Experimental Platform for Sensor Fusion Positioning Methods Evaluation

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Abstract—Position and context awareness is becoming greater in importance as one of the key enablers of the Industry 4.0 concept, with impact on analysis and optimizing production processes, their direct control, increasing and ensuring the safety of personnel and technology, as well as enabling traceability of products. There are many approaches to achieve a real-time location system (RTLS) capable of providing positioning data, yet each approach usually has its limits given by the physical principles of technology which it is primarily based on; mostly a wireless signal transmission where the performance boundaries lay in non-line-of-sight (nLoS) scenarios. Current literature already presents various approaches capable of dealing with these shortcomings and presents various combinations of sensors based on different phenomena, the drawbacks of which are mutually compensated, known as sensor fusion. This work presents practical design of a compact platform, which utilizes Ultra-WideBand (UWB) as one of the predominant wireless technologies for wireless positioning with with IEEE 802.15.4z compliant radio integrated circuits in cooperation with a 9-axis absolute orientation sensor, expandable with add-on boards.

Keywords—UWB, IMU, sensor fusion, SR040, SR150, positioning, localisation

1. INTRODUCTION

The spectrum of the Industry 4.0 concept is really broad, as are the benefits and new possibilities of flexible manufacturing that the implementation of digital technologies can bring to manufacturing. The digitization focuses on automation and optimization of production as a whole: it benefits from machine to machine communication (M2M), collects data, helps to better plan, manage and predict production. Thus, application of digital technologies can significantly increase the production and competitiveness of manufacturing companies. Position awareness is an integral part of the Industry 4.0 concept of Industrial Internet of Things (IIoT) usually referred to as Real Time Location System (RTLS) or Indoor Positioning System (IPS). Such scalable localization systems for industrial applications reduce asset search time, speed up manufacturing and logistics processes, and optimize material flow with dynamic real-time location data for each product or a part of the production [1].

The use of any GPS-like system is problematic inside buildings, because the signal is usually weak to penetrate the walls, hence it is necessary to design and manage a special local infrastructure for an indoor location system. There are many approaches to do so, utilizing technologies based on various physical principles, both passive and active wireless radio technologies, such as RFID, Wi-Fi, Bluetooth or Ultra-Wide Band (UWB), or motion sensors, such as accelerometers, gyroscopes and magnetometers. Each of these technologies have fundamental pros and cons, stemming from the nature of the physical principles on which they are based. To overcome these shortcomings, descriptions of the principle called sensor fusion appears in the literature, with already promising results published. It involves various data filters, algorithms for the data fusion, including machine learning classification, and many other aspects opened for research and practical industrial applications.

As for the wireless part, the UWB impulse radio is now in the spotlight as very promising, accurate and robust technology for precise localisation and positioning with centimeter accuracy, becoming one of the key enablers of industrial RTLS systems. With new chips available in the market and their integration to mobile devices by major players such as Apple or Samsung followed by others, wearables, and other consumer electronics, or automotive key fobs, there is a significant stimulation of innovation and integration of UWB radio. Estimated number of sold UWB chips is expected to further grow at least by 2025, as presented with reference to [2] in publicly available documents [3], which in terms of numbers means over 1 billion annual UWB technology-enabled device shipments [1], opening new opportunities along with new challenges to cope with.

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2. UTILIZATION OF UWB AND SENSOR FUSION IN REAL TIME LOCATION SYSTEMS

The ultra-wideband (UWB) technology operates in a spectrum of 3.1–10.6 GHz [1]. This technology is not entirely new, but it is experiencing a renaissance these days thanks to new possibilities of using the radio spectrum, sanctioned by the FCC (US) and ETSI (EU) especially considering transmission power levels and spectrum usage. Thanks to its simplicity, robustness and time granularity given by transmission of short impulses in a wide band (channels of 500 MHz) and thus ability to obtain an accurate Time-of-Flight (ToF) between the transmitter and receiver, it is able to calculate nearly instantly mutual relative position of the two devices within ranges exceeding higher tens of meters. This is incomparable to systems relying for example on received signal strength indication (RSSI), which can be easily attenuated by real world environment, where multi-path and interference occurs.

![Figure 1: The History of UWB, image inspired by [1]](image)

Based on results available in literature, using the inertial measurement units (IMU) in combination with the UWB to optimize positioning accuracy appears to be potentially advantageous in general, because each of these technologies is based on a different physical principle, which provides unique desired properties, but on the other hand creates certain limitations, deviations and errors.

The potentially positive effects of the combination and integration of the IMU with the UWB are especially valuable in the case of non-line-of-sight (nLoS) scenarios, where barriers between the transmitter and receiver in the environment lead to degradation or complete loss of the UWB radio signal. On the other hand, the published literature describes the sole use of only IMU sensors for localization rather than problematic, as these sensors generally suffer from instability of their own bias, noise and cumulative position drift error after a certain period of operation. With accumulation it becomes a systematic error and thus the accuracy of the results decreases [4, 5, 6, 7].

It would have been worth a complex, comprehensive research review of its own to describe the variety of the sensor fusion methods already implemented or opened to discussion, which is out of the scope of this work, with and will be the goal closer to achieve only after the evaluation of the device presented in this work. Therefore, this part shall present a paradigm, based on fact that literature offers already a lot of methods of sensor fusion. With a suitable combination of accelerometer, gyroscope and magnetometer, all angles to the horizontal starting position can be determined and mutual drift can be compensated, or the mean square error can be further reduced using more reference sensors [7, 8]. There are also algorithms and methods of signal filtering that can contribute to further suppression of the mentioned inaccuracies, such as the Kalman filter and its varieties [4, 5].

Table I shows comparison of several works from recent time period, which usually refer to to Quorvo (formerly Decawave) DWM1000 chip as the base for UWB communication, compliant with the standard IEEE 802.15.4-2011. There is not yet any larger research or evaluation hardware capable of the latest IEEE 802.15.4z, presented as the mainstay of this work by the NXP SR040 (and SR150 respectively), either as UWB tag alone or in sensor-fusion context. This encourages the development of an own, open platform, capable of meeting the latest standards and trends as a basis for comparative experiments.

**Table I:** Comparison of sensor fusion methods, means of their evaluation and error correction towards pure UWB

<table>
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<tr>
<th>Reference</th>
<th>Year</th>
<th>Method</th>
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<tr>
<td>[7]</td>
<td>2021</td>
<td>simulation</td>
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<tr>
<td>[8]</td>
<td>2019</td>
<td>simulation, DWM1000 on Pozyx platform (IEEE 802.15.4-2011), PX4 Flow sensor</td>
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However, there are also two major throwbacks of sensor fusion tag technology mass production, where cost plays significant role. Firstly, the introduction of algorithmic methods generally increases the overall performance requirements and secondly, more accurate data samples require a higher sample rate, which in both cases increases the overall power requirements, which is a critical parameter for a battery-powered device with long battery life expectation. This even further increases with the number of sensors used together with the dimensions of the final device design and its final price. Yet, this might remain an application-dependent question.

As an example, let us discuss a publicly available data-set accompanied by article reference [8], which can be used for describing the data fusion in terms of principles of algorithms and their results. The authors present a simulator, which they designed based on their own measurement campaign in a known environment from a set of real sensors utilizing physics simulator tool called Gazebo and machine learning methods to describe the model of environment based on collected data samples, in which authors simulate tracking of a forklift model. Algorithm used in this case utilizes Kalman filter, a method widely used to address tracking problems, in this case iterated extended Kalman filter (IEKF). The IEKF is then applied by the authors to the pure UWB x, y coordinates data, then UWB plus IMU and finally UWB, IMU and PX4 optical flow sensor. Their results show mean absolute error with 95% confidence interval. For using solely UWB in their strongly nLoS scenarios the average error exceeded 1 m with large variance, but adding IMU reduces the error considerably to tenths of a meter. On top of that, introducing optical flow sensor gets the error below 0.2 m. Considering LoS situation, the results of each approach are closely bounded around expected (true) trajectory.

Authors of [8] claim, that UWB location accuracy is strongly LoS dependent, and thus justify the sensor fusion method as a clear way to increase the overall localization accuracy of a RTLS system. Yet, if the authors admit, that when there is a strong LoS for UWB, it is capable enough on its own, thus opening question of the system cost – on the one hand, mass production of such tracking tags can increase the cost of acquiring them, but at the same time it can save the cost of covering larger spaces with a sufficient number of UWB anchors to ensure sufficient LoS; on the other hand, if the target environment of the deployed RTLS system contains previously known obstacles, or the location of the anchors is sufficient for normal operation of this system, then the remaining sensors would remain practically unused, thus being redundant both in cost and occupied space.

### 3. DESIGN OF RTLS TAG PLATFORM FOR SENSOR FUSION EVALUATION

The design is based on the evaluation kit by MobileKnowledge [9] and is intended to become its modular extension, as well as being able to get integrated into any other existing RTLS ecosystems. The core is QN9090 MCU by NXP, which incorporates low-power MCU based upon Arm Cortex-M4 CPU, equipped by Bluetooth Low-Energy (BLE 5.0), and NFC capabilities. Via the SPI bus, the SR040 UWB radio integrated circuit is connected to the MCU, intended to be used as a tag (transmitter) with its counterpart SR150 as an anchor (receiver). The I2C bus is mainly used to communicate with the BNO055 9-axis sensor, which is highly integrated inertial measurement unit consisting of an accelerometer, a magnetometer and a gyroscope. On top of that, being based on the capabilities of the tags in the kit, NXP EdgeLock secure element SE050 is also part of this platform, utilizing the I2C bus. As the proposed device is not a customer-oriented product, but is intended to provide a data acquisition platform for research and evaluation, the space constraints play no role here and thus all the buses and leftover GPIO pins are accessible, with the idea of prototyping in mind. Also, as the time advances, USB-C enters consumer electronics as well as the designer labs, hence USB type C connector will be incorporated for powering and communication.
At the beginning of the project, there was an idea to utilize a planar antenna directly on the board, as there are this kind of solutions available for free on-line (e.g. Quorvo). This solution would however require pretests and evaluation, especially with intention to use higher frequencies (e.g. 8 GHz of UWB Channel 9). Thus, being a prototyping board, a SMA / U.FL antenna connector was chosen to consider to be used to further open abilities of the platform to also assess various antenna designs in practical scenarios. All the signal paths shall be calculated to 50 Ω to meet impedance matching.

Embracing the portability and universality, the board keeps Arduino-compatible shield pin-header layout, as this platform is used by authors of the corresponding kit for their anchor board, and other manufacturers kits such as most of the NXP dev kits, STM Nucleo boards etc., so it can work either standalone or become an extension itself, based solely on the developer’s preferences of intended MCU and other functionalities to be used. This opens versatility for data collection across many common embedded development platforms, as well as utilizing other already available Arduino-compatible shields with other various sensors, with the possibility to incorporate them into the sensor fusion system.
4. CONCLUSION

In this paper, the concept of sensor fusion approach to RTLS and IPS systems is described. This idea shall address the performance boundaries of purely wireless-radio based systems, which lay in nLoS scenarios, affected by distortion, multi-path or signal loss. These methods published in literature seem promising in terms of position accuracy improvements and overall error reduction, which represents a generally accepted paradigm, that sensor fusion is worth its attention.

On the other hand, available results of algorithmic methods are usually scattered among various types of hardware used for data acquisition. This is the key motivation for developing of a testing platform for evaluation, whose center of gravity is the UWB, as one of the predominant RTLS technologies, together with IMU sensors and extended modularity which benefits from versatility of Arduino-platform shield pinout. Another key contribution besides ability to change the antenna for any off-the-shelf or custom type is that the proposed platform can itself get integrated into an ecosystem of most available evaluation and development kits, making it a more versatile platform for wider variety of applications.

This all-in-one platform shall open way for comparative evaluation and validation studies of sensor fusion methods, which is a natural follow-up step for the future work. Attention will also be focused on verification and possible optimization of the proposed design in another iterations.

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REFERENCES