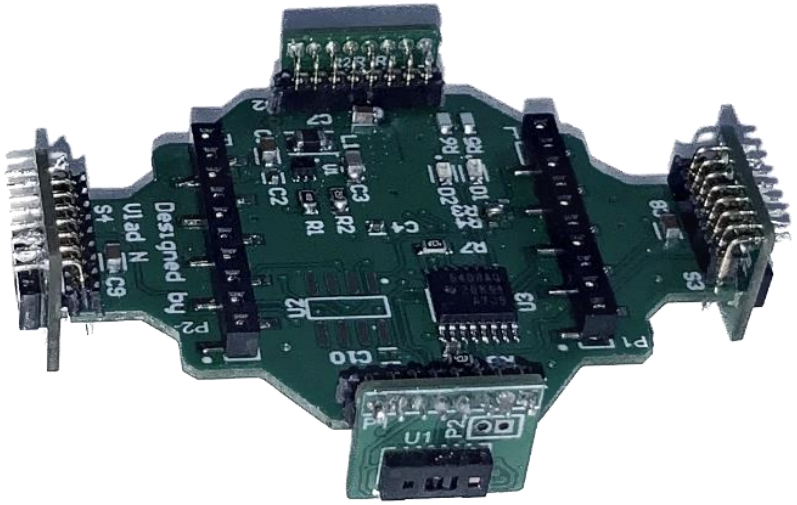
Nano-Drone autonomous navigation challenge: Try to catch me!



Author: **Lukas von Briel**

Date: 6 June 2023, Zürich

Supervisors: Dr. T. Polonelli, V. Niculescu

Professor: Prof. Dr. L. Benini

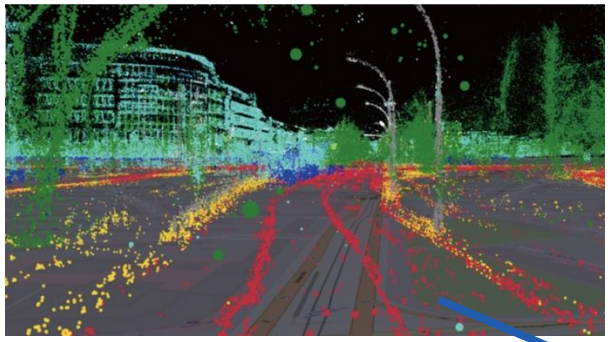


Fig. 1

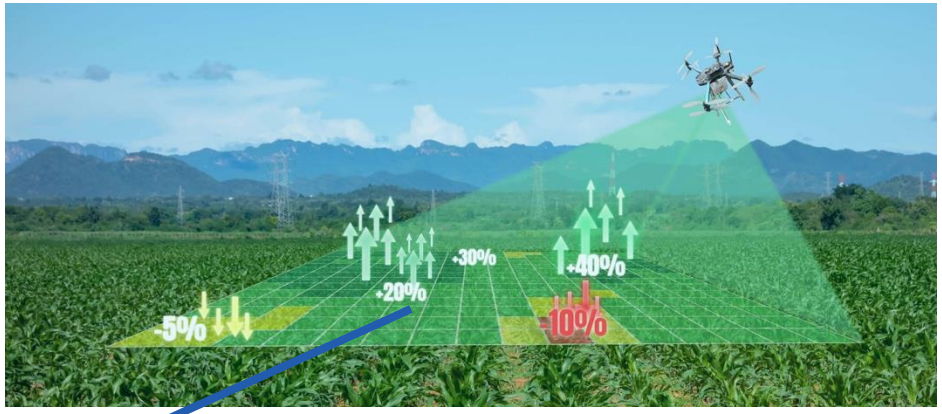


Fig. 3

Basic Avoidance

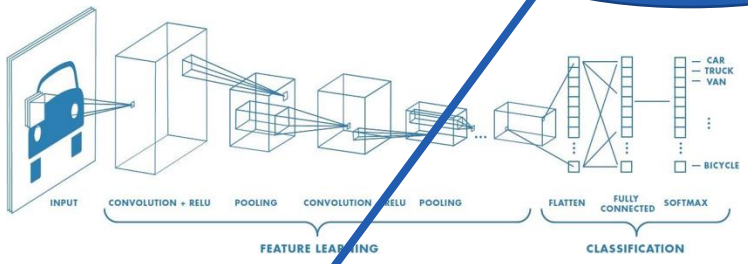


Fig. 2

Fig. 4

Thesis goal:

"Design a custom control policy to autonomously fly the Crazyflie 2.1 in 2D in challenging situations with high-speed moving obstacles relying only on onboard sensors and computional resources."

Robust and Efficient Depth-based Obstacle Avoidance for Autonomous Miniaturized UAVs

Hanna Müller, *Student Member, IEEE*, Vlad Niculescu, *Student Member, IEEE*, Tommaso Polonelli, *Member, IEEE*, Michele Magno, *Senior Member, IEEE* and Luca Benini, *Fellow, IEEE*

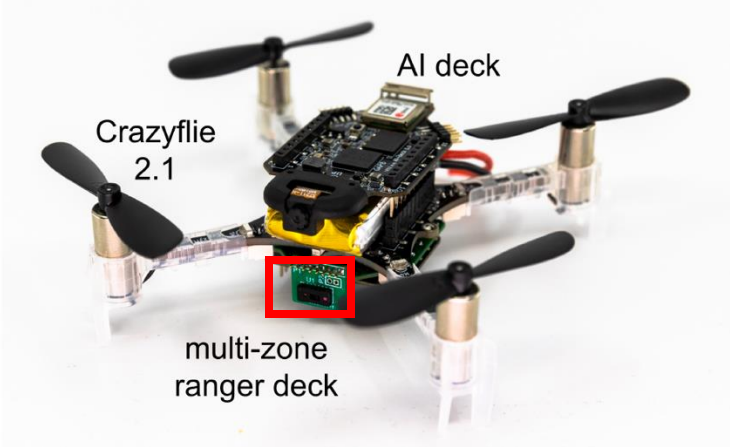


Fig. 9

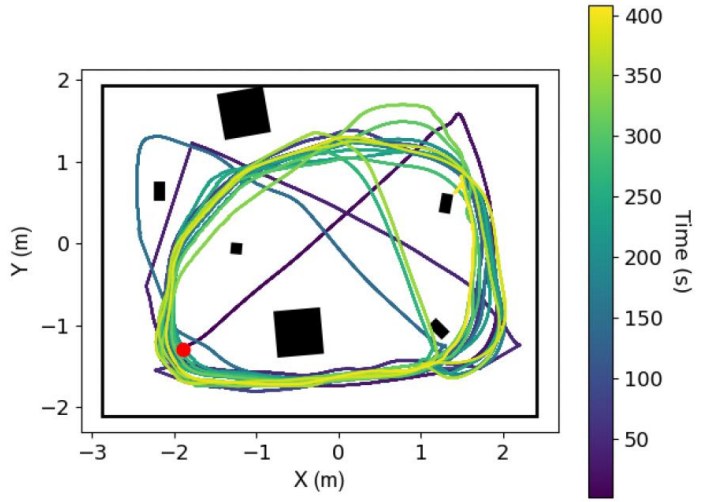


Fig. 10

bitcraze Crazyflie 2.1

Fig. 5

- STM32F4 (168 MHz, 192 kb SRAM)
- Flight time: 7 min
- Weight: 27 g
- Max payload: 15 g
- Expansion Decks !

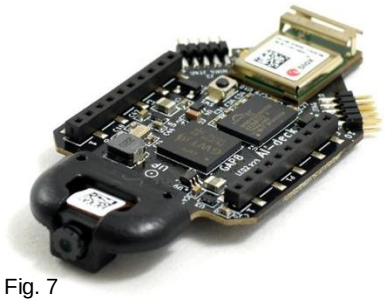


Fig. 7

Fig. 6

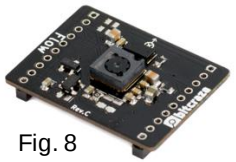
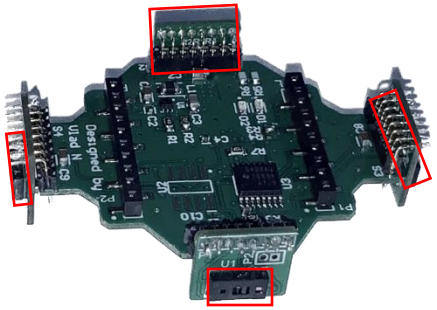


Fig. 8

By: Vlad Niculescu

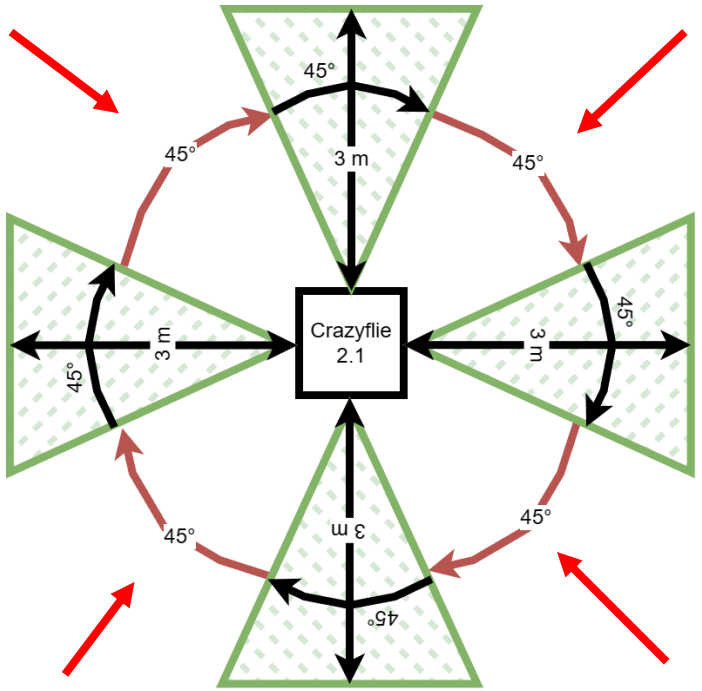
Crazyflie 2.1 ToF Expansion Deck



- 8x8 multi-zone time of flight ranging sensor (VL53L5CX) by STM:
  - 45° FoV (horizontal and vertical)
  - 15 Hz refresh rate
  - 313 mW (continous mode)
  - ≈ 3 m ranging distance

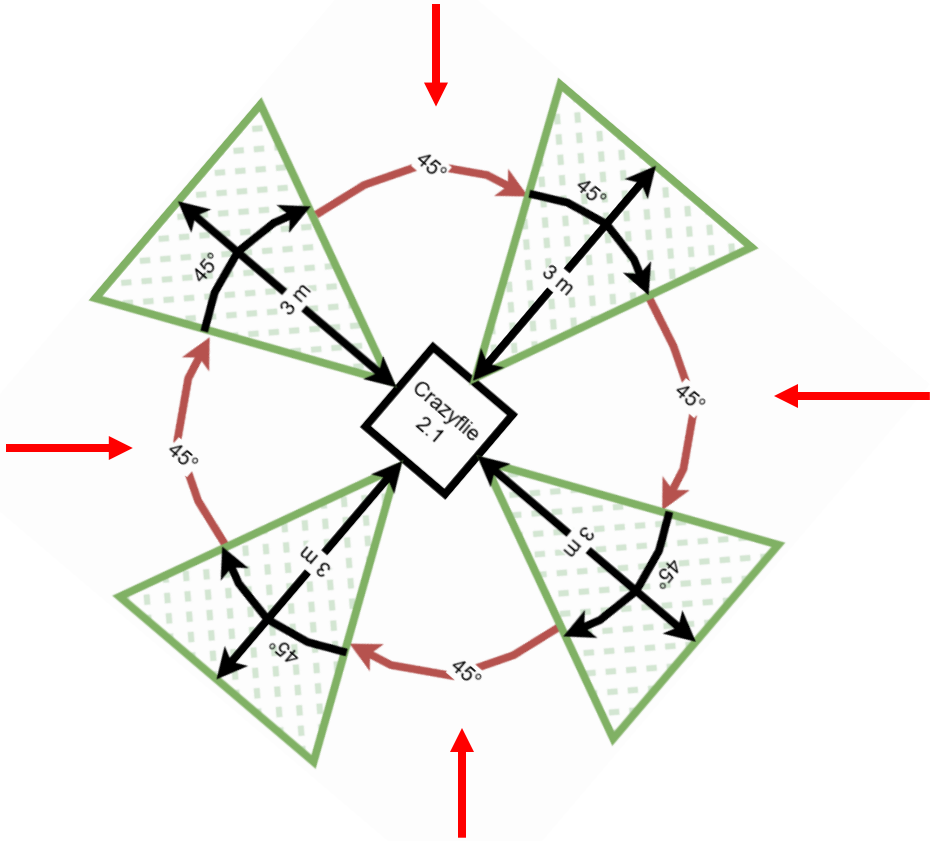
-1	-1	-1	-1	-1	-1	-1	-1
-1	-1	0.715	0.688	-1	-1	-1	-1
-1	-1	0.727	0.708	-1	-1	-1	-1
2.67	-1	0.755	0.748	0.788	-1	-1	-1
-1	0.768	0.754	0.761	0.764	0.784	-1	-1
0.751	0.743	0.725	0.734	0.735	0.746	0.778	-1
-1	-1	0.691	0.703	0.709	0.712	0.774	-1
0.728	0.711	0.671	0.683	0.690	0.708	0.781	0.756

2D area cover:

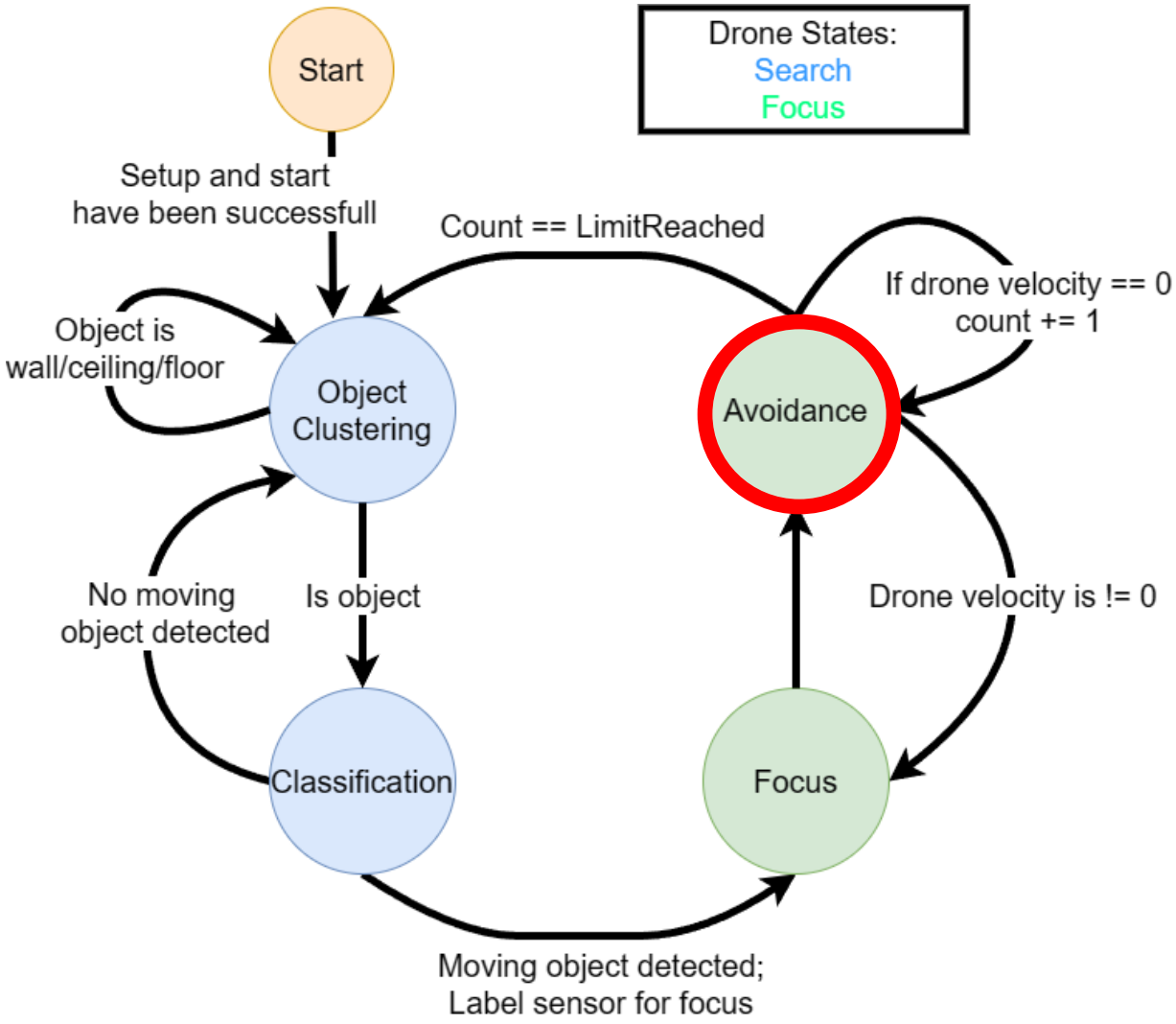


⇒ Cumulative FoV is only 180°
⇒ However, compesate by rotation

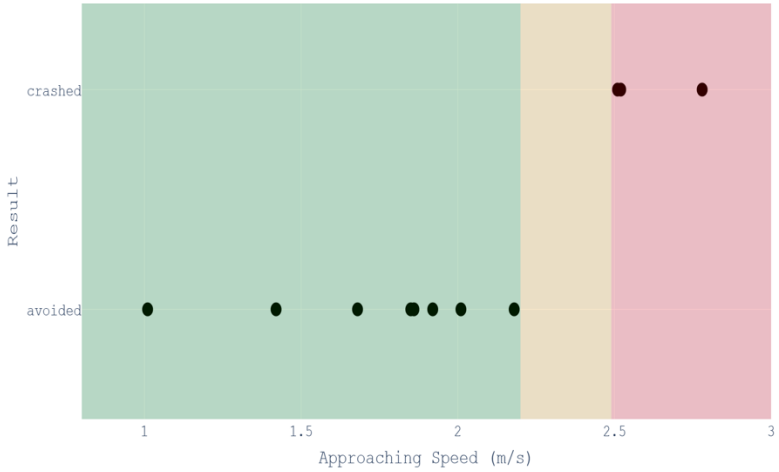
2D area cover:

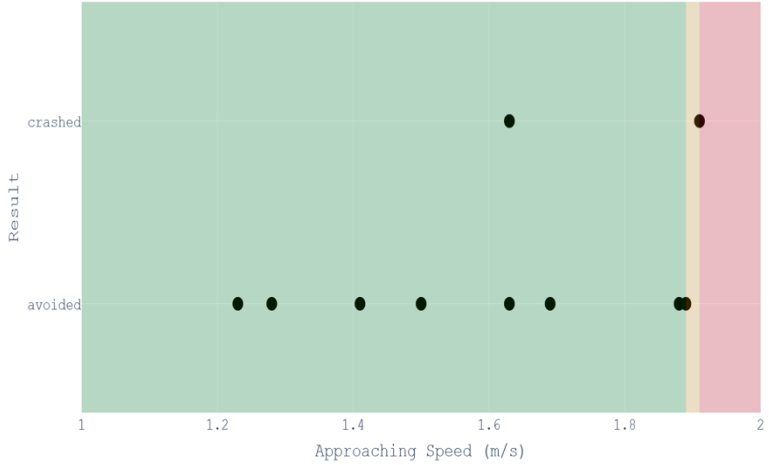


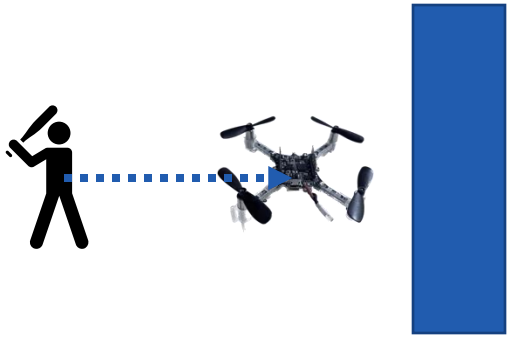
⇒ Cumulative FoV is only 180°
⇒ However, compesate by rotation

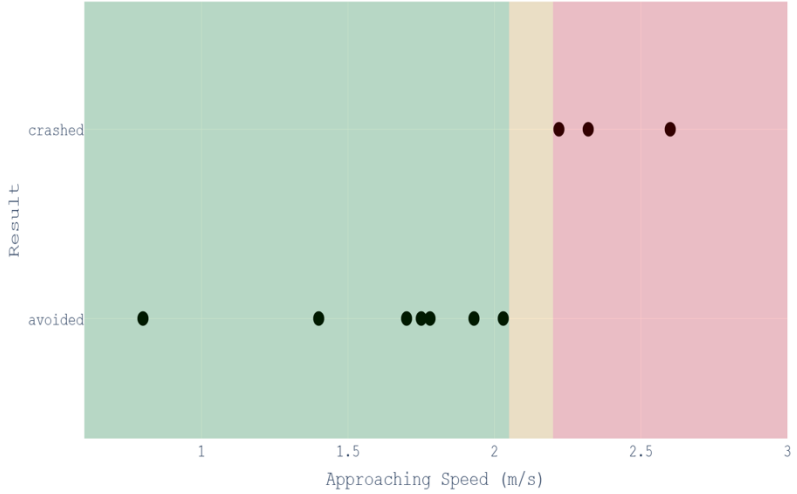

Start
Drone States:
Search
Focus
Setup and start
have been successfull
Count == LimitReached
If drone velocity == 0
count += 1
Object is
wall/ceiling/floor
Object
Clustering
Avoidance
No moving
object detected
Is object
Drone velocity is != 0
Classification
Focus
Moving object detected;
Label sensor for focus

Basic Avoidance:

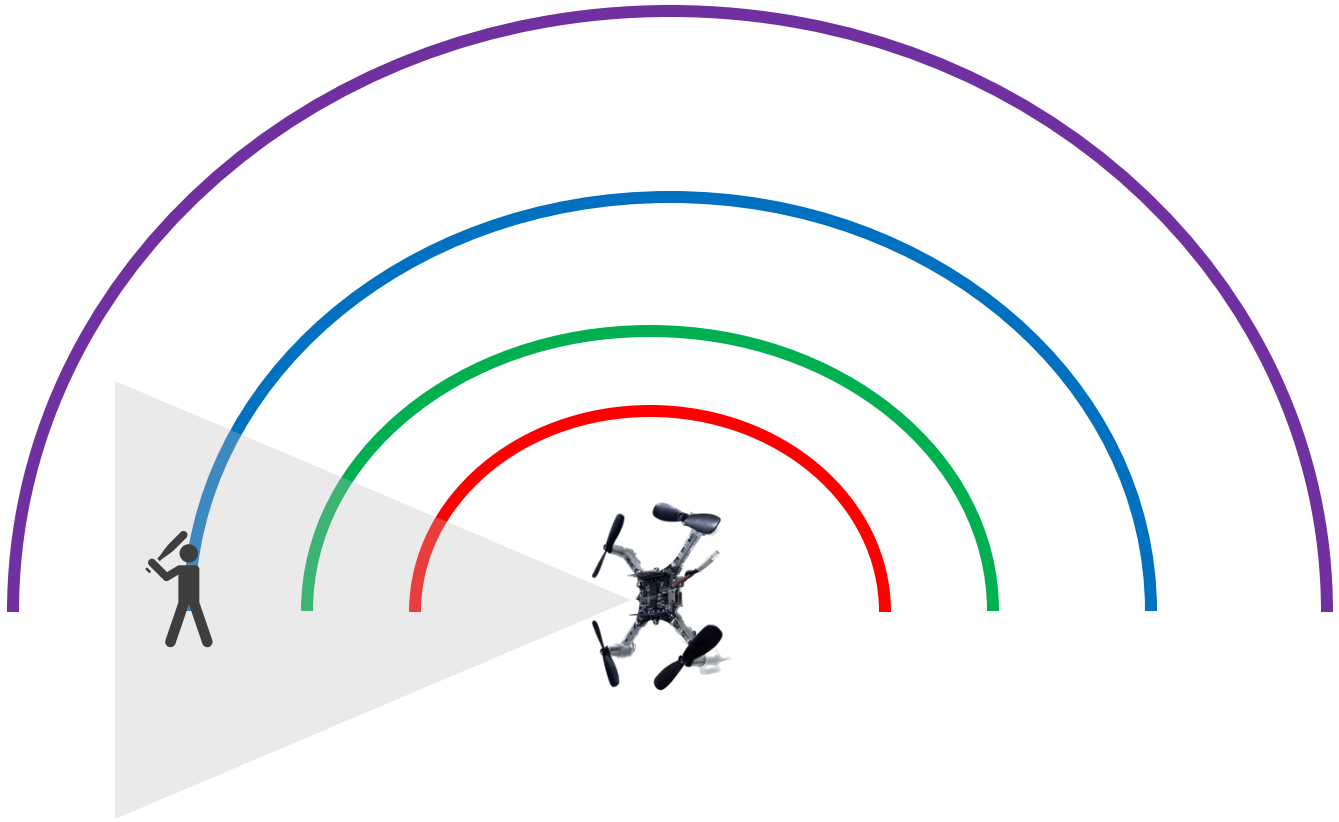








Focus:



Distance in [m]	$\frac{\text{keeps focus}}{\text{n test}} = success\ Rate$
3	$\frac{0}{5} = 0\%$
2	$\frac{5}{5} = 100\%$
1	$\frac{5}{5} = 100\%$
0.5	$\frac{1}{5} = 20\%$

Fast rotation causes instability!

Mapping:

25 degree/sec

$$\Rightarrow \frac{Moving\ Object\ Detected}{n\ test} = \frac{8}{10} = 80\ \%\ success\ rate$$

Full system:

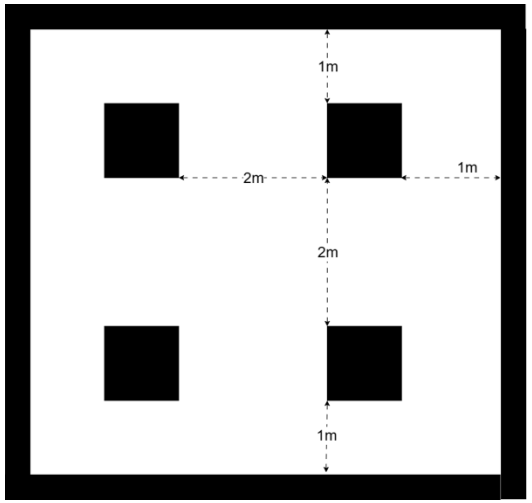
Test Setup:

- Open Space 7x7 m
- 2 min flights
- Walking speeds of 1,5 m/s in average
- Avoidance
- Focus
- Mapping

Nr	Flight Time
1	2 min
2	2 min
3	2 min
4	2 min
5	2 min
6	2 min
7	1 min 30 sec
8	2 min
9	2 min
10	2 min

Out of 20 min
it flew 19 min 30 sec
=> 97,5 % success rate

Maze:



Test Setup:

- Maze like below
- 2 min flight
- Walking speeds of 1 m/s in average
- Only avoidance

Nr	Flight Time
1	51 sec
2	2 min
3	1 min 30 sec
4	1 min 5 sec
5	50 sec
6	34 sec
7	1 min 35 sec
8	54 sec
9	1 min 9 sec
10	28 sec

Out of 20 min
it flew 10 min 56 sec
=> 54,7 % success rate

High Speed:

Test Setup:

- Small 3x3 m cage
- 1 min flights
- Walking speeds of 2,5 m/s in average
- Only avoidance

Nr	Flight Time
1	1 min
2	1 min
3	10 sec
4	34 sec
5	45 sec
6	1 min
7	1 min
8	55 sec
9	45 sec
10	1 min

Out of 10 min
it flew 8 min 9sec
=> 81,5 % success rate

Thesis goal:

"Design a custom control policy to autonomously fly the Crazyflie 2.1 in 2D in challenging situations with high-speed moving obstacles relying only on onboard sensors and computational resources."

Goals	Result
Challenging situation	Maze 55% success rate; however, low speeds only
High speed moving obstacle	80% success rate during high speed; only "clean" environment
Custom control policy	Full system control policy with blind spot compensation via moving object detection and focus
Relying on onboard sensors and computational resources	Fully implemented in c code with execution time 4-10 ms

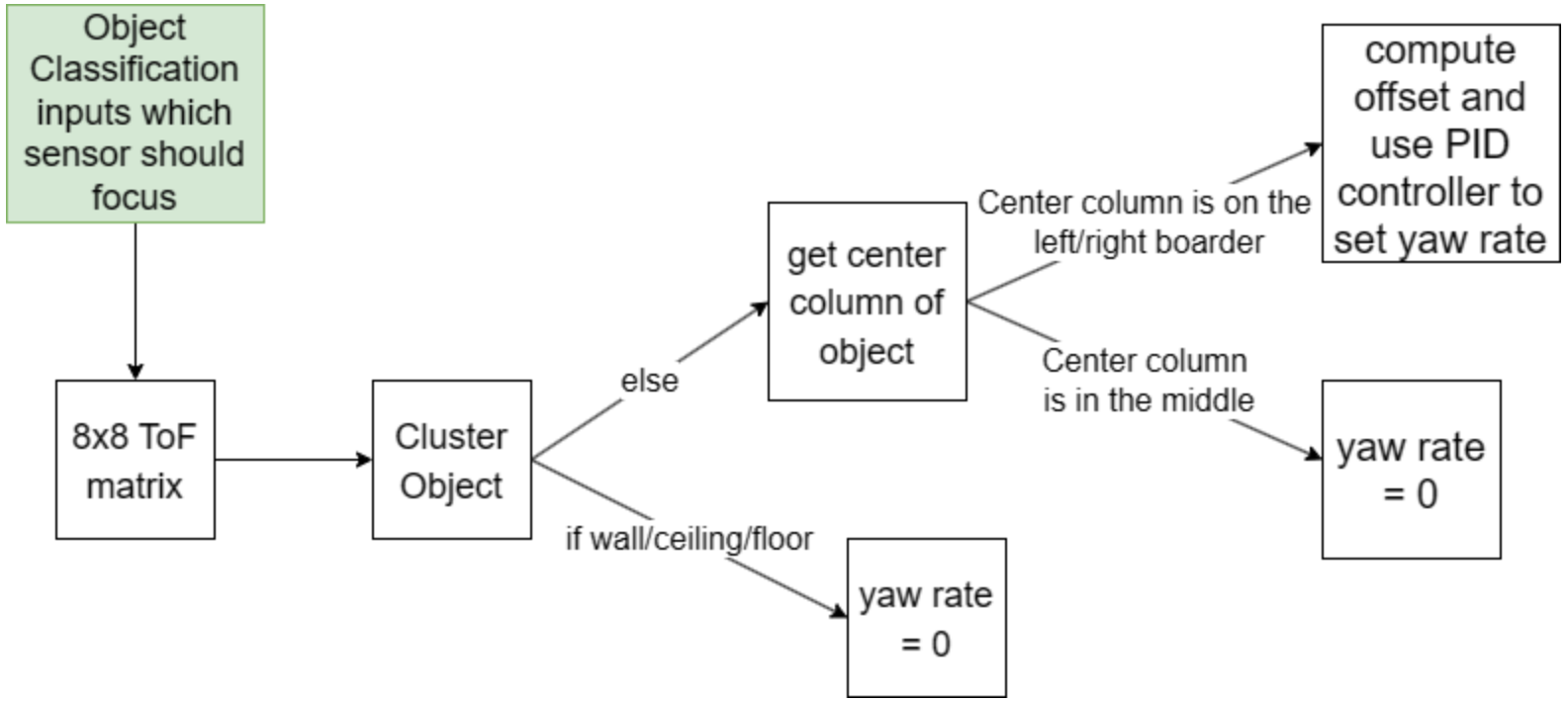
QUESTIONS ?

Additional Cluster

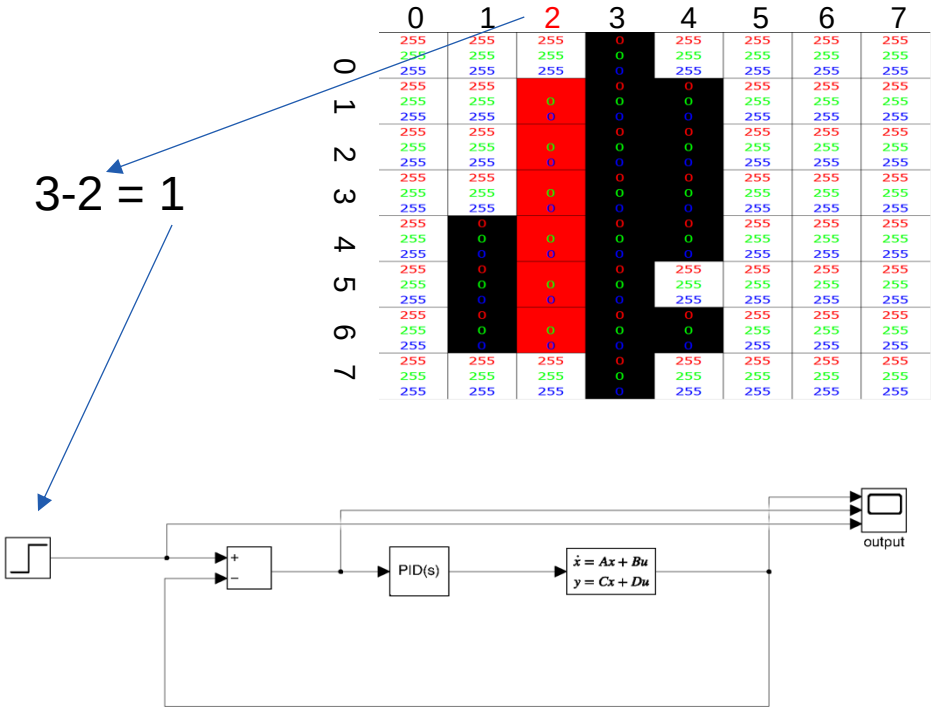
-1	-1	-1	-1	-1	-1	-1	-1
-1	-1	0.715	0.688	-1	-1	-1	-1
-1	-1	0.727	0.708	-1	-1	-1	-1
2.67	-1	0.755	0.748	0.788	-1	-1	-1
-1	0.768	0.754	0.761	0.764	0.784	-1	-1
0.751	0.743	0.725	0.734	0.735	0.746	0.778	-1
-1	-1	0.691	0.703	0.709	0.712	0.774	-1
0.728	0.711	0.671	0.683	0.690	0.708	0.781	0.756

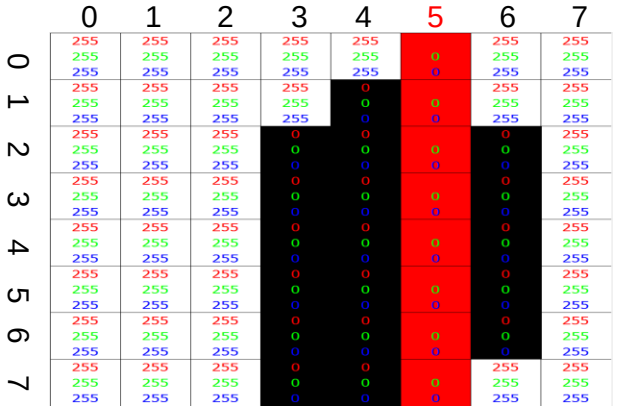
0	0	0	0	0	0	0	0
0	0	1	1	0	0	0	0
0	0	1	1	0	0	0	0
0	0	1	1	1	0	0	0
0	1	1	1	1	1	0	0
1	1	1	1	1	1	1	0
0	0	1	1	1	1	1	0
1	1	1	1	1	1	1	1

Additional Focus



Additional Focus

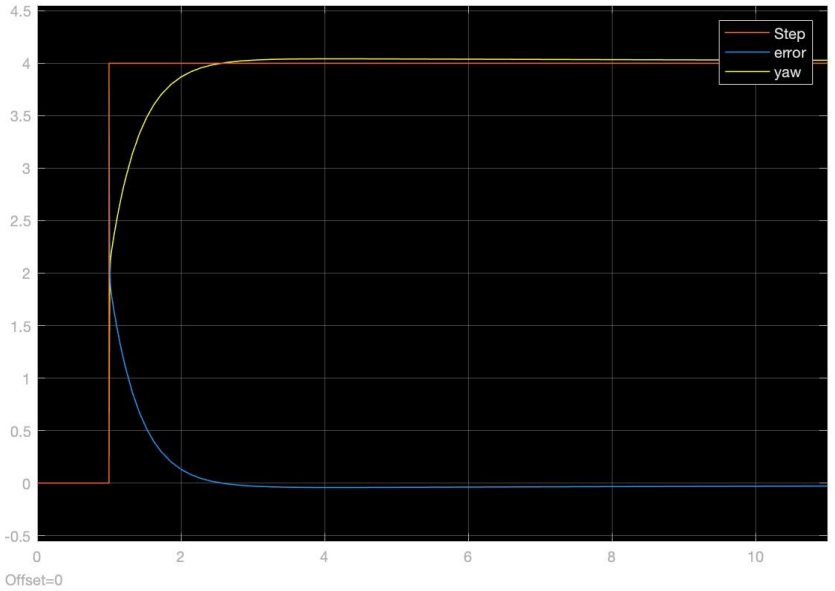




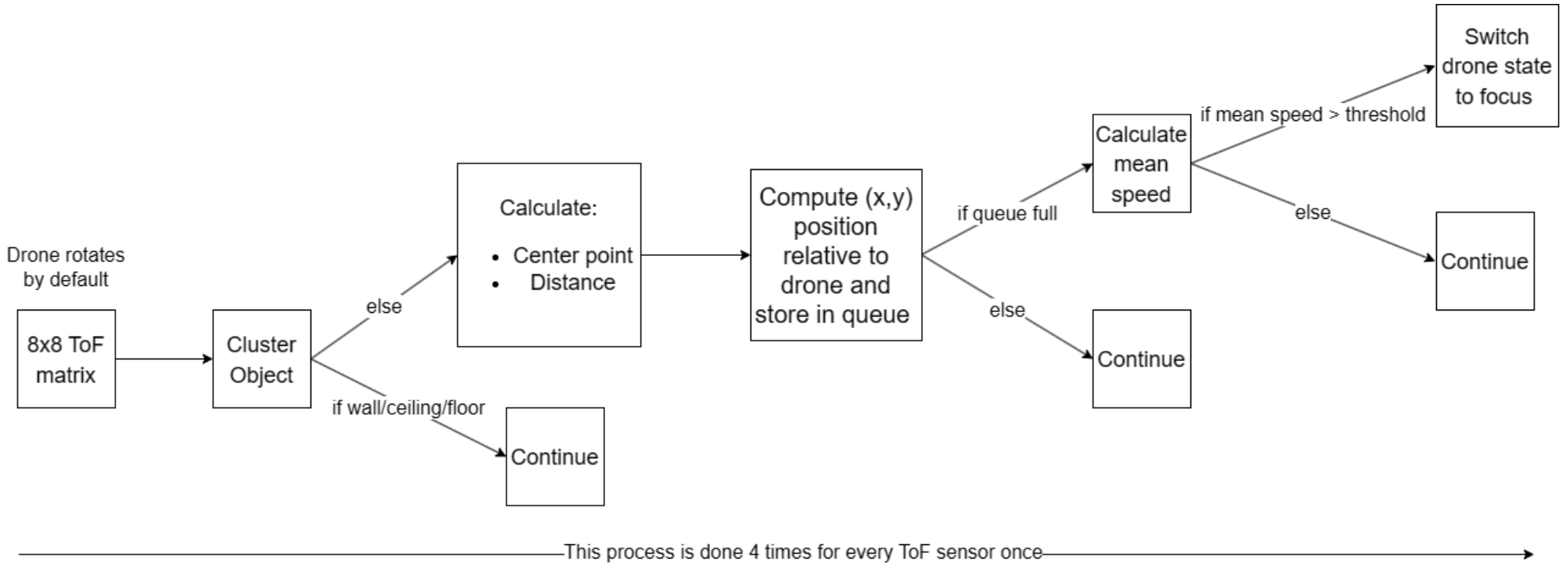
$k = 5$
$k_d = 1$
$k_i = 0.3$

$x = yaw$
$u = y\dot{a}w$

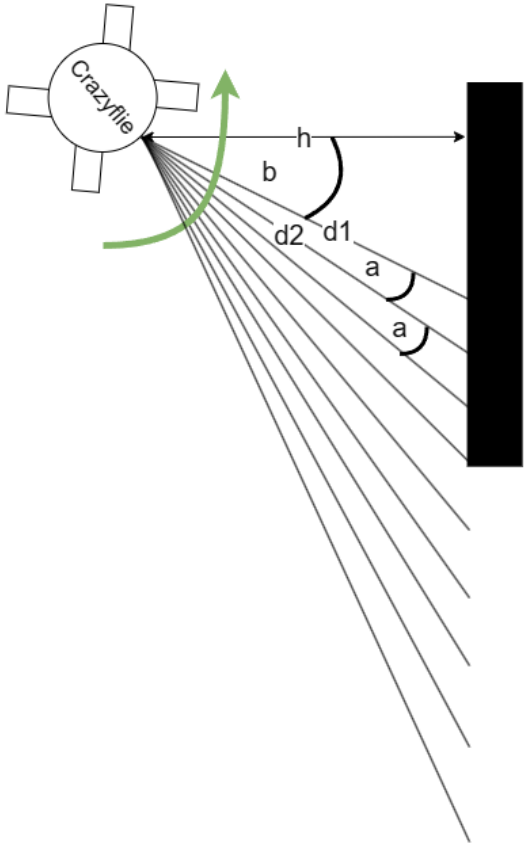
$A = 0\ B = 1$
$C = 1\ D = 0$

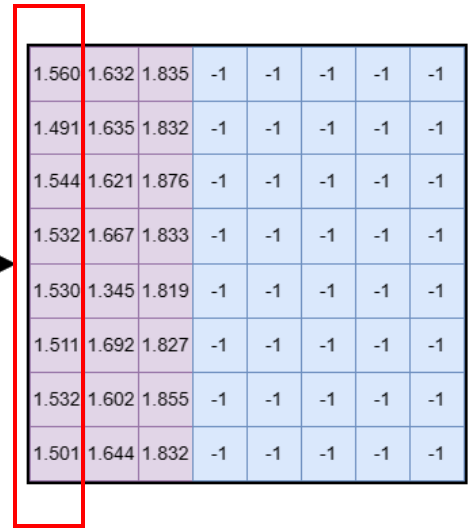


Additional Mapping



Additional Wall detection





1.560	1.632	1.835	-1	-1	-1	-1	-1
1.491	1.635	1.832	-1	-1	-1	-1	-1
1.544	1.621	1.876	-1	-1	-1	-1	-1
1.532	1.667	1.833	-1	-1	-1	-1	-1
1.530	1.345	1.819	-1	-1	-1	-1	-1
1.511	1.692	1.827	-1	-1	-1	-1	-1
1.532	1.602	1.855	-1	-1	-1	-1	-1
1.501	1.644	1.832	-1	-1	-1	-1	-1

$$h = d_1 * \cos(b)$$
$$h = d_2 * \cos(b + a)$$

$$\Rightarrow \cos(b + a) = \frac{d_1}{d_2} * \cos(b)$$

$$with\ c = \frac{d_1}{d_2}$$

$$\Rightarrow b = \arccos\left(\frac{\sin(a)}{\sqrt{-2c*\cos(a)+c^2+1}}\right)$$

$$\Rightarrow h = d_1 * \cos(b)$$

$$\Rightarrow d_3 = \frac{h}{\cos(b+2a)}$$

Additional Avoidance

4 time 8x8 ToF matrix

Convert into 32 sector probability of collission (PoC) array

Apply Smoothing

Get:

- maxPoC
- minPoc
- farest Direction

if maxPoC > 0.8

Direction regularization

New direction

Set new velocity

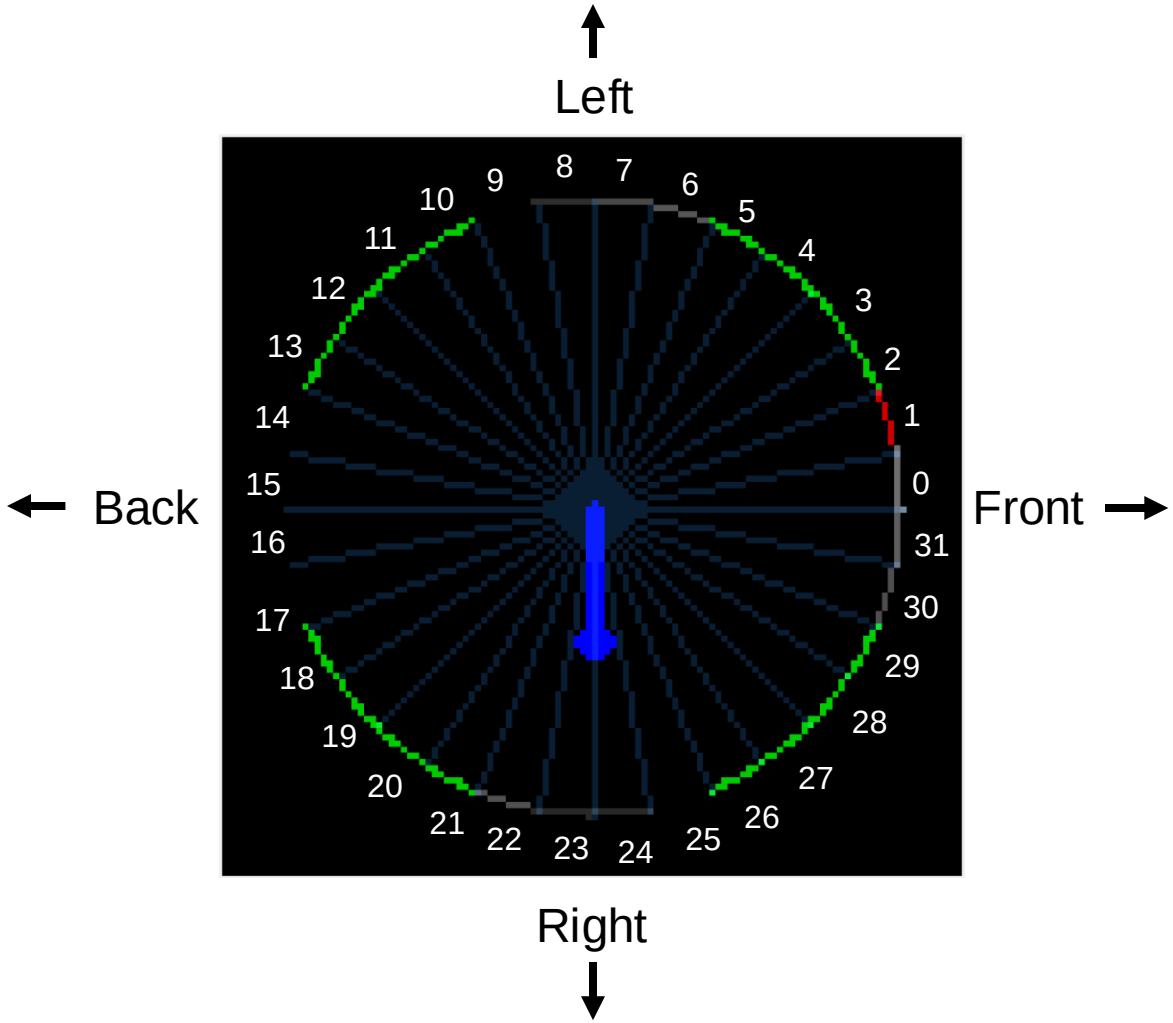
Same direction

Keep velocity same

if maxPoC < 0.8

Drone velocity = 0

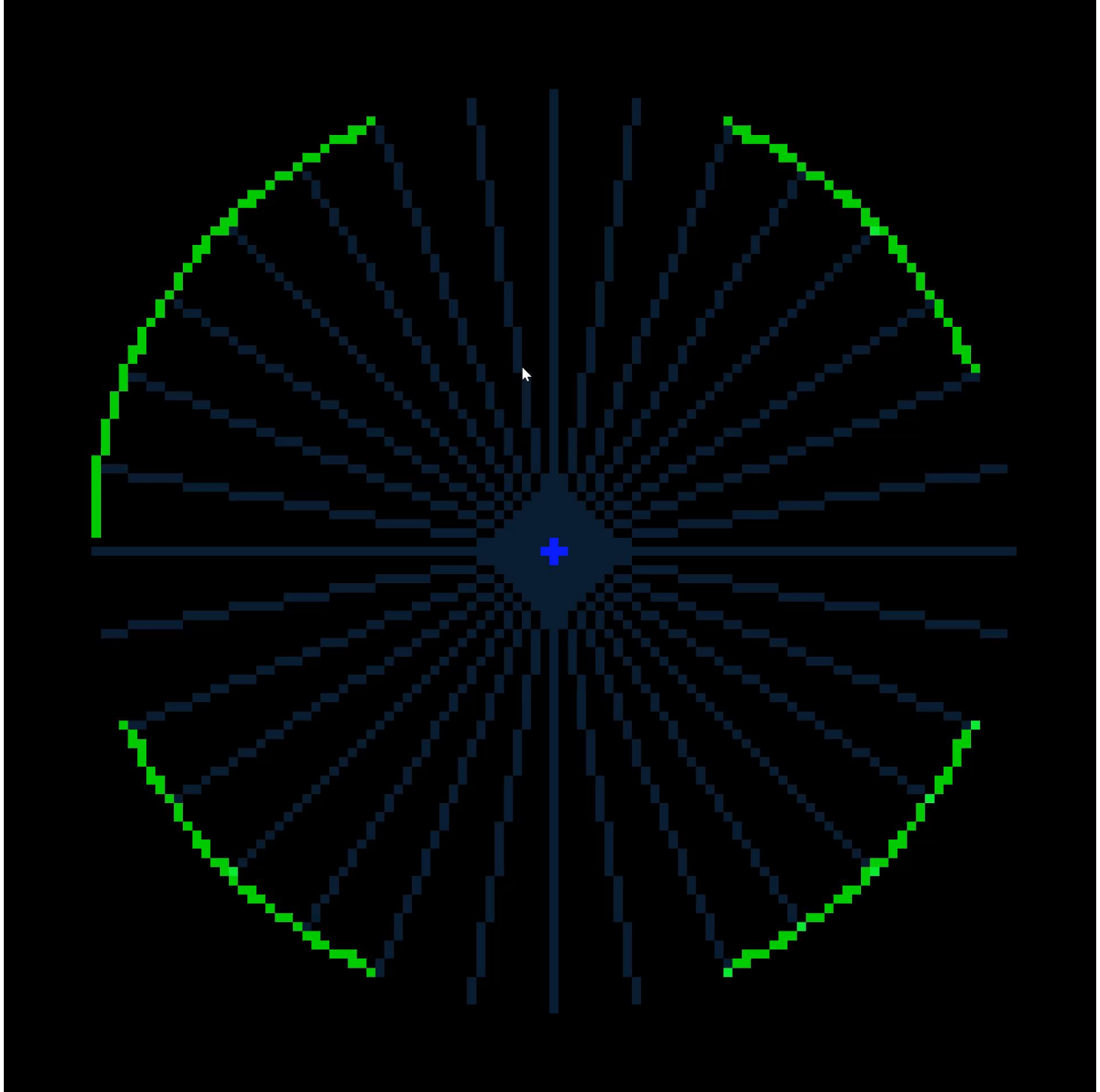
Additional Avoidance



Legend:

- Area which is not covered by sensor or invalid area
- Closest area
- Low probability of collision -> high probability of collsion
- Moving direction (short slow; long fast)
- Areal segments for discretization

ETH zürich



CENTER FOR PROJECT-BASED LEARNING

References

Figures:

- Fig. 1 Simultaneous Localization and Mapping (SLAM):
  - url: https://d33wubrfki0l68.cloudfront.net/a7664cf19de33b2c71a482629f27a0d70f715b77/6949d/images/blog/a-comprehensive-guide-to-convolutional-neural-networks-the-eli5-way.jpg
  - Online: 01.06.2023
- Fig. 2 Convolutional Neural Network (CNN):
  - url: Simultaneous Localization Mapping (SLAM): An Introduction (linkedin.com)
  - Online: 01.06.2023
- Fig. 3 Precise agriculture:
  - url: https://mapware.com/wp-content/uploads/Precision-Agriculture-Field-and-remote-sensing-2048x887.jpeg
  - Online: 01.06.2023
- Fig. 4 Package delivery:
  - url: https://th.bing.com/th/id/R.99553637c80620af3755ccfb5dabc45a?rik=MYc0d9O1%2b0ExvQ&riu=http%3a%2f%2fww1.prweb.com%2fprfiles%2f2019%2f05%2f17%2f16321309%2fIMG_4110_smaller.jpg&ehk=EVnlDYgMdtSIkZExBGvIdINvQf39I6w2VdcBXgSGYAE%3d&risl=&pid=ImgRaw&r=0
  - Online: 01.06.2023

References

Figures:

- Fig. 5 Bitcraze Logo:
  - url: Datasheet Crazyflie 2.1 - Rev 3 (bitcraze.io)
  - Online: 01.06.2023
- Fig. 6 Classification table:
  - url: https://www.91-cdn.com/pricebaba-blogimages/wp-content/uploads/2017/11/rsz_drone_comparison.png
  - Online: 01.06.2023
- Fig. 7 AI expansion deck:
  - url: https://www.exp-tech.de/media/image/f9/00/5d/crazyflie-ai-deck_2_600x600.jpg
  - Online: 01.06.2023
- Fig. 8 Flow deck:
  - url: https://www.bitcraze.io/wp-content/uploads/2017/07/flow_deck_585px-1.jpg
  - Online: 01.06.2023
- Fig. 9 Crazyflie 2.1:
  - url: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=9806701
  - Online: 02.06.2023
- Fig. 10 Test setup:
  - url: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=9806701
  - Online: 02.06.2023