The Loco Positioning System

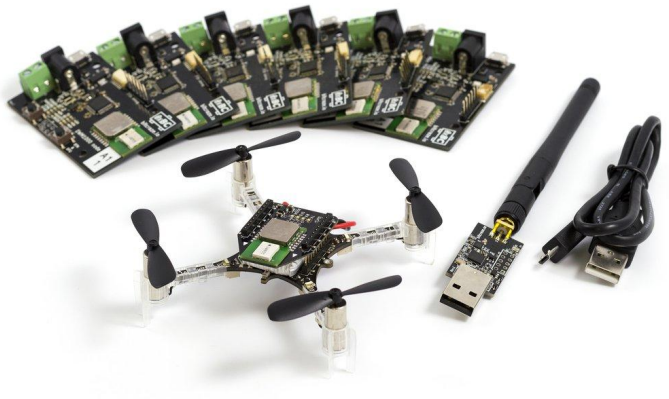
Components and concepts

Goal

An understanding of the components in the LPS system, modes and concepts

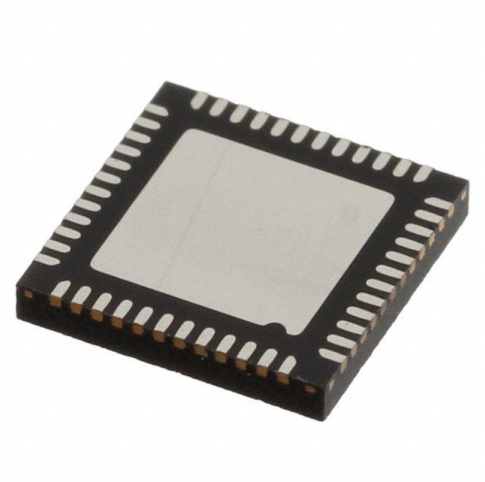
Fundamentals

- Radio based - UWB
- Comparable to indoors GPS
- 2D or 3D positioning
- The position is calculated in the robot
- Precision around 10 - 20 cm
- Affordable - $1500 USD



Based on DW1000

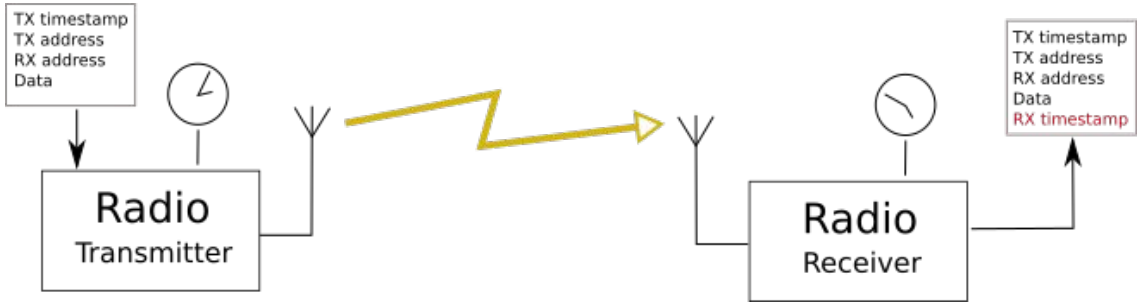
- From Decawave
- UWB radio + high precision timer
- Standard based: IEEE802.15.4a UWB PHY
- 500MHz bandwidth with 5 channels from 3 to 7GHz
- 64GHz timer, 1.5ps timer tick ⇒ ~5mm
- Specifies +/-100mm distance measurement accuracy
- Specifies maximum range around 300m
- Off-the-shelf chip
- Very common chip in UWB implementations



DWM1000

- From Decawave
- Module with the DWM1000 chip + antenna

Conceptual sketch



- Transmitter sends when clock reaches TX timestamp
- Receiver records RX timestamp
- Clocks are not synchronized
- Clocks run at different rates and change over time
- TX and RX timestamps are recorded by different clocks

Time to distance

- If we know time of flight for a radio packet we can calculate the distance by multiplying with the speed of light
- Antenna delay
  - There is a propagation time from transmitter through the antenna, we call this antenna delay
  - The same delay exists on the receiver side
  - The delay is in the order of 150 m when converted to distance
  - Must be compensated for in some algorithms

Terminology

- Anchor - static position
- Tag - moves around, tracked
- Sniffer - eavesdrops on UWB traffic

Hardware components in the LPS

- Node
- LPS deck for the Crazyflie
- Roadrunner

Hardware - Node

- STM32F072 Cortex-M0 MCU
- DWM1000 UWB module
- Firmware using FreeRTOS
- Open source DW1000 driver
- Upgradable and configurable via USB
- Limited configuration via UWB radio
- Power via USB or connector
- Can be used as Anchor, Tag or UWB sniffer. This is why it is called Node and not Anchor

Hardware - LPS Deck

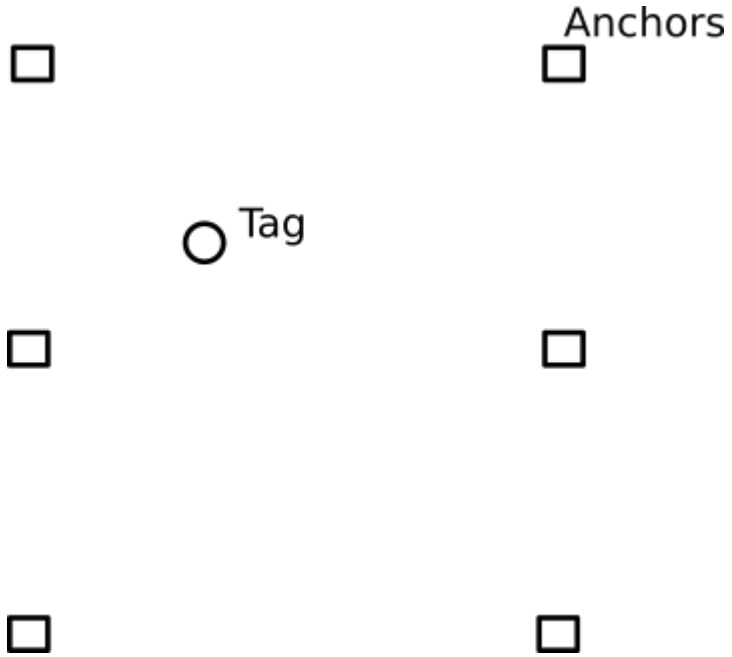
- Based on DWM1000 UWB module
- Ranging, positioning and control implemented in Crazyflie firmware

Hardware - The Roadrunner

- Roadrunner = Crazyflie + LPS deck - motors
- Connector with power and UART
- Can be used on ground robot for instance

LPS system architecture

- Anchors along the edges, usually 8 for 3D positioning
- Anchors have known positions
- Anchors do not move



- The Tag is what we want to locate
  - Crazyflie with LPS deck
  - Roadrunner
- The Tag is free to move around

2D and 3D positioning

- 2D positioning
  - Anchors around the useful area
  - Good for ground robots
  - 3 or more Anchors, 4 recommended
- 3D positioning
  - Anchors forming a “box” around the useful space
  - Good for flying robots
  - 4 or more Anchors, 8 recommended

The convex hull

- The space enclosed by the Anchors
- Imagine a sheet of rubber stretched around the system of Anchors
- Performance is better inside the convex hull than outside, but it is not binary

Modes

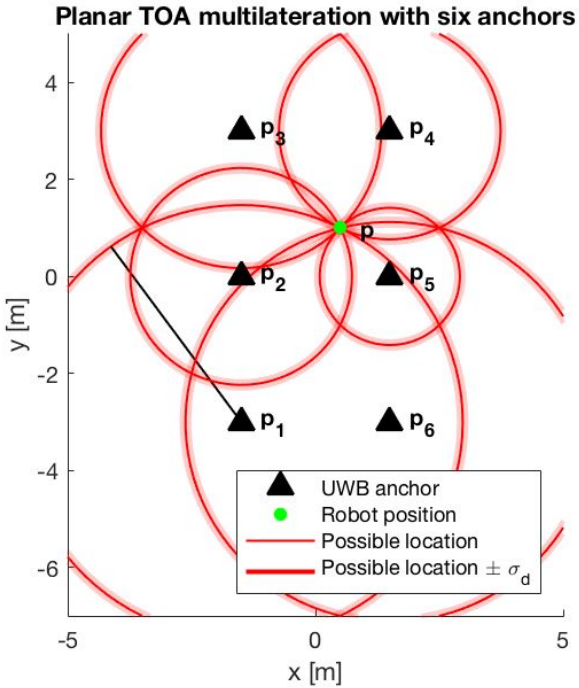
- Two Way Ranging (TWR)
  - Measures distance from Tag to each Anchor
- Time Difference of Arrival (TDoA)
  - Measures difference in distance from Tag to two Anchors
  - TDoA2
  - TDoA3

Two Way Ranging (TWR)

- Measures distance from Tag to each Anchor
- Each measurement requires both Tag and Anchor to transmit and receive messages (ping - pong) - hence the name
- Does not scale in number of Tags
- Supports one Tag
- The Tag is master, initiates measurements

Two Way Ranging - geometry

- Tag at intersection of
  - Circles in 2D case
  - Spheres in 3D case
- Noise properties scale well with distance
- Good performance in and near the convex hull

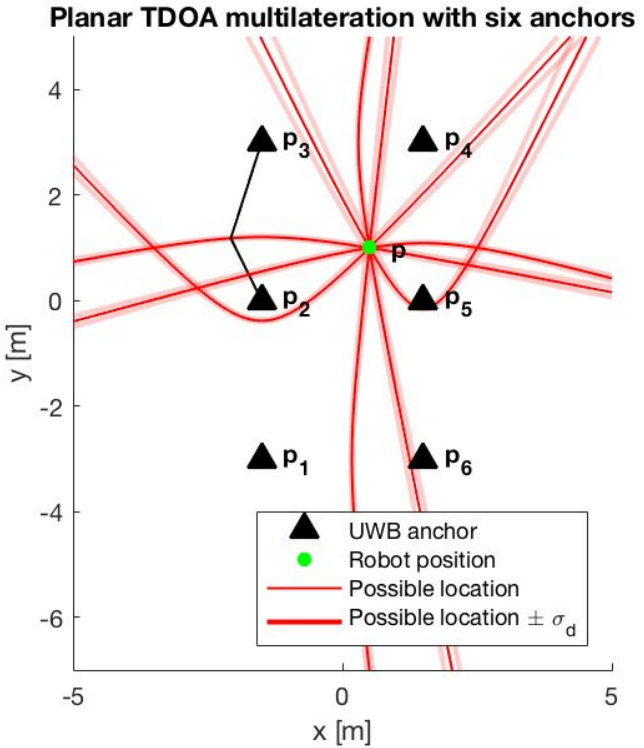


Time Difference of Arrival (TDoA)

- Measures difference in distance from Tag to two Anchors
- Do not know distance from Tag to Anchor
- Only Anchors are transmitting, Tag is listening (passive)
- Scales in number of Tags
- Supports “unlimited” number of Tags
- Transmission time controlled by Anchors
- Very similar to GPS

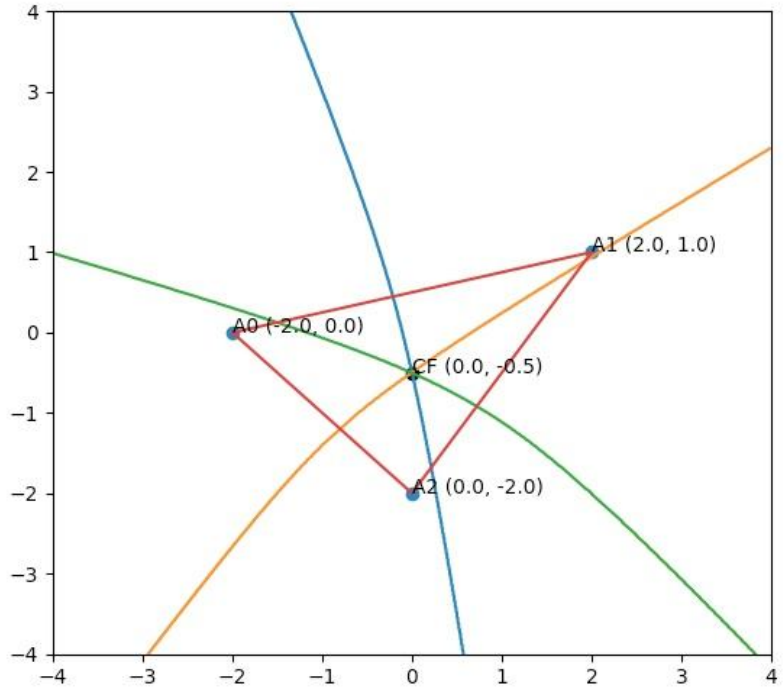
Time Difference of Arrival - geometry

- Tag at intersection of
  - Parabolas in the 2D case
  - Paraboloids in the 3D case
- Tag needs to be inside the convex hull for good precision



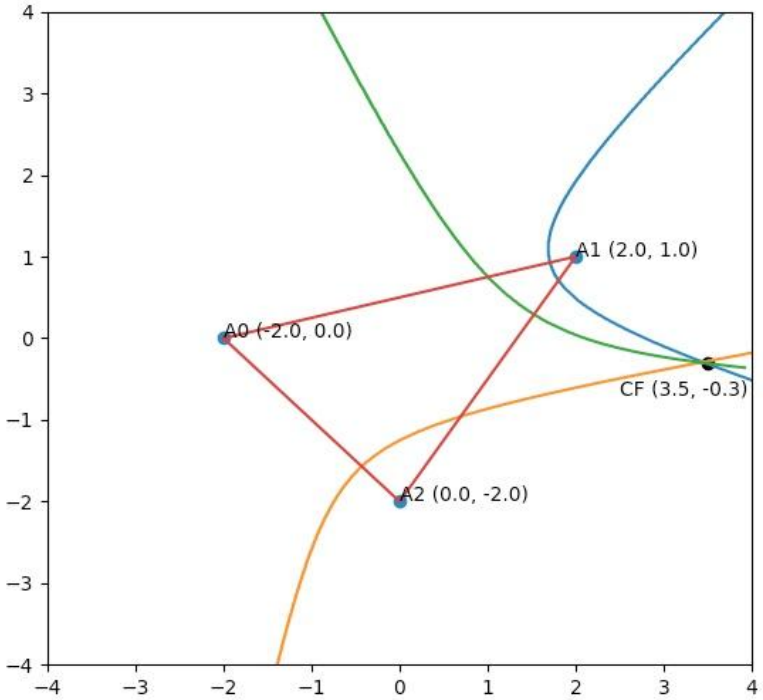
Time Difference of Arrival - inside the convex hull

- 2D example
- Three anchors
- Tag at intersection of parabolas
- Tag inside convex hull
- Good estimate of the position



Time Difference of Arrival - outside the convex hull

- 2D
- Three anchors
- Tag outside convex hull
- Not as good estimate of the position



LPP packets

- Extra information added to the data of UWB packets
- Used to transfer configuration information from Crazyflie to Anchors
  - Setting Anchor position
  - Changing mode in Anchor
  - Setting TX power in Anchor

System range

- Default range around 4 meters
- Increase TX power ⇒ around 8 meters (common)
- Add more anchors in TDoA3 (experimental)
- Long preamble and low bitrate ⇒ around 100 meters (experimental)
    - Mainly for 2D since the covered space is very flat

Precision

- DW1000 chip specified to +/-100mm distance measurement accuracy
- Real world 10 - 20 cm
- Depends on
  - Anchor placement
  - Antenna orientation
  - Mode
  - Radio environment
  - Physical environment
  - Obstacles
  - Non linearities at close range
  - Bugs in the chip

Conclusions

- Anchor VS Tag
- Hardware components: Node, LPS deck, Roadrunner
- Modes: TWR, TDoA