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Wireless Ranging in Swarm Robotics

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Bachelor Thesis

Wireless Ranging in Swarm Robotics

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Sebastian Mai: *Wireless Ranging in Swarm Robotics*
Bachelor Thesis, Otto-von-Guericke-Universität
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1 Prior Art

1.1 The FINken Robot Platform

The FINken project aims to create a swarm of autonomously flying quadcopters to research swarm intelligence beheaviour on robots. Many algorithems in swarm intelligence are based on distance-values. On this occasion it is important to find a sensor that is capable to measure distances and to integrate it into the FINken robots.

source

1.1.1 Actuators and Dynamic

The FINken Robot is a quadcopter. Like most quadcopters the FINken Robots are propelled by four rotors that are directly attached to a brushless motor. In combination the motors can be controlled to change the direction of the thrustvector (pitch and roll), to change the overall amount of lift generated (thrust) and to change the orientation of the airframe (yaw). The speed of each motor is controlled by an the LisaMX 2.1 autopilot-board[1] using the opensource autopilot firmware Paparazzi[2].

put this subchapter into introduction

1.1.2 Environment

The FINken Robots fly in an area of 2m by 3m that can be expanded to about 4m by 3m and in 50cm to 1m height. The flight area is enclosed by netting and ultrasound-reflecting foil. It is possible to create virtual environmental factors by using a projector and an rgb-sensor mounted on top of the robots. This virtual environment can be used assign a certain task to the robot, e.g. finding the brightest spot.

1.1.3 Sensor Concept

1.1.4 Hardware interfering with ranging

There are different ranging technologies that might be used in a FINken quadcopter. However there are different components that can interfere with the new sensor that shall be integrated e.g. by disturbing the measurments made by the new sensor.

Sonar Sensors Sonar sensors to measure distances of the nearest object in four directions (front, back, left, right)

Motors Four brushless motors that may cause RF-interfercene and noise

Telemetry BTLE-/Zigbee modules to exchange data with the ground station

RC-Control 2.4GHz based Radio Control to manually control the robots

fink3?

Supply Lithium polymer batteries with nominally 6.6V output voltage that is converted to 5V and 3.3V by the power distribution hardware

weight

payload

Payload The overall weight of the copter in the current configuration is about g with about g headroom for additional equipment

Size The copter has a rotor to rotor distance of 10cm, and a sensor tower that is about 4cm by 4cm wide to use the existing mounting holes would be favourable

1.2 Evaluation of Existing Ranging Solutions

mehr fokus auf andere copter projekte

There are some technologies that can be used for ranging, however the usual application for most of those technologies in research is positioning. For that reason it is interesting to search for positioning applications that use range measurements, however many of those positioning technologies are base on other principles than multilateration[1]. [3]

The usual technologies used for ranging are based on time of flight measurments, signal strength, optical tracking, and phase diffence measurments in signals.

1.2.1 Indor Time of Flight

The obvious approach for replacing the GPS signal that is aviable outdoors is to use a simmilar approach indoors. http://robotics.eecs.berkeley.edu/ pister/290Q/Papers/Location/Lanzisera%20RF%20TOF%20WISES06.pdf states, that an accuracy of $2.6m_{RMS}$ was achieved indoors. With an operating area only $2m$ wide this approach is not suited for our robots. However this research is focused on using cheap sensor-nodes.

quellify

find commercial solutions with better accuracy

http://www.researchgate.net/profile/Bardia_Alavi/publication/224315086_Measurement_and_
Based_Ranging_in_Indoor_Multipath_Environments/links/0912f50b396c340971000000.pdf

Another approach to provide an indoor GPS-like solution is iGPS. http://www.nikonmetrology.com/de_EU/Produkte/Grossvolumige-Messaufgaben/iGPS/iGPS however is not ranging-based but uses angulation as underlying technology and is therefore useless to us. * IGPS http://porto.polito.it/2438175/2/IJAMT_iGPS_and_LT.pdf

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deka-wave

[1] The usual methods for positioning are: *multilateral*—which is what we are interested in because only ranging measurments are used, *multiangular*—which is no use to us, because angle measurements are used and by *orientating in a map* with different factors like beacon-positions–which is also no use to us.

1.2.2 Cricket / Active Bat

Quelle, Quelle

A very clever approach to ranging is used by ranging solutions like cricket and active bat. RF-Signals travel at the speed of light and therefore you need to be able to measure very short timings in time of flight scenarios. Sound however travels at a speed much slower than RF. Cricket and Active Bat use this to measure the time difference an RF-signal and an ultrasound pulse need to travel from transmitter to reciever to calculate the range between two sensor nodes.

thunderstorm and ligthning very very frightning

accuracy / price, moving objects, medium access (number of nodes)

There are two big problems with this approach that stem from the current setup of the FINken-Robots. The FINken Robots use ultrasound sensors to measure the distances to nearby objects. Those technologies would interfere with the ultrasound sensors already used and a replacement would be needed.

measure noise, PWM-frequency of speedcontrollers

Another problem is the noise created by motors and propellers. The sound made by the quadcopters is not ending in the hearable spectrum but also extends to the ultrasound range.

1.2.3 RSSI-based ranging

A property that can be used to do RF-based ranging is signal strength. The further the source of the signal is away the weaker the signal gets. RSSI-based ranging is done for serveral different technologies: Bluetooth, WLAN, RFID– There are even approaches using maps created of different RSSI-ranging sources. http://www.gnss.com.au/JoGPS/v9n2/JoGPS_v9n2p122-130.pdf

quelle

quelle

quelle

quellify

The main factor that rules out RSSI-based ranging is that radio-waves are not propageted equally in every direction. Antenna-orientation might have a much bigger impact on signal strength than distance. Additionally radio waves might be weakend when travelling through the FINken robots and by doing so passing wires and electronic components.

typical propagation pattern picture

1.2.4 External Tracking

1.2.5 Atmel RTB, Dresden Elektronik, Meterionic

2 Concept

2.1 Hardware

2.1.1 Ranging Hardware

2.1.2 Autopilot

2.2 Interconnect

There are diffrent solutions to connecting the ranging board to the Paparazzi autopilot.

2.2.1 Pulse width modulation / Analog value

Using a single GPIO pin or analog value is completely impractical, but a good example to explain the problems the honest solutions need to address. First of all there is a limited number of GPIO or ADC-pins on both boards. On the autopilot board those pins are quite rare, especially because they cannot be shared easily between components. The second problem is that we do not only need to read a range value from the sensor but we also need to tell the sensor which value to fetch. Therefore some kind of bidirectional communication between autopilot and sensor need to take place. The big advantage of using a GPIO pin would be that only one single wire[1] would be needed to connect autopilot and sensor.

2.2.2 UART

The "Universal Asynchronous Receiver/Transmitter"-Protocol uses two wires to establish communication between devices. [14]

The Disadvantage of UART-style Protocols is that it is a bidirectional connection. That two pins are needed on sender and reciever side and if another device should be connected two new pins are needed. On the Lisa/MX autopilot there are 4 dedicated UART connections that might be used, but already 3 of them are used.

2.2.3 SPI

2.2.4 CAN bus

2.2.5 I2C

I2C is a two wired bus protocol that can be used to connect multiple slave devices to one master device. There already are multiple sensors connected to the autopilot via I2C. All of the ultrasound-sensors and also the optionalcolorsensor use I2C to communicate with the autopilot. The autopilot board also supports to have two independent i2c-networks.

Especially the fact that there already is a sensor network on the Finken makes it the best choice as a communication protocol for the new sensor.

problem: slaves can block the bus

[1] Plus two wires for voltage supply

3 Implementation

Somehow the sensordata needs to find its way into the control loops of the autopilot. We have established that i2c is the hardware solution to transmit the data.

Now it is important to pin down in which way the measurements get triggert and when and how the result is transmitted back.

3.1 Communication Protocol

There are two possible ways to talk to the sensor. You can define independent commands to start a measurement and retrieve data. The obvious disatvantage of this method is, that there is a bit of communication overhead and the master device won't read the data from the sensor as soon as it is possible—the master might event start a new measurement without even reading the result at all.

The other way to do things is that the slave device writes the data onto the bus as soon as it is arriving. This way of sending results however has disatvantages that ar e far worse then reading measurements a bit later and even missing some measurements. Those disatvantages are caused by the way i2c handles slave writes.

polling vs writing to the bus, when data is available

"TWI", "Phillips-I2C", "..."

3.2 Paparazzi Module for Ranging

Treiber für Ranging

(optional)Treiber für Pseudo GPS

3.3 Python Scripts

For testing the sensor nodes and also for aquiering the data for evaluating the sensors I set up a RapsberryPi minicomputer as i2c master. Using this setup for testing has proven really effective even before integrating attaching the sensor nodes to one of the finken robots. Python might also be a very powerfull tool to prototype mathematical processing of the sensor inputs like filtering and fusion of different ranging results.

4 Evaluation

4.1 Robustness of Implementation

4.1.1 Bus hangup

4.1.2 i2c errors per time

4.1.3 Integration Test for Quadcopter

4.2 Ranging Accuracy

4.2.1 Influence of DQF on Range Values

One value the ranging api provides is the DQF[1]-value. It is reasonable to expect a huge amount of scatter for lower DQF values. As Figure 4.1 shows this is not how the range value behaves.

For the values measured with 1m real distance we can see that the values measered with lower quality do not have the same mean value as those with higher quality. Also values measured with lower quality are closer to each other than those with higher signal quality. As long as we only look at the values taken at 1m real distance it seams like we could be able to improve the range estimate by including the dqf value into the computation of the distance. To

[1]Data Quality Factor

do that this behaviour would need to be stable accross different distances, i.e. no matter if the measurement is taken at 1m or 3m distance the when the dqf is low the measured range is lower and if dqf is high the measured range is higher.

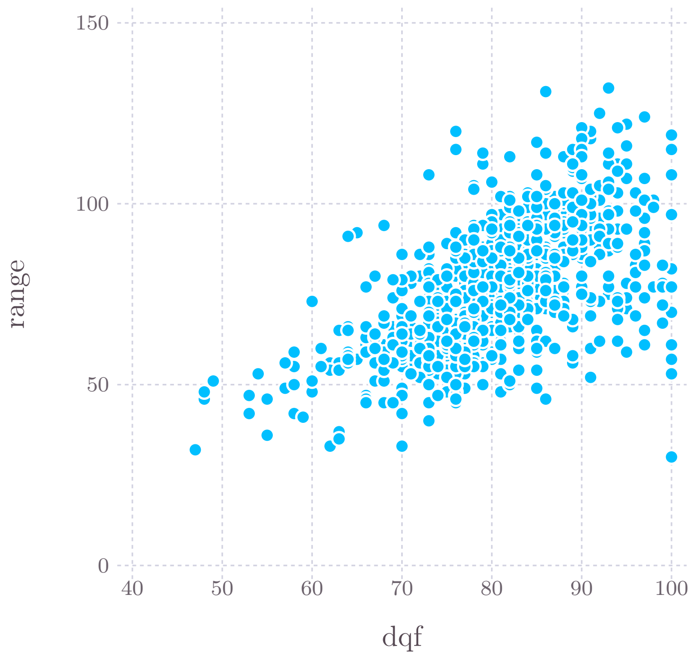

Figure 4.1: 1000 values measured at 1m distance

Figure 4.2 shows measurements taken at different distances. The values for further distances have far more noise than values for lower distances.

Porvide variance/mse values for all ranges

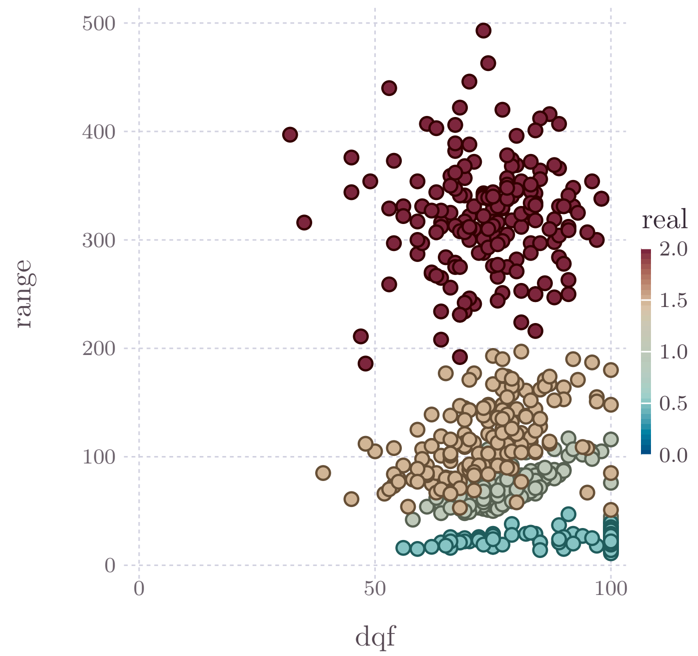

Figure 4.2: values measured at 0.5 to 2m real distance

4.2.2 Antenna Orientation

(diversity, no diversity) * (parallel, perpendicular)

4.2.3 Influence of Distance

4.2.4 Orientation of Devices

4.2.5 Moving Nodes

4.2.6 Ranging on FINken Robots

4.3 Properties of a Distance Function

The ranging sensor on the FINken robot shall be used to provide a distance between two quadcopters, similar to a distance measure used in swarm intelligence algorithms. In the pure mathematical sense a distance function has to fullfill certian properties.

If $f(x, y)$ is a distance function it has to have the following properties.

$$f(x, y) \geq 0 \tag{4.1}$$

$$f(x, y) = 0 \iff x = y \tag{4.2}$$

$$f(x, y) = f(y, x) \tag{4.3}$$

$$f(x, z) \leq f(x, y) + f(y, z) \tag{4.4}$$

Of course the value measured by any real sensor will not completly accomplish to satisfy those conditions. For use in swarm robotics it is therefore very interesting to know in which way the range values break the pattern of a mathematical distance function.

4.3.1 Non-negativity and Coincidence

4.3.2 Symmetry

4.3.3 Triangle Inequality

4.4 Conclusion

5 Future Work

5.1 Formation Flying using Swarm Behaviour

5.1.1 Direction

5.2 Point to Point vs. Multicast-Ranging

5.3 Flying with Pseudo-GPS

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