a large variety of such solutions and products. Nevertheless, we would like to point out three specific products that in our opinion are among the most promising currently market-available candidate solutions for indoor localization. One of these is the RTLS eco-system provided by Nanotron; a tag example is illustrated in Figure 2(a). The Nanotron RTLS was originally developed for professional applications and provides monitoring attendance, movement and care center service delivery. Tags are configurable via a wireless interface and supports Time-of-Arrival (ToA) and Time-Difference-of-Arrival (TDoA) based triangulation. The developing company claims an outstanding accuracy of down to 10 cm for 90 % of localization events [8].

The notch is another system that is able to measure movement, speed and acceleration of the user. A set of 6 tags may be attached to various positions on the user's body and provide accurate localization, capable of tracking user's limbs and their relative positioning. Furthermore, this technology is equipped with wireless connectivity abilities that will connect to smartphones, allowing the user to view their fitness performances and analyze movements [9]. A set

of 6 Notch tags side-by-side with a snapshot of the respective app on an Android phone is illustrated in Figure 2(b). Finally, Localino is an open-source platform for indoor localization and RTLS [10]. It is open-source with respect to both hardware and software points of view and offers an unparalleled freedom of customization and programming. The claimed accuracy of the Localino RTLS is down to 10 cm for indoor environments, which is similar to that of Nanotron. Figure 2 (c) displays a Localino anchor and tag; physically, anchors and tags are the same device and they are assigned a specific role by the RTLS server system.

The selection of Localino indoor localization platform was based on the criterion of open source availability and ease of use for customized solutions developers. This feature and its localization accuracy, which is similar to that offered by Nanotron, were the two main factors that affected our decision to use Localino with our proposed T-shirt development.

2. SOLAR PANEL AND POWER BANK SUPPLY

A power bank and solar panel combination is used to supply the necessary power to the Localino tag. More specifically, the power supply (bank) is charged either by a normal wall-mounted charger or by the solar panel when the user is moving in outdoor environments. The idea is that the user will use the T-shirt throughout the day and when she/he is found outdoors, then the T-shirt will charge the power bank in order to extend its operational lifetime.

A market research revealed a large variety of solar panels available that are suitable for our application. The requirements that were set during our research were for a panel with a size that will easily fit on the back of the T-shirt and will provide an output of 5-6 V and at least 500 mA of current. The larger the current the faster the charging, but given the size constraints it was decided that a current of 1000 mA would be suitable (a wall-mounted fast charger normally provides an output current of 2.0-2.1 A). A summary with the information on the solar panels that were found on the market is shown in Table 1.

Table 1: Market-available solar panels for the proposed application

Brand / Model	Dimensions (mm)	Weight (gr)	Output Voltage (V)	Output Current (mA)	Price (\$)	Other Characteristics
Jiang [7]	100 x 200	27	6	160	20	Ultra flexible, waterproof, efficient lifetime
Sunwalk [8]	260 x 170	125	5	1000	14	Semi-flexible, regulator included
Sunpower [9]	275 x 200	244	5	1200	40	Semi-flexible, USB output and regulator included
Powerfile [10]	45 x 59	5	6	100	-	-

Drawing from Table 1 it can be concluded that two possible candidates would be the Sunwalk and Sunpower solar panels. In the case where a smaller output current would be sufficient, one might opt to use more than one Jiang panels in parallel and provide a larger output current; this would also come with the extra benefit of a flexible configuration and maybe smaller size too. Nevertheless, taking into account the market and shipping constraints, it was selected to proceed with the Sunpower panel that was sufficient for our power requirements, had a USB plug-and-play output and was also the easiest to order, ship and deliver in due time during the duration of our Project.

In similar fashion, a market research revealed a large variety of available power bank supplies for our application. In this case, the most important criteria for us were its size and weight since a power bank of large capacity will come with extra size and weight. After an extensive research it was concluded that the best market-available solution at that moment was a power bank offered by Sandberg [11], mainly due to its design, which is small, similar to a credit card and light. It has a capacity that is equal to 2500 mAh.



Figure 3: Sandberg Excellence power bank supply

T-SHIRT FABRICATION DETAILS AND INTEGRATION

The proposed T-shirt was fabricated using 1 m² of cotton textile fabric. A small pocket was implemented in the front of the T-shirt in order to host the Localino tag unit, and a larger pocket was implemented at the back in order to host the power bank device. Photos of the implemented T-shirt are given in Figure 4 for the front and the back side (Figure 4 (a) and 4 (b) respectively).

Furthermore, the solar panel charger was mounted on the back of the T-shirt and on top of the back pocket, as shown in Figure 4 (c). The solar panel is equipped with four adjustment holes in its perimeter, so these holes were used in order to sew the panel on the T-shirt by hand.

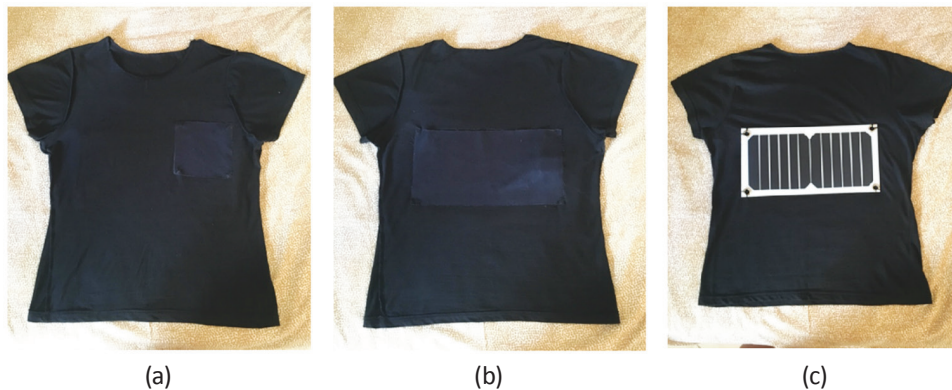


Figure 4: Photos of implementation steps for the developed T-shirt (a) front side pocket (b) back side pocket and (c) back side with the adjusted solar panel charger

Finally, fabric lining is sewn over the T-shirt in order to host the cables that will connect the solar panel with the power bank on the one hand and the power bank with the Localino tag on the other hand. Details of the fabric strip linings and the interconnecting cables are shown in Figure 5. More specifically, Figure 5 (a1-a2) displays the back pocket cable that will connect the power bank with the solar panel and Figure 5 (b1-b2) displays the front pocket cable that will connect the power bank with the Localino tag.

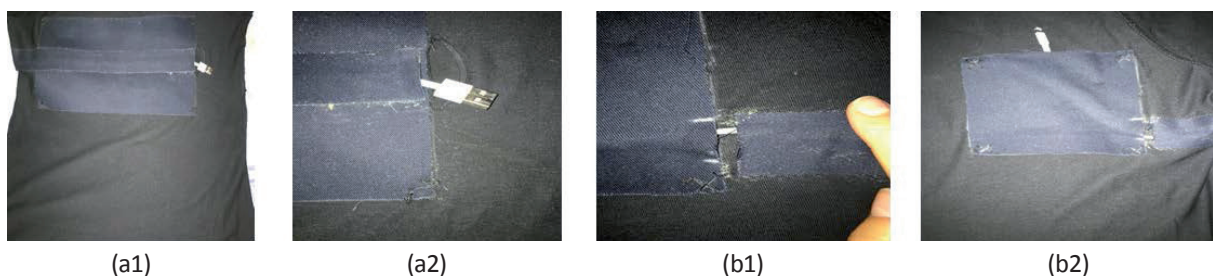


Figure 5: Photos of T-shirt details for (a1-a2) the back pocket cabling and (b1-b2) the front pocket cabling

LOCALIZATION ACCURACY MEASUREMENTS RESULTS

The Localino platform includes a localization server that calculates the position of the user tag using the ranging measurements provided by Localino anchors, stores the output data in csv files and displays the anchors and tag locations in a real-time updated output diagram. A photo of a laptop that was loaded by the Localino server and a sample output diagram with the tag and anchor locations are illustrated in Figures 5 (a) and 5 (b) respectively.

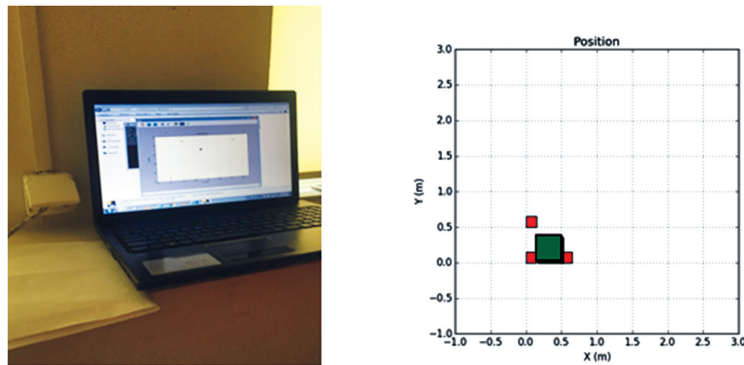


Figure 5: (a) Laptop with the Localino platform (b) A sample output diagram of anchors and tag locations

Table 2: Anchor real positions coordinates

	X_{real} (m)	Y_{real} (m)
Anchor 1	4	0.8
Anchor 2	12	0.7
Anchor 3	1.9	-7.4

The anchor's real position coordinates during the experiments are shown in Table 2. Furthermore, the test points' real coordinates and their respective real distances with respect to the three anchors are shown in Table 3.

Table 3: Test points' real coordinates and real distances to anchors

	X_{real} (m)	Y_{real} (m)	Distance to Anchor 1 (m)	Distance to Anchor 2 (m)	Distance to Anchor 3 (m)
Point 1	9.60	1.36	4.01	6.25	5.49
Point 2	8.70	5.54	8.07	7.93	8.08
Point 3	5.40	1.60	5.54	5.10	4.98
Point 4	0.70	2.28	5.55	6.18	6.09
Point 5	3.40	6.45	5.93	5.95	5.92

Furthermore, Figure 6 illustrates the mean distance between each test point and the respective anchor in a total number of 100 distance measurements. From Figure 6, it becomes evident that the achieved localization accuracy using the proposed Localino platform was outstanding. As an example, the mean distance between test point #1 and anchor #1 is approximately equal to 4.0 m as can be seen from the blue bar at the leftmost side of the chart in Figure 6, while the real distance between the test point #1 and anchor #1 is equal to 4.01 m; this translates to a localization accuracy error of 1 cm or 0.25 % (percentage calculated as localization error vs. real distance). Moreover, the mean measured distances between test point #1 and the remaining anchors #2 and #3 were equal to 6.20 m and 5.46 m

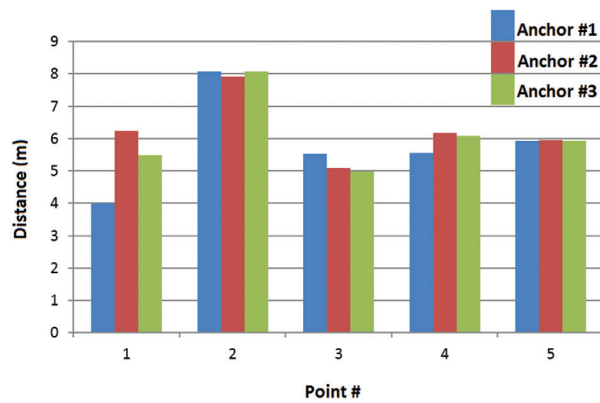


Figure 6: Mean distance measurements results between each test point (from test point #1 to #5) and anchor (from anchor #1 to #3)

respectively, which translates to corresponding localization errors equal to 5 cm (0.80 %) and 3 cm (0.55 %) respectively. Similar results hold for the remaining test points and anchors.

CONCLUSION

A smart T-shirt for real-time indoor localization is presented in this paper. The smart T-shirt comprises a Localino tag for indoor localization, as well as a power bank and a solar charger for power supply and charging respectively. The proposed T-shirt is open source due to its design and also due to the utilization of the Localino localization platform that is open source from both the hardware and the software point of view. The proposed T-shirt may be used for indoor localization and healthcare in ambient assisted living of elderly and toddlers or for recreation purposes. Future work includes the integration of GPS sensors for outdoor positioning, as well as a tactile actuator sub-system for providing feedback to visually impaired people.

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