A POSTURE ESTIMATION SYSTEM FOR UNDERGROUND MINE VEHICLES

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ABSTRACT

Platform pose is a key requirement for autonomous systems. The severe natural conditions and complex terrain of underground mines diminish the performance of classical localization systems. This paper proposes a pose (localization and orientation) estimator that utilizes ultrasonic and electromagnetic signals to facilitate a time-of-flight (TOF) based trilateration. This system decreases maintenance costs by utilizing a wait mode and only operational once a receiver is in the vicinity. The trilateration algorithm utilized is an Ordinary Least Square (OLS) estimator. The pose estimator has two ultrasonic receivers at a fixed separation distance. The two ultrasonic receivers each calculate its unique position. The orientation of the object is obtained from the orientation of a line segment joining the two positions on the object.

Keywords: Trilateration, Time-of-flight, Pose estimator, ultrasonic, Radio frequency

1 INTRODUCTION

South Africa plays a major role in the international mining fraternity. Location aware devices are expected to advance the realization of wireless sensor networks (WSN) which are persistent and ubiquitous environmental monitoring systems. These systems are also of crucial importance for mobile robotics in global positioning system (GPS) deprived environments.

Opencast mines utilize the GPS to obtain location information. The unavailability of this technology in underground mining has actuated numerous researchers to investigate possible solutions to the problem. These attempts exploit new sensors that measure inter-nodal ranges, signal strengths, acceleration or angles for location as well as research high sensitivity algorithms for signal acquisition and tracking in harsh environments [1]. The combination or integration of these sensors has also been investigated to some degree. The common signal technologies used in localization systems include radio frequency (RF), ultrasound, infrared, vision and magnetic fields [1].

Ultrasonic based localization has received most focus in recent years. This is mainly due to their power efficiency and hence suitability for untethered or wireless systems. The latest, and well publicized, research in indoor localization include the Active Bat [1], a derivative of the work done at Olivetti Research Lab under the banner of the Active Badge [1], the DOLPHIN [2][3], which introduced a robust least square (RLS) algorithm and is developed at the University of Tokyo, and the Crickets [4], a hardware and software platform developed at the Massachusetts Institute of Technology. All these projects use beacons that transmit a RF pulse and an ultrasonic chirp simultaneously. Listeners utilize the RF signal to identify the transmitting beacons and the difference in arrival times between the RF signal and the ultrasonic chirp to estimate distances between the receiver and the transmitter. The main difference between the three systems is their implementation.

This paper describes an implementation of a posture estimation system for underground mine vehicles. The paper is organized as follows. In the next section, a brief description of the posture estimation algorithm implemented in the ABPES is described. Sections 3 and 4 describe the architectures of the Beacons and ABPES receiver. The final sections express the issues encountered in the implementation, propose mitigation techniques and conclude.

2 POSTURE ESTIMATION ALGORITHM

The active beacon posture estimation system (ABPES) proposed in this paper is a 2D system that is intended for mine tunnels and excavations of the order of 30 m x 30 m x 1 m in tabular ore bodies, as explained by Ferreira [5]. The vertical height in the application environment is limited and plays no significant value. The environment is populated by a number of beacons with known positions. The posture estimator requires a predetermined number of beacons to localize itself and determine the orientation of the platform. Localization in indoor environments requires higher precision, in order of centimeters, as compared to outdoor, in order of meters, because of the general higher density of obstacles in indoor environments.

The posture or pose of a vehicle is its orientation and localization. Localization is achieved by implementing a trilateration algorithm using an ordinary least squares (OLS) estimator. This approach only requires the distances between the receivers and the beacons and the position of the beacons to estimate the location of the vehicle. The OLS estimator is selected, instead of analytical methods, because only the approximate distances can be measured because of various environmental factors and system noise [5].

The ABPES determines the distance to a given beacon by measuring the difference in time-of-flight (TOF) of the ultrasonic signal and the RF signal emitted by a beacon. The TOF is proportional to the distance between the beacon and the ABPES. The translational speed of the ultrasonic wave is the proportionality constant. The initial time of transmission and clock synchronization are required for the TOF measurement. This is accomplished by periodically transmitting an ultrasonic signal and a RF signal simultaneously. The RF signal acts as a synchronization mechanism and provides the initial time of transmission for the TOF. The technique assumes an instantaneous flight time for the RF signal. The ABPES acquires distance measurements from different beacons until the sufficient number of distances required for posture estimation.

Bearing measurement is performed based on the localization output. Two points can define a line, when the two ultrasonic transmitters on the ABPES localize themselves in the beacon reference frame, the gradient of this line can be calculated.

3 BEACON IMPLEMENTATION

Beacons exist in a common environment and periodically transmit information that is utilized by any number of ABPES receivers within coverage. This information includes the synchronized ultrasonic and electromagnetic signals used for ranging, a form of unique identification and the beacon's own location. It should be possible for an object to uniquely identify a beacon in order to associate ranging results with the transmitting beacon. The location of a beacon is surveyed during installation and stored in memory on the beacon.

3.1 Hardware and Software Implementation

In the design, location and identification information are transmitted with a radio. The radio signal is used for a number of functions. Apart from transmitting a beacon's location and identification, the start of the transmission serves as the synchronization mechanism and during transmission the carrier is used to avoid transmission collisions. The following figure illustrates the timing of the events during the transmit process.

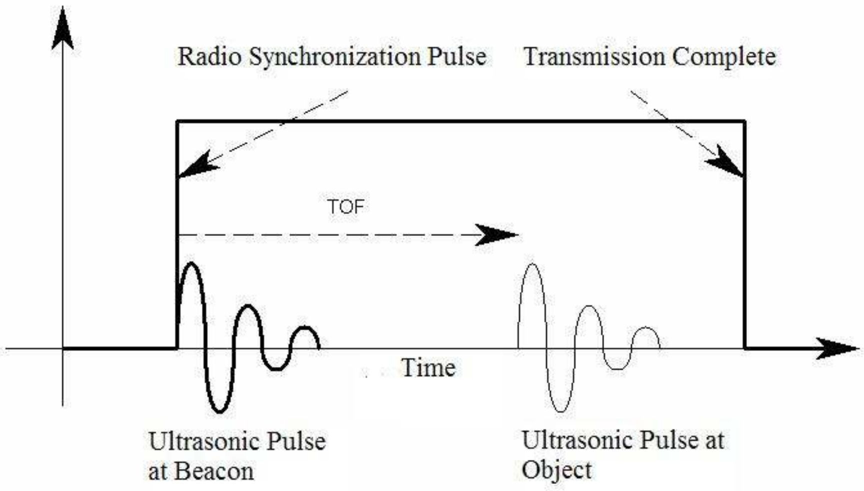

Figure 1: Beacon transmit cycle

The radio is designed around a CC1100 transceiver, which is configured and controlled through its onboard Serial Peripheral Interface (SPI). Before transmission, the transceiver is loaded with a packet and configured to only start transmitting after a clear channel assessment is completed to avoid collisions. An ATmega128 microprocessor is used as the main controller in the system. The transceiver generates an interrupt on the controller at the instant transmission begins, at which time an ultrasonic pulse is emitted.

A piezoelectric transducer is used to generate the 40 kHz ultrasonic pulse. The transducer is driven with a 40 V peak-to-peak signal with the aid of a bridge driver and a boost converter. The main controller is responsible for generating the control sequence to emit the ultrasonic pulse, with software programmable duration. Typically, the transmission has duration of 16 cycles.

The radio frequency carrier is only turned off after enough time has passed for each object to have received all the information and the ultrasonic pulse, ensuring collisions can be avoided during the complete ultrasonic and radio transmission cycle. This is achieved by taking into account that the greatest distance an ultrasonic pulse needs to travel is approximately 30 m, assuming the pulse takes longer to reach the objects than a complete data transfer over the radio link. The flow diagram in Figure 2 summarizes the described transmit process that is implemented on the main controller.

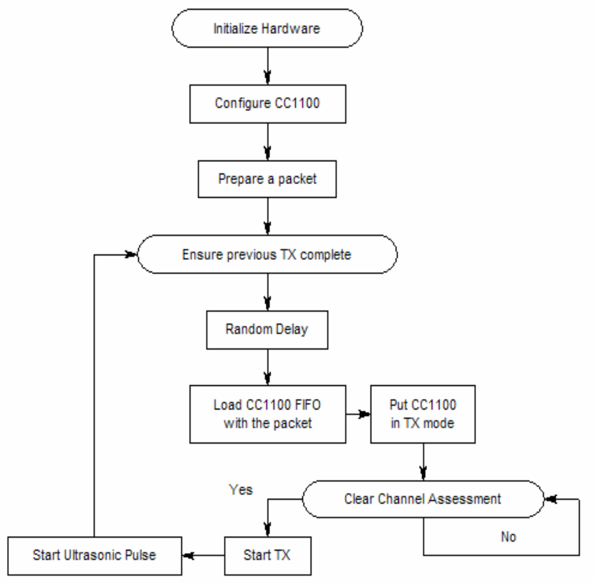

Figure 2: Beacon transmit process

Power consumption is improved by turning the ultrasonic transmitter off when it is not transmitting. This increases battery life and reduces noise emissions.

4 ABPS IMPLEMENTATION

The receiver's main task is to acquire information from a sufficient number of beacons and then determine its pose information using this information. The ABPES has to first identify a unique beacon and then determine the distance between itself and that beacon. This information is then stored and the process repeated for different beacons. After enough information has been acquired, the ABPES will execute the estimation algorithms on the acquired information.

4.1 Hardware and Software Implementation

The receiver also utilizes a CC1100 radio transceiver but the ATmega32A microprocessor is replaced with the more powerful ATmega128 microprocessor as the main system controller. The fundamental components of an ABPES are the ultrasonic receiver systems. The ultrasonic receivers are implemented using a two-stage amplifier having a large input impedance and high gain, allowing an object to detect faint ultrasonic signals over a range of 30 m. The amplifier also offers some band-pass filtering to reduce noise.

In order for the receiver to measure the TOF of the ultrasonic pulse, the radio transceiver interrupts the main controller at the instant reception is started. The controller then starts a timer with microsecond resolution, pending the reception of the ultrasonic pulse. Concurrently during this time, the packet transmitted from the beacon is being transferred into the receive FIFO of the radio transceiver, containing the beacon identification and location.

The output of the ultrasonic receiver is rectified and applied to the controller's onboard analogue comparator. A simple fixed threshold detector is implemented with the analogue comparator, which interrupts the controller upon detection. The detector can easily be expanded to dynamically adjust the threshold of the detector by taking the received signal strength indicator (RSSI), supplied by the radio transceiver, into account.

The time on the controller is immediately recorded when the first ultrasonic pulse is detected by the analogue comparator. The system then waits for the second detection. The timer is immediately stopped after the second ultrasonic detection. The speed of sound in 0°C dry air is approximately equal to 331.3 $m.s^{-1}$. The temperature is currently taken to be the average temperature of the operating environment and other external effects such as humidity and pressure are calibrated once by adding a constant offset to the speed estimation of sound. Should conditions vary more than expected, the temperature sensor onboard the radio transceiver can be used to compensate for changes in temperature.

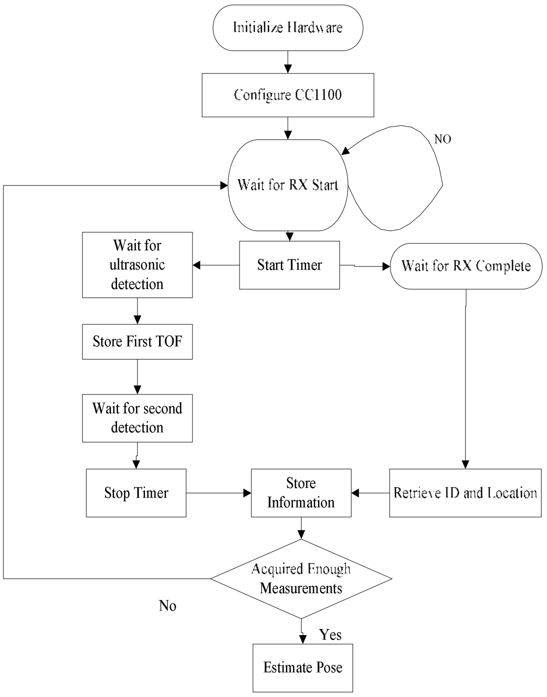

Figure 3: ABPES receive process

The orientation of the vehicle is estimated for the given beacon. The calculated distance is stored with the orientation information and the beacon information that is transferred from the radio transceiver. The process is repeated until the minimum number of required beacons has been detected, after which the OLS algorithm is executed. The algorithm returns the ABPES's estimated location. This information is made available over a serial communication interface. The flow diagram in Figure 3 summarizes the receive process implemented on the main controller.

4.2 Evaluation of Accuracy

In this section, simulations are conducted to evaluate the feasibility and accuracy of the proposed ABPES algorithms. The simulations investigate the static performance of the system.

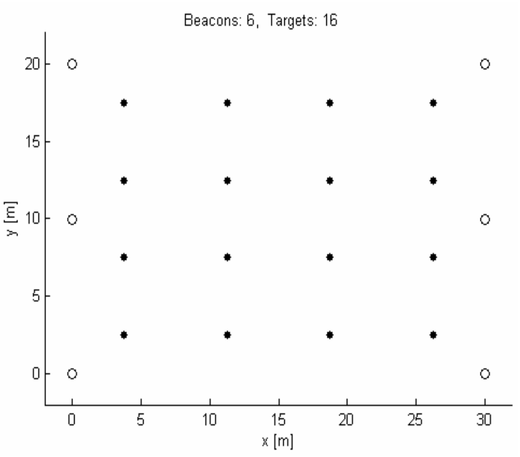

Figure 4: Experimental setup

The experimental setup and simulation results are presented in this section. Figure 4 illustrates the typical configuration of the system, with beacons installed on opposite sides of the excavation, approximately 30 m apart, and a number of objects inside the excavation.

Let $B_i = (x_i,y_i)$ denote the i^{th} beacon with surveyed location and $\rho = (x,y)$ an unknown object's location. The exact distance between the object and the beacon is denoted with $d_i(\rho)$. A method of linearization is used by W. Navidi et al.[6], in which a reference point is introduced at the mean of the beacon locations.

The distance between a beacon and the reference point is denoted by d_{ir} and the distance from the object to the reference point by $d_r(\theta)$. The actual measurement made by an object for the distance between itself and the i^{th} beacon is denoted by r_i.

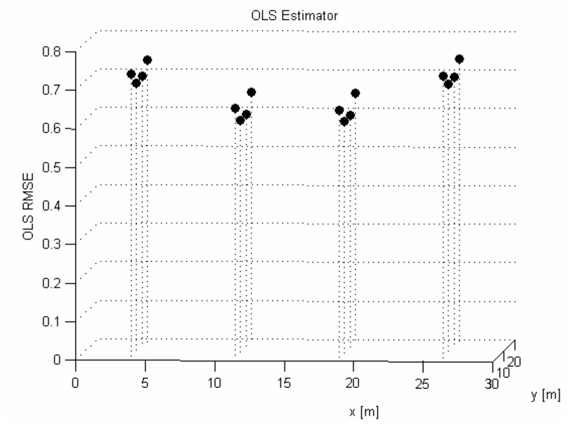

Figure 5: Performance of OLS estimator

The simulation result is shown in Figure 5, in which the OLS estimator's performance was investigated as a function of the object's location within the excavation. Measurements were simulated with a uniform error distribution, using a standard deviation of 1 m and zero mean. The RMS error in the estimate is plotted for each object in Figure 5 and was typically better than 70 cm. It was noted that location estimates for objects closer to the center of the excavation were more accurate than estimates for objects close to the sides of the excavation, as expected.

5 CONCLUSION

The formulation process of ABPES was described in this paper. The system consists of two types of elements, i.e. the beacons with surveyed locations and the receivers which estimate their location and orientation in the environment. The receivers estimate there location using trilateration algorithm with an OLS estimator. This method requires only the distances between the receiver and the beacons and the location of the beacon to estimate the location of the receiver.

The location of the two ultrasonic receivers is used to estimate the orientation of the ABPS by estimating the gradient of the line segment joining the 2 points. The ABPS has the ability to estimate its position and orientation with only 2 beacons if necessary. This is done using coordinate geometry of triangles and the rule of cosines.

6 ACKNOWLEDGEMENTS

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7 RECOMMENDATIONS

The next part of the research will include measuring the environmental conditions and deriving self-propagating networks. Humidity and barometric pressure need to be taken into account as the deployment environment is approximately -1500m below sea level and air pressure is significantly higher there, consequently the speed of sound will be higher. Humidity will also play a significant role as it will vary a lot depending on the ventilation and mining cycle.

The beacons must be inexpensive because they will get destroyed during the blasting process. The network should also be expendable without having to survey the coordinates of new beacons. This implies that the beacons should be able to calculate their position, with respect to known beacon positions, before they can begin to transmit. This can also be done using an ABPES. The ABPES can be placed below the beacon, if possible. The ABPES will calculate its location and use RF communication to program the beacon with its location. The beacon then joins the network and expands coverage.

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