Ultrasound-based Cooperative Indoor Localization for Robotic Applications

Extended Abstract

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ABSTRACT

We present a real-time indoor localization system which performs cooperative localization. Our system is primarily designed for the use in autonomous robotic applications and will be deployed for the localization of team and opponent robots in the Eurobot contest. It features a custom hardware architecture that performs ranging measurements based on ultrasound signals. Infrared signals are used for synchronization of the sensor nodes during the Eurobot contest, while an RF synchronization option is available to cover larger areas. The 2018 Eurobot contest rules allow the installation of four anchor nodes at the perimeter of the playing area, mobile nodes on two team robots and additional sensor nodes on the opponent robots. This provides a typical scenario with four mobile nodes where cooperative localization is beneficial. We enable cooperative localization through ranging measurements between all four mobile nodes and a communication protocol that allows for the exchange of the measurements between the nodes. The cooperation enables the mobile nodes to perform localization when an insufficient number of anchor nodes is visible. It also improves the accuracy in situations with good anchor visibility.

KEYWORDS

Cooperative Positioning, Cooperative Localization, Ultrasound, TOA, TOF, Robotics, Eurobot Contest

1 INTRODUCTION

Autonomous robots in indoor environments generally require highly accurate localization and high update rates in order to be able to perform manipulation tasks and collision avoidance. With a limited budget, this makes the design of the localization system for the robotic units used in the Eurobot contest [3] a particularly challenging task. Extremely precise solutions, such as commercial laser scanning sensors, often have to be ruled out due to excessive costs. In the past many participants solely relied on a solutions based on odometry, that operate on the drive system of the robot. Additionally, to achieve improved results over the course of a match, a number of absolute localization systems have been proposed [1, 2, 4–6, 8, 9]. Most of these system, which are specially designed for the use in the Eurobot contest, either rely on infrared or ultrasonic signals. The measurements are either angle or range measurements between a unit on the robot and stationary beacons located at the border of the playing field. A frequently used approach is a design with a combination of infrared and ultrasonic signals. This enables a simple way of synchronization as the propagation speed of the infrared pulses can be assumed to be infinite relative to the ultrasonic wave. The ultrasonic signal is then used for ranging, which directly results from time of flight (TOF) measurements. Our presented system uses the same approach and primarily determines the locations from multilateration with respect to stationary beacons. The hardware components, used for the stationary beacons as well as for the mobile nodes, are shown in Fig. 1. A second hardware version replaces the infrared synchronization with radio frequency (RF) signal based synchronization. This helps to reliably cover larger areas.

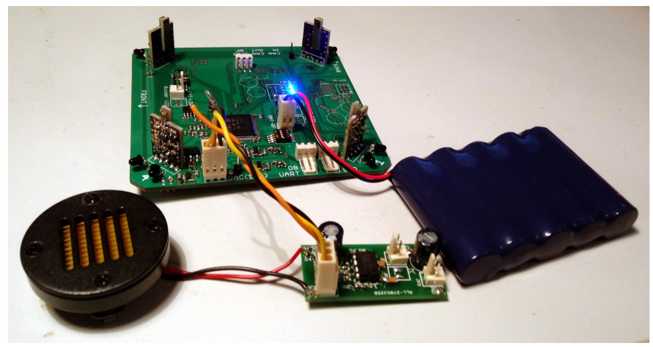

Figure 1: The components of the ultrasonic sensor used for the anchor and mobile nodes.

2 COOPERATIVE LOCALIZATION

A rather recent trend in localization research is so called cooperative localization, wherein the mobile nodes take measurements between each other and are able to communicate. This has been shown to improve the results and robustness of the system [7, 12] To the best of our knowledge, this approach has not yet been implemented in the Eurobot contest before. Furthermore, there is fewer literature presenting cooperative implementations, such as [10, 11], than implementations solely relying on measurements from fixed anchors. This is presumable caused by the increased complexity resulting from the communication requirements, which rapidly grow with the number of mobile nodes in the system. Our system implements cooperation for up to four mobile nodes and can handle up to ten simultaneously active nodes, including mobile and anchor nodes, in the same room. In every update cycle the master node first sends a synchronization signal, which is followed by an ultrasound ranging pulse from all nodes. Each mobile node then obtains ultrasound range measurements from the received ultrasound signals of all visible anchor points and each of the up to three other mobile nodes. A location update is calculated internally by each mobile node, using all available measurements and a Newton method based estimator. Each mobile node then broadcasts its own location estimate and is thereby serving as an additional auxiliary anchor. The additional information is taken into account in the next estimation update of the other nodes.

3 HARDWARE ARCHITECTURE AND SYSTEM PARAMETERS

The presented localization system features an embedded architecture based on a STM32F407 microcontroller. Ultrasound signals are transmitted with a Daytonaudio AMT Mini-8 Motion Transformer Tweeter and incoming ultrasound signals are recorded with Knowles SiSonic MEMS microphones. The circuit board design contains four microphones, one in each corner, together with 2 infrared LEDs for synchronization as seen in Fig. 1. Furthermore, a nRF24L01 based RF module is available to communicate between the mobile nodes and as a secondary way of synchronization. The wireless module is also used to collect measurements taken by the anchors and perform a self-localization, i.e. automatic calibration of the system during the setup phase. This requires a number of well known reference points in the target area.

As for the ranging signals, ultrasound signals with a bandwidth of 1 kHz on different carrier frequencies around 40 kHz are used. This enables simultaneous transmission of all signals on different frequencies. The waveform consists of 10 ms long unmodulated pulses followed by a guard interval. All signal processing for the TOF ranging and location estimation is performed on the microcontroller. The location estimates of a single node can be streamed through a UART connection to a host computer and displayed in real-time. RF communication signals are broadcasted using a time division duplex scheme. The resulting update rate of the system is up to 20 Hz. As a means of improving the system performance and abilities in the future, the circuit boards have been prepared for the mounting of a Bosch BNO055 inertial measurement unit.

4 RESULTS

Initial results have been recorded in a minimal setup, as shown in Fig. 2, by manually moving one mobile node along a reference line and having a second resting mobile node for cooperation. The observed precision of the location estimates for a resting mobile node is in the order of ± 1 cm. In moving scenarios the observed absolute localization errors are sometimes slightly higher. This can be attributed to multipath reflections, the quality of the calibration, the visibility of the anchors, the movement velocity, interference and other factors such as dilution of precision.

5 CONCLUSION

We have presented a robotic localization system that is able to perform cooperative localization. The system firmware is able to cope with a varying number of visible nodes in real-time and can compensate situations with insufficient anchor visibility using other mobile nodes as additional auxiliary anchors.

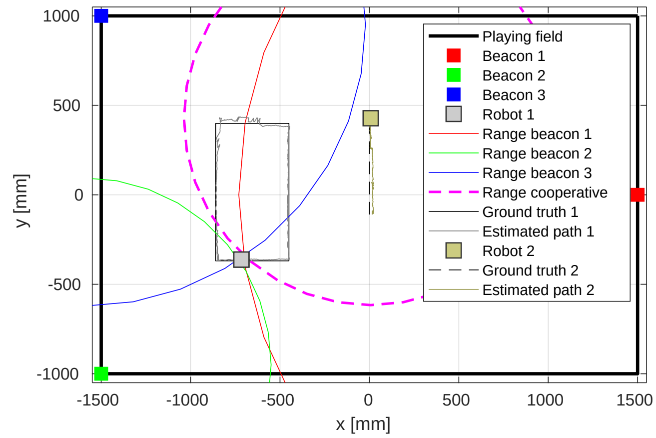

Figure 2: Cooperative measurement result recorded on the typical Eurobot playing field with a minimum setup of three beacons and two mobile sensor nodes.

6 ACKNOWLEDGMENTS

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REFERENCES

[1] Oliver Bittel and Michael Blaich. 2011. Mobile robot localization using beacons and the Kalman filter technique for the Eurobot competition. In *International Conference on Research and Education in Robotics*. Springer, 55–67.

[2] Valentin Durst, Daniel Hagel, Jan Vander, Michael Blaich, and Oliver Bittel. 2011. Designing an omni-directional infrared sensor and beacon system for the eurobot competition. In *International Conference on Research and Education in Robotics*. Springer, 102–113.

[3] Eurobot Association website. Accessed: February 2018. International Students Robotic Contest. http://www.eurobot.org/.

[4] Tran Duy Khanh, Zidek Martin, Benda Jan, Kubias Jiri, and Sojka Michal. 2007. Autonomous robot running Linux for the Eurobot 2007 competition. In *Proceeding of the 9th Real-Time Linux Workshop, Linz, Austria*.

[5] Milan Lukic, Miodrag Brkic, and Jovan Bajic. 2011. An autonomous robot localization system based on coded infrared beacons. In *International Conference on Research and Education in Robotics*. Springer, 202–209.

[6] Brkić Miodrag, Milan Lukić, Jovan Bajić, Bojan Dakić, and Milorad Vukadinović. 2012. Hardware realization of autonomous robot localization system. In *MIPRO, 2012 Proceedings of the 35th International Convention*. IEEE, 146–150.

[7] Neal Patwari, Joshua N Ash, Spyros Kyperountas, Alfred O Hero, Randolph L Moses, and Neiyer S Correal. 2005. Locating the nodes: cooperative localization in wireless sensor networks. *IEEE Signal processing magazine* 22, 4 (2005), 54–69.

[8] Marek Peca. 2009. Ultrasonic localization of mobile robot using active beacons and code correlation. In *International Conference on Research and Education in Robotics*. Springer, 116–130.

[9] Vincent Pierlot and Marc Van Droogenbroeck. 2014. BeAMS: a beacon-based angle measurement sensor for mobile robot positioning. *IEEE Transactions on Robotics* 30, 3 (2014), 533–549.

[10] Ioannis M Rekleitis, Gregory Dudek, and Evangelos E Milios. 2002. Multi-robot cooperative localization: a study of trade-offs between efficiency and accuracy. In *Intelligent Robots and Systems, 2002. IEEE/RSJ International Conference on*, Vol. 3. IEEE, 2690–2695.

[11] J Spletzer, Aveek K Das, Rafael Fierro, Camillo J Taylor, Vijay Kumar, and James P Ostrowski. 2001. Cooperative localization and control for multi-robot manipulation. In *Intelligent Robots and Systems, 2001. Proceedings. 2001 IEEE/RSJ International Conference on*, Vol. 2. IEEE, 631–636.

[12] Henk Wymeersch, Jaime Lien, and Moe Z Win. 2009. Cooperative localization in wireless networks. *Proc. IEEE* 97, 2 (2009), 427–450.