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Ultra-Wideband (UWB) Positioning System Based on ESP32 and DWM3000 Modules

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Introduction

We present an indoor UWB positioning system that capitalizes on advanced hardware and sophisticated algorithms, resulting in an exceptional level of accuracy and reliability.

Our UWB system comprises six identical boards, all based on the ESP32 microcontroller, a versatile and powerful platform known for its capabilities in wireless communication and processing. These boards are equipped with DWM3000 modules from Quorvo, renowned for their high-performance UWB capabilities.

One of these boards is designated as the "Tag", responsible for initiating Two-way-Ranging (TWR) measurements with the remaining five "Anchor" boards. The innovative aspect of our system lies in its ability to perform accurate localization without reliance on external infrastructure or centralized processing.

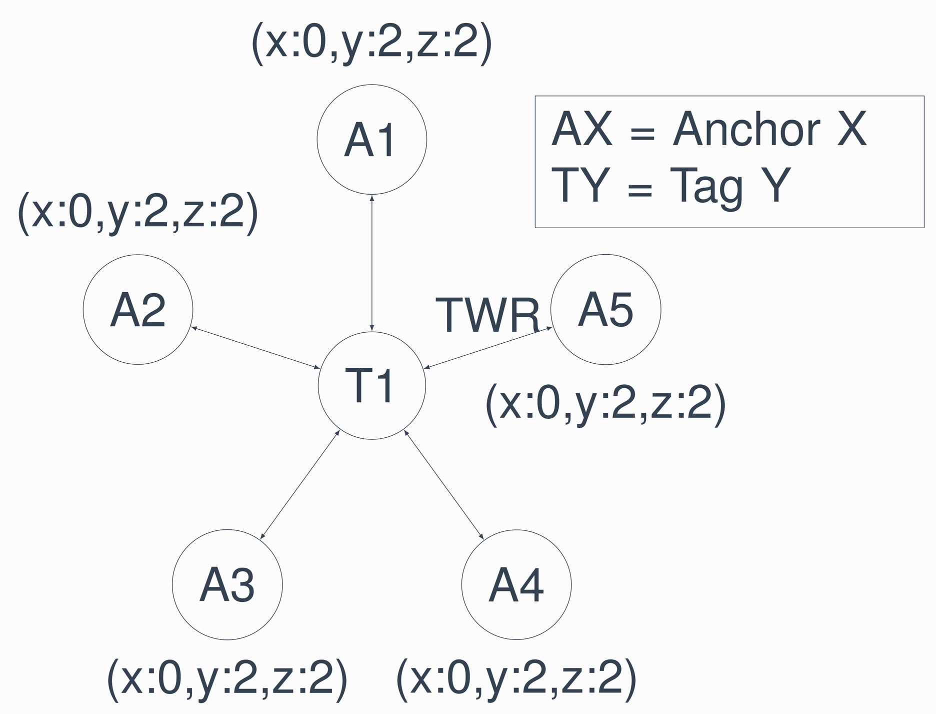

Figure 1. Systemarchitecture for Positioning

Hardware

The hardware design of our system draws inspiration from pre-existing DWM3000 Evaluation boards [2]. However, our proprietary board development enables specialized component selection tailored to their intended use cases. User-friendliness was a paramount consideration during the design process, resulting in the integration of multiple user buttons and LEDs. Additionally, the PCB incorporates a convenient LiPo battery charging capability via USB-C.

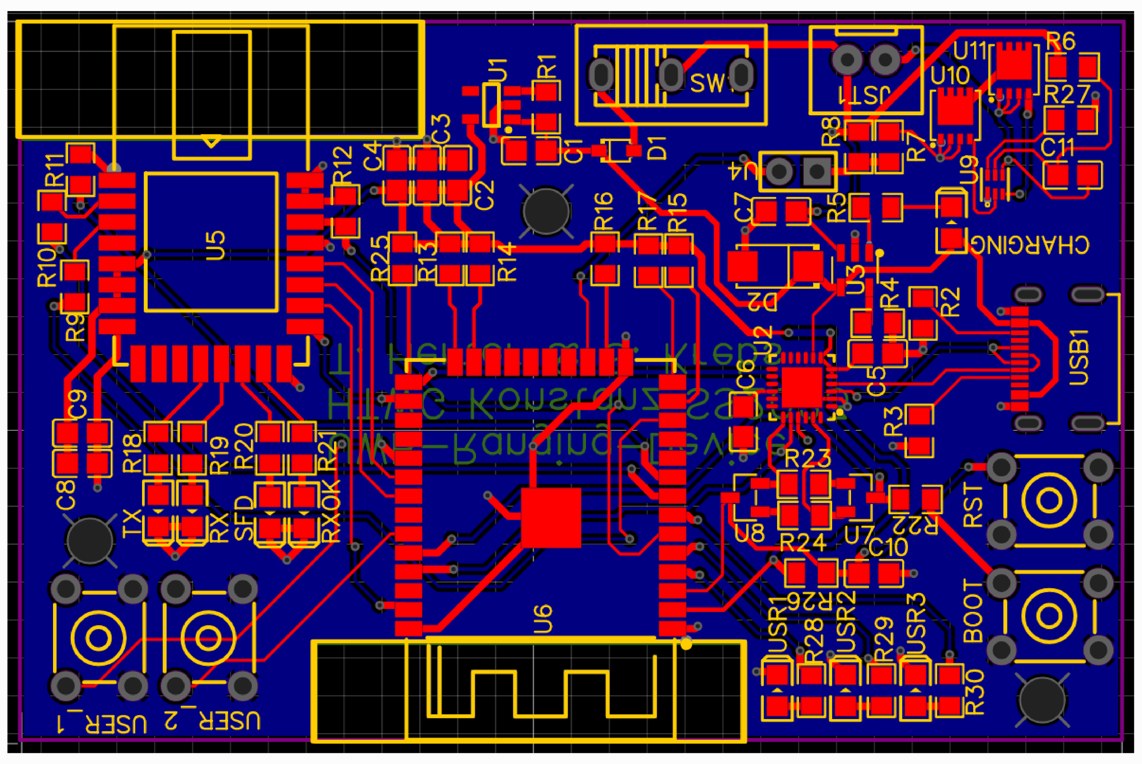

Figure 2. PCB-Design for UWB Device

Notably, our PCB design ensures a consistent layout across all boards, regardless of their specific application. Below the antennas of both the DWM3000 and ESP32, the ground plate has been selectively omitted to enhance antenna radiation characteristics and enable more precise measurements. This meticulous hardware design approach not only optimizes performance but also prioritizes user convenience.

Two-way-Ranging (TWR)

Two-Way Ranging (TWR) is our foundational technique for obtaining precise distance measurements within the UWB positioning system. It relies on the time it takes for signals to travel from a Tag board to Anchor boards and back again.

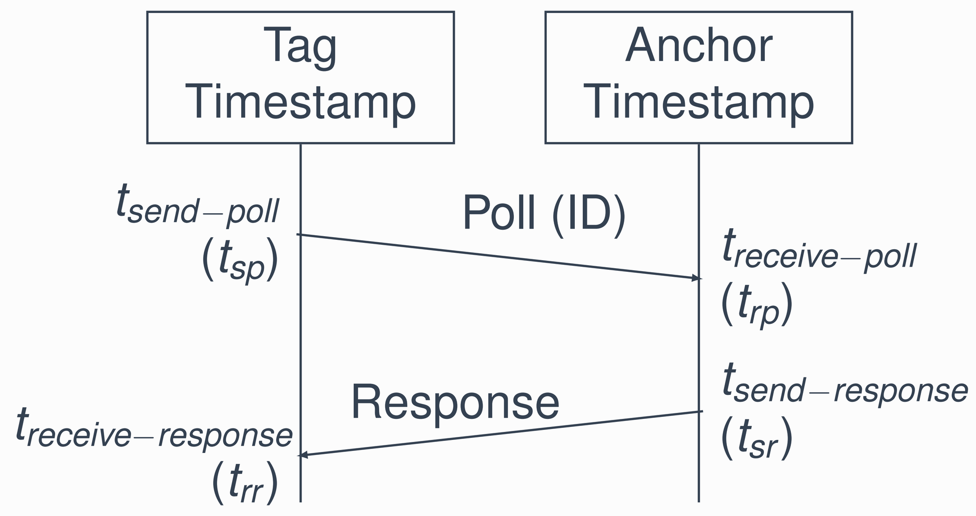

Figure 3. Timingdiagram of Two-Way-Ranging

Given the timestamps the Tag is able to calculate the corresponding time-of-flight aswell as the distance between both devices by using the following Formula:

$$t_{tof} = \frac{(t_{rp} - t_{sp}) + (t_{rr} - t_{sr})}{2}$$
$$dist = t_{tof} * v_{light}$$
$$v_{light} \approxeq 299.792.458,0\frac{m}{s}$$

Using this technique the standarddeviation of die distance estimation is approximatly between 4cm to 10cm, depending on the conditions of measurement. The estimation error increases significantly if there is a non-line-of-sight condition.

Firmware

The Firmware [3] for both the Tags and Anchors shares a common codebase with only a minor distinction during device startup. Upon booting, the current role of the device is read from the EEPROM, and based on this role, the appropriate tasks are executed.

The development of firmware built on FreeRTOS[1] offers the capability to seemingly execute multiple tasks in parallel. Leveraging the dual cores of the ESP32 microcontroller allows us to genuinely achieve parallelism.

The versatility of FreeRTOS enables the design of firmware that seamlessly adapts to the requirements of both Tags and Anchors. This design approach ensures efficient resource utilization and effective task management, ultimately contributing to the system's overall performance.

Firmware Tasks:

- **TOF-Task**: used for executing UWB measurements, eather as Initator or as Responder.
- **EKF-Task**: combines Distance measurements and creates a position estimation.
- **BLE-Task**: opens up a Bluetooth server which serves as configuration and feedback interface.

Extended-Kalman-Filter

The Kalman filter primarily consists of three steps. First, the state for the next timeiteration is predicted based on the current estimated state. Next, a measurement is predicted based on the predicted state. Finally, the actual measurement is compared to the predicted measurement, and the state estimation is corrected based on the estimation error. This process leads to the convergence of the estimation towards the ground truth.[4]

The following blockdiagram shows how the different steps interact to generate a state estimation based on the current measurement.

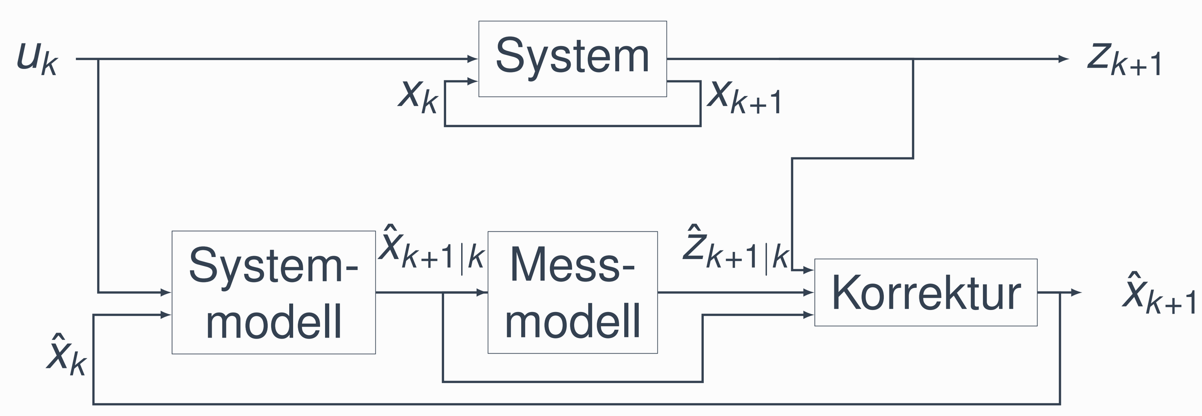

Figure 4. Blockschaltbild des Kalman Filters

In this context, u_k represents control commands that input into the system. z_k describes the observed measurement at time k, and x represents the current system state. In the case of our application, x contains the three-dimensional coordinates of the tag, and the vector z encompasses all distance measurements to the landmarks, which are the anchors. Every time a variable is marked with a hat, that means that this is an estimation of the given variable.

Tests

Ground-Truth	**mean**	**standarddeviation**
(x, y, z)	$mean(x, y, z)$	$std(x, y, z)$
(a, b, c)	(a, b, c)	(a, b, c)
(a, b, c)	(a, b, c)	(a, b, c)
(a, b, c)	(a, b, c)	(a, b, c)
(a, b, c)	(a, b, c)	(a, b, c)

Table 1. Presentation of Testresults

References

[1] FreeRTOS Homepage. https://www.freertos.org/index.html, Aug 2023.

[2] Makerfabs Homepage. https://www.makerfabs.com/esp32-uwb-dw3000.html, 2023.

[3] S. Krebs and T. Herter. uwb-tracking. https://github.com/krebsbstn/uwb-tracking, 2023.

[4] Qiang Li, Ranyang Li, Kaifan Ji, and Wei Dai. Kalman filter and its application. In *2015 8th International Conference on Intelligent Networks and Intelligent Systems (ICINIS)*, pages 74–77, 2015.

sourcecode: SCAN ME

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