Indoor 2D Tracker Based on UWB with Kalman Filtering.

Project Work.

Motivation

GPS is not precise to cm level [1].

High signal interference with GPS [2].

GPS & Bluetooth consume high power [3].

GPS requires LOS [1].

Ultrawide-band (UWB)

- Short-range radio communication [4].
- Wide Bandwidth [5].
- Transmits high levels of signal energy [5].
- Causes no interference [5].

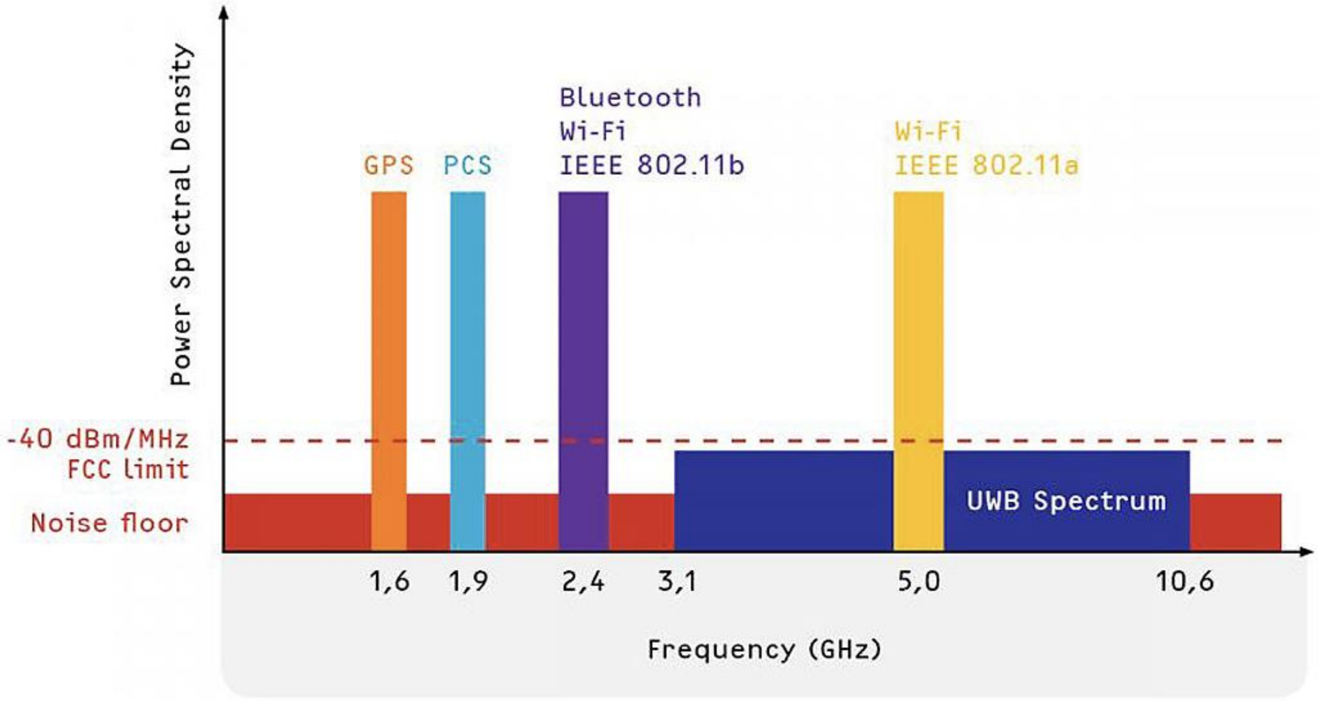


Fig. 1: Frequency spectrum [5].

Conclusions from previous works:

- Better accuracy under LOS condition (±0.36 m) over NLOS (±0.93 m) [6].
- No synchronization is necessary for Two-way Ranging [7].
- Consistent height level between tag and anchors is imminent [8].
- Kalman filter with Moving Average (MA) filter [9].

Use Case Diagram

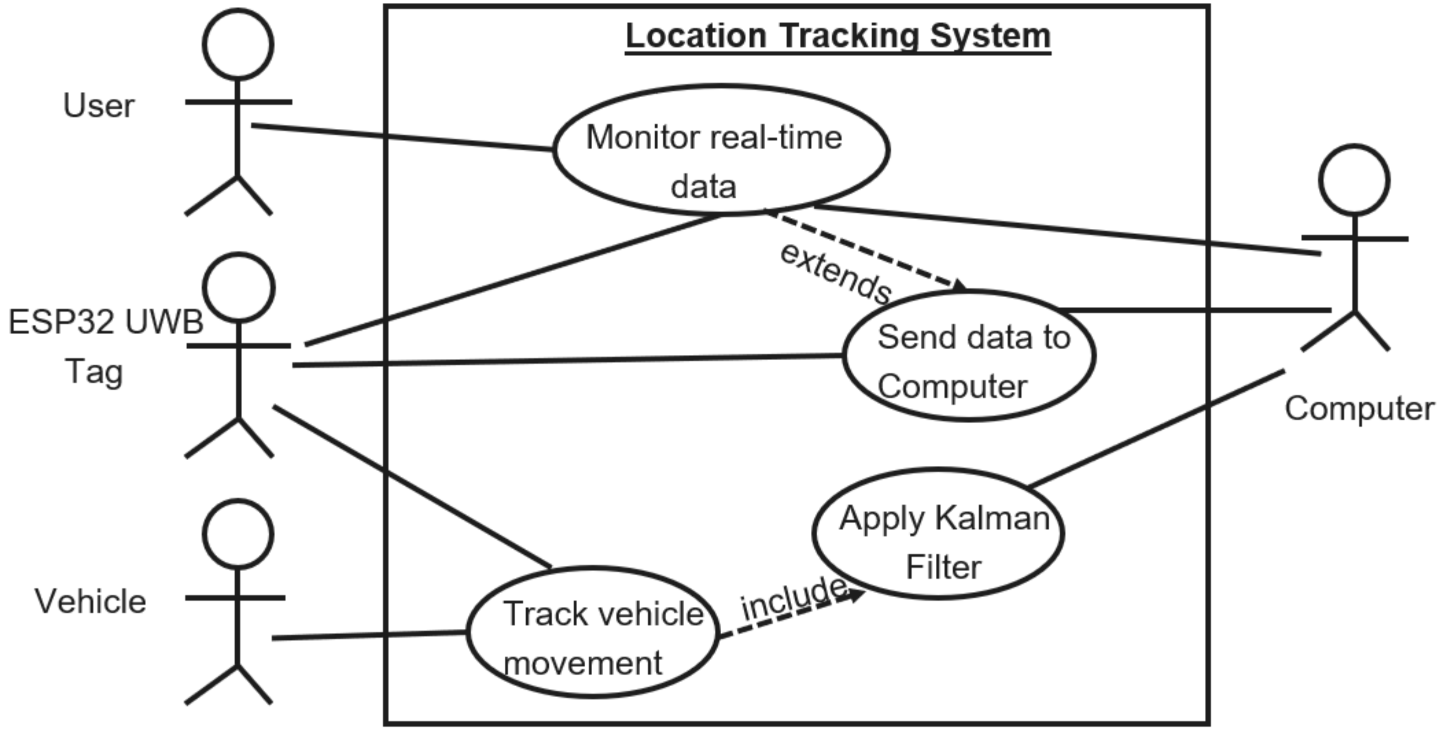


Fig. 2: Use case diagram for the Project.

Requirement Diagram

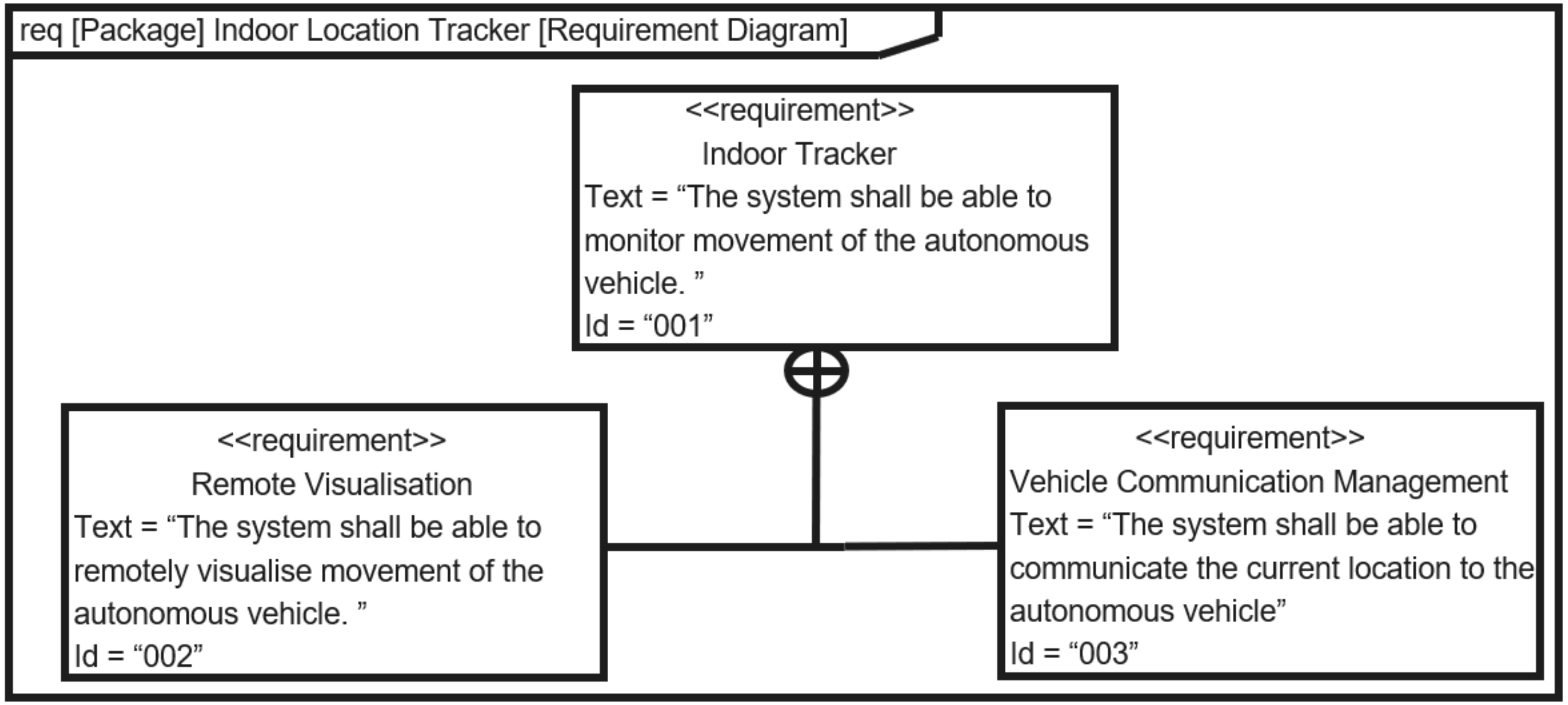


Fig. 3: Requirement diagram for the project.

Two-way Ranging (TWR)

- Circular positioning method [10].
- Common time base not required [6].
- Distance calculated using stored timestamps [10].

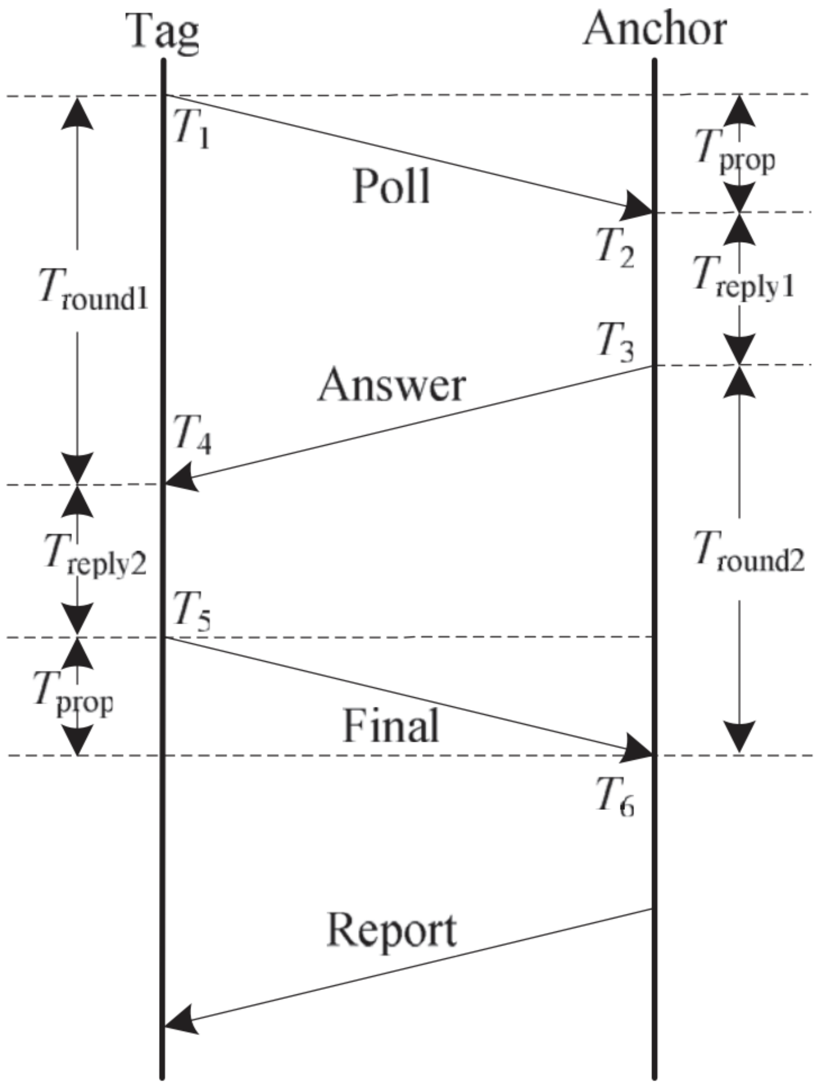


Fig. 4: DS-TWR Concept [6].

Triangulation

- **Anchors**: A and B.
- **Tag**: C.
- **Known distance**: c.
- **Calculated distance**: a and b.
- **Origin (0,0)** : A
- **X coordinate of C**: b cos α .
- **Y coordinate of C**: b sin α .

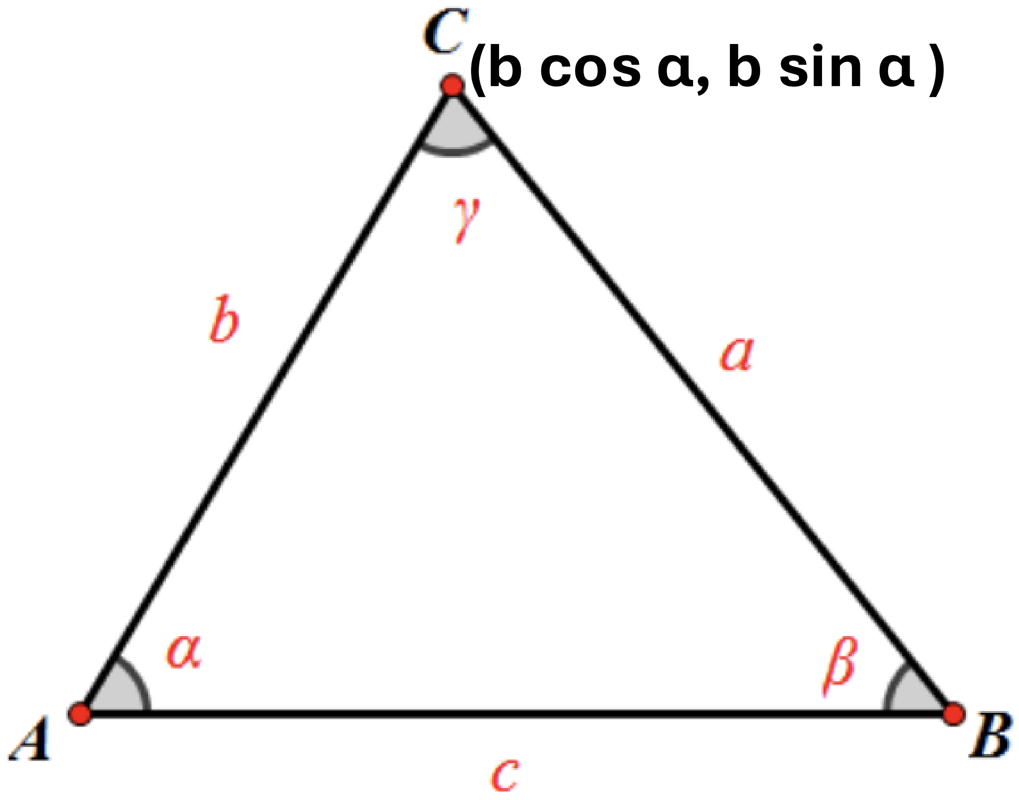


Fig. 5: Triangle with all known sides[11].

Kalman Filter

- Reduces measurement noise [5].
- Ideal for real-time problems [12] .
- Fast & light on memory [12].

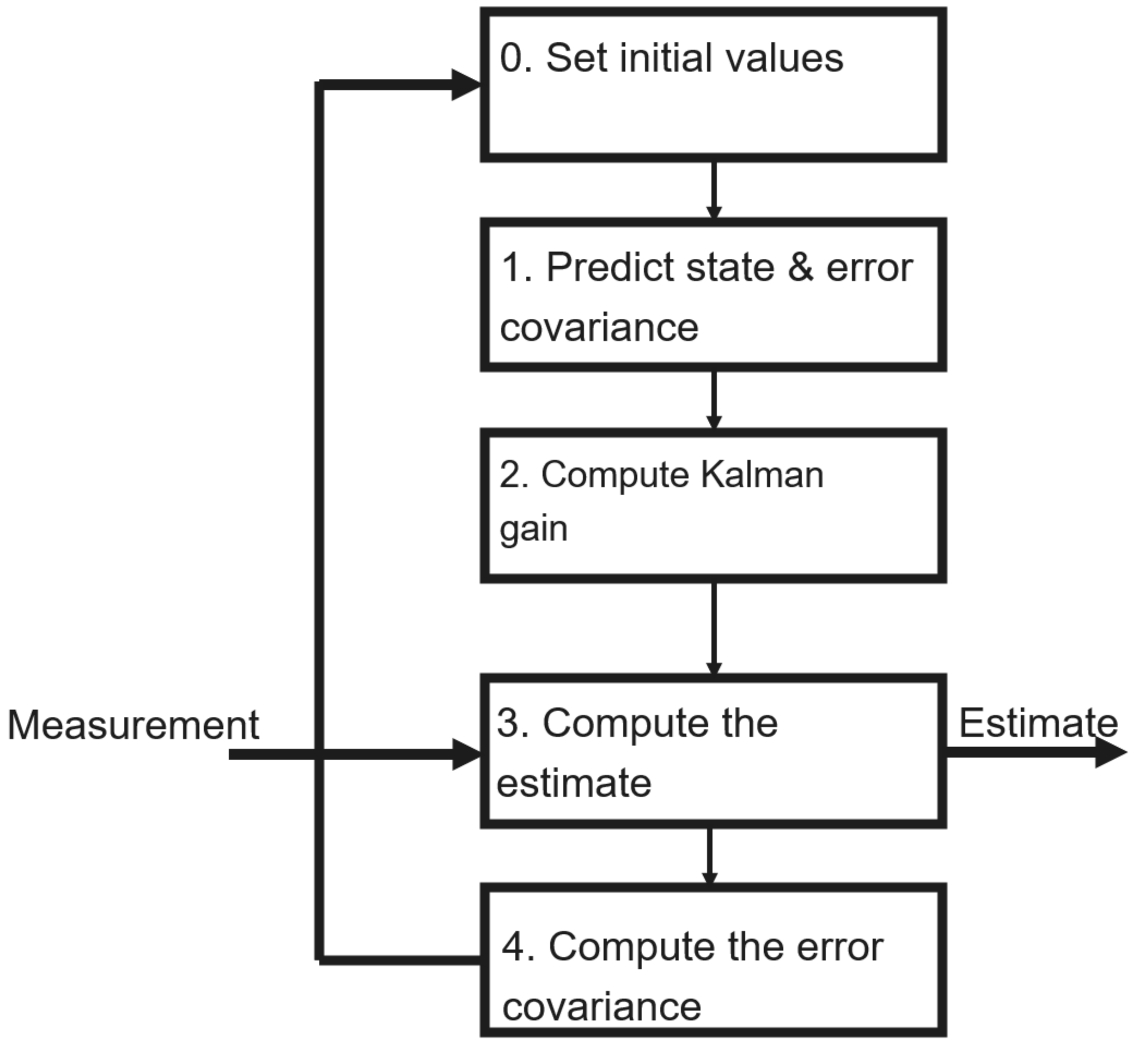


Fig. 6: Kalman Filter

Hardwares

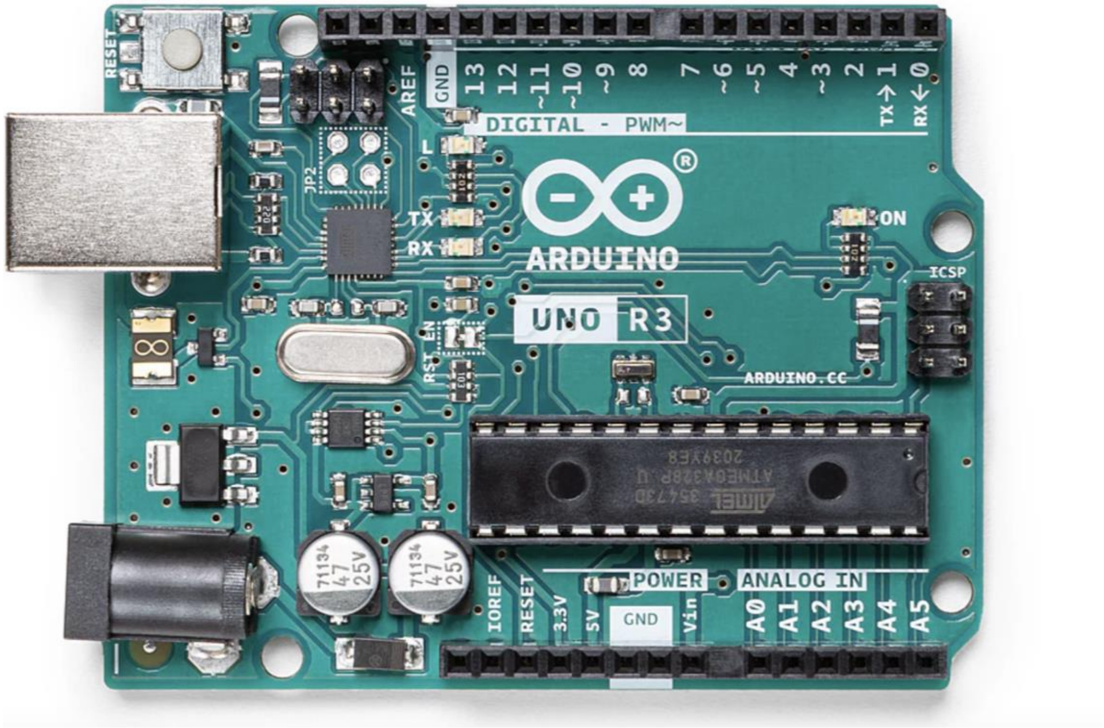


Fig. 7: Arduino Uno [13]

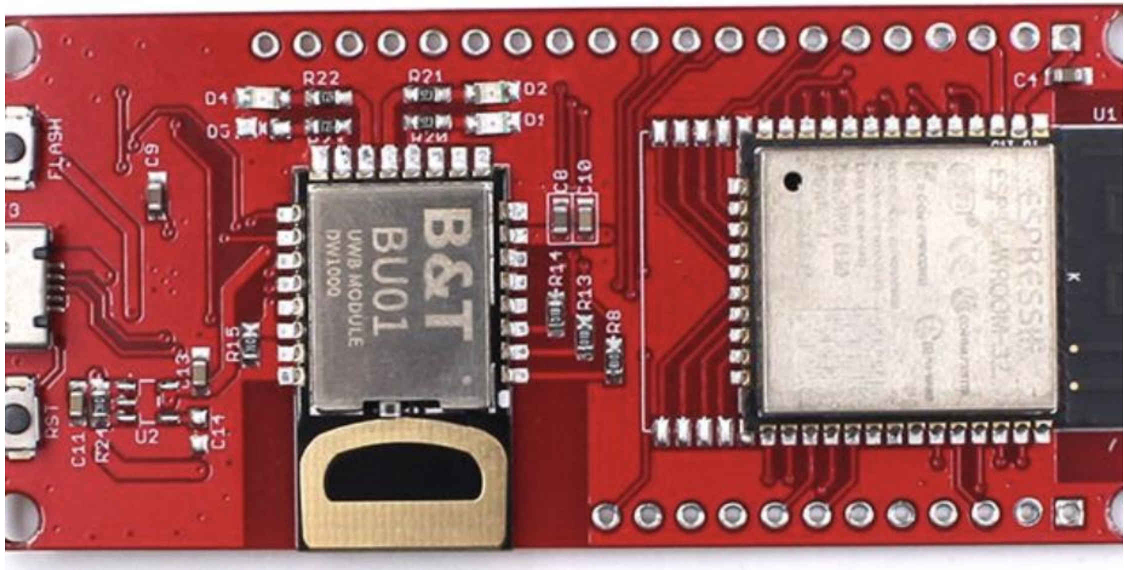


Fig. 8: Makerfabs ESP32UWB [14]

Activity Diagram

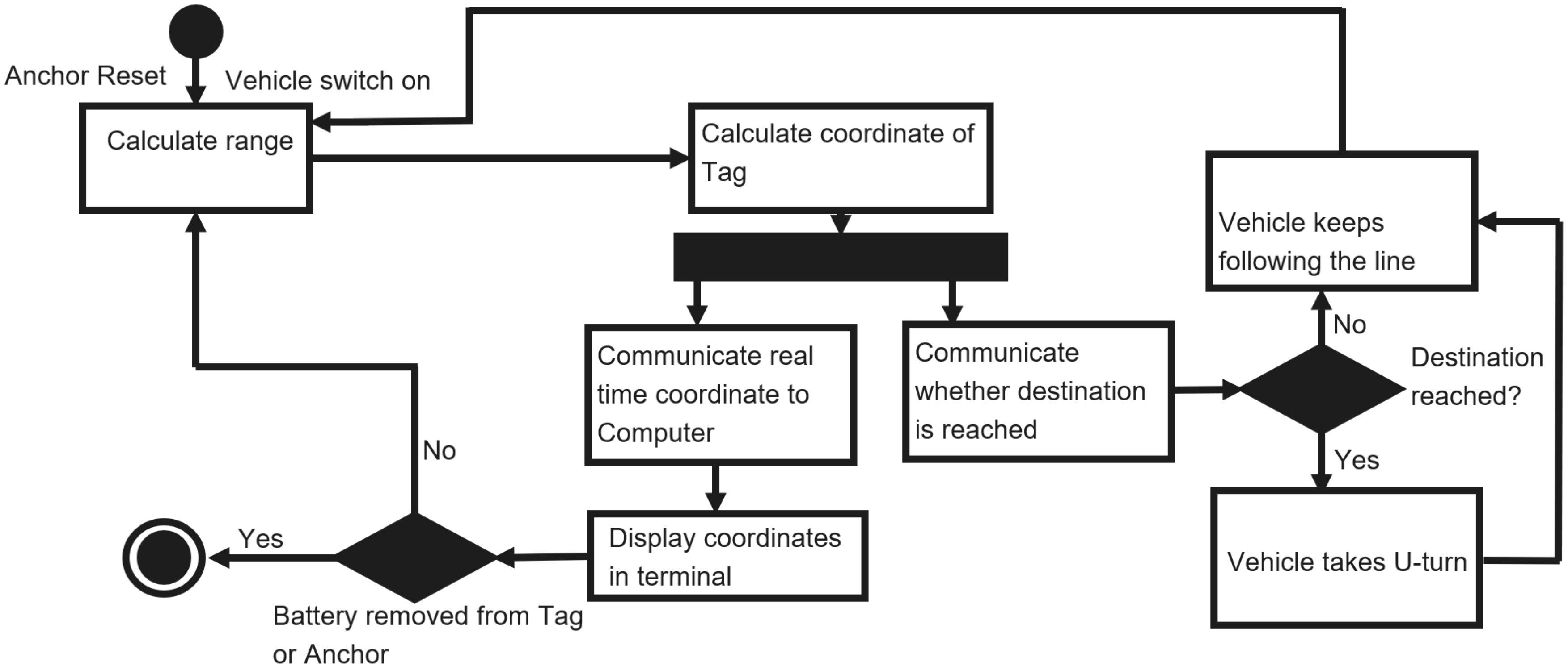


Fig. 9: Activity Diagram for the Project

The Planned Set-up

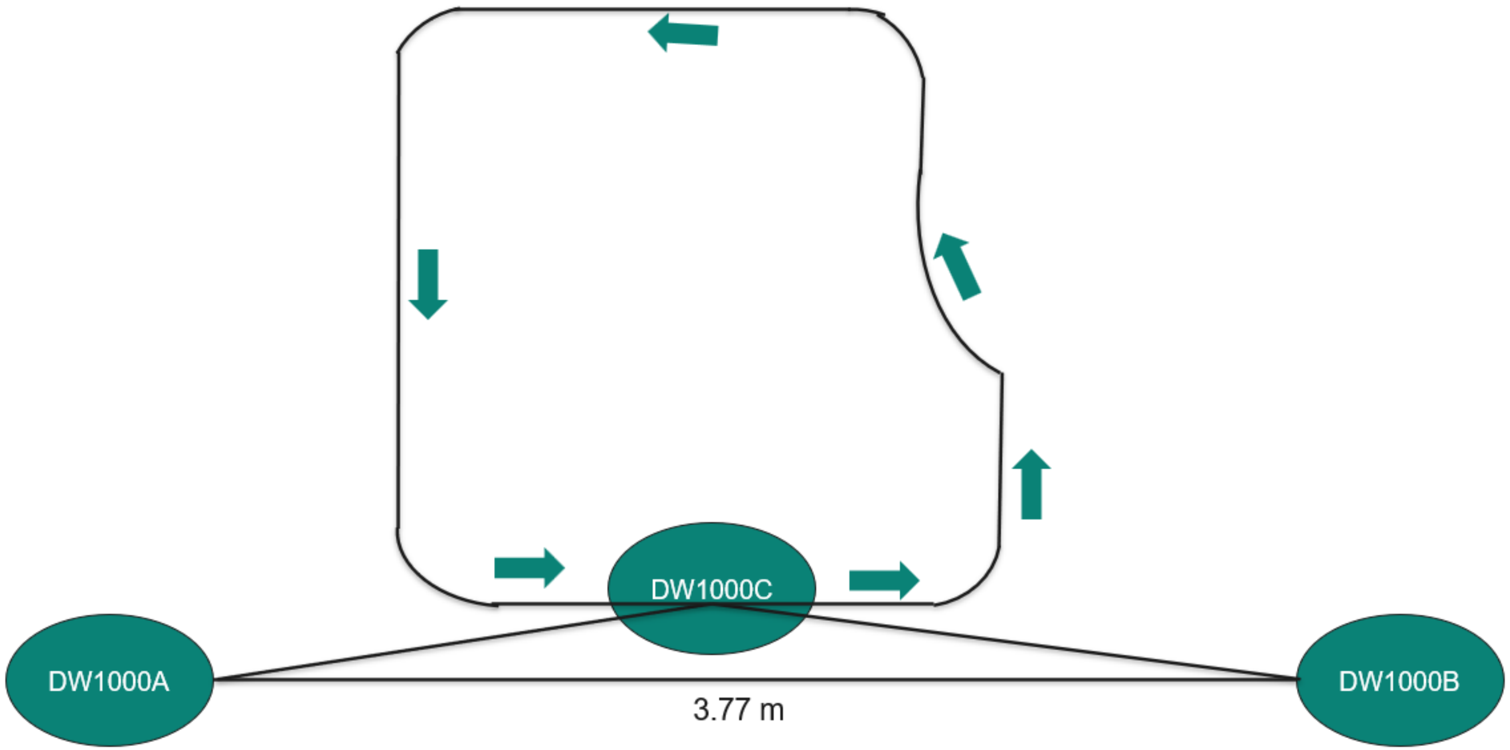


Fig. 10: 2D Setup

Fig. 11: Vehicle moving on a track

The Scene

Tag

The Set-up

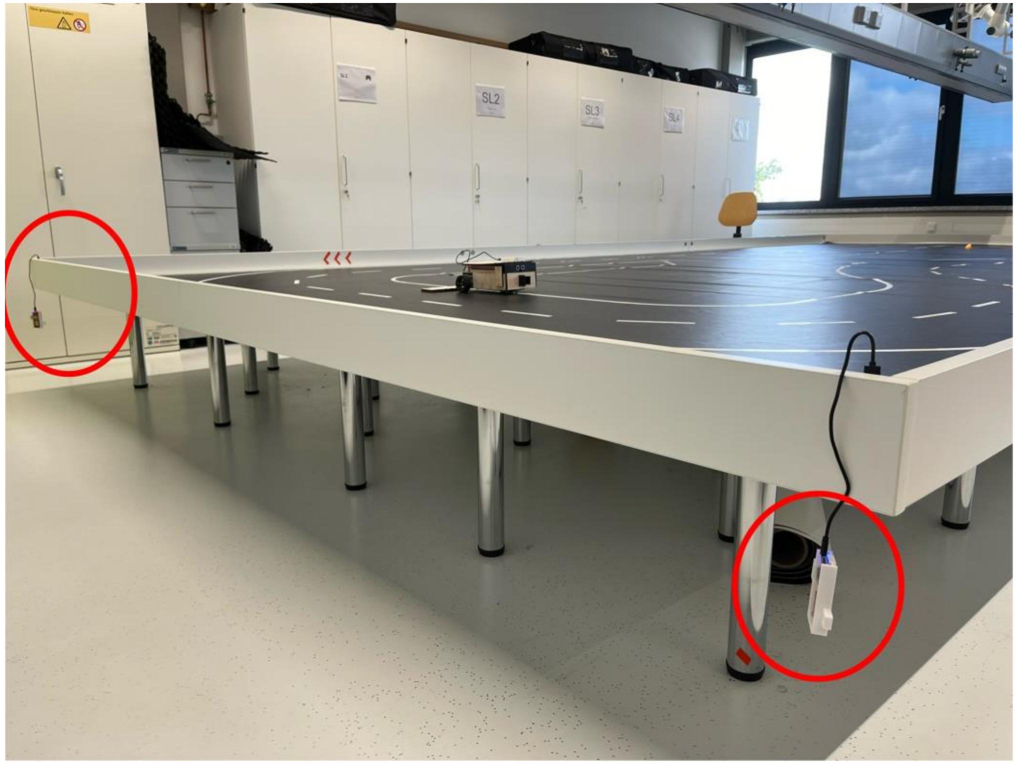


Fig. 12: NLOS

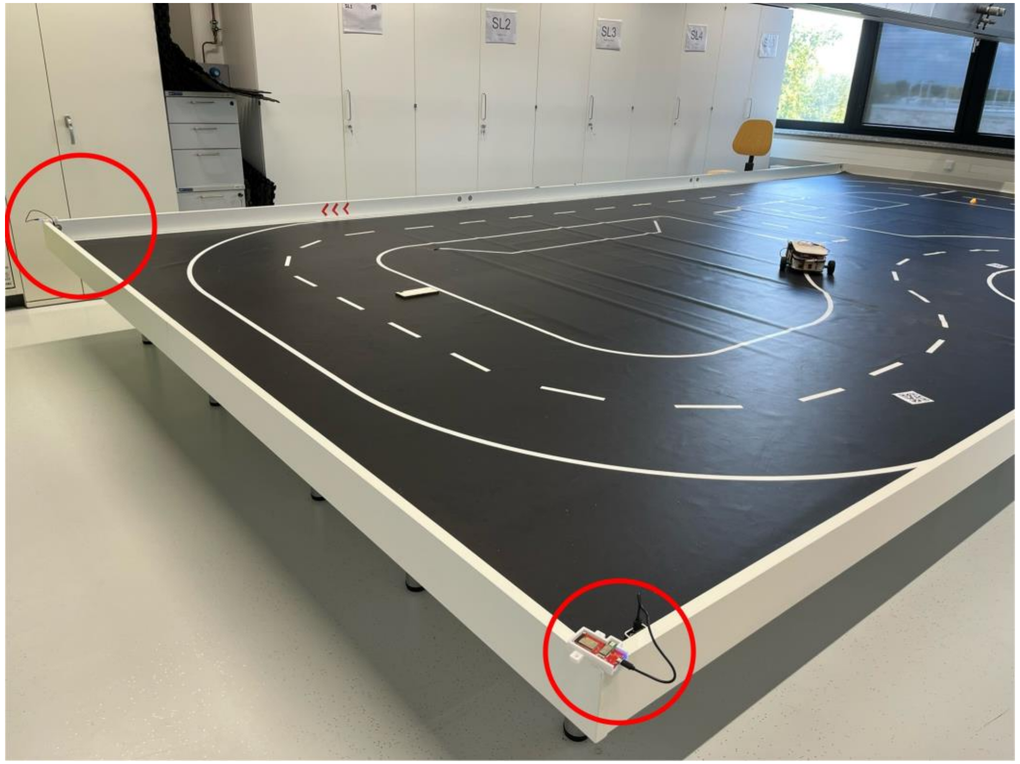


Fig. 13: LOS

Threshold Algorithm

```
if (AtoC > 0 && BtoC > 0) {
  calculateCoordinate(AtoC, BtoC);  // Calculate x and y
  if ((abs(x - prev_x) <= 0.8) && (abs(y - prev_y) <= 0.8)) {
    prev_x = x;
    prev_y = y;
    String message = "Coordinates: x = " + String(x, 2) + ", y = " + String(y, 2) + "\n";
```

Fig. 14: Threshold algorithm to reduce spikes.

I/O Communication

```
if ((x >= 1.8 && x <= 2.5) && (y >= 3.4)) {
  digitalWrite(12, HIGH);
  delay(10);
}
digitalWrite(12, LOW);
}
```

Fig. 16: ESP32 passing the message to Arduino

Arduino with ESP32

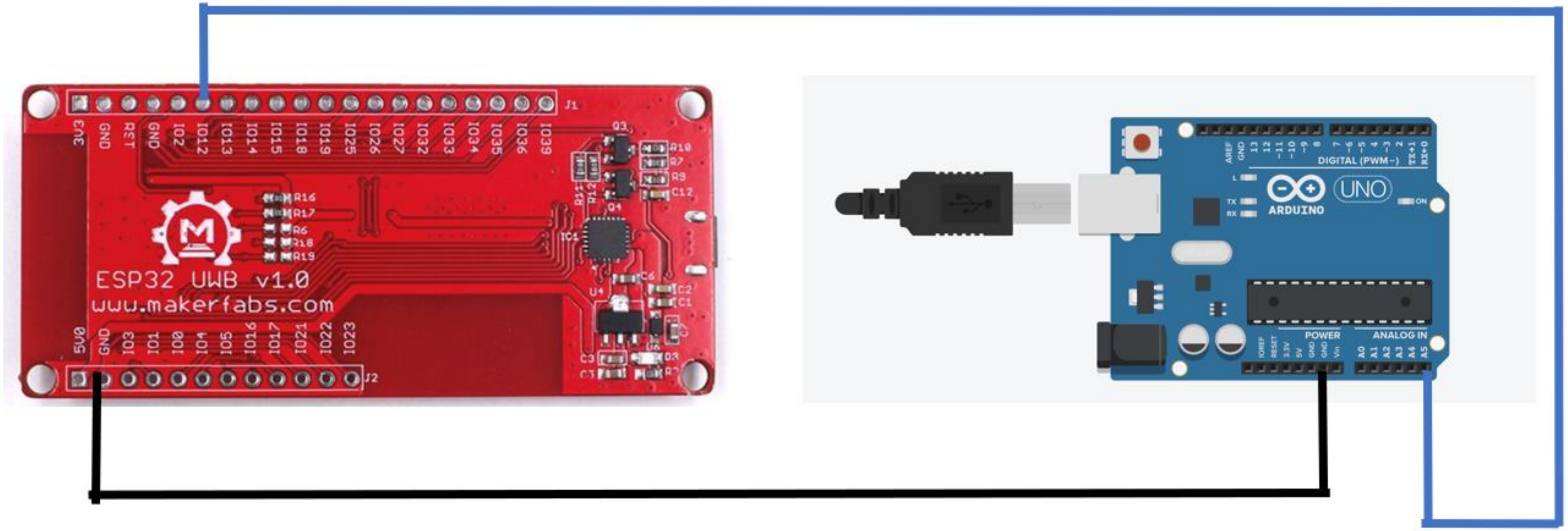


Fig. 15: I/O connection between ESP32 & Arduino Uno

Evaluation

Case: Stationary

- Preciseness of approx. 2 cm.

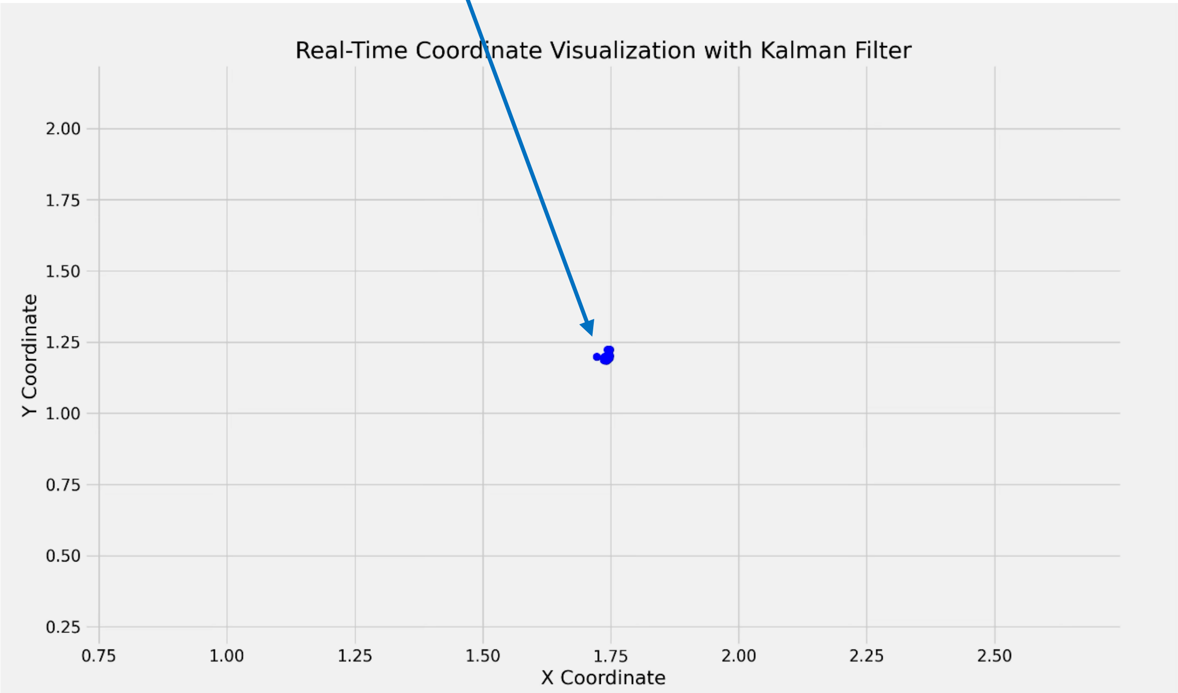


Fig. 18: LOS

- Preciseness of approx. 10 cm.

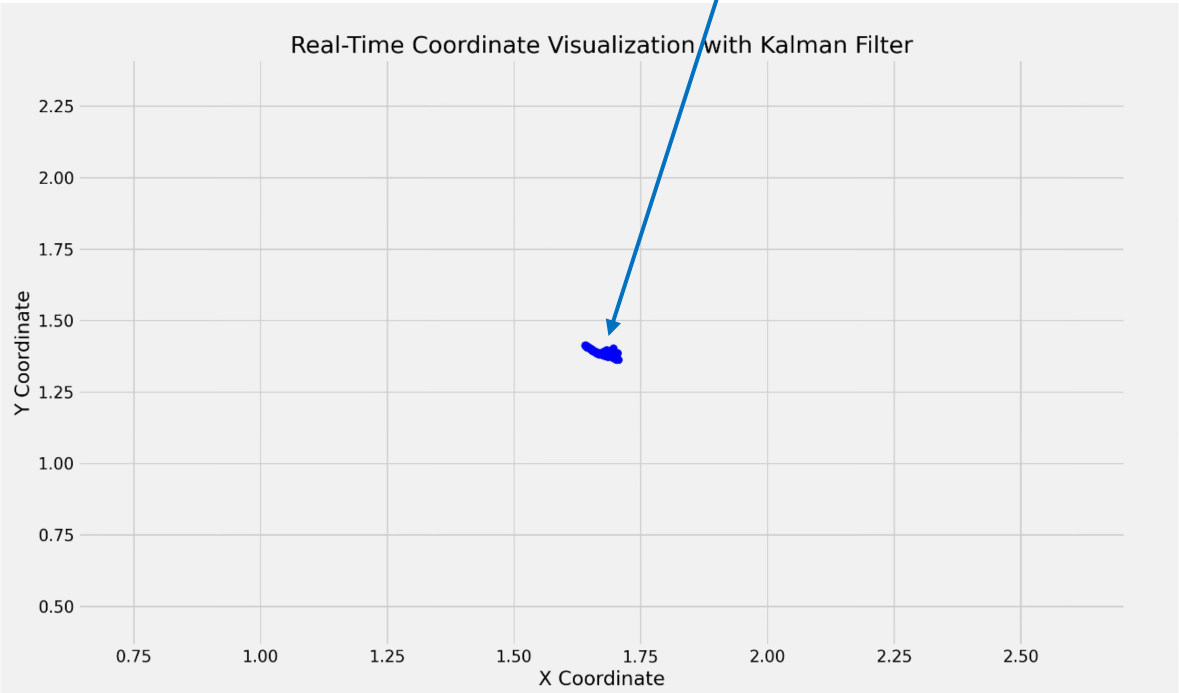


Fig. 19: NLOS

Evaluation

- Fewer spikes.

Case: Moving

- Too many spikes in NLOS.

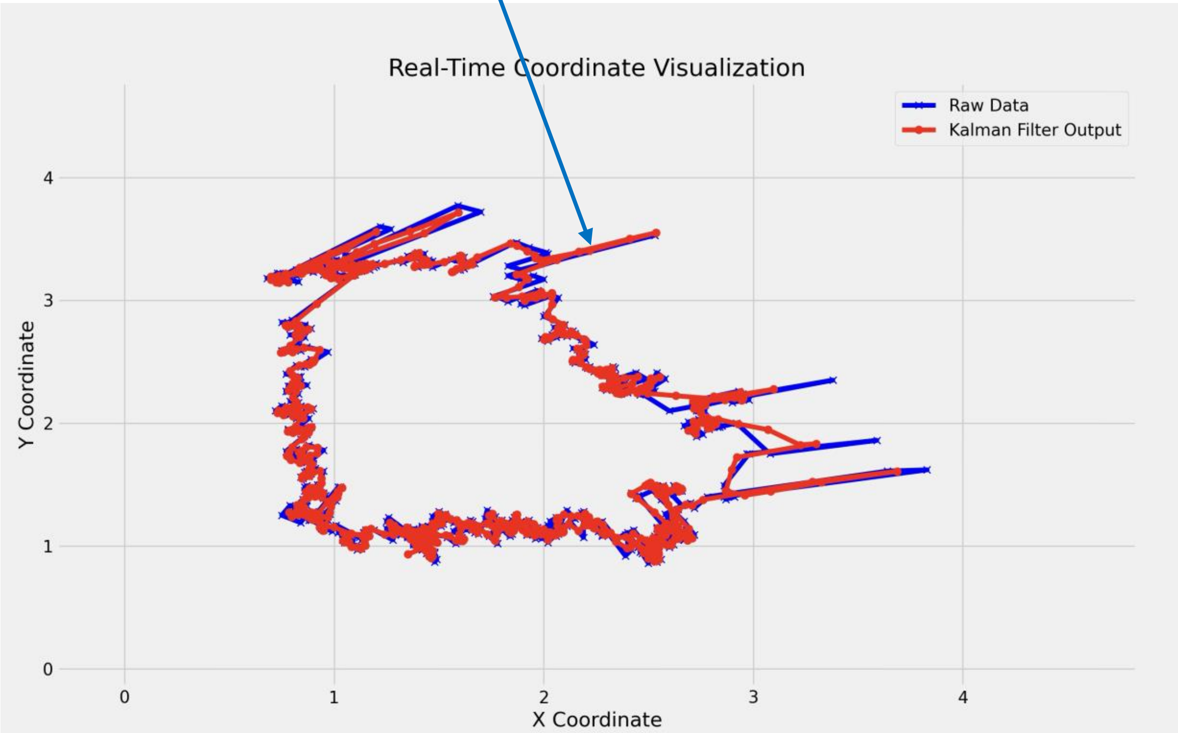


Fig. 20:

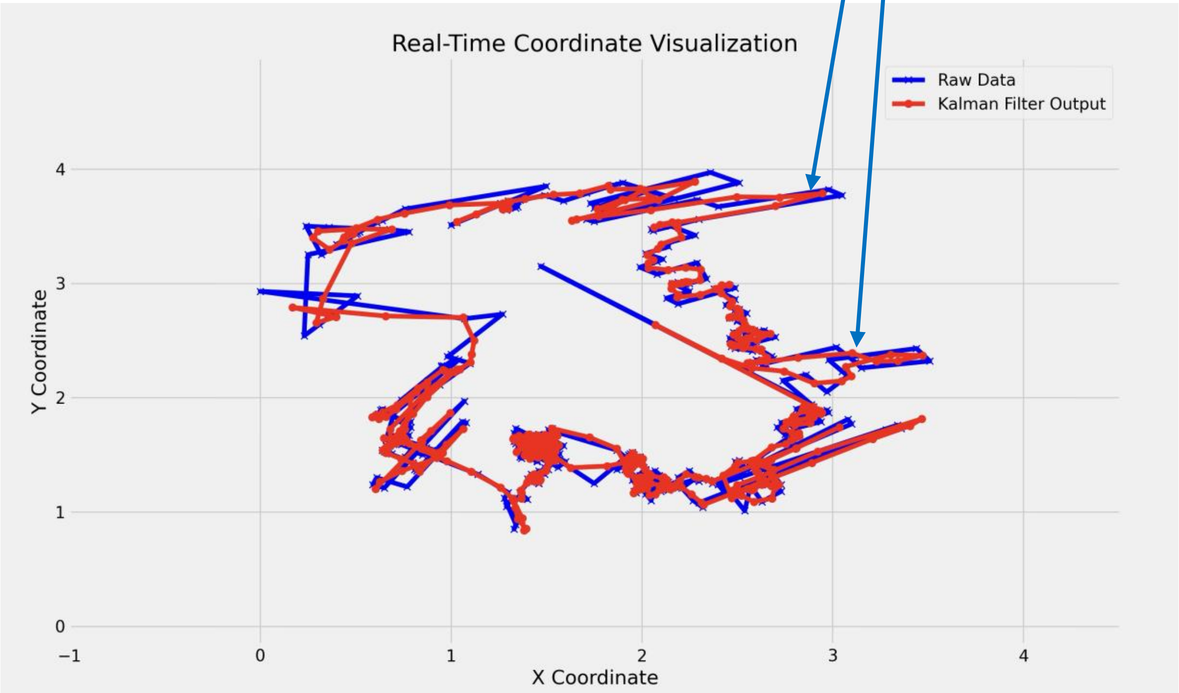


Fig. 21:

Evaluation

Case: Kalman Filter + Threshold Algorithm

- Vehicle U-turned at $1.8 < x < 2.5$ & $y > 3.4$

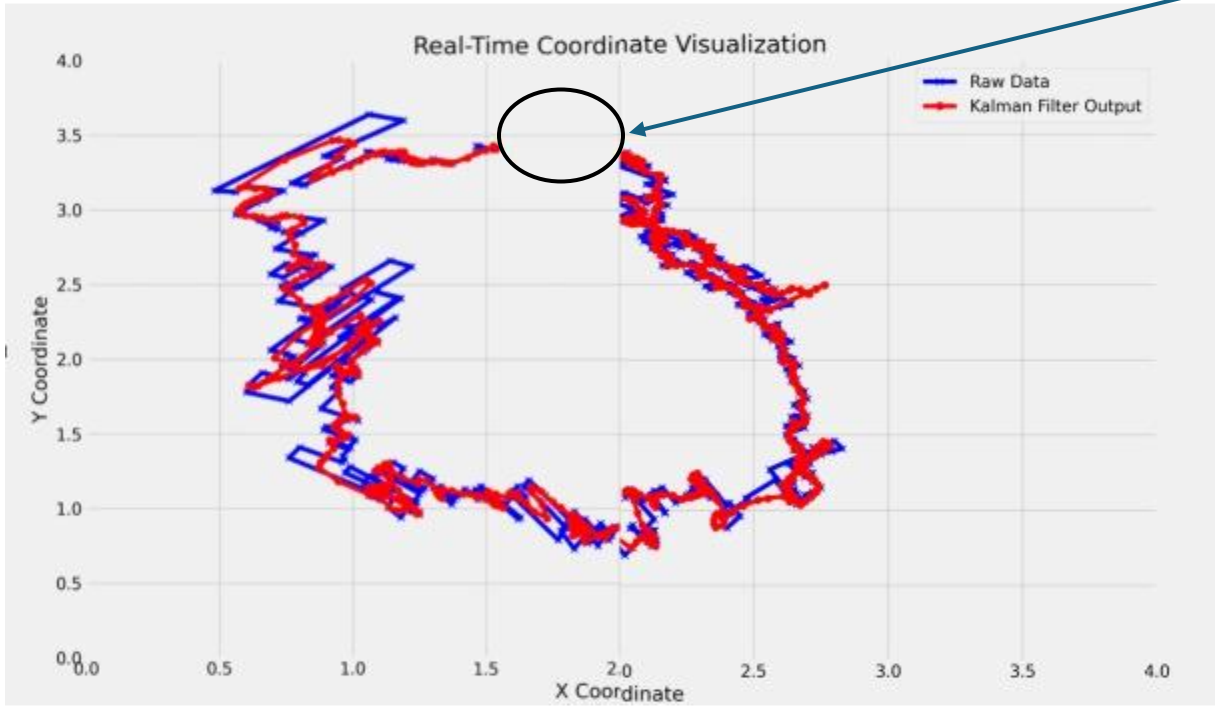


Fig. 22: Real-time plot with final implementation

Final Implementation

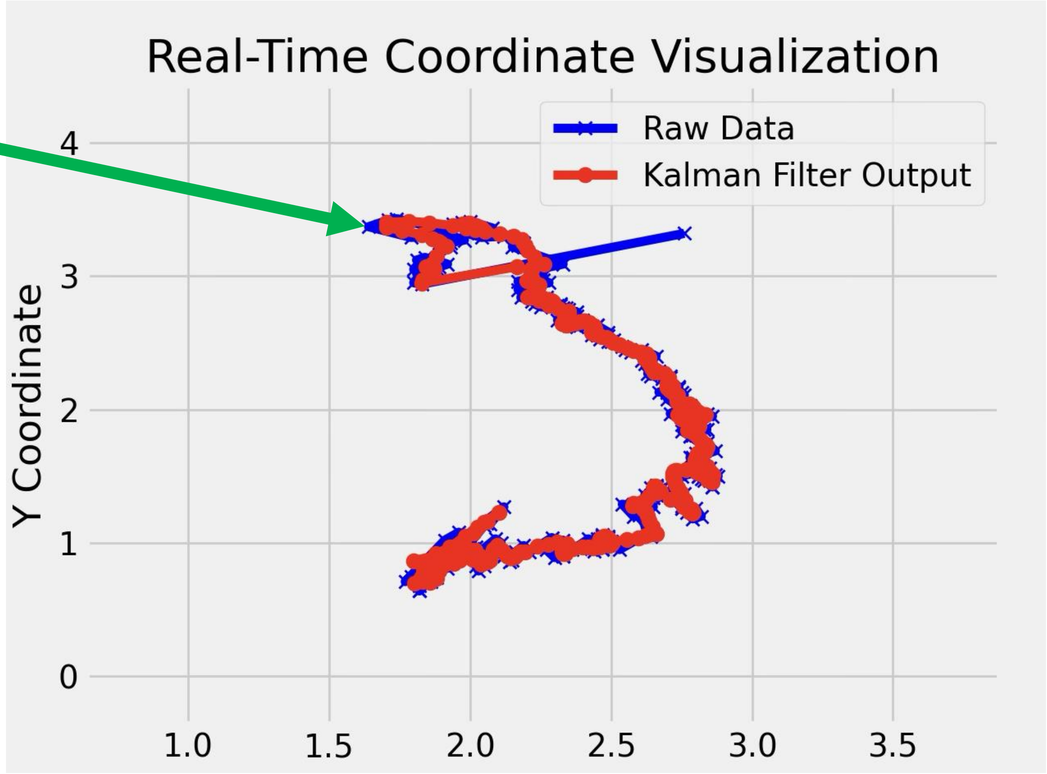
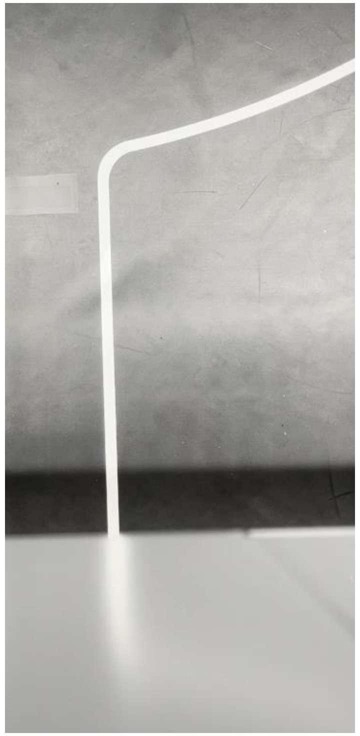
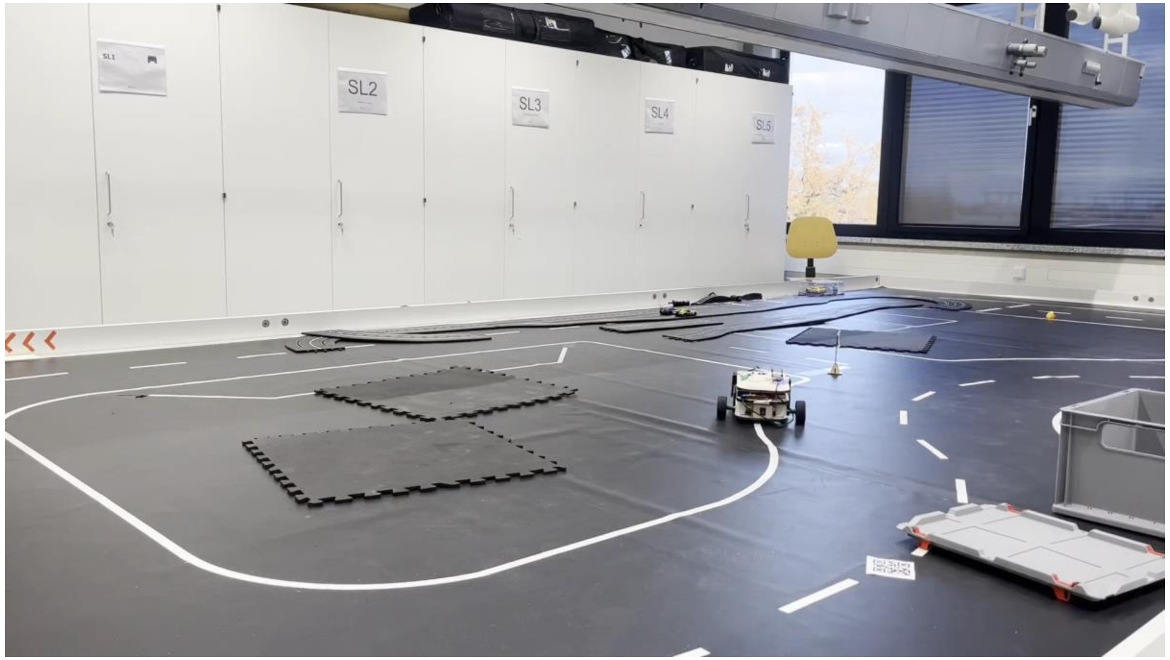


Fig. 23: Plot to display car taking U-turn.

Practical Verification (Part 1)

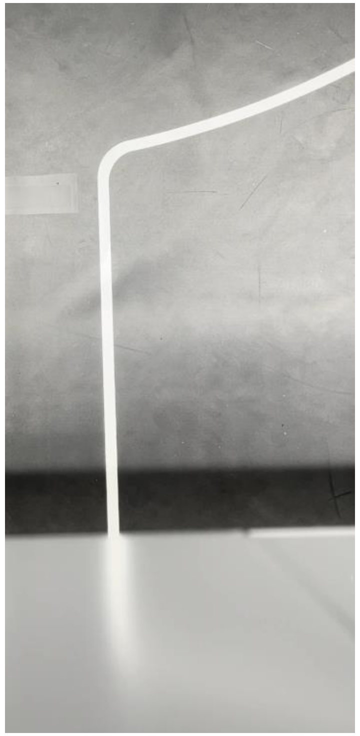
- **<u>Zone</u>**: $1.8 \le \mathbf{x} \le 2.5$ and $\mathbf{y} \ge 3.4$





Practical Verification (Part 2)

- <u>**Zone**</u>: $1.8 \le \mathbf{x} \le 2.5$ and $\mathbf{y} \ge 3.4$



Overview

Higher preciseness in LOS conditions

More spikes seen in NLOS condition.

Kalman Filter reduces noise but not spikes

Threshold Filter reduces spikes

Preciseness of 10-20 cm while moving.

Future Work

- Extension to 3-D plane (z-axis).
- Extended Kalman Filter.
- Real-time coordinate-based instructions.
- Another tag as an indicator of a U-turn zone.

References

- [1] Melanie Deputter, "UWB versus other tracking technologies ," pozyx [Online] Feb 27, 2024. Available: https://www.pozyx.io/newsroom/uwb-versus-other-technologies [Accessed Dec 11, 2024].
- [2] RF Wireless World, UWB vs GPS | Difference between UWB and GPS, RF Wireless World [Online]. Available: https://www.rfwireless-world.com [Accessed Dec 11, 2024].
- [3] Chipolo, "Bluetooth vs GPS vs UWB - A short guide," Chipolo. Available: https://chipolo.net/en/blogs/bluetooth-vs-gps-vs-uwb-a-short-guide [Accessed Dec 11, 2024].
- [4] Stephan Sand, Armin Dammann, and Christian Mensing. Positioning in Wireless Systems, pages 189–192. Springer, 2014.
- [5] Youssef Ibnatta, Mohammed Khaldoun, and Mohammed Sadik. Indoor localization techniques based on uwb technology. In Halima Elbiaze, Essaid Sabir, Francisco Falcone, Mohamed Sadik, Samson Lasaulce, and Jalel Ben Othman, editors, Ubiquitous Networking, pages 3–15, Cham, 2021. Springer International Publishing.
- [6] Simon Tewes, Ludwig Schwoerer, and Patrick Bosselmann. Designing a basic ir-uwb-rtls - raw-data position estimation utilizing twr. In Smart SysTech 2017; European Conference on Smart Objects, Systems and Technologies, pages 1–5, 2017.
- [7] Matteo Ridolfi, Samuel Van de Velde, Heidi Steendam, and Eli De Poorter. Analysis of the scalability of uwb indoor localization solutions for high user densities. Sensors, 18(6), 2018.
- [8] Boyang Sun, Yanfeng Xia, Xiaofeng Wang, You Zhang, Ruanming Huang, Shuhan Wang, and Aimin Tang. A reliable and efficient uwb-based indoor localization scheme. In 2023 IEEE 15th International Conference on Advanced Infocomm Technology (ICAIT), pages 186–191, 2023
- [9] Nuradlin Borhan, Izzati Saleh, Azan Yunus, Wan Rahiman, Dony No- valiendry, and Risfendra. Reducing uwb indoor localization error using the fusion of kalman filter with moving average filter. In 2023 IEEE International Conference on Automatic Control and Intelligent Systems (I2CACIS), pages 55–59, 2023.
- [10] Yu Songcan, Liu Yongxin, and Li Gen. Twice correction indoor positioning algorithm using ultra-wideband technology. In 2019 Chinese Automation Congress (CAC), pages 3748–3753, 2019.
- [11] Makerfabs, ESP32 UWB Indoor Postioning Test, Makerfabs [Online]. Available: https://www.makerfabs.cc/article/esp32-uwb-indoor-positioning-test.html [Accessed Dec 11,2024]
- [12] Jing Wang, Yao Tang, José-María Muñoz-Ferreras, Roberto Gómez-García, and Changzhi Li. An improved indoor localization solution using a hybrid uwb-doppler system with kalman filter. In 2018 IEEE Radio and Wireless Symposium (RWS), pages 181–183, 2018.
- [13] “Uno R3,” Arduino,[Online].Available:https://docs.arduino.cc/hardware/uno-rev3/. [Accessed Dec 11, 2024].
- [14] “ESP32 UWB (Ultra Wideband),” Makerfabs, [Online].Available: https://www.makerfabs.com/esp32-uwb-ultra-wideband.html . [Accessed Dec 11, 2024].