Finding objects using UWB or BLE localization technology: A museum-like use case

A.R. Jiménez, F. Seco
Centre for Automation and Robotics (CAR)
Consejo Superior de Investigaciones Científicas (CSIC)-UPM
Ctra. Campo Real km 0.2, 28500 La Poveda, Arganda del Rey, Madrid, Spain
e-mail: {antonio.jimenez, fernando.seco}@csic.es
web: http://www.car.upm-csic.es/lopsi

Abstract*—Some location-aware use cases imply that a person desires to find an object relative to his position. This is the case of museum visits or any indoors/outdoors activity where the objects of interest are not geo-referenced or even can move with time. For these use cases, a user does not need an absolute localization, but a relative information consisting of the range to the object and the heading angle between that object and the user's moving direction. In this paper we study two different radio technologies for finding an object of interest: Ultra-Wide-Band (UWB) and Bluetooth Low Energy (BLE). Range and orientation estimation performance is studied when using just the distance or the Received-Signal-Strength (RSS) provided by UWB and BLE systems, respectively. Both approaches are combined with Pedestrian Dead-reckoning (PDR) estimation in order to analyze the benefits that PDR information provides. For completeness we compare the cases where only one tag is fixed to the object to locate (the simpler and more flexible case) with the more ideal case where several geo-referenced objects of interest, each one with a tag, jointly cooperate to improve the relative location to one of the objects of interest (in both cases the user carries a mobile phone with BLE 4.0 or UWB radio). The UWB ranging radio, not common in most smartphones, but very accurate, is used as our reference to define the best achievable performance goal, in order to compare with BLE RSS-based performance. We demonstrate that the common BLE low ranging-accuracy technology combined with smartphone-based PDR estimation is capable, after some initial user's walking, of finding with decent range and heading accuracy the objects of interest in a museum-like set-up.

Keywords*—*UWB, BLE, Distance Measurement, localization, Finding objects, Estimote, Bespoon.

I. INTRODUCTION

Some location-aware use cases imply that a person desires to find an object relative to their position. When the absolute object's position is known and the user's location is also known, using a GNSS receiver or any indoor localization approach [1], [2], [3], the problem is straight forward. However there are situations when the object to locate is not geo-referenced or its position can change frequently. Additionally we can be in a site where no location system is available or accurate enough to guide the user to the object of interest. In these situations, if the user is only interested in approaching a specific object, then a relative infrastructure-less person-to-object localization is a desired technology. Typical use cases of these situations occur in museums, where a person is interested in finding a particular famous painting or sculpture within a big hall or building [4]. The museum objects of interest can change its position from to time to time when new exhibitions are deployed. The user also in outdoor spaces could want to find objects of interest in parks or exposition gardens. For these use cases, we as users do not need an absolute localization, but a relative information that can be the range to the object and the horizontal heading angle from our field of view perspective.

Different technologies are available for range and heading estimation. For example vision, ultrasonic or radio frequency radars with array antennas in order to infer the range and heading to a particular object. In our case, we are interested in simple, small and cheap devices already available in gadgets such as a mobile phone. Under these requirements the spectrum of technologies focus on two main approaches: UWB and BLE. With these systems we can conceive a use case solution where a tag is attached to each object of interest and a common smartphone is used for BLE or UWB range-related information reading.

UWB radio technology [5], [6], can obtain a ranging performance of 0.2 m in Line-of-Sight (LOS) cases and a maximum ranging capability of more than 100 m. UWB can penetrate walls in buildings and can resolve individual multipath components due to its large bandwidth. However in Non-Line-of-Sight (NLOS) scenarios UWB performance deteriorates [7]. The NLOS effect causes a deterioration of range measurements with larger dispersion and in-excess ranges (outliers) that could be larger than one meter in typical usage. Also, the maximum measurable range can be reduced to less than 10-15 meters in apartment type spaces. In any case, UWB is the most accurate ranging system available today for indoor scenarios or spaces with multiple reflectors or obstacles. Several commercial system exists even some of them on-chip integrated into mobile phones.

BLE is another radio technology, that is very popular nowadays since the iBeacon standard definition [8], [9]. These tags broadcast at regular intervals their identification code, as well as other parameters of interest (motion, temperature, pressure, etc.). The range estimate is deduced from the received signal strength (RSS) using path loss models. The point-to-point ranging performance using BLE is low, and similar to the achievable using WiFi or RFID beaconing, i.e. about 1-2 meters at short ranges (lower than 5 m), but range can not be accurately estimated for larger distances or when persons or blocking objects attenuate the radio signal. Nevertheless, when using several BLE tags as beacons in cooperation, the localization performance can be between 2-5 meters in larger areas [10]. Finding an object using point-to-point BLE ranging is a challenge, and other sources of information, such as the motion of the user could be beneficial.

The motion of a person carrying a mobile phone can be deduced by processing the inertial sensors contained (accelerometers and gyroscopes). Solutions that mainly rely on dead-reckoning methods using inertial sensors are called Pedestrian Dead Reckoning (PDR) [11], [12], [13], and we think are of great interest for the use cases we are interest in. In fact the orientation of the object respect to the user location can not be estimated in point-to-point ranging if the user motion is unknown.

In this paper we propose to perform a novel study using two different radio technologies for range or proximity estimation: Ultra-Wide-Band (UWB) and Bluetooth Low Energy (BLE), analyzing system's performance in ranging and orientation of the object with respect to the user's pose. Both approaches will be optionally combined with Pedestrian Dead-reckoning (PDR) estimation in order to see the benefits that it can provide. For completeness we compare the cases where only one tag is fixed to the object to locate, and the user carries a mobile phone with BLE 4.0 or UWB radio, and the more ideal case where several objects of interest, each one with a tag, jointly cooperate to improve the relative location to one of the objects of interest. The UWB positioning system, not common in most smartphones but very accurate, is used as our reference to define the best achievable performance goal, in order to compare with BLE RSS-based ranging performance. We will demonstrate that the common BLE low ranging-accuracy technology combined with smartphone-based PDR estimation, and after some initial user movement, is capable of finding the objects of interest in a museum-like set-ups with decent range and heading accuracy.

This paper presents a description of the main features and specifications of UWB and BLE ranging systems in section II, the experimental ranging performance of UWB and BLE is analyzed in section III. The join range and heading estimation performance is analyzed in section IV. Finally, in the last section, we give some conclusions and future work.

II. UWB AND BLE SYSTEMS

This section presents the basics of UWB and BLE technology and shows the main features of the two commercially-available systems used in this paper: Bespoon and Estimote (Fig. 1).

A. UWB technology and Bespoon features

Ultrawideband (UWB) technology was originally used for communication but also has a great potential for accurate ranging and localization [14]. This radio technology consists of emitting very short pulses (Gaussian pulses and their derivatives, usually called monopulses), that is why it is also known as Impulse Radio or IR-UWB. Therefore, as its name reveals, they use a large wide bandwidth, which has the advantage of allowing to resolve any individual multipath components from its direct path. The time of arrival of the received signal can be estimated with high accuracy if the LOS arriving path can be detected. In order to not interfere with other equipment, they follow some FCC regulations,

a) Bespoon

b) Estimote

Fig. 1. Tags used for object finding in the museum-like use case. a) UWB tag from the Frech company BeSpoon, b) BLE tag from the Estimote company.

which define a maximum emission power and bandwidth limit: an absolute -10 dB bandwidth greater than 500 MHz or a relative bandwidth greater than 20%. The IEEE 802.15.4a (last version IEEE 802.15.4-2011) specifies two physical layers using ultra-wideband (UWB) and chirp spread spectrum (CSS). The UWB layer has three frequency ranges: below 1 GHz, between 3.2 and 4.8 GHz, and between 5.9 and 10.2 GHz. Companies like BeSpoon use the 802.15.4a impulse radio standard specification to define its physical layer.

BeSpoon is a French start-up company which has developed a miniature IR-UWB system. They were the first manufacturer to demonstrate that UWB technology can be successfully integrated into a smartphone. The SpoonPhone, consisting in a phone with the UWB radio and several UWB tags (Fig. 1a) is a prototype that was sold for research and evaluation purposes. This device is no longer available; Now they changed the sale strategy and their products are sold as general purpose modular kits (UM100). Both Spoonphone and the new modules offer the possibility to achieve good precision (down to 10 cm), ranging (up to 880 m in Line of Sight) and receiver sensitivity (down to -118 dBm). They use UWB channel 2 (3.99 GHz).

The SpoonPhone's UWB radio can be activated as any WiFi or Bluetooth radio in a phone, i.e. by switching "on" the corresponding tab in the Android-based configuration menu . The UWB antenna is also used for WiFi communication, and it is located top-left when looking at he phone's screen. An SDK API is made available to programmers so as to access in real-time to the ranging data from the phone to the different miniature tags. The average rate of range measurements is 2.5 Hz.

B. BLE technology and Estimote Features

Bluetooth 4.0, also known as Bluetooth Smart or Bluetooth Low Energy (BLE), is a radio comunication protocol that is specially designed for the internet of things. BLE is a totally different implementation from earlier Bluetooth versions (1.0, 2.0 and 3.0), which were devoted to audio or data streaming, and as a wireless sustitution of RS-232 comunications. BLE main purpose is to achieve device discovery and connectivity with low battery consumption even at the cost of lower comunications speeds. BLE use UHF radio waves in the ISM band from 2.4 to 2.485 GHz, and it allocates in that band 40 channels, each 2 MHz wide. The BLE protocol uses very short duration messages for advertisement. This beaconing for discovery can also include some payload with other relevant information such as sensor reading (temperature, pressure, humidity, etc.). This approach allow the implementation of a network of BLE motes deployed to monitor and inform about the status of the environment.

BLE has several advantages over WiFi-based beaconing. When using a phone to register the WiFi signals by passive scanning, the duration while the phone is waiting at the Service Set Identifier (SSID) can be as large as 4 seconds, so scanning rate could be below 0.25 Hz. Wifi also buffers the readings and are provided in a single bunch with no AP differentiating timestamps. BLE allows advertisement rates upto 10 Hz, and the Received Signal Strength (RSS) is obtained in real time without any buffering. Additionally BLE tags last several months with small batteries, and the phone reading broadcast messages consumes less energy than in a WiFi scan. Finally, BLE tags can be easily deployed since they are small and battery-powered.

BLE uses 3 channels for advertising in quick sequence. These channels are nominated 37, 38 and 39 but are widely spaced at 2402 MHz, 2426 MHz and 2480 MHz. This diversity is employed for minimizing interference with common WiFi deployments. A problem that could occur at BLE reception is that only the RSS value is registered, but not the channel on which it was received (only available for iOS 7 or above). Depending on the final channel used for RSS registration some important fading can occur with drops of 30 dB in very close positions [10]. This challenge should be taken into account by temporal filtering of the signals.

The Estimote tags used are model: "Long Range Location Beacons" (Fig. 1b). Tags have a lifetime of 5 years, a maximum range of 200 m (in free space), use iBeacon and Eddystone protocols, and include 5 sensors (3-axis acceleration, Temperature, Ambient light sensor, Magnetometer sensor), NFC, GPIO (for controlling or reading external sensors) and 1Mb EEPROM. We configured them with a transmission power of -12 dBm, and an update rate of 5 Hz.

a) b) c)

Fig. 2. Experimental localization set-up at main CAR-CSIC building corridor: a) Details of the tag distribution, calibrations points and different user trajectories. b) Distribution of 6 pictures along the corridor with 1 BLE and 1 UWB tag in each one. c) Detail of how two different phones: SpoonPhone with UWB (right) and Samsung Galaxy S4 with BLE (left) are positioned with a tripod on calibration points.

III. Ranging performance

In the following subsection we present the scenarios where we deployed the UWB and BLE equipment, as in a museum-like set-up, and the ranging performance that we obtained after moving the mobile phone to different known locations:

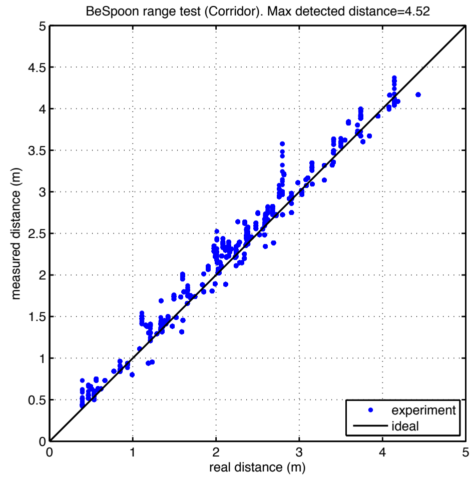
A. *Test set-ups*

We tested the system in a set-up with a total of six paintings (poster panels) along a corridor, three paintings at two opposing walls. The corridor width is 2.5 meters. Approximately the lateral separation is 1.35 m center to center. This set-up is quite small with a user's visualization area of about 2.5 by 5 meters (12.5 square meters). A layout and a picture of this set-up is shown in Fig. 2. Each painting has one Bespoon-UWB tag stick to it, and another Estimote-BLE tag close to the UWB one.

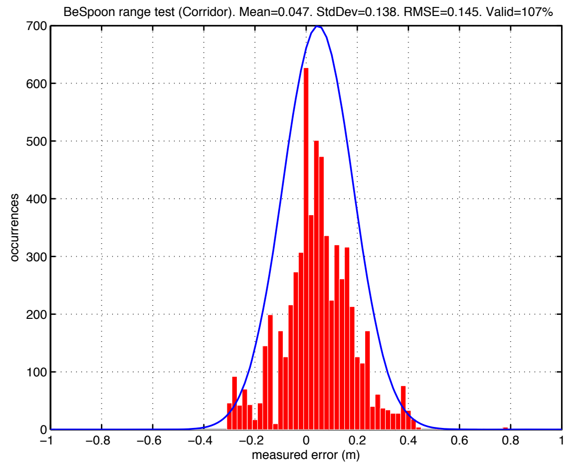
B. UWB ranging performance

This subsection aims to assess the performance in point-to-point ranging, both in the UWB case (we already know it should be quite good [15]), but specially in the BLE case where range is estimated indirectly from noisy RSS measurements. For the initial calibration and raw ranging tests both phones (SpoonPhone with UWB and Samsung Galaxy S4 with BLE) are positioned on a tripod at the same height as the tags in paintings, keeping tags and phones on the same horizontal 2D plane (see Fig. 2b). We define 21 points on the floor of the corridor in a 7 by 3 m grid (black marks in Fig. 2a and b); these points are our ground-truth positions that allow us to estimate the true range between each tag and the mobile phones. This measurement procedure is not ideal but guarantees an accuracy of about 2-3 cm, enough to analyze expected ranging errors of about ± 10 cm in the best of the cases. The acquisition of UWB range data and BLE RSS data was done in parallel but recorded individually at each phone with an independent logfile recording app.

Taking the UWB range information we plotted the relationship among the real and measured distances (see Fig.3a). Even under this scenario that is mainly LOS, due the presence of some people during the recording phase to make it more realistic, it can be seen that the measured ranges are not ideal and differ in ± 0.4 meters from their straight LOS path. The ranging error (measured range minus true range) is shown in detail in Fig.3b as a histogram with the number of occurrences for different range errors. There is a low-sigma Gaussian distribution (± 0.14 m) around zero error. Results are in consonance with expected results for UWB [16].



a)



b)

Fig. 3. Real versus measured distances using the UWB Bespoon system: a) Represented in comparison with ideal relationship (black line); b) histogram of range errors.

C. BLE ranging performance

The same study than in last subsection but now for BLE is presented here. In fact the experimentation was the same, but the data in this case is conformed with RSS signals captured with the BLE radio of a Samsung Galaxy S4 phone. The first thing we did was to represent the decay of the RSS signals with distance. In Fig. 4a we present the signal strength with respect to the real distance in an histogram representation. This data is fitted using a Simplex function minimization procedure [17] to a classical path-loss model:

$$\text{RSS} = \text{RSS}_0 - 10 \cdot p \cdot \log_{10}\left(\frac{d}{d_0}\right) + v, \qquad (1)$$

where RSS is the received power in decibels, RSS_0 is a mean RSS value obtained at the reference distance $d_0 = 1m$, d is the distance between emitter and receiver, p is the path loss exponent, and v is a Gaussian random variable with zero mean and standard deviation σ_{RSS} that accounts for the random effect of shadowing [18].

The experimental RSS data in Fig. 4a is fitted to the path-loss model (eq. 1) and the result presented in Fig. 4b. We found a path loss exponent for the corridor case of $p = 1.8$ (lower than 2 due to the narrowness of the corridor). The RSS_0 value at a 1 meter distance is -70 dB, and the mean RSS standard deviation, σ_{RSS}, is about 5 dB.

The ideal distance d_{ideal} obtained by inverting the path loss model (eq. 1) without taking into account RSS noise and dispersion is:

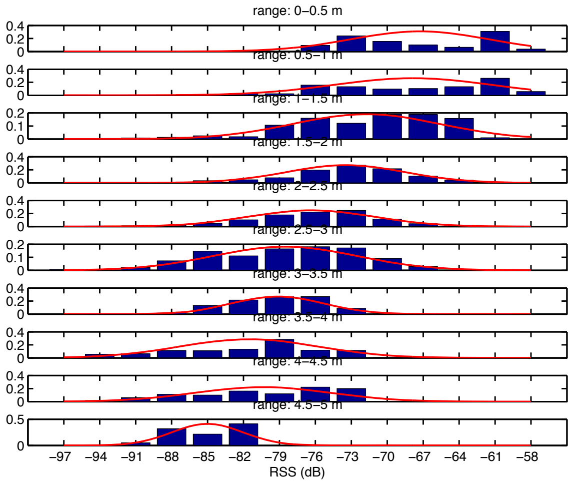
$$d_{\text{ideal}} = d_0 \cdot 10^{\frac{\text{RSS}_0 - \text{RSS}}{10 \cdot p}}, \qquad (2)$$

however this direct solution, according to the non-linearity of the path-loss model, is biased for real noisy RSS measurements (with dispersion σ_{RSS}). The unbiased estimate of d is given by [19]:

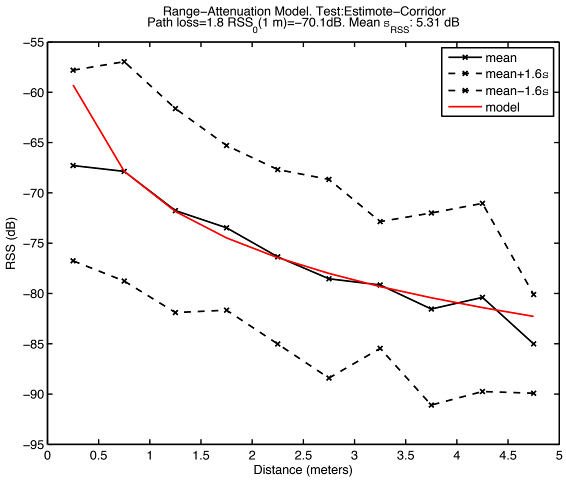
$$d = d_{\text{ideal}} \exp^{-0.5\left(\frac{\sigma_{\text{RSS}} \ln 10}{10p}\right)^2}. \qquad (3)$$

Even with bias correction, when observing the non-linearity of the path loss model and the important dispersion of RSS values (Fig. 4b), it is expected to have a very noisy non-gaussian range estimation with increasing dispersion at low RSS signals.

When we represent the real distance vs. the re-estimated range values, computed from the RSS values and the path-loss model, we obtain the relationship shown in Fig. 5a. The



a)

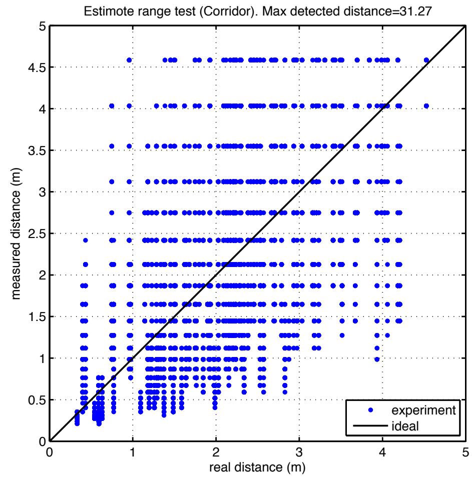


b)

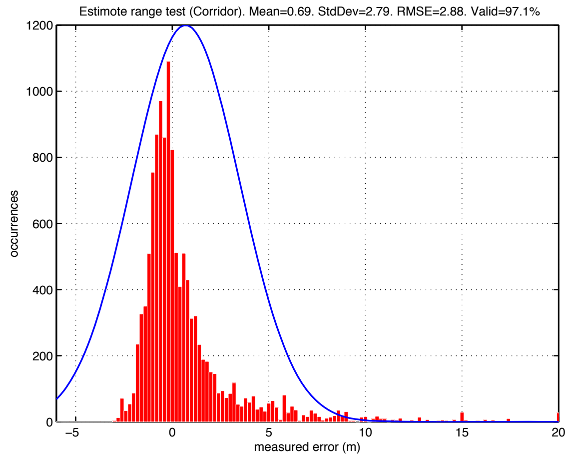
Fig. 4. Calibration of BLE RSS-based Estimote system: a) Histogram with experimental RSS values (in dBm), for different real ranges; b) Experimental data vs real distance represented by its mean and 1.6 standard deviation. A path loss model is fitted (red line) to experimental data (path loss exponent 1.8 and RSS_0 for d_0=1m is -70 dBm)

horizontal quantization is due to the relatively low diversity of total ground-truth ranges (21 points x 6 tags: 126 different ranges). The vertical quantization, which is also exponentially growing, is due to the fact that the captured RSS values are integers, so according to the path loss model, one dB change in the strong -60 dB signals represents a few centimeters change (typical at close range), but one dB change in the range of -90dB can be as large as 0.5 m.

For a better visualization of the range error we present in Fig. 5b a histogram of range errors (with a gaussian blue plot as reference). It can be seen the non-gaussian distribution of errors and that there are range errors even larger than 10 meters (caused by very weak RSS values). Therefore a very challenging situation is to try to estimate range from BLE data, specially when working with isolated point-to-point RSS data (i.e. not under the typical joint multi beacon-based positioning).



a)



b)

Fig. 5. Real versus estimated distances using the BLE RSS-based Estimote system: a) Dispersion is large compared to ideal distance (black line); b) Histogram of range errors, which can be more than 5 meters in many cases.

IV. Range and Heading Estimation

This section explains the different methods used for relative orientation determination between a person and an object of interest. We analyze its performance using separate Cumulative Distribution Functions (CDF) of range and angle.

A. Different Case Studies

We assume that each object to locate (painting, sculpture,etc.) has an emitting tag stuck to it with a unique identification code. The user carries a mobile phone with BLE 4.0 or UWB radio capacity. All our use cases will consist of a total of 6 objects (6 tags in total) and the goal is to determine the relative location of each of the objects with respect to the users pose. We will study 2 different configurations for finding each object:

- *Cooperative trilateration-based finding*. In this case we assume that we know the localization of all objects (absolute position or at least the realive localization among them), so it is possible to jointly estimate the user's position by trilateration and from that

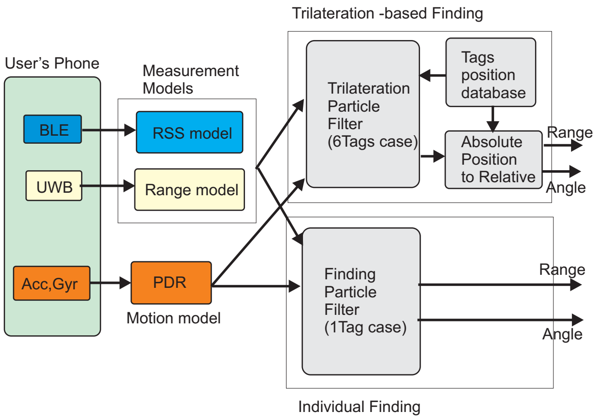


Fig. 6. Scheme with the two fundamental finding algorithms implemented.

information deduce the range and heading to each of the individual tags. This is the most ideal case, since it assumes that all the cooperative objects are geo-referenced with accuracy and their state is maintained along time.

- *Individual finding*. In this case, we do not rely in any cooperation, we just use the information available from the tag attached to the object of interest. This is the more versatile situation and can adapt to objects that move with time or does not require a geo-reference maintenance. In fact this is the use case more challenging, in principle less reliable, and the one we are more interested in for its novelty and applicability.

As we are also testing the influence of adding PDR information to the estimation processes for each of the two different configurations: "Cooperative trilateration-based finding" and "Individual finding", then we finally have 4 case studies. For convenience we will denominate them as: 6Tags, 6Tags+PDR, 1Tag, 1Tag+PDR. Where the "6Tags" label is used for the "Trilateration-based finding" and the "1Tag" label is used for "Individual finding". Since we also use two different technologies: UWB and BLE, then will will finally study a total of 8 configurations, as we will present in next subsections.

B. Range and Heading Algorithms

There are two fundamental algorithms developed for the two main configurations "Trilateration-based finding" and "Individual finding" (or 6Tags and 1Tag approaches, respectively). In both cases we implemented the estimation using a particle filter and a location engine. See Fig. 6 for a block diagram of these algorithms.

The 6Tags case, is a typical trilateration algorithm using a Bayesian estimation with a measurement model that depends on the technology used. If UWB distance measurements are processed then a combined LOS+NLOS model is used as in [16]. If RSS measurements are received from the BLE system, then a generic path loss model is used with the parameters deduced in last section. The particle filter uses 4 states, 3 for 3D position and one for absolute heading of the person (his phone in fact). When the PDR information is used the the movement model is improved by displacing the particles the amount measured with a stride length estimator, and the

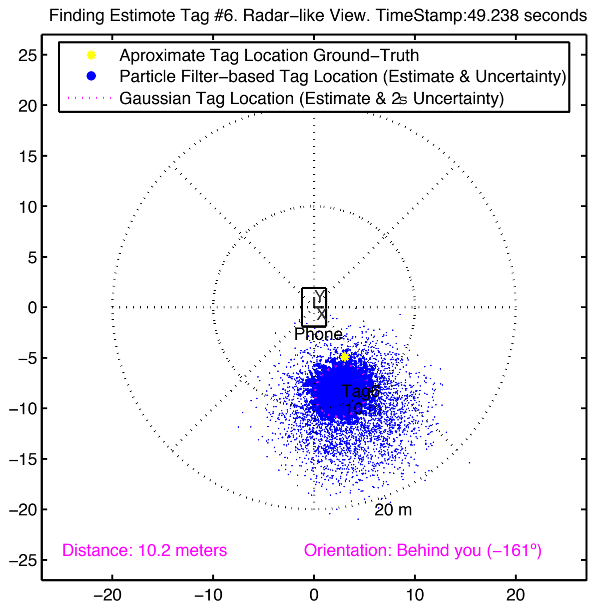


Fig. 7. Example of relative localization using a particle filter for the "1Tag+PDR" (or "Individual finding" assisted by PDR) in the most challenging case of BLE RSS-based estimation. The Radar-like view shows the particles in blue, the ground-truth in yellow, the finding results: distance and orientation.

heading change observed from the PDR attitude-and-heading-reference-system (AHRS).

The 1Tag case, is a special relative localization approach that is implemented using a particle filter and a Bayesian approach. In this case the particle filter used 3 states, only the 3D position of the object respect to the phone's main axis. The measurement model is the same that in the previous case but contributes in a less informative way to the position determination since only two actors are involve in the process, the phone and the object's tag. So Particle weighting is done by circumferences centered always on the phone's place (a ring-like shape distribution). This estimation process is only able to deduce the range to the object but never the orientation to that object. The only way to estimate the object's orientation is by adding PDR information. In this case, the particles can be moved backwards when a user step is detected, and can be rotated respect to the phone position when PDR detect a turn. After a succession of several RSS (or ranges) measurements and several steps detected with some turns, it is when the object's orientation with respect to the user can be deduced. This is the more challenging case, when using BLE instead of UWB, since measurement modes are very inaccurate and PDR detection at a phone is not so reliable as foot-mounted PDR.

A representative vision of the particles distribution, object's estimation and ground-truth data, for the 1Tag+PDR or "Individual finding" case, is shown in Fig. 7. After some walking and one turn, the initial ring-like particle distribution converges to a more clustered distribution, and it is then possible to estimate the object's location with respect to the phones's pose. In this case the object is behind the user at a distance of 10 meters.

Different experiments, with different trajectories around the paintings area were performed. For these cases, and in order to ease the PDR estimation, zig-zag and "s"-like trajectories are performed. Any trajectory with 90 or 180 degrees turn are good for achieving angular information when PDR is active. Walking straight all the time does not give information for the particles filter cloud to converge. So our trajectories contain turns to make the estimation feasible.

The ground-truth position or Range/heading ground-truth is obtained in our case from PDR estimations when we give the known initial position and the correct orientation. This is a very practical way to obtain the ground-truth, not too precise, since is subject to a discrepancy between the foot motion and the actual phone movement, but enough to observe the performance limitations and achievements from the cases we want to explore.

C. UWB Range and Heading Performance

Here we will show the performance of the more ideal UWB case (Bespoon) for the 4 configurations described above: 6Tags, 6Tags+PDR, 1Tag, 1Tag+PDR, all preceded with label "UWB" since we are in that case. Since two independent estimations are required for relative finding: range and heading, then the results are presented in two separate CDF, one for range, and another for angle. In Fig. 8 we present these results.

From Fig. 8a we can see that the range estimation is better for the "Trilateration-based finding" (6Tags cases) than for the "Individual finding" (1 Tag cases). This is logical since more information is used. The contribution of PDR information is irrelevant and no improvement is achieved. This is again consequence of the high quality of UWB ranging process, and PDR does not add any value to UWB system.

From Fig. 8b we can see that the angular estimation is not so ideal even for the 6Tags case; in this case the contribution of PDR helps somehow for a better orientation determination. On the other side we see that the 1Tag case is unable, as expected, to determine any kind of orientation, however using 1Tag+PDR is possible to obtain a decent orientation estimation, after some walking. In fact in our experiments 40% of the time the orientation was lost (particles in ring-like shape) but after some walking the orientation was deduced with less than 30 degrees error in 80% of the cases. The time were the estimation was lost is included in the CDF.

D. BLE Range and Heading Performance

This subsection will analyze the same situations as the last one, but in this case using BLE technology (Estimote tags). In Fig. 9 we present these results.

From Fig. 9a we see a good performance in range estimation when using 6Tags, and even better range estimation with PDR. The results in range for the BLE:6Tags+PDR are almost as good as for the UWB case, which is a good achievement. When using only 1Tag the performance in range estimation is not very accurate (about 3 meters error in 60% of the cases) and no significant improvement is obtained from PDR in these cases (4 m error in 90% of the case for the PDR case). This is due to the poor measurement models of BLE technology when no RSS redundancy exists.

From Fig. 9b we deduce that Orientation is more difficult to deduce, even for the 6Tags case, however when adding

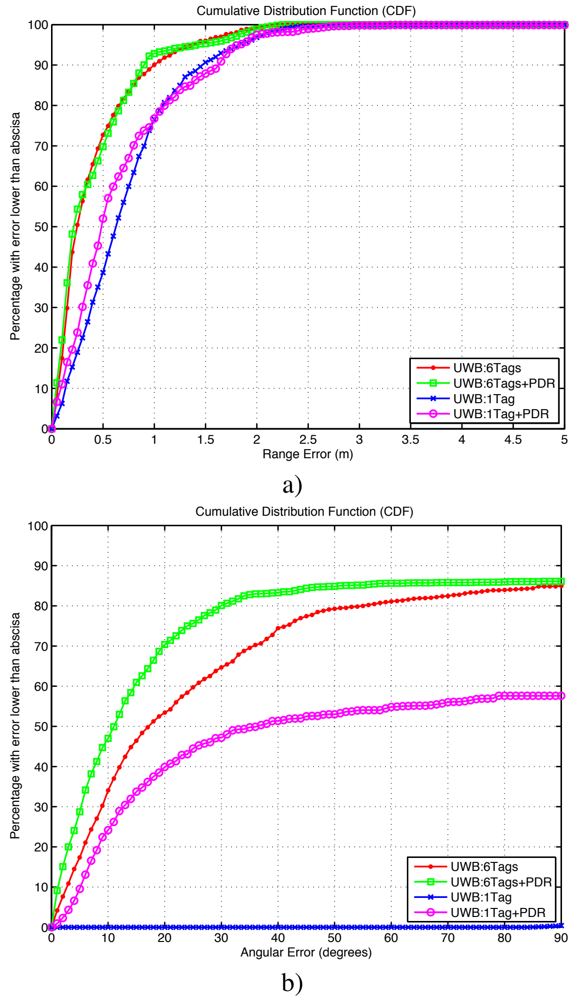
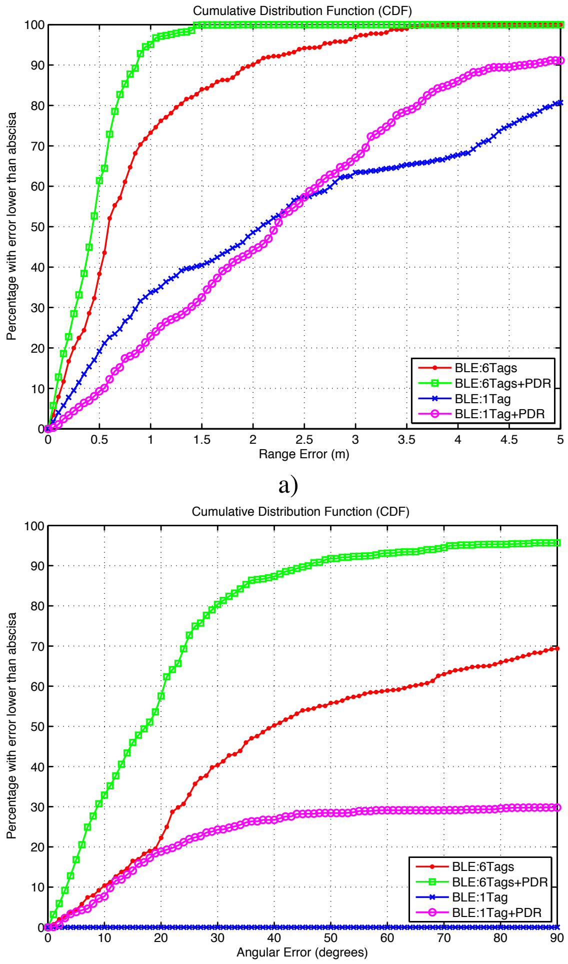


Fig. 8. Cumulative Distribution Functions for the UWB-Bespoon technology: a) Distance CDF; b) Angular CDF.

PDR information angular estimation improves significantly (less than 30 degrees error in 80% of the cases). As expected the orientation estimation from the challenging 1Tag case with BLE data is problematic. However after a long period where the particles have not clusterized yet (70% of the experimentation time), the angular estimation is good with error below 30% in 80% of the cases, similar to the UWB case. This result demonstrate that using Estimote RSS based technology combined with PDR, even for objects tagged with no geo-referentiation, it is possible to find the object of interest after walking a while around the undiscovered object.

V. CONCLUSIONS

We have presented an experimental evaluation of different approaches for finding an object of interest respect to the pose of a user's phone. The range and orientation is computed from two approaches: 1) a cooperative trilateration method where several geo-referenced tags jointly cooperate providing tag-to-phone ranges, and 2) a novel an much more challenging use case where only one unreferenced individual tag is transmitting range information. These two approaches are complemented with PDR information to analyze its contribution and benefits. The case of two different technologies are analysed: UWB



a)

b)

Fig. 9. Cumulative Distribution Functions for the BLE-Estimote technology: a) Distance CDF; b) Angular CDF.

and BLE, using commercially available devices (Bespoon and Estimote, respectively). After this analysis, we demonstrate that the common BLE low ranging-accuracy technology combined with smartphone-based PDR estimation is capable, after some initial user's walking, of finding with decent range and heading accuracy the objects of interest in a museum-like set-up, but also valid for outdoors applications for finding objects of interest.

Future research will include the experimentation in larger spaces, in more realistic scenarios like museums and botanic parks. The convergence time versus the traveled trajectory will be studied. The detection rate, or confusion matrices when trying to use this estimation to receive augmented information from a particular object and not from the ones close to it, will be another future work to implement. These future studies can open the potential to other fine-grained finding in museums or spaces with a higher density of objects that we could want to discern.

Acknowledgment

The authors thank the financial support received from projects: TARSIUS (TIN2015-71564-C4-2-R (MINECO/FEDER)), REPNIN (TEC2015-71426-REDT) and SmartLoc (CSIC-PIE Ref.201450E011).

References

[1] R. Mautz, *Indoor Positioning Technologies*. PhD thesis, ETH Zurich, 2012.

[2] Y. Gu, A. Lo, and I. Niemegeers, "A Survey of Indoor Positioning Systems for Wireless Personal Networks," *IEEE Communications Surveys and Tutorials*, vol. 11, no. 1, pp. 13–32, 2009.

[3] J. Hightower and G. Borriello, "Location Systems for Ubiquitous Computing," *Computer*, vol. 34, no. 8, pp. 57 – 66, 2001.

[4] Z. He, B. Cui, W. Zhou, and S. Yokoi, "A proposal of interaction system between visitor and collection in museum hall by iBeacon," *10th International Conference on Computer Science and Education, ICCSE 2015*, no. Iccse, pp. 427–430, 2015.

[5] J. Tiemann, F. Schweikowski, and C. Wietfeld, "Design of an UWB Indoor-Positioning System for UAV Navigation in GNSS-Denied Environments," in *International Conference on Indoor Positioning and Indoor Navigation (IPIN)*, pp. 1–7, 2015.

[6] I. Guvenc, C. C. Chong, and F. Watanabe, "NLOS identification and mitigation for UWB localization systems," *IEEE Wireless Communications and Networking Conference, WCNC*, pp. 1573–1578, 2007.

[7] S. Maranò, W. M. Gifford, H. Wymeersch, and M. Z. Win, "NLOS identification and mitigation for localization based on UWB experimental data," *IEEE Journal on Selected Areas in Communications*, vol. 28, no. 7, pp. 1026–1035, 2010.

[8] M. Kouhne and J. Sieck, "Location-Based Services with iBeacon Technology," *Proceedings - 2nd International Conference on Artificial Intelligence, Modelling, and Simulation, AIMS 2014*, pp. 315–321, 2014.

[9] D. E. Grzechca, P. Pelczar, and L. Chruszczyk, "Analysis of Object Location Accuracy for iBeacon Technology based on the RSSI Path Loss Model and Fingerprint Map," *International Journal of Electronics and Telecommunications*, vol. 62, no. 4, pp. 371–378, 2016.

[10] R. Faragher and R. Harle, "Location fingerprinting with bluetooth low energy beacons," *IEEE Journal on Selected Areas in Communications*, vol. 33, no. 11, 2015.

[11] E. Foxlin, "Pedestrian tracking with shoe-mounted inertial sensors," *IEEE Computer Graphics and Applications*, vol. 25, no. 6, pp. 38–46, 2005.

[12] A. R. Jiménez, F. Seco, J. C. Prieto, and J. Guevara, "Indoor Pedestrian Navigation using an INS/EKF framework for Yaw Drift Reduction and a Foot-mounted IMU," in *WPNC 2010: 7th Workshop on Positioning, Navigation and Communication*, (Dresden), pp. 135 – 143, 2010.

[13] R. Harle, "A Survey of Indoor Inertial Positioning Systems for Pedestrians," *IEEE Communications Surveys and Tutorials*, vol. 15 (3), no. December 2012, pp. 1281–1293, 2013.

[14] L. M. M. Ghavami and R.Kohno, *UltraWideband: Signals and systems in communication engineering*. John Wiley & Sons, 2004.

[15] A. R. Jimenez and F. Seco, "Comparing Decawave and Bespoon UWB location systems: indoor / outdoor performance analysis," in *6 Int. Conference on Indoor Positioning and Indoor Navigation (IPIN)*, no. October, pp. 4–7, 2016.

[16] A. Jimenez and F. Seco, "Comparing Ubisense, Bespoon and Decawave UWB location systems: indoor performance analysis," *IEEE Transactions on Instrumentation and Measurement*, no. 99, pp. 1–12, 2017.

[17] J. Nelder, R. Mead, B. J. a. Nelder, and R. Mead, "A simplex method for function minimization," *Computer Journal*, vol. 7, pp. 308–313, 1965.

[18] S. Mazuelas, A. Bahillo, R. M. Lorenzo, P. Fernandez, F. a. Lago, E. Garcia, J. Blas, and E. J. Abril, "Robust Indoor Positioning Provided by Real-Time RSSI Values in Unmodified WLAN Networks," *IEEE Journal of Selected Topics in Signal Processing*, vol. 3, pp. 821–831, oct 2009.

[19] G. Zanca, F. Zorzi, A. Zanella, M. Zorzi, and M. Max, "Experimental comparison of RSSI-based localization algorithms for indoor wireless sensor networks," in *Proceedings of the workshop on Real-world wireless sensor networks*, (Glasgow), pp. 1–5, 2008.