Localization based on wireless sensor network

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Abstract - It is required for any autonomous or semi-autonomous robot, that the robot knows its own location in order to navigate and maneuver safely. This is the case for ground based robots as well as airborne robots, but in the case of airborne robots like unmanned aerial vehicles (UAV) the need to know location expands from two dimensions to three dimensions because of the altitude level. This project investigates a few ways to improve on a previously developed system for localization in three dimensions. It is investigated whether high precision pressure sensors can improve the accuracy of the estimated position by difference of pressure. A solution allowing fixing the anchors flat on any surface without jeopardizing the result is also proposed.

Introduction

The main objective of this project, has been to determine whether a highly sensitive pressure sensor on each node of the localization system, could be used to increase the accuracy of the position estimate. This could be the case through a better height estimate courtesy of difference of pressure on the tags and anchors in the system. Furthermore it has been investigated whether a ground plane behind the antenna, would eliminate the need for each node to be 15 cm from all obstacles as described in the datasheet of the ranging modules in use [1].

Previous Work

The localization system used in this project has been developed during a previous project [2], where a basic three dimensional localization was shown as a proof-of-concept of the technology. The system consists of at least four anchors and a tag equipped with DWM1000 modules, allowing precise time of flight ranging, in order to do trilateration. This system did however turn out to come with some limitations, such as the need for all the nodes to be positioned at a minimum distance of 15 cm from all obstacles and a rather jumpy height estimate of the system, in the case where all the anchors are placed in the same Z-plane.

Implementation

For this project a new set of anchors and tags has been developed, with the addition of a battery charging circuit, a sensitive pressure sensor and a smaller Cortex-M0 processor for the anchors, allowing less power consumption as well as USB programming.

Pressure Sensor

To include a pressure sensor into the existing nonlinear least squares implementation of the system, the underlying set of equations must be expanded. It was chosen to test only the approach of using one extra equation, containing information of all the anchors pressure measurements combined and then compared with the pressure measurement of the tag. This approach was chosen mainly because it would lead to the smallest computational increase compared to no pressure compensation. The basic idea, is to calculate the altitude above sea level of all the pressure measurements by

$$ASL(p) = (1 - \frac{p}{1013.25}^{0.190263}) \cdot 44330.8 \qquad [m] \tag{1}$$

This way it is possible to average the altitude above sea level of the fixed anchors, in order to find the difference between the actual height of the anchors and the height calculated from the pressure. The same procedure could be done for the tag, with the unknown being the actual height, for which it would be possible to solve. The equation to be included in the set of equations for the nonlinear least squares approximation would then be given as:

$$ALS(P_0) - G^T A_0 - ALS(M_p) + G^T c = 0 \tag{2}$$

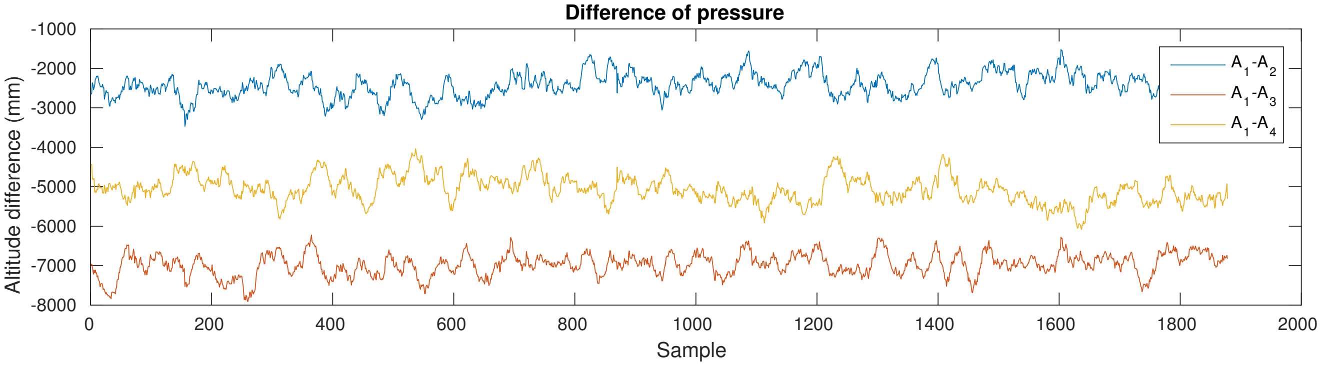

Figure 1: Difference of altitude calculated through the pressure of four anchors. Difference can be seen to vary around a meter, making the difference of pressure an nonviable method of getting a more accurate estimate.

with M_p being the mean of the pressure measurements from the anchors, P_0 being the pressure measurement of the tag, A_0 being the position of the tag, c being the average of the positions of the anchors and $G = [0\,0\,1]^T$ being a simple vector to select only the height part.
The pressure equation is weighted by a constant W, allowing to make the pressure weigh more or less than the distance measurements in the final position estimate. From the set of N+1 equations, it is then possible to calculate a performance index to minimize given by:

$$\begin{aligned} S(A_0) = &\sum_{i=1}^{N}[(A_i - A_0)^T(A_i - A_0) - r_i^2]^2 \\ &+ W(ALS(P_0) - G^T A_0 - ALS(M_p) + G^T c) \end{aligned} \tag{3}$$

with r_i being the distance measurement between the i'th anchor, A_i, and the tag. This optimization problem can be solved in numerous ways. As stated already it has been chosen to solve it through a nonlinear least squares approximation in this case. Specifically the nonlinear least squares algorithm has been chosen to be the *Levenberg-Marquardt* algorithm, as this is able to solve the set of equations and it is fairly easy to implement in C at a later stage.

Ground Plane

In order to allow mounting the anchors of the system flat on eg. the ceiling or a wall, it was been investigated whether it would be possible to add a ground layer underneath the antenna to overcome the limitation of the DWM1000 modules of needed at least 15 cm to all obstacles when mounting. This limitation is in place in order to avoid as much variation in the reflected signals coming from behind the antenna as possible. To test the proposed solution, a test setup has been created, in where a tag is fixed at one end of a wood beam and two anchors, one with the proposed solution and one without, at the other end of the beam. A sketch of the combined setup can be seen in figure 2.

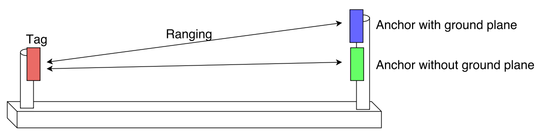

Figure 2: Test setup to evaluate the proposed shielding of background antenna noise.

With this test setup the properties of the system could be investigated in different situations, without the risk of changing the actual distance between the tag and anchors.

Results

The purpose of this project has been to investigate whether pressure sensors could be used to heighten the quality of the position estimate, as well as investigate ways of fixing anchor points flat on ceilings and walls without having disruptive reflections ruining the system.

Pressure Sensor

The pressure sensors turned out to contain way to much uncorrelated noise to use for this. The individual pressure sensors contains measurement noise equivalent to $10 - 20$ cm, which in itself would not be devastating for this application. Unfortunately the sensor signals also contain a low

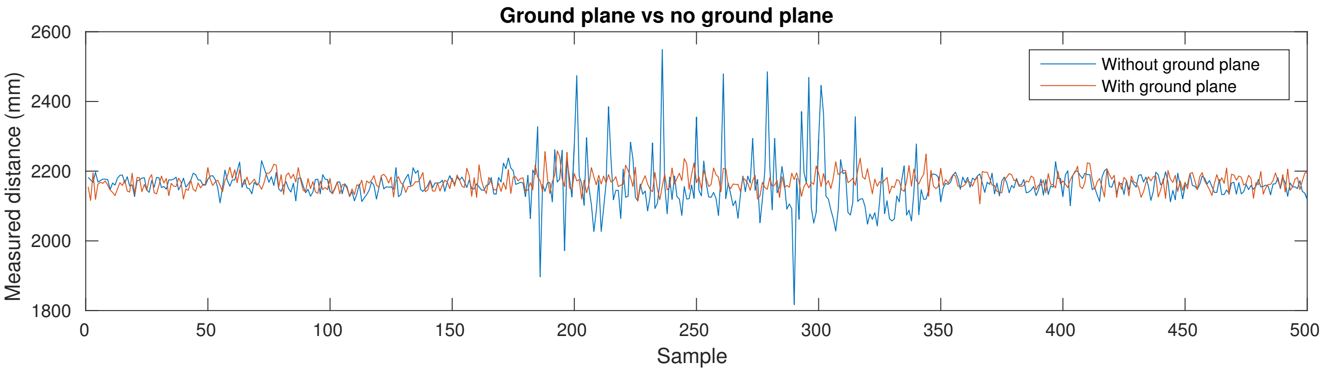

Figure 3: Distance measurements of two anchors, one with ground plane behind the antenna and one without. Both affected by the same disturbance behind the anchors.

frequency component that seems to wander ±50 cm, in a totally uncorrelated fashion if comparing multiple equivalent sensors. A simple difference comparison of the pressure sensors can be seen in figure 1, where the best case expected outcome should have been a constant difference between the sensors, meaning that even though the pressure of the room changes, the multiple sensors would be able to compensate. As it can be seen on figure 1 however, the difference between the sensors varies about one meter, meaning that the difference of pressures are useless in regards to obtaining a height estimate within the target of 10-20 cm.

Ground Plane

The proposed solution of extending the ground plane underneath the antenna of the anchors, in order to avoid disturbing reflections from behind, has proven much better results than the pressure sensor. The difference between an anchor with the ground plane fix applied and one without can be seen in figure 3. It can be seen how a disturbance in the form of waving a large metal sheet behind the antenna is affecting the two distance measurements. It can be seen on figure 3, how the disturbance is fully shielded by the proposed ground plane solution.

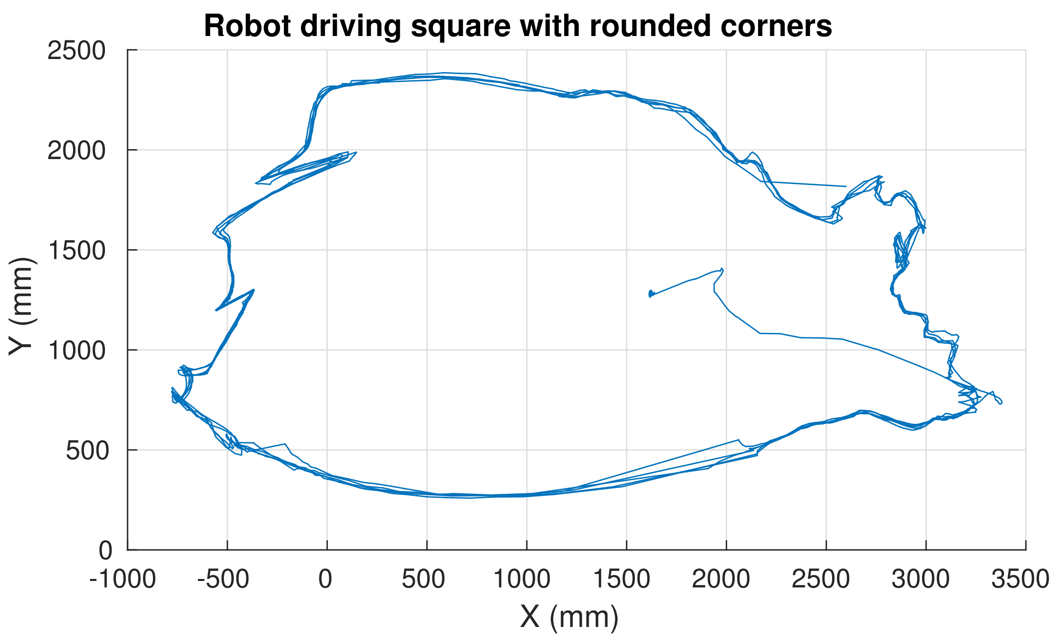

Figure 4: Position estimate of small robot driving square with rounded corners. Estimated position of each round can be observed as being very close to the other rounds, meaning measurements are very repeatable.

In figure 4, the combined system can be seen evaluated by a mobile robot driving along a line in the shape of a square with rounded corners. The results of the test is very similar to the tests performed previously with large metal sheets behind the anchors to shield from behind and also similar to the tests performed with the anchors positioned 20 cm from all obstacles [2].

The results are however still nothing like the actual square, one could wish for. The reasons for this and the potential solutions can be many and will have to be investigated further in future project work, for the system to reach its full potential.

Discussion

During this project it has been ruled out to use a pressure sensor to obtain a more accurate position estimate through sensor fusion. The only real advantage of having the pressure measurements available with regards to estimating position in three dimensions, would be to rule out potential dualities in the solution of the nonlinear least squares estimate. It has however been decided, that this small advantage is not worth the extra cost and complexity added by the pressure sensor.

Conclusion

All the tests evaluated on the system has proven, that the distance measurements and thus the position estimate has an extremely high repeatability, which means that even though the position estimate is not always equal to the actual absolute position of the tag, the estimated position always evaluates to the same estimate under the same conditions. This leads me to conclude that the error in the estimated positions are not caused by noise in the distance measurements and that it thus might be possible to calibrate the system to compensate for the error.

Future Work

Working on with the system there is enough to work on, including finding the actual cause of the wrong position estimates as the main priority, introducing *mesh-ranging* into the system to allow all nodes in the system to range with each other, and not just tag to anchor. This would also eliminate the need for measuring the position of the anchors by hand. Furthermore it would be interesting to use either an ultrasonic sensor or an infrared sensor to obtain a precise height measurement instead of the proposed pressure solution. It would also be interesting to fuse the output estimate of this system with an IMU and the actuator inputs in a Kalman filter to obtain a truly accurate position of a drone.

References

[1] DecaWave. *DW1000 User Manual*. URL: `http://www.decawave.com/support/download/file/nojs/692`.

[2] Mathias Koch and Nicolai Sahl-Tjørnholm. "In-door Localization based on Ultra Wide Band Distance Sensor". In: (2015).