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Wireless Ranging in Swarm Robotics



FAKULTÄT FÜR
INFORMATIK

Some Department

Bachelor Thesis

Wireless Ranging in Swarm Robotics

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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 behaviour on robots. Many algorithms 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 intro-
duction

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 measurements 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-interference 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** The overall weight of the copter in the current configuration is about g with about g headroom for additional equipment

payload **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 based on other principles than multilateration¹. [3]

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

¹The usual methods for positioning are: *multilateral*—which is what we are interested in because only ranging measurements 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.

1.2.1 Indor Time of Flight

The obvious approach for replacing the GPS signal that is aviable outdoors is to use a simmlar 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

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

find commercial solutions with better accuracy

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

quellify

quellify

deka-wave

1.2.2 Cricket / Active Bat

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.

Quelle, Quelle

thunderstorm and lightning very very frightening

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.

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

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.

measure noise, PWM-frequency of speedcontrollers

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 several 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

typical
propaga-
tion pattern
picture

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

1.2.4 External Tracking

1.2.5 Atmel RTB, Dresden Elektronik, Meterionics

2 Concept

2.1 Hardware

2.1.1 Ranging Hardware

2.1.2 Autopilot

2.2 Interconnect

There are different 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 wire¹ 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]

¹Plus two wires for voltage supply

The Disadvantage of UART-style Protocols is that it is a bidirectional connection. That two pins are needed on sender and receiver 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.

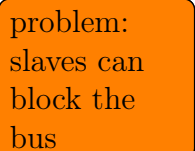
2.2.3 SPI

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 optional color sensor 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

3 Implementation

3.1 Communication Protocol

3.2 Paparazzi Module for Ranging

3.3 Python Scripts

polling vs
writing to
the bus,
when data
is available

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

Treiber für
Ranging

(optional) Treiber
für Pseudo
GPS

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 Antenna Orientation

4.2.2 Influence of Distance

4.2.3 Orientation of Devices

4.2.4 Moving Nodes

4.2.5 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 fulfill certain properties.

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

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 completely 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

Bibliography

- [1] Lisa/MX V2.1 Autopilot.
- [2] PaparazziUAV.
- [3] Multilateration, July 2015. Page Version ID: 670629691.
- [4] N.A. Alsindi, B. Alavi, and K. Pahlavan. Measurement and Modeling of Ultrawideband TOA-Based Ranging in Indoor Multipath Environments. *IEEE Transactions on Vehicular Technology*, 58(3):1046–1058, March 2009.
- [5] Johann Borenstein, Hobart R. Everett, Liqiang Feng, and David Wehe. Mobile robot positioning-sensors and techniques. Technical report, DTIC Document, 1997.
- [6] Pierre-Jean Bristeau, François Callou, David Vissiere, Nicolas Petit, and others. The navigation and control technology inside the ar. drone micro uav. In *18th IFAC world congress*, volume 18, pages 1477–1484, 2011.
- [7] Center for History and New Media. Zotero Quick Start Guide.
- [8] Slawomir Grzonka, Giorgio Grisetti, and Wolfram Burgard. Towards a navigation system for autonomous indoor flying. In *Robotics and Automation, 2009. ICRA'09. IEEE International Conference on*, pages 2878–2883. IEEE, 2009.
- [9] Mike Hazas and Andy Hopper. Broadband ultrasonic location systems for improved indoor positioning. *Mobile Computing, IEEE Transactions on*, 5(5):536–547, 2006.
- [10] Ling Pei, Ruizhi Chen, Jingbin Liu, Heidi Kuusniemi, Tomi Tenhunen, and Yuwei Chen. Using inquiry-based Bluetooth RSSI probability distributions for indoor positioning. *Journal of Global Positioning Systems*, 9(2):122–130, 2010.
- [11] Nissanka Bodhi Priyantha. *The cricket indoor location system*. PhD thesis, Massachusetts Institute of Technology, 2005.

- [12] Dan Stoianovici, Louis L. Whitcomb, James H. Anderson, Russell H. Taylor, and Louis R. Kavoussi. A modular surgical robotic system for image guided percutaneous procedures. In *Medical Image Computing and Computer-Assisted Intervention—MICCAI’98*, pages 404–410. Springer, 1998.
- [13] Zheng Wang, Luca Mastrogiacomo, Fiorenzo Franceschini, and Paul Maropoulos. Experimental comparison of dynamic tracking performance of iGPS and laser tracker. *The International Journal of Advanced Manufacturing Technology*, 56(1-4):205–213, September 2011.
- [14] Neal T. Wingen, Eric Lai, Arnaud Moser, Ronald De Vries, and Ramaswamy Subramanian. *Automatic upgradeable UART circuit arrangement*. Google Patents, May 2004. US Patent 6,742,057.
- [15] Jun Wu, Jigui Zhu, Linghui Yang, Mengting Shen, Bin Xue, and Zhexu Liu. A highly accurate ultrasonic ranging method based on onset extraction and phase shift detection. *Measurement*, 47:433–441, January 2014.