Project Report

Commissioning and Testing of a UWB-based positioning system for mini-drones

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Project overview

Project description

This project aims to set up a Crazyflie (CF) drone with the Loco positioning system to enable autonomous flight. The precision and accuracy of this system is compared with the Optitrack motion-capturing positioning system.

The Loco Positioning System operates through Ultra-Wide-Band (UWB) technology. Anchors positioned within the environment communicate with the Crazyflie, determining the distances between them. For this setup, eight anchors are used.

In contrast, the Optitrack system relies on infrared cameras to track a passive marker fixed to the Crazyflie. For that project, seven cameras are deployed.

To ensure synchronization between the Loco and Optitrack Coordination systems, precise measurements of the loco anchors' positions are taken using the Optitrack system already in use. Subsequently, a series of test flights is conducted, while position data from both systems is compared.

This data gives information on how accurately the Loco system can work. This data can also improve accuracy by adding an appropriate offset to the system parameters.

Setup

This project uses several hardware and software parts. Setups for specific parts are listed below.

Hardware

- Host-PC (Crazyflie)
  Provides communication and control between user and crazyflie
- Host-PC (Optitrack)
  Provides the optitrack data

Crazyflie

- Crazyflie, v2.1
  Small drone, which is used in the project. It weighs 27g and it's dimensions are (92mm x 92mm x 29mm)
- loco_positioning_deck
  expansion deck, mounted on the drone to enable communication between anchors and Crazyflie

Figure 1: Loco anchor

- marker_deck with one passive marker
  expansion deck, mounted on the drone, to enable localization by Optitrack
- crazy_radio antenna
  enables wireless communication between host-pc and crazyflie

Positioning hardware

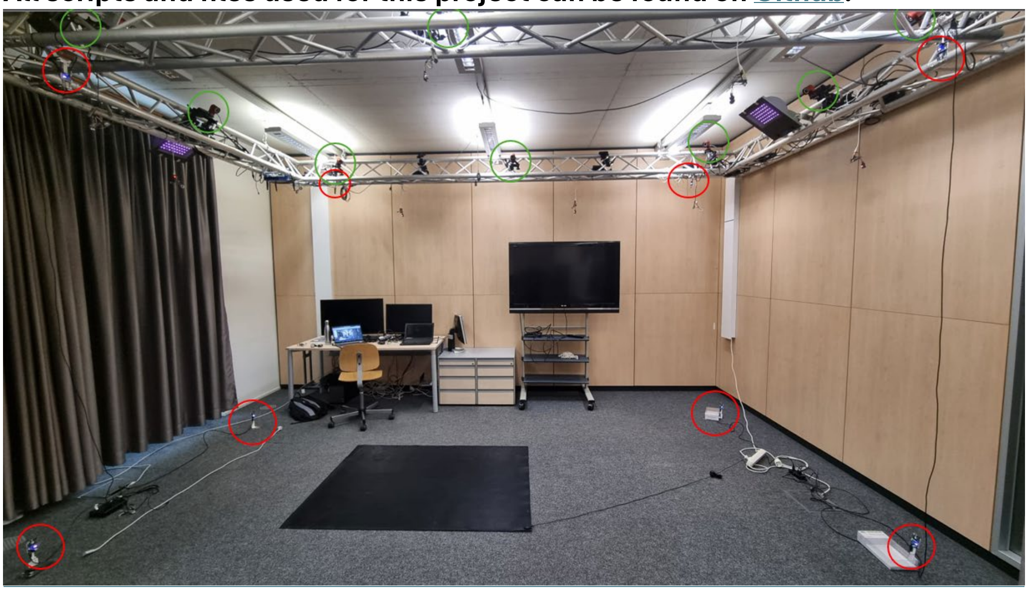
- Optitrack, a total of seven infrared cameras
  these cameras are connected to a Host-PC and can track the drone via the marker on the drone, they are located on the aluminum mount.
- Loco positioning anchor, a total of eight
- These anchors are placed in the corners of the flying area and are connected to a power source by USB

Software

- cfc client (Crazyflie)
  client to configure the position of the loco anchors
- LPS configuration tool (Loco)
  Tool, to flash the anchors and assign an ID
- Motive (Optitrack)
  Software to track, display and process the data gained from Optitrack
- Matlab (evaluation)
  Matlab was used mainly for data evaluation and for graphical representation of results
- Python (execution)
  Python is the language to control the CF via the cf_lib (open source)

Detailed documentation of Crazyflie setup and the Loco positioning system is available on bitcraze.io.
Documentation for setup and calibration of the Optitrack.

All scripts and files used for this project can be found on Github.



Flying area
4,5m x 2.5m x 3m

Loco anchors (red)

Optitrack cameras (green)

Figure 2:Setup

System overview

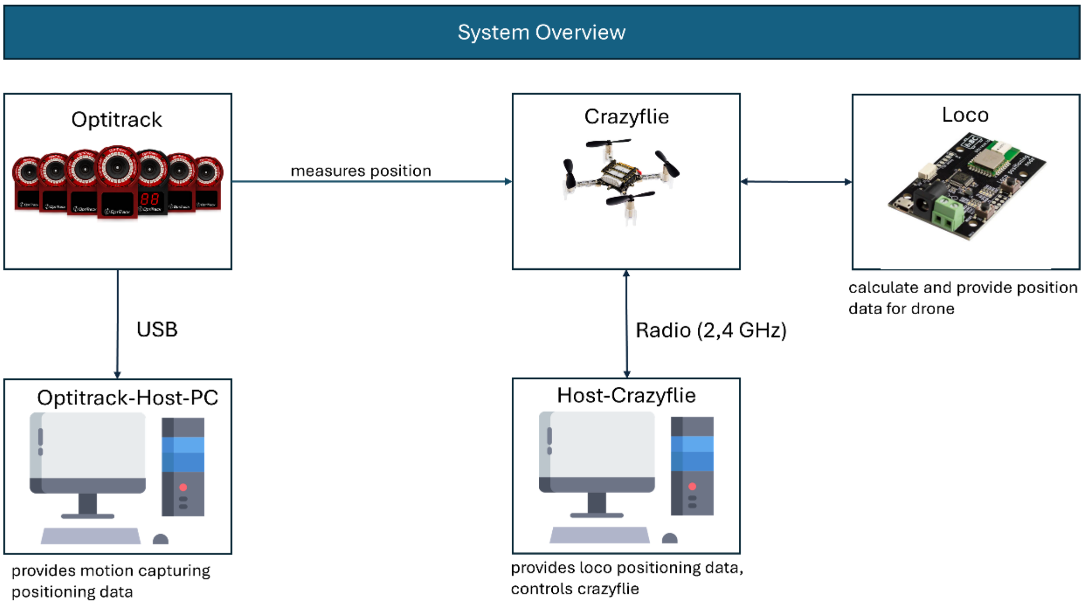


Figure 3: System Overview

Measurements

Two measurement parts are conducted to assess the accuracy of the loco system at varying heights. One dynamic measurement, where the drone flies at different heights autonomously, and a static measurement, where the drone rests. Statistical averages of the error were calculated and displayed.

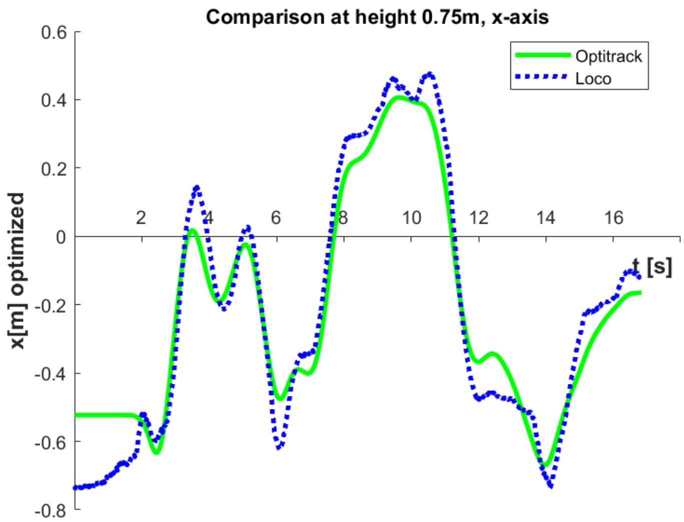
Square pattern test

The measurement focuses on executing a simple flight, moving to four points arranged in a square pattern at heights of 0.75 m, 1 m, and 1.5 m.

At first, every flight was evaluated separately. Synchronization between the datasets was achieved by minimizing the error (loco-optitrack) between the positioning datasets when shifting the time axis in Matlab. Then the offset, which reduces the RMS error for each coordinate most, is used for adjusting the loco system. This is calculated in matlab (s_square_075.m, s_square_1.m, s_square_15.m)

These measusrements were performed three times. Measurement 1 is displayed. The results are compared in *Table 1*.

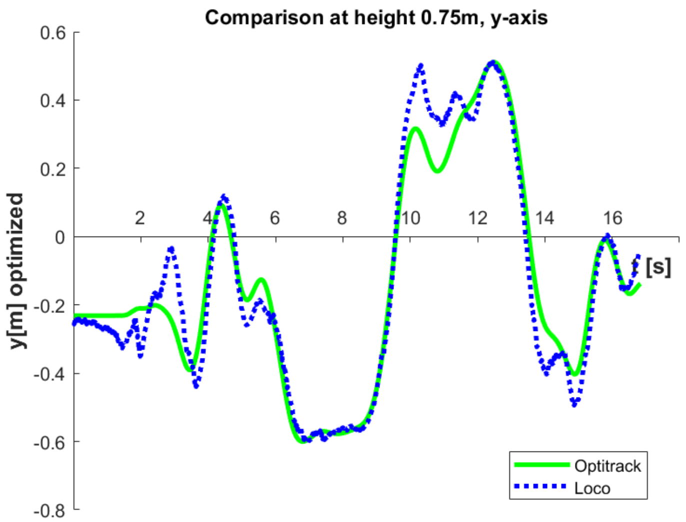
Flight at height 0.75 m



X-axis error averages

offset: -6.5 cm
absolute mean: 7.6 cm
RMS = 9.1 cm
maximum error = 21.42 cm
standard deviation = 9.13 cm

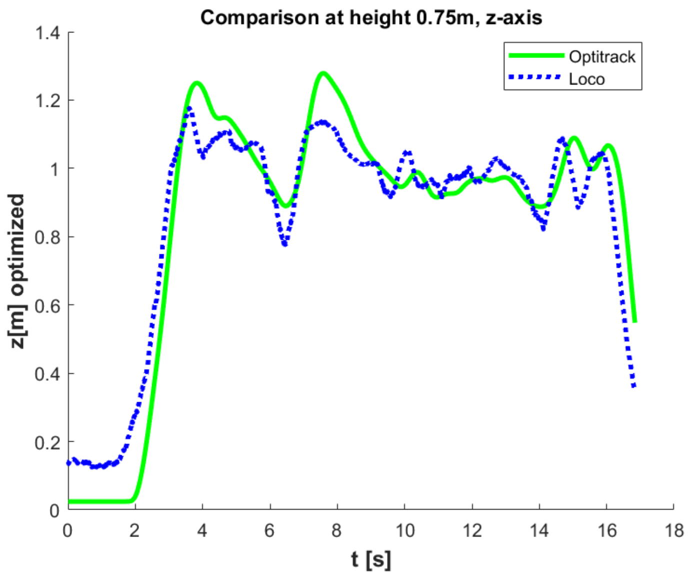
Figure 4: Flight at 0.75 m, X-Axis



Y-axis error averages

offset: -6.2 cm
absolute mean: 5.5 cm
RMS = 7.29 cm
maximum error = 21.49 cm
standard deviation = 7.29 cm

Figure 5: Flight at 0.75 m, Y-Axis

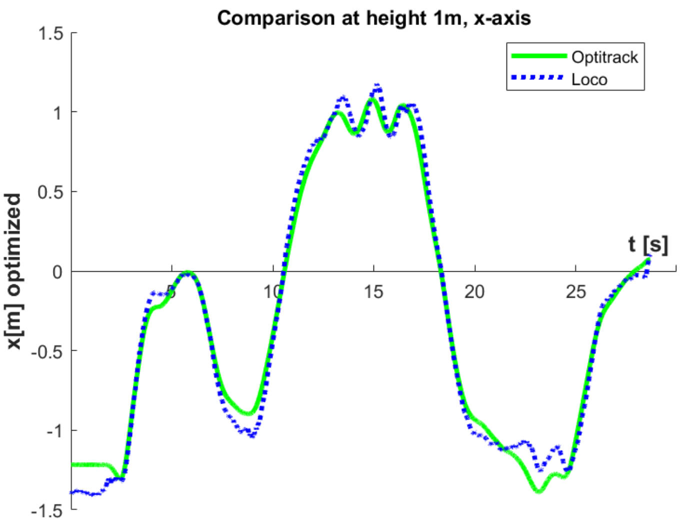


Z-axis error averages

offset: 20.9 cm
absolute mean: 8.43 cm
RMS = 10.96 cm
maximum error = -31.07 cm
standard deviation = 10.9 cm

Figure 6: Flight at 0.75 m, Z-Axis

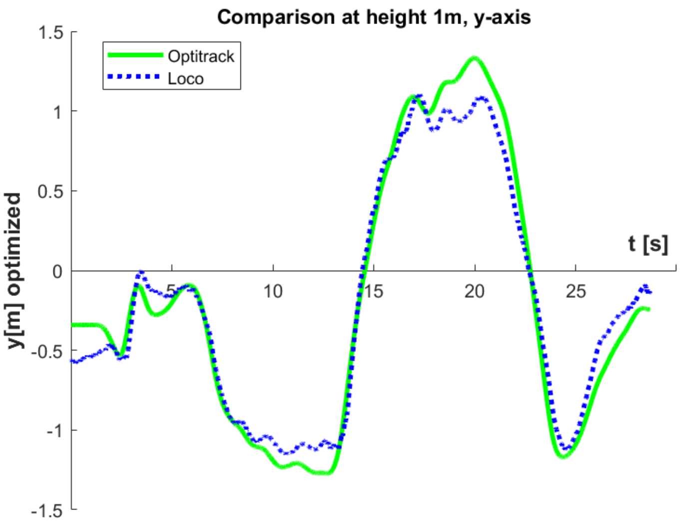
Flight at height 1m



X-axis error averages

offset: -4.9 cm
absolute mean: 6.94 cm
RMS = 8.85 cm
maximum error = 22.73 cm
standard deviation = 8.85 cm

Figure 7: Flight at 1 m, X-Axis



Y-axis error averages

offset: -7.7 cm
absolute mean: 11.67 cm
RMS = 13.89 cm
maximum error = -33.13 cm
standard deviation = 13.89 cm

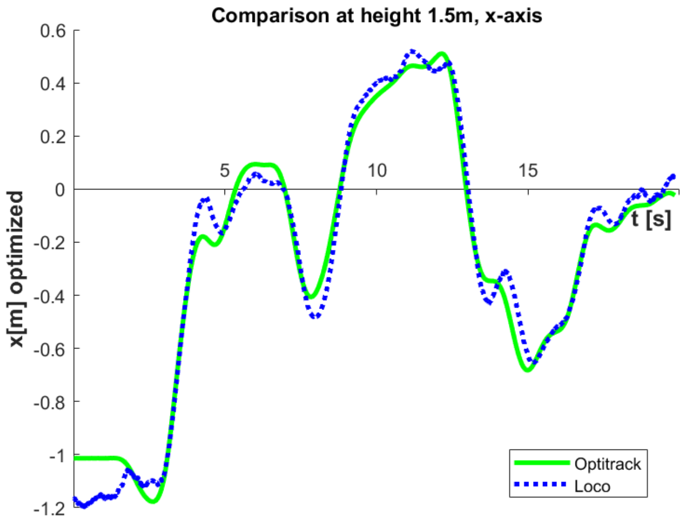
Figure 8: Flight at 1 m, Y-Axis

Z-axis error averages

offset: 14.8 cm
absolute mean: 6.49 cm
RMS = 8.45 cm
maximum error = -22.89 cm
standard deviation = 8.45 cm

Figure 9: Flight at 1 m, Z-Axis

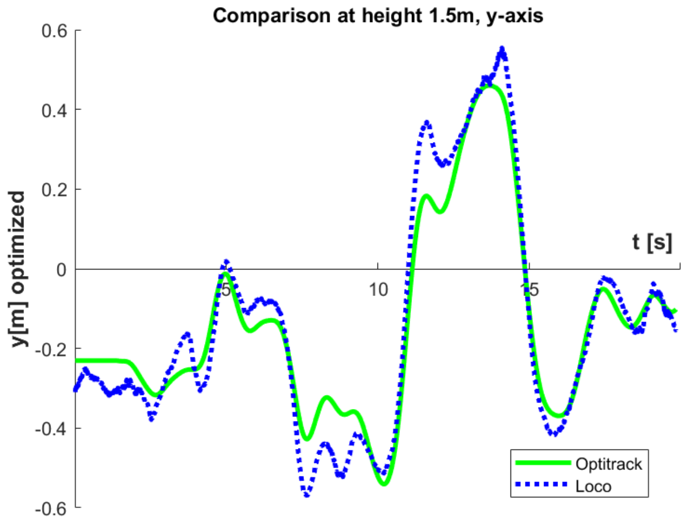
Flight at height 1.5 m



X-axis error averages

offset: -2.6 cm
absolute mean: 5.35 cm
RMS = 6.98 cm
maximum error = -18.66 cm
standard deviation = 6.99 cm

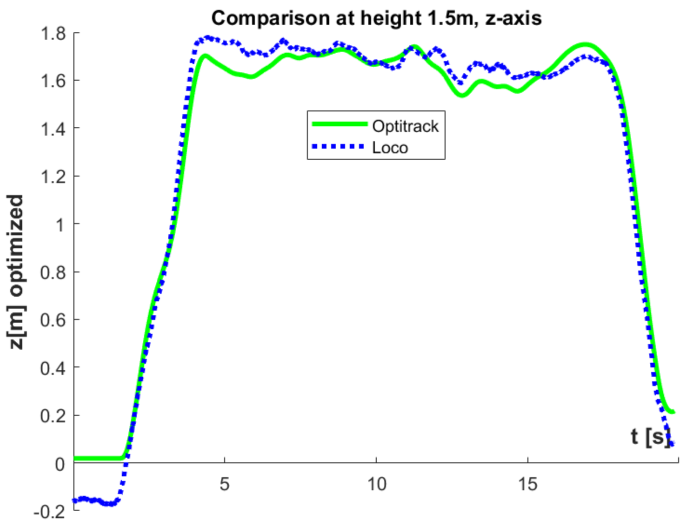
Figure 10: Flight at 1.5 m, X-Axis



Y-axis error averages

offset: -5.3 cm
absolute mean: 5.4 cm
RMS = 6.88 cm
maximum error = 18.5 cm
standard deviation = 6.88 cm

Figure 11: Flight at 1.5 m, Y-Axis



Z-axis error averages

offset: 13.3 cm
absolute mean: 6.54 cm
RMS = 8.09 cm
maximum error = -19.58 cm
standard deviation = 8.1 cm

Figure 12: Flight at 1.5 m, Z-Axis

Height 0.75 m	**Offset adjustment**
Measurement 1: Error_x = 9.1 cm Measurement 2: Error_x = 12 cm Measurement 3: Error_x= 7.7 cm	-6.5 cm -1.7 cm 0.9 cm
Error_y = 7.29 cm Error_y = 8.84 cm Error_y = 13.8 cm	-6.2 cm -15.5 cm 1.1 cm
Error_z = 10.96 cm Error_z = 13.23 cm Error_z = 8.9 cm	20.9 cm 20.5 cm 10 cm
Height 1 m	
Error_x = 8.85 cm Error_x = 10.48 cm Error_x = 4.9 cm	-4.9 cm -1.8 cm -3.8 cm
Error_y = 13.89 cm Error_y = 10.48 cm Error_y = 12.75 cm	-7.7 cm -16.6 cm -3.2 cm
Error_z = 8.45 cm Error_z = 7.35 cm Error_z = 10.4 cm	14.8 cm 13.3 cm 11.7 cm
Height 1.5 m	
Error_x = 6.98 cm Error_x = 10.54 cm Error_x = 4.35 cm	-2.6 cm -2.6 cm -4 cm
Error_y = 6.88 cm Error_y = 11.9 cm Error_y = 10.26 cm	-5.3 cm -8.2 cm -1 cm
Error_z = 8.09 cm Error_z = 9.24 cm Error_z = 7.9 cm	13.3 cm 13.1 cm 13 cm

Table 1: Measurement comparison of all three takes

Measurements 1 and 2 were taken with crazyflie Firmware (2023). For the last measurement the drone had the latest firmware (03.2024).

Combined flights with statistical averages without adjusting the offset

To get a general overview of the system's accuracy at different heights, all the test flight data will be compared to calculate the statistical averages. As before, only measurement 1 is shown below.

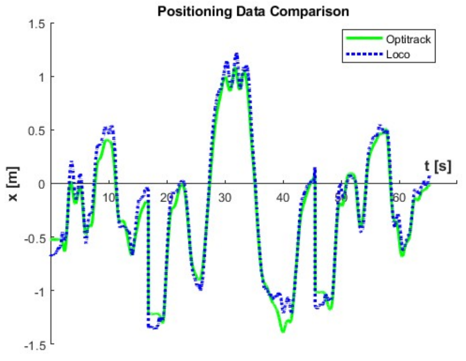


Figure 13: X-Coordinates, combined flights

X-axis error averages

absolute mean: 7.96 cm
RMS = 9.71 cm
maximum error = 27.62 cm
standard deviation = 8.54 cm

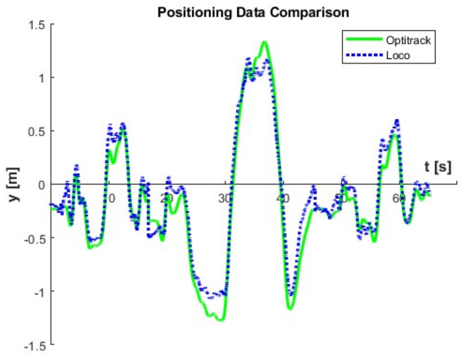


Figure 14: Y-Coordinates, combined flights

Y-axis error averages

absolute mean: 6.56 cm
RMS = 12.52 cm
maximum error = 30.185 cm
standard deviation = 10.67 cm

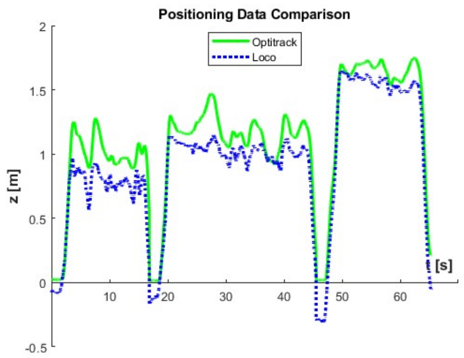


Figure 15: Z-Coordinates, combined flights

Z-axis error averages

absolute mean: -15.94 cm
RMS = 18.585 cm
maximum error = -51.97 cm
standard deviation = 9.55 cm

Optimized offset to minimize the RMS error

To improve the loco system's accuracy, the coordination system's origin will be adjusted. The values for each axis were calculated in MATLAB using “s_square_complete.m”.

The adjustments yield an improvement in the statistical averages.

Measurement 1

X-axis error, offset of -4.6 cm

absolute mean: 6.74 cm
RMS = 8.53 cm
maximum error = 23.03 cm
standard deviation = 8.54 cm

Y-axis error, offset of -6.6 cm

absolute mean: 8.32 cm
RMS = 10.68 cm
maximum error = -32.03 cm
standard deviation = 10.67 cm

Z-axis error, offset of 15.9 cm

absolute mean: 0.074 cm
RMS = 9.55 cm
maximum error = -36 cm
standard deviation = 9.55 cm

Measurement 2

X-axis error, offset of -1 cm

absolute mean: 7.82 cm
RMS = 11.15 cm
maximum error = -38.57 cm
standard deviation = 11.15 cm

Y-axis error, offset of -13.2 cm

absolute mean: 8.72 cm
RMS = 11.11 cm
maximum error = -36.15 cm
standard deviation = 11.11cm

Z-axis error, offset of 15.4 cm

absolute mean: 8.35 cm
RMS = 10.67 cm
maximum error = -33.76 cm
standard deviation = 10.68 cm

Measurement 3

X-axis error, offset of -2.4 cm

absolute mean: 5.27 cm
RMS = 6.58 cm
maximum error = -18.9 cm
standard deviation = 6.58 cm

Y-axis error, offset of -1 cm

absolute mean: 9.33 cm
RMS = 12.4 cm
maximum error = 42 cm
standard deviation = 12.4 cm

Z-axis error, offset of 11.7 cm

absolute mean: 7.03 cm
RMS = 9.19 cm
maximum error = -29.6 cm
standard deviation = 9.19 cm

Below, the RMS error for x and y is displayed in a heat diagram, which provides a good overview of the accuracy of the positioning data over the flight area.

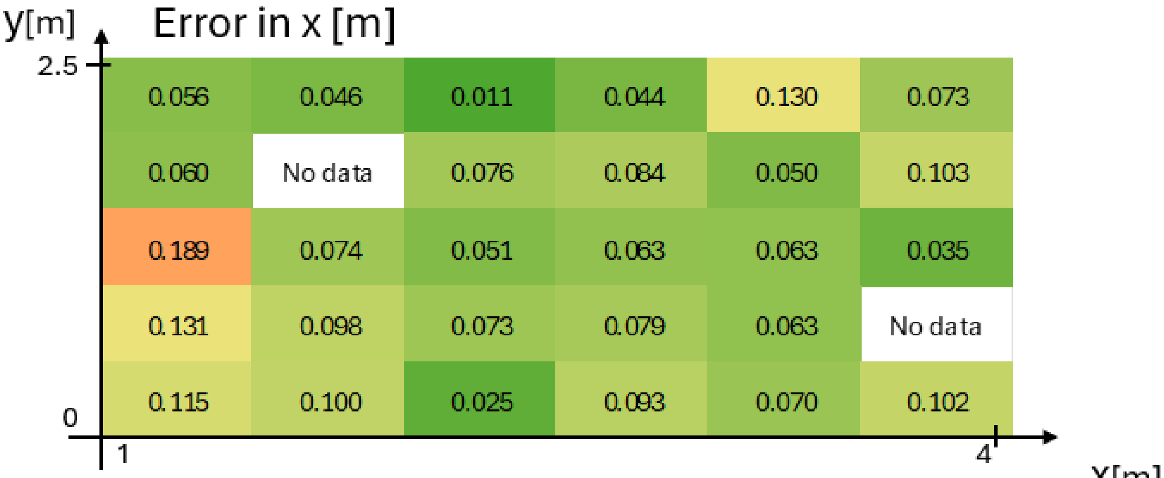


Figure 16: Heat diagram, x-error, RMS

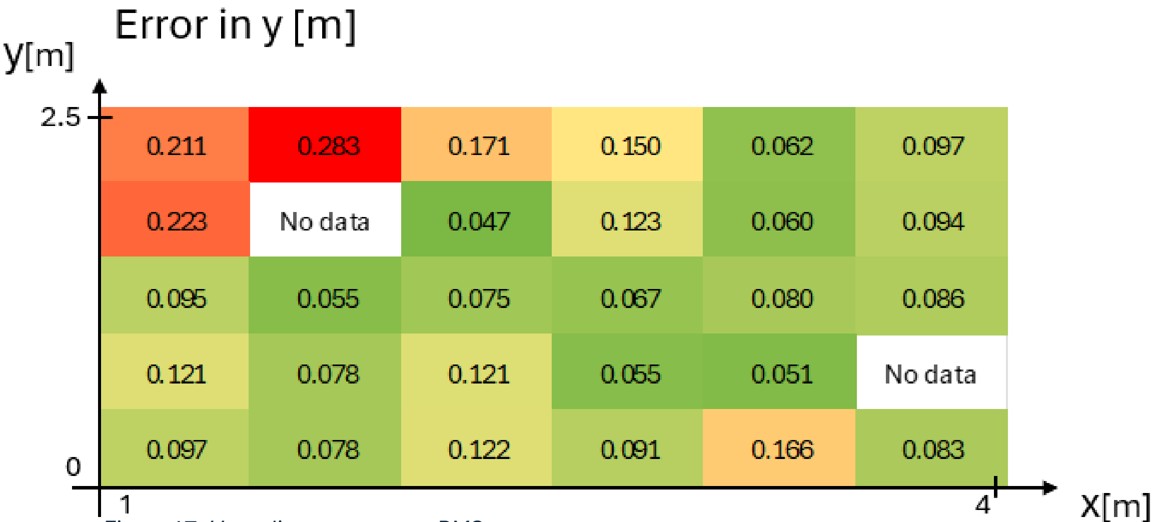


Figure 17: Heat diagram, x-error, RMS

Plane Measurement

A second type of dynamic measurement was conducted to cover the whole x,y plane better by flying a line from -x to +x and changing the y-position in between. This measurement is depicted below(Figure 18). Duration of the measurement flight: 1min

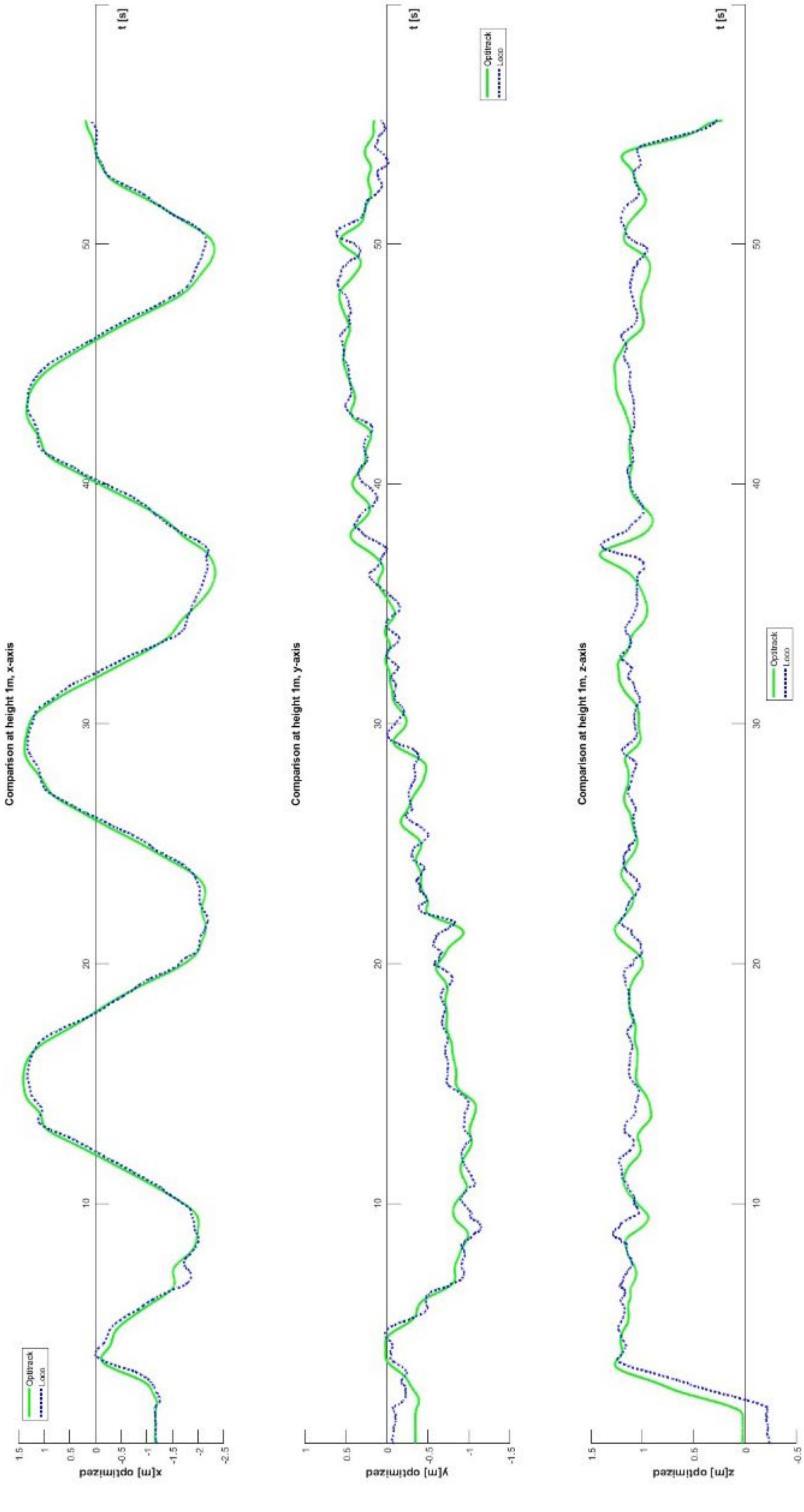


Figure 18: Trajectory Measurement 2

The RMS error for x and y is displayed in a heat diagram again.

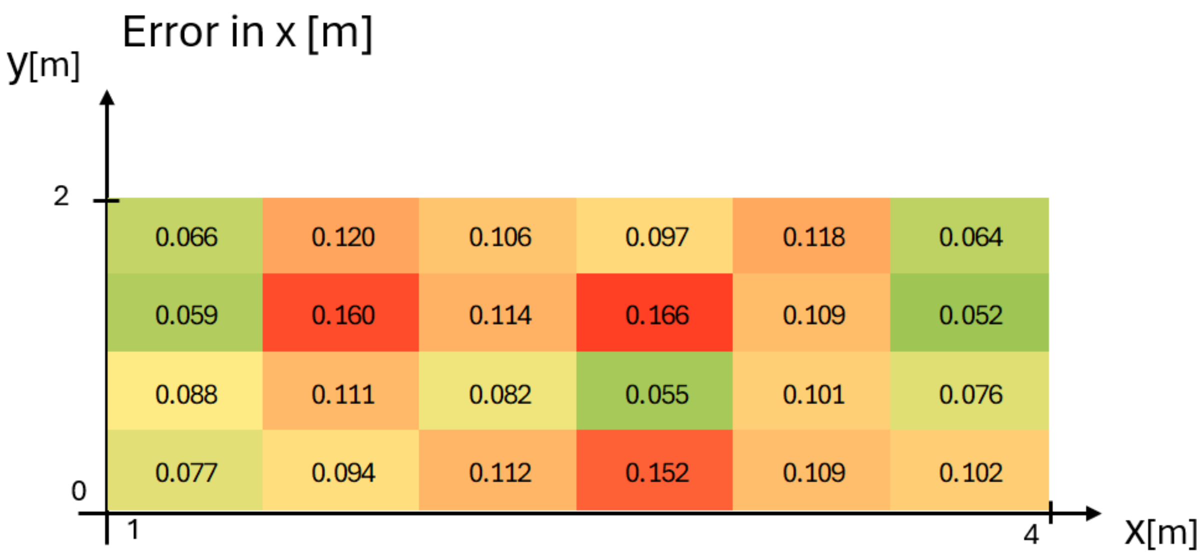


Figure 19: Heat diagram, x-error, RMS, measurement 2

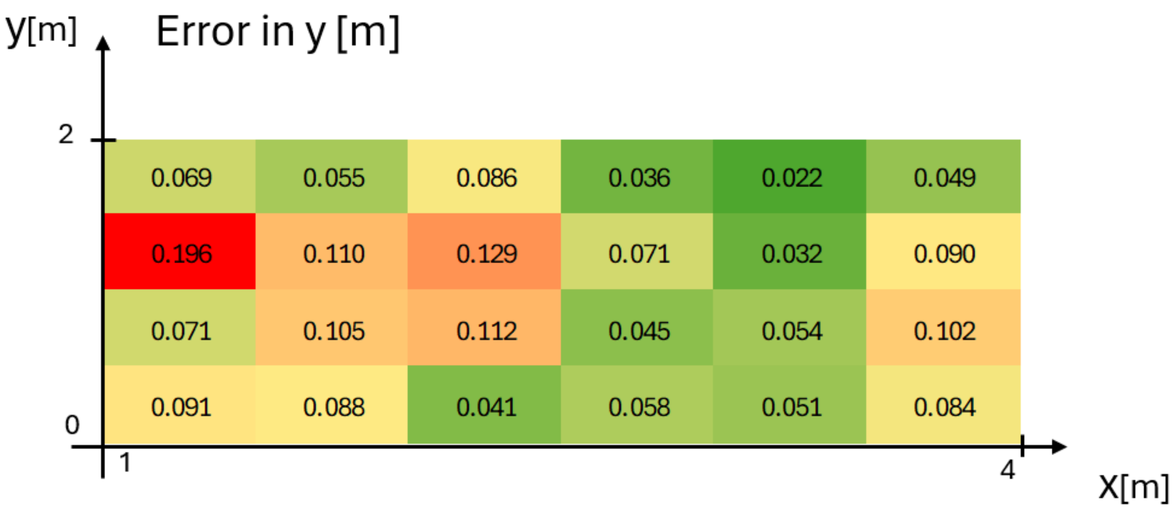


Figure 20: Heat diagram, y-error, RMS, measurement 2

Static measurement

Manual measurements of static positions were conducted on the floor, i.e., at a height of 0 cm. The error between Loco and Optitrack is visualized in the heat maps below.

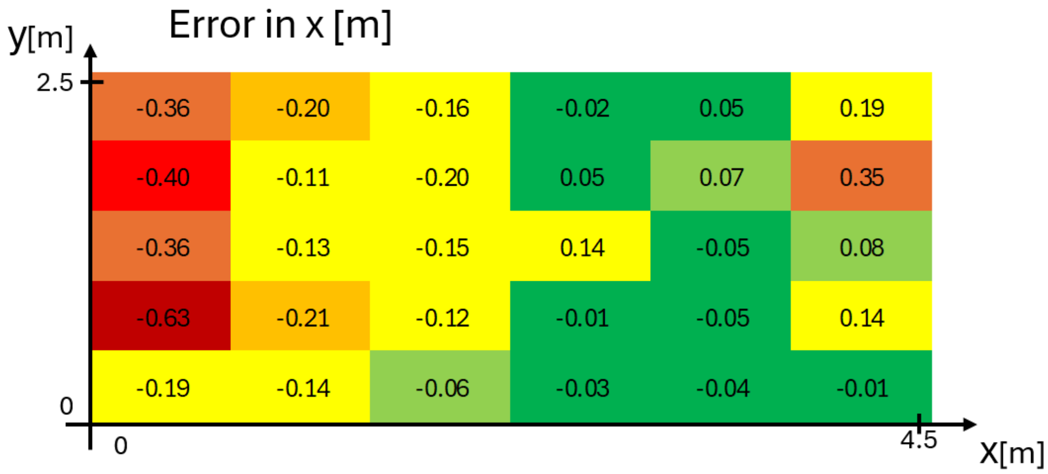


Figure 21: Error in x, static measurement

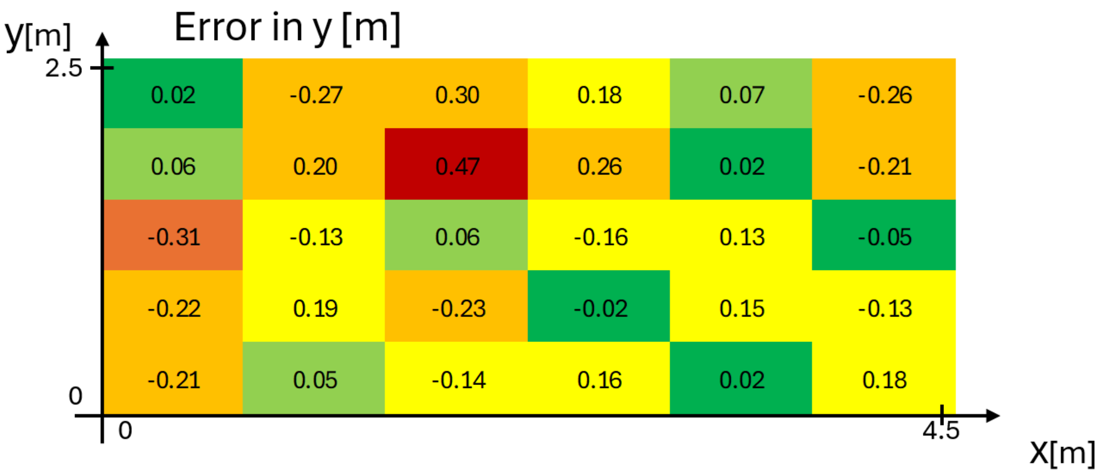


Figure 22: Error in y, static measurement

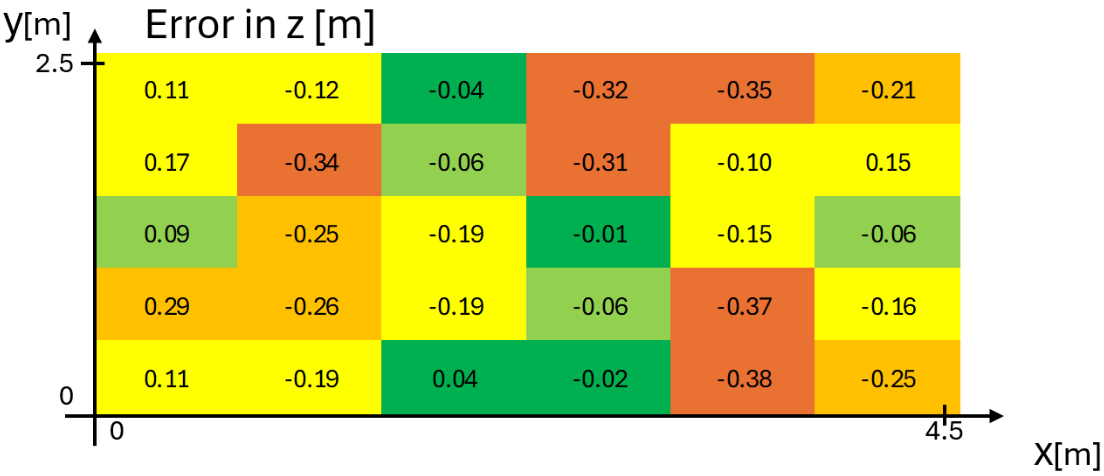


Figure 18: Error in z, static measurement

Interestingly, the Loco System is more accurate in the middle of the flying environment in the **x-direction**, but this cannot be seen in the y- and z-direction. On the left side, the position values were too left; on the right-hand side, they were too right.

The error in **y-direction** is irregular; the error gets better with the counter-diagonal to the bottom right.

In **z-direction**, the error jumps between -38cm and -1cm in the middle section; Loco measures the z coordinates on the left side too much and to the right too low.

Due to problems while trying to fly the Crazyflie, additional measurement flights could not be executed. Fixing this problem is still ongoing.

References

https://www.bitcraze.io/

https://docs.optitrack.com/quick-start-guides/quick-start-guide-getting-started