A Data Fusion Technique for Wireless Ranging

Performance Improvement

**Abstract**

**The increasing diffusion of mobile and portable devices provided with wireless connectivity makes the problem of distance measurement based on radio-frequency technologies increasingly important for the development of next-generation nomadic applications. In this paper, the performance limitations of two classic wireless ranging techniques based on received signal strength (RSS) and two-way time-of-flight (ToF) measurements, respectively, are analyzed and compared in detail. On the basis of this study, a data fusion algorithm is proposed to combine both techniques in order to improve ranging accuracy. The algorithm has been implemented and tested on the field using a dedicated embedded prototype made with commercial off-the-shelf components. Several experimental results prove that the combination of both techniques can significantly reduce measurement uncertainty. The results obtained with the developed prototype are not accurate enough for fine-grained position tracking in Ambient Assisted Living applications. However, the platform can be successfully used for reliable indoor zoning, e.g., for omnidirectional and adjustable hazard proximity detection. Most importantly, the proposed solution is absolutely general, and it is quite simple and light from the computational point of view. Accuracy could be further improved by using a more isotropic antenna and by integrating the ToF measurement technique at the lowest possible level on the same radio chip used for communication. Usually, this feature is not available in typical low-cost short-range wireless modules, e.g., for wireless sensor networks. Thus, the results of this research suggest that combining RSS with ToF measurements could be a viable solution for chip manufacturers interested in adding ranging capabilities to their radio modules.**

**Existing system**

The fact, achieving both Omni directionality and accuracy in the short range is notoriously quite Hard, and consequently, it is still a hot research topic worldwide. Several approaches relying on different sensing technologies have been proposed for indoor positioning and ranging, e.g., based on laser rangefinders ultrasound devices infrared sensors inertial platforms and video cameras or combinations thereof. Camera-based solutions are very effective in terms of accuracy, even in the presence of partial occlusions. However, they are not always usable because of privacy issues and because they suffer from scalability problems. To overcome the directional constraint of such systems, pan tilt and unidirectional cameras have been also proposed. Their main drawback is the high computational burden when multiple targets have to be recognized and tracked. In addition, they could exploit the same wireless modules used for communication, and they are particularly suitable for wearable applications. In wireless RF ranging techniques, the distance between two objects is indirectly measured from some distance related parameters of the RF signals. The two most common approaches are based on received signal strength (RSS) and message time-of-flight (ToF) measurements. The RSS-based methods rely on the relationship between the measured received signal power and the transmitter–receiver distance. If the transmitted power and the signal propagation model are known, the distance from the transmitter can be estimated by reversing the equation of the model. Usually, the RSS can be easily measured without additional circuitry, because most of the integrated wireless chips are natively equipped with an RSS indicator. RSS-based ranging has been widely analyzed in recent years, both theoretically and experimentally.

**Disadvantages**

* Unfortunately, these systems are very expensive. Radio frequency (RF)-based ranging techniques are inherently less sensitive to obstacles and dissipate less power than optical and ultrasound solutions.
* The most accurate approach is provided by laser scanning heads that also address the target pointing problem.

**Proposed System**

The calibration procedure, about 5000 RSS and RTT values were collected by the MTS from the FA. The path loss coefficient can be estimated through linear regression, after applying the base-10 logarithm function to both terms. From this procedure, it follows that with negligible uncertainty. In the standard uncertainty and the RMSE patterns associated respectively, are plotted as a function of the real distance. The solid lines result from a Type-A uncertainty evaluation at different known distances from the FA, after removing the static position-dependent offsets. The dotted lines refer to the theoretical worst-case standard uncertainty respectively. Clearly, the theoretical and experimental uncertainty patterns are in good agreement. In particular, the uncertainty associated with the RSS data tends to grow with distance, whereas the uncertainty related to estimates is approximately constant, as expected. The dashed represent the experimental RMSE patterns including the effect of both random fluctuations and position-dependent offsets.

**Module Description**

**Data Fusion Algorithm**

Assuming that one node is fixed, whereas the other is moving, the distance can be measured by either node, as soon as it receives the response or acknowledgment message sent by its partner. Thus, every distance value estimated through either is intrinsically event driven. If the communication between nodes periodically occurs, the time interval *Tc* between two consecutive messages received by the node measuring the distance can be regarded as the *sampling period* of the ranking system. In theory, *Tc* can be arbitrarily set by the user. The lower bound to *Tc* is given by the sum of the minimum RTT value including the time spent to process any sent or received packet and the computing time due to the distance estimation algorithm. Of course, *Tc* is generally subject to some fluctuations.

**Data Acquisition and Filtering**

An essential preliminary step to improve ranging accuracy is data filtering. The purpose of this operation is not only to reduce the random fluctuations affecting raw measurement results but also to remove possible values that are not compatible with the movement of a real target.

**Data Fusion**

The respectively. In principle, only one of the two KFs should be used. However, both of them are suboptimal since the distribution of the uncertainty contributions is unknown and no stationary both in time and in space. As a consequence, the most sensible approach is to run both KFs in parallel and then to weight.

**Hardware Platform Description**

The performance of the data fusion algorithm described in Section III, a new wireless node prototype developed in cooperation with Trento, Italy, was used for all experimental activities. The block diagram and a snapshot of the respectively. The system results from the evolution of the node employed for similar experiments but it is smaller in size, and it is equipped with a faster microcontroller (MCU) and a larger memory.

**Accuracy Analysis in Dynamic**

The performance of the algorithm in dynamic and realistic repeatable conditions, two kinds of orthogonal experiments was conducted in the Domotic Application Lab. In all cases, the FA was steadily kept on top of a fixed 90-cm plastic pole located in different positions, but always at about 1 m from the walls of the room. The MTS instead was manually held by the moving user just in front of the body at about 1 m from the floor, with the MTS and FA antennas reasonably parallel to each other and always in LOS conditions. No obstacles or bodies were used to steadily obstruct the LOS communication between the two wireless devices.

**CONCLUSION**

This paper deals with a data fusion algorithm merging RSS and ToF measurement results in order to improve wireless ranging accuracy. Both approaches have been analyzed in detail in order to evaluate the main uncertainty contributions affecting either measurement procedure. The proposed algorithm has a general validity (i.e., independent of the chosen implementation), and it relies on two MA filters to reduce the input wideband noise, a heuristic criterion able to easily remove possible large position-dependent offsets, and two KFs that use RSS- and ToF-based measurement results in a complementary manner. Due to its moderate complexity, the algorithm could be integrated in future transceiver chips to support possible positioning services (e.g., for wireless sensor networks). At the moment, the algorithm has been implemented and tested on the field using a dedicated embedded system made up of commercial off-the-shelf (COTS) components. The estimated accuracy is generally about 1 m, but it can be so small as 50–60 cm around a given reference distance. Accordingly, such a distance can be also set as a threshold for adjustable and unidirectional proximity detection. Unfortunately, the accuracy of the developed prototype is limited by the features of some hardware components, particularly the antenna that

is not so isotropic as specified in the data sheet. Moreover, ToF measurement accuracy could be much better if message time stamping was done in the transceiver front end as soon as the first symbol of any packet is sent or received. However, this is not possible with COTS components. Due to the limitations above, the developed prototype cannot be used in AAL applications with tracking accuracy requirements on the order of a few tens of centimeters. Nevertheless, the system is accurate enough for reliable indoor zoning and proximity detection. For instance, the platform is going to be used in an AAL project where the staff assisting mentally disabled people should be alerted as soon as patients enter into potentially dangerous areas, e.g., within 1 m from windows, doors, staircases, or gas cookers.

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