DESIGN AND IMPLEMENTATION OF AN INDOOR LOCALIZATION SYSTEM FOR THE OMNIBOT OMNI-DIRECTIONAL PLATFORM

Sasha Ginzburg, Florentin von Frankenberg, Scott Nokleby
Faculty of Engineering and Applied Science, University of Ontario Institute of Technology, Oshawa, Ontario, Canada
E-mail: scott.nokleby@uoit.ca

Received October 2009, Accepted November 2009
No. 09-CSME-54, E.I.C. Accession 3140

ABSTRACT

The design and implementation of an indoor absolute localization system for a novel three-degree-of-freedom (DOF) omni-directional mobile platform is presented. This localization system is a modification of the Cricket indoor localization system developed at the Massachusetts Institute of Technology (MIT) and is similar to the Global Positioning System (GPS) used in outdoor applications. The designed system has an active mobile architecture with actively transmitting beacons mounted on the mobile platform, and receivers (listeners) fixed at known positions on the ceiling of the operating environment. Position estimates of the mobile beacons, relative to a global coordinate system, are obtained using trilateration; a technique that determines the position of a beacon using distance estimates between the beacon and the fixed listeners. The distance estimates between the beacons and listeners are calculated using the time-of-flight of radio frequency and ultrasonic signals. Testing of the localization system was performed and experimental results are presented. These preliminary results indicate that the modified Cricket system has improved accuracy in distance and position estimation compared to the original system, as well as a higher position update rate when performing tracking of the mobile platform.

Keywords: localization; active mobile system; omni-directional platform.

CONCEPTION ET RÉALISATION D'UN SYSTÈME DE LOCALISATION INTÉRIEURE POUR LA PLATEFORME OMNI-DIRECTIONNELLE DU OMNIBOT

RÉSUMÉ

L'objectif de la recherche est la conception et la réalisation d'un système de localisation intérieure pour une nouvelle plateforme omni-directionnelle à trois-degrés-de-liberté (DOF). Ce système de localisation est une modification du système de localisation intérieure *Cricket* développé au *Massachusetts Institute of Technology (MIT)*, et est semblable au *Global Positionning System (GPS)* utilisé à l'extérieur. Le système que nous avons conçu se caractérise par une architecture mobile active avec des balises électromagnétiques de transmission actives montées sur la plateforme mobile, et des receveurs (écouteurs) fixés dans des positions connues sur le plafond de l'environnement opérationnel. Les estimations de positions des balises mobiles, en relation avec un système de coordonnées globales, sont obtenues par la technique de trilatération; une technique qui détermine la position d'une balise en utilisant les estimations de distance entre la balise et les écouteurs fixes. Les estimations de distance entre les balises et les écouteurs sont calculées en utilisant la radiofréquence temps de vol et des signaux ultrasoniques. On a procédé à des tests expérimentaux dont les résultats sont présentés ici. On note dans ces résultats préliminaires que le système *Cricket* modifié présente une amélioration dans la précision en distance et l'estimation de position quand on le compare avec le système original, de même qu'un taux plus élevé de mise à jour de position de repérage de la plateforme mobile.

1. INTRODUCTION

Autonomous mobile robot navigation is the process of a robot moving from one location to another in a safe manner. The general problem of robot navigation can be described by the following three questions [1]: ''Where am I?'', ''Where am I going?'', and ''How do I get there?''. The first question defines the problem of localization, which means determining the location of the robot relative to its environment. The second question refers to the problem of goal recognition, which is the ability of the robot to identify goals in its environment for performing various tasks. The final question defines the problem of path planning, which is the ability of the robot to find a route to reach a goal. Out of the three problems that comprise the general problem of autonomous robot navigation, the most fundamental is considered to be localization. A robot needs to know where it is located in order to decide what actions to take. For this reason, acquiring a solution to the localization problem is necessary to being able to solve the goal recognition and path planning problems. A solution to the localization problem is achieved by implementing a localization system that uses a single method or a combination of methods for location estimation.

To localize itself within its operating environment, a robot requires information. The information for localization can either be a-priori information which is available to the robot before it begins navigating or information obtained from sensor measurements during navigation [2]. During navigation, a robot senses its own motion and the environment around it. Measurements made by sensors that only look at the robot itself are called relative position measurements, whereas measurements made by sensing the environment are called absolute position measurements. The information obtained from sensor measurements is combined with a-priori information to estimate the robot's position and orientation [2].

Numerous methods have been developed and implemented for localizing mobile robots. The various localization methods can be categorized into two groups: relative and absolute position measurements [4, 5]. Methods that obtain information by only sensing the motion of the robot are referred to as relative position measurement methods. The process of obtaining relative measurements is known as dead-reckoning [2]. Alternatively, methods that obtain information by sensing the surrounding environment are called absolute position measurement methods. Examples of some existing localization systems implemented on mobile robots can be found in [6–11].

Relative position measurement (dead-reckoning) methods determine the robot's location by integrating a sequence of measurements over time, which means that the current location estimate depends on previous estimates. Since location estimates are obtained by the integration of sensor measurements, this leads to the unbounded accumulation of location errors over time. Location estimates determined from absolute position measurements are independent of any previous estimates because location is obtained from a single or a set of measurements without integrating measurements over time. Using this approach the location error does not accumulate boundlessly over time [2].

The focus of this paper is on the design and implementation of an absolute localization system for a 3-DOF omni-directional mobile platform [3], operating in an indoor structured environment. The purpose of the localization system is to determine the pose of the omni-directional platform relative to a defined global coordinate system, and to track its motion as it navigates through its operating environment. To achieve this objective, the localization system presented in this paper performs positioning of active beacons (transmitters) mounted onboard the mobile platform based on distance measurements to fixed listeners (receivers) at known positions in the environment.

2. OMNIBOT OMNI-DIRECTIONAL PLATFORM

The omni-directional platform (Fig. 1), or Omnibot, for which the localization system must be implemented was built in the Mechatronic and Robotic Systems (MARS) Laboratory at the University of Ontario Institute of Technology (UOIT). The platform was built to serve as a base for a mobile manipulator which would consist of a robotic manipulator mounted on top of the platform. The design of this platform allows it to perform omni-directional travel which is the ability to travel in any direction while maintaining a fixed orientation [12]. This means that the platform can translate in any direction, rotate about its geometric center, and perform a combination of translation and rotation simultaneously.

The structure of the platform is composed of an aluminum frame with a symmetric design. Placed at each corner of the platform is an omni-wheel, which is supported by a spring dampening system, used for absorbing vibrations that occur during motion. Each omni-wheel is driven by a DC motor through a drive shaft linkage. The motors are placed along the sides of the platform and contain digital encoders that count the revolutions of each wheel. Each motor is connected to a motor controller that controls its operation using pulse width modulation (PWM). A HC(S)12 microcontroller is used to generate the PWM signals that are used by the motor controllers for controlling the motors to achieve the desired motion of the platform. The power for all the components and systems on the omni-directional platform is supplied by an onboard power supply composed of three 12V batteries connected in parallel.

3. LOCALIZATION SYSTEM DESIGN

The localization system was designed for the purpose of determining the pose of the omni-directional platform operating in an indoor structured environment. The pose of the platform is defined by the set of variables (x, y, θ), where x and y are the position coordinates and θ is the orientation of the platform, relative to a defined global coordinate system.

3.1. System Architecture

The design of the localization system for the omni-directional platform is based on the Cricket indoor localization system (Fig. 2) developed at the Massachusetts Institute of Technology (MIT) [13]. Cricket is an active beacon localization system. The hardware used in

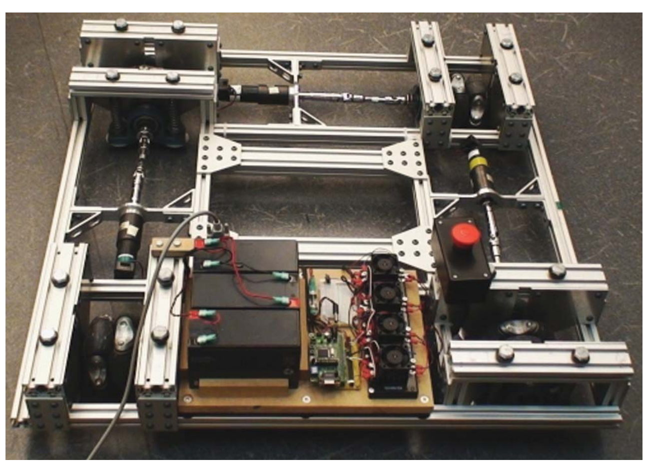

Fig. 1. Omni-directional platform.

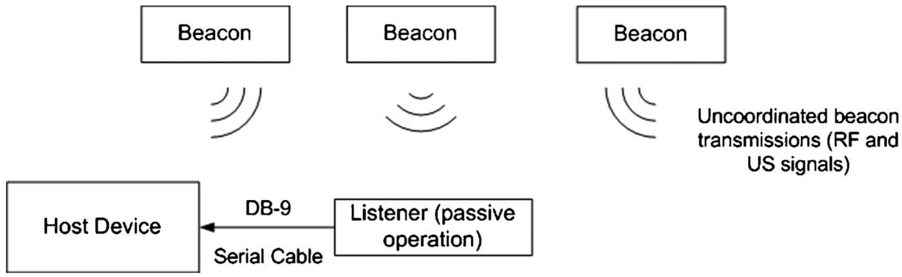

Fig. 2. Original cricket system architecture.

the Cricket system consists of Cricket nodes, which are small hardware units that are configured to operate as either beacons or listeners. Cricket uses a passive mobile architecture with actively transmitting beacons placed at known positions in the operating environment. These beacons form the infrastructure of the localization system and are typically attached to the ceiling and walls of a building. Each beacon periodically transmits radio frequency (RF) and ultrasonic (US) signals. The RF signal contains beacon specific information, including the unique beacon identification (ID) and the beacon position coordinates, whereas the ultrasonic pulse does not carry any data. One or more receivers, called listeners in the Cricket system, are attached to the object that needs to be located. The function of the listeners is to passively listen to beacon transmissions and measure the distances to those beacons using the difference of arrival times of the RF and US signals. Listeners provide the distance measurements and the information contained in the RF signals to an attached host device via DB-9 serial cables using RS-232 serial communication. The distance measurements to three nearby beacons with known coordinates are used by the host device to compute the position coordinates of the listeners with respect to the defined reference frame [13].

The localization system designed for the omni-directional platform is a modification of the Cricket indoor localization system. The modified Cricket localization system (Fig. 3) uses an active mobile architecture with listeners fixed to a ceiling at known positions and two actively transmitting beacons mounted on the omni-directional platform. The listeners mounted on the

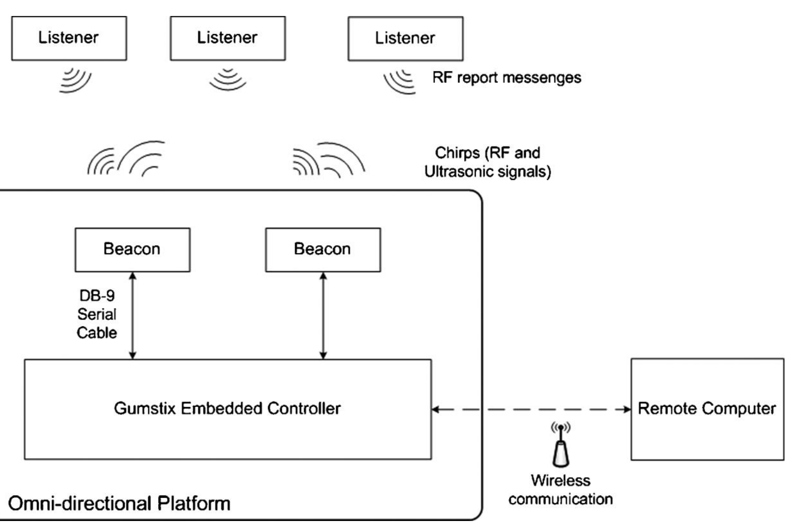

Fig. 3. Modified cricket localization system architecture.

ceiling form the global coordinate system with respect to which the mobile beacons are positioned. Each of these listeners is manually assigned position coordinates relative to this global coordinate system. The active beacons are mounted at the corners of the omni-directional platform and move in a plane below the one formed by the ceiling mounted listeners. Both beacons are connected to a Gumstix embedded controller, which consists of a motherboard attached to two expansion boards. The Gumstix communicates with the beacons using RS-232 serial communication via DB-9 serial cables connected to the serial ports on one of the expansion boards. A wireless communication link is established between the onboard Gumstix embedded controller and a remote computer over a dedicated 802.11b/g network. Wireless protocols are used to send data between the remote computer and the Gumstix embedded controller.

3.2. Modified Cricket Localization System Operation

In the modified Cricket localization system (Fig. 3) the program running on the Gumstix embedded controller sends commands to the beacons mounted on the platform using RS-232 serial communication. These commands are used to trigger each beacon to transmit signals. A beacon transmission (chirp) consists of simultaneously sending out a RF signal and an US pulse. When a beacon transmits (chirps), all the listeners that are within the ultrasonic range and have line-of-sight to the beacon will receive the signals. The listeners attached to the ceiling will first receive the RF signal and after some time interval receive the US pulse. Based on the difference in the arrival times of the RF and US signals and the propagation speeds of these signals, each listener calculates the distance to the triggered beacon. After performing the distance calculation, each listener responds by transmitting a RF report message containing the distance estimate, its ID number, and a timestamp.

The RF report signals sent from the ceiling mounted listeners are received by the triggered beacon on the omni-directional platform. The beacon transfers the data stored in the RF reports to the onboard Gumstix embedded controller using serial communication. This data is then acquired and processed by the program executing on the Gumstix controller. If distance estimates to three or more listeners with a-priori known positions are obtained, the Gumstix program performs trilateration calculations to determine an estimate of the position coordinates of the triggered beacon with respect to the global coordinate system. The beacon position estimates are then wirelessly sent from the Gumstix controller to a remote computer over the wireless network. Estimates of the position and orientation of the omni-directional platform are computed on the remote computer using the beacon position estimates and the known distances between them on the platform. This process for determining estimates of the omni-directional platform's pose is repeated continuously by the localization system.

3.3. Position Estimation Algorithm

The position estimation algorithm, developed for the modified Cricket system, uses the method of trilateration to calculate position estimates of a mobile beacon, based on the measured distances to ceiling mounted listeners. As shown in Fig. 4, three distance estimates to fixed listeners at known positions are required for estimating a beacon's position. For a given beacon transmission, if at least three distance estimates are obtained, then the trilateration positioning method involves finding the intersection of the surfaces of three spheres centered at the listeners with radii given by the distance estimates from these listeners to the mobile beacon. Mathematically, this problem can be solved by setting the equations of the three spheres equal to each other, and is achieved by solving the following three simultaneous equations for $i=1,2,$

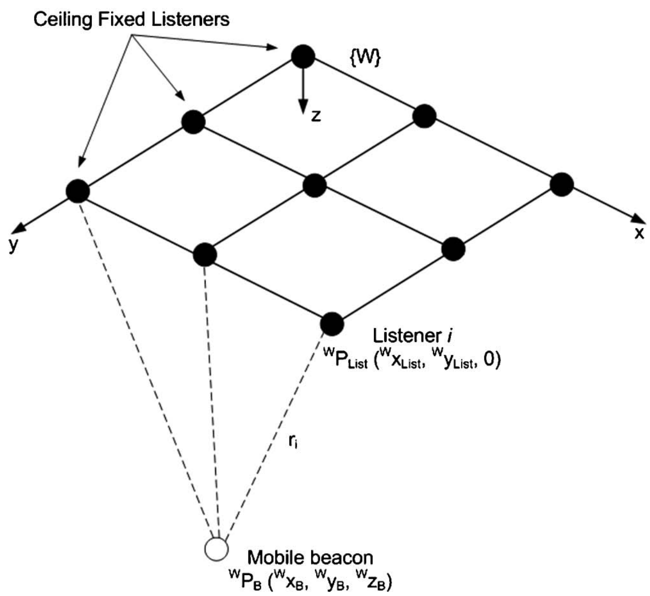

Fig. 4. Trilateration of the mobile beacon position.

and 3:

$$r_i^2 = (x - X_i)^2 + (y - Y_i)^2 + (z - Z_i)^2 \tag{1}$$

where x, y, and z are the position coordinates of the beacon, r_i is the distance estimate to listener i, and X_i, Y_i, and Z_i are the x, y, and z coordinates of listener i for i=1,2, and 3, respectively. The trilateration calculations in Eq. (1) can be simplified by applying several constraints to the centers of the three intersecting spheres, which are the listener positions. The constraints are that all the listeners be coplanar and lie on the $z = 0$ plane, one listener be located at the origin, and another listener be located on the x-axis. The result of applying these constraints to the equations of the three spheres, Eq. (1), is the following set of simplified trilateration equations:

$$x = \frac{r_1^2 - r_2^2 + X_2^2}{2X_2} \tag{2}$$

$$y = \frac{r_1^2 - r_3^2 - x^2 + (x - X_3)^2 + Y_3^2}{2Y_3} \tag{3}$$

$$z = \pm\sqrt{r_1^2 - x^2 - y^2} \tag{4}$$

The application of this set of simplified trilateration equations for the solution of the beacon's position (x, y, z) relative to the global coordinate system, first requires that three distance estimates be selected from the set of n distance estimates acquired from the fixed listeners. A local coordinate system is then constructed using the three listeners associated with the selected distance estimates, as shown in Fig. 5. This local frame is constructed following the constraints used for deriving the simplified trilateration equations, such that one of the three listeners is located at the origin and another lies on the x-axis.

The relationship between the constructed local frame and the global frame, relative to which the listener position coordinates are known, is described by the following homogeneous transform:

$$ {}^{W}_{L}\mathbf{T} = \left[\begin{array}{ccc|c} & {}^{W}_{L}\mathbf{R} & & {}^{W}\mathbf{p}_{Lorg} \\ 0 & 0 & 0 & 1 \end{array}\right] \tag{5}$$

where, ${}^{W}_{L}\mathbf{T}$ is a 4×4 transform matrix that describes frame $\{L\}$ relative to frame $\{W\}$, ${}^{W}_{L}\mathbf{R}$ is a 3×3 rotation matrix of $\{L\}$ relative to $\{W\}$, and ${}^{W}\mathbf{p}_{Lorg}$ is a 3×1 position vector that locates the origin of $\{L\}$ relative to $\{W\}$. The rotation matrix, ${}^{W}_{L}\mathbf{R}$, and the position vector, ${}^{W}\mathbf{p}_{Lorg}$, are defined as:

$$ {}^{W}_{L}\mathbf{R} = \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{6}$$

$$ {}^{W}\mathbf{p}_{Lorg} = \begin{bmatrix} {}^{W}x_{Lorg} \\ {}^{W}y_{Lorg} \\ {}^{W}z_{Lorg} \\ 1 \end{bmatrix} \tag{7}$$

where θ is the rotation angle of frame $\{L\}$ relative to frame $\{W\}$ about the z-axis, and ${}^{W}x_{Lorg}$, ${}^{W}y_{Lorg}$, and ${}^{W}z_{Lorg}$ are the position coordinates of the origin of frame $\{L\}$ relative to frame $\{W\}$.

Having defined the relationship between the local and global coordinate systems, the following step is to map the known position coordinates of the listeners from the global frame to the local frame as:

$$ {}^{L}\mathbf{p}_{List} = {}^{L}_{W}\mathbf{T}\,{}^{W}\mathbf{p}_{List} \tag{8}$$

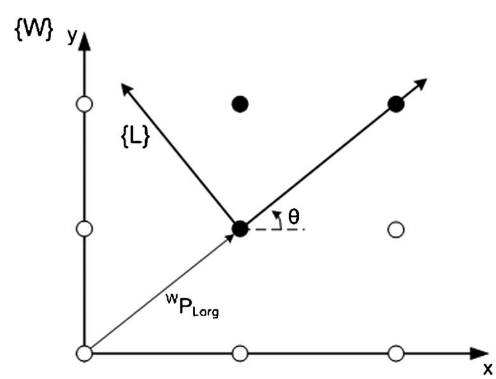

Fig. 5. Listener local coordinate system.

where ${}^{L}\mathbf{p}_{List}$ and ${}^{W}\mathbf{p}_{List}$ are the position coordinates of a listener relative to the local and global frames, respectively, and ${}^{L}_{W}\mathbf{T}$ is the homogeneous transform that describes frame $\{W\}$ relative to frame $\{L\}$. This transform matrix is defined as:

$$ {}^{L}_{W}\mathbf{T} = {}^{W}_{L}\mathbf{T}^{-1} = \left[\begin{array}{ccc|c} & {}^{W}_{L}\mathbf{R}^{T} & & -{}^{W}_{L}\mathbf{R}^{T\,W}\mathbf{p}_{Lorg} \\ 0 & 0 & 0 & 1 \end{array} \right] \tag{9} $$

With the position coordinates of the three listeners expressed relative to the constructed local frame, the set of simplified trilateration equations, Eqs. (2) to (4), are solved to obtain the x, y, and z coordinates of the mobile beacon relative to the local frame. The beacon position coordinates are then mapped from the local frame to the global frame as:

$$ {}^{W}\mathbf{p}_{B} = {}^{W}_{L}\mathbf{T}^{L}\mathbf{p}_{B} \tag{10} $$

where ${}^{W}\mathbf{p}_{B}$ and ${}^{L}\mathbf{p}_{B}$ and the position coordinates of the beacon relative to the global and local coordinate systems, respectively.

Having determined an estimate of the mobile beacon's position for one combination of three listeners from the set of n listeners that reported distance estimates for a given beacon transmission, the algorithm is then executed for every other possible combination of three listeners. After all combinations of three listeners have been used in the algorithm, the results are averaged to obtain the final position estimate of the mobile beacon, relative to the global coordinate system.

3.4. Hardware

Cricket nodes (Fig. 6) are the hardware units used for the beacons and listeners in the localization system. A Cricket node is composed of the following primary components: a microcontroller, a RF transceiver, an US transmitter and receiver, and an RS-232 interface. Each Cricket node is configured to operate as a beacon (transmitter) or listener (receiver) in the Cricket embedded software. The signals transmitted by beacons travel in a 40° cone shaped

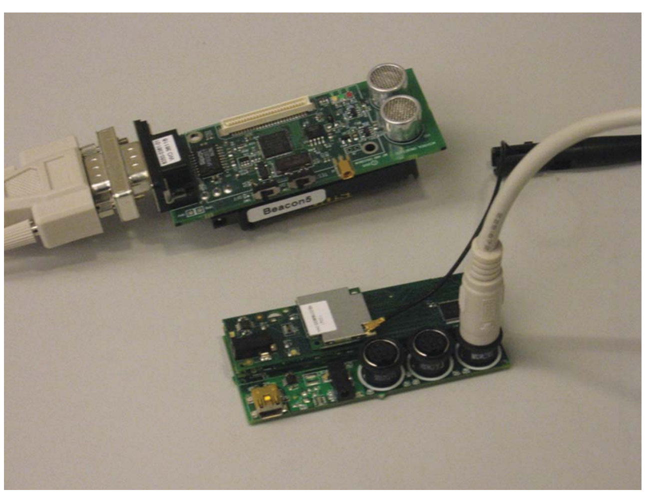

Fig. 6. Cricket node (top) and gumstix embedded controller (bottom) hardware.

propagation pattern. The maximum range of the ultrasonic signals is 10.5 m when there are no obstacles between the listener and the beacon and they are facing each other [15].

The Gumstix embedded controller (Fig. 6) used in the localization system is a hardware unit that is composed of a Connex motherboard connected to the Console-vx and Wifistix expansion boards. The Connex motherboard is a single-board computer that runs the Linux operating system. The Gumstix program used in the localization system runs on the Connex motherboard. The Console-vx expansion board has three RS-232 serial ports to which the two beacons on the platform are connected via DB-9 cables. The Wifistix expansion board provides wireless connectivity for the Gumstix. Wireless communication between the Gumstix embedded controller and a remote computer is performed over a dedicated 802.11b/g network using wireless protocols.

4. IMPLEMENTATION OF THE LOCALIZATION SYSTEM

4.1. Cricket Node Software

The Cricket localization system uses TinyOS 1.x [15]. This is an operating system specifically designed for use with embedded sensor networks. The operating system minimizes power consumption by using an event-driven C-based programming language called nesC. Due to the nature of the language, applications can be built by wiring together separate, pre-existing applications (called modules). This type of approach also minimizes code size, which is another benefit in embedded sensor networks.

The same code is used for both the listeners and the beacons. This allows a Cricket node to be configured as either a beacon or a listener, and makes it easy to switch the mode without reprogramming. The software is composed of six primary events, shown in Figs. 7 and 8: *Sending Radio Signal*, *Receiving Radio Signal*, *Ultrasound Detected*, *Serial Send*, *Receiving Serial Data*, and *Ultrasound Send*. The rest of the code is associated with initialization, hardware drivers, communication protocols, and other low level programming. Whenever one of the six events occurs, a series of commands is executed. The way a Cricket node responds to a firing of an event depends on whether it is configured as a beacon or a listener.

On a beacon, when the *Receiving Radio Signal* event is triggered, this means that a distance report from a listener has been received. The *Serial Send* function is then called, and the

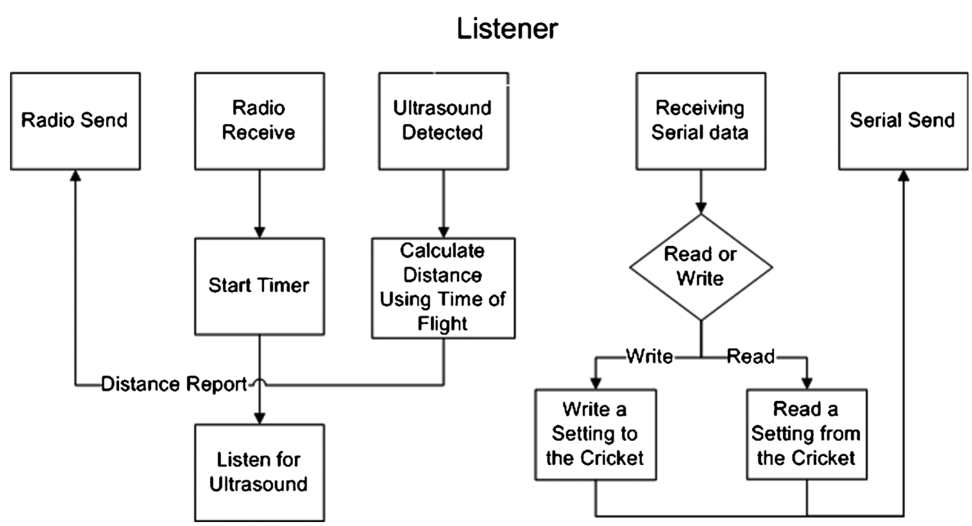

Fig. 7. Listener events diagram.

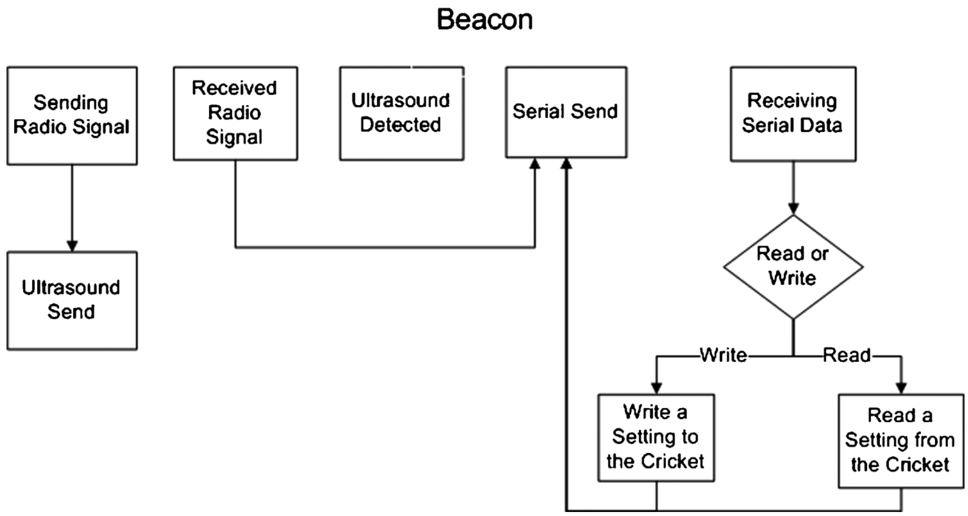

Fig. 8. Beacon events diagram.

distance report is sent to the beacon's serial port. On a listener, if the *Receiving Radio Signal* event is triggered, a timer is started so that the flight time of the US signal can be obtained. The *Ultrasound Detected* event in a listener stops the timer, and calculates the distance to the beacon from which the signal originated. On a beacon, the *Ultrasound Detected* event does nothing. On a listener, the *Serial Send* event gives the user feedback during configuration, and on a beacon the event is used to relay distance report information received from the radio. The *Ultrasound Send* event is only used by the beacons.

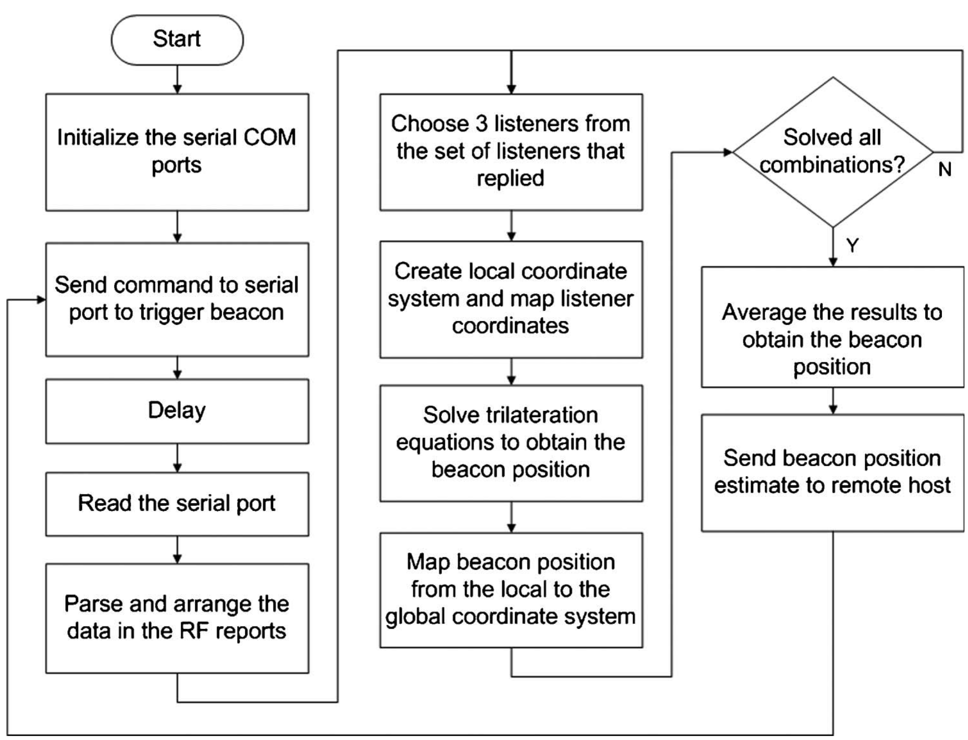

Fig. 9. Gumstix embedded controller program flowchart.

4.2. Gumstix Embedded Controller Software

The Gumstix embedded controller used in the localization system executes a software program written in the C programming language. This program was developed on a computer running a Linux operating system using a cross-compilation toolchain. Using this toolchain the program code was compiled on the Linux development machine and then transferred to the Gumstix controller for execution.

The structure and operation of the software program implemented on the Gumstix controller is shown in Fig. 9. At the start of execution, the program initializes the serial communication (COM) ports on the Console-vx expansion board. Each of the three COM ports is enabled and configured by setting the values of all the required parameters for serial communication, such as the baud rate. The program then commands a particular beacon to chirp, by sending the string 'p ch' to one of the Gumstix's serial ports. The beacon connected to the serial port to which the message was sent is triggered and simultaneously transmits a RF signal and an US pulse. Listeners that detect the triggered beacon's transmission calculate estimates of the distance to that beacon and report the values back in RF messages along with their IDs. The triggered beacon on the platform receives these RF report messages and sends the data contained in the messages to the Gumstix controller using serial communication.

In the Gumstix controller, after a beacon is triggered to chirp the program waits a fixed amount of time for its input buffer to be filled with data from the beacon. Following this delay in the program execution, which is set to 200 ms, the program reads the serial port to which the triggered beacon is connected and obtains the string of listener RF report messages. Contained within this string are the distance estimates, associated listener IDs, and timestamps provided by all the listeners that detected the triggered beacon's transmission. The data in the string of listener reports is then processed before it is used for calculating the position estimate of the beacon. The data processing step is performed by first parsing the string of RF reports to extract the distance estimates and associates listener IDs, then converting these values to the required formats, and finally arranging the values in a specific order. The resulting processed data is used in the position estimation algorithm to calculate an estimate of the triggered beacon's position. The resulting beacon position estimate is sent to a remote computer over the wireless network. This process for determining position estimates of the mobile beacons is continuously performed by the Gumstix program by successively triggering each connected beacon.

5. TESTING AND RESULTS

The current implementation of the modified Cricket system was tested to evaluate its performance and determine how it compares to the original Cricket system developed at MIT. For the evaluation of the system's performance, static distance and position estimation, and dynamic tracking testing were performed.

To evaluate the distance estimation accuracy of the localization system, a beacon connected to a computer was placed on the ground, aimed horizontally, and a listener was placed at known distances away from the beacon. The computer commanded the beacon to chirp at each listener distance by sending commands over a serial cable. The distance measurements calculated by the listener were recorded, and the resulting data is shown in Fig. 10. A linear trend-line was fit to this experimental data, and its equation is also shown in Fig. 10. After applying the correction given by the equation of the linear trend-line to the Cricket measured distances, the mean absolute error was determined to be 0.24 cm. This result is an improvement over the original Cricket system that was reported to have a distance estimation accuracy of 5 cm [13].

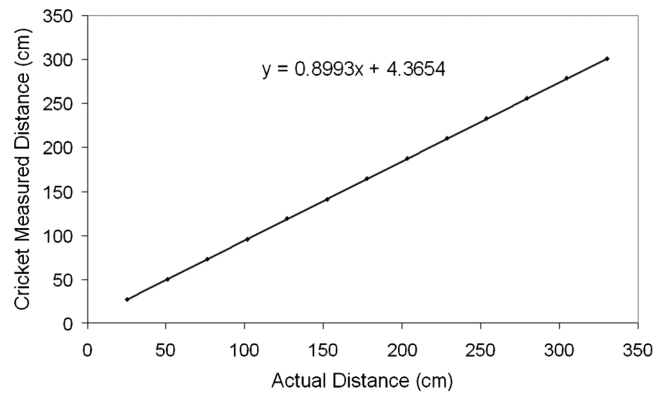

Fig. 10. Distance estimation test results.

To measure the position estimation accuracy of the modified Cricket system, a beacon was placed at eight known positions in a plane parallel to the plane containing the ceiling mounted listeners. At each test position the beacon was left stationary for a period of time, until the localization system obtained 50 position estimates of the beacon. The recorded beacon position estimates at the eight test positions are shown in Fig. 11. The position estimation error (position offset) at each test position was determined by calculating the Euclidean distance between the actual position and the estimated position. For the eight test points used in this experiment the mean position estimation error was found to be 3.27 cm. For the original Cricket system the position estimation accuracy was reported to be 10 cm [13], which means that the modified Cricket system achieved a higher accuracy.

To test the tracking performance of the localization system an experimental setup was constructed. This experimental setup consisted of a Lego train set placed under the area covered by the listeners, with a beacon and Gumstix controller attached to the moving train. In the experiment, the train was controlled to move along the assembled circular track, with a radius of 32 cm, at a speed of 0.215 m/s. The center of the circular track was positioned at $x = 60$ cm and $y = 60$ cm, relative to the listener coordinate system. The tracking test was performed over a 60 second time interval, during which 235 beacon position estimates were recorded. A graph

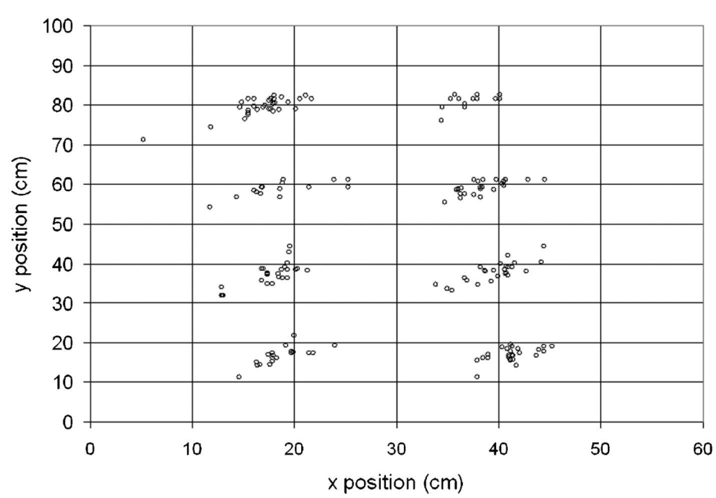

Fig. 11. Position estimation test results for 8 beacon positions.

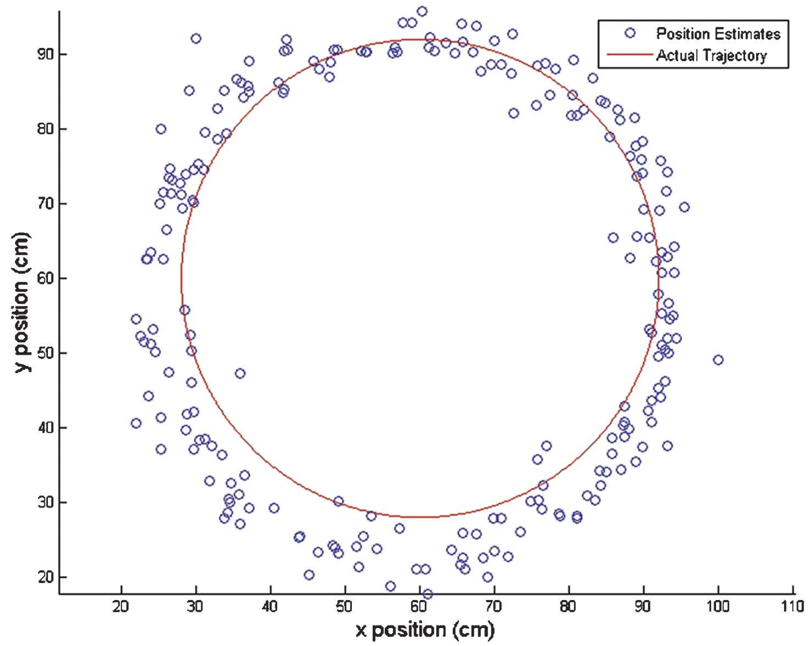

Fig. 12. Tracking test results for a beacon moving at 0.215 m/s around a circular track for a period of 60 s.

showing the recorded beacon position estimates together with a schematic of the train's true trajectory is shown in Fig. 12. The results of this tracking experiment indicate that the localization system was able to calculate a position estimate of the mobile beacon every 0.255 seconds, which means that the system has a position update rate of 3.92 Hz. In comparison, in the original Cricket system it would take at least 0.5 to 1 second to obtain three distance measurements, which is the minimum amount necessary for calculating a position estimate [14]. Thus, the result of this tracking experiment shows a definite improvement in the position update rate for the modified Cricket system.

6. FUTURE WORKS

Development of the localization system is currently ongoing and further work will be done to add additional functionality, such as the ability to determine the platform's orientation using two beacons. In addition, other position estimation algorithms will be investigated to determine if the performance of the system can be further improved. Specifically, the possibility of using a Kalman filter to increase the accuracy and reliability of the location estimates during tracking of the mobile platform will be explored. When it is determined that the localization system has acceptable performance, it will be required to integrate this system with the other systems onboard the Omnibot platform. The objective is to have the localization system provide position and orientation feedback to a position controller for performing position control of the Omnibot.

7. CONCLUSIONS

The design of an indoor absolute localization system for the Omnibot omni-directional mobile platform was presented. The localization system was designed by modifying and adapting the Cricket indoor localization system, originally developed at MIT. The modified

Cricket system uses an active mobile architecture with beacons attached to the mobile platform and listeners fixed at known positions in the platform's workspace. The mobile beacons are localized using trilateration based on distance estimates to nearby listeners. These distance estimates are obtained using a combination of RF and US signals transmitted from the beacons to the listeners. The position estimates of the mobile beacons are calculated by an embedded controller to which the beacons are interfaced onboard the platform.

Testing of the modified localization system at this stage of development was performed to determine its performance relative to the original system. Both static and dynamic testing of the localization system were performed. The results of the static distance and position estimation testing indicate that modified system has improved accuracy over the original system. In addition, the dynamic tracking test results show that the modified implementation has a higher position update rate than the original Cricket system.

ACKNOWLEDGEMENTS

The authors wish to thank the Natural Sciences and Engineering Research Council (NSERC) of Canada, the Canada Foundation for Innovation (CFI), and Cameco Corporation (through the Cameco Research Chair in Nuclear Fuel at UOIT) for providing funding to support this research.

REFERENCES

1. Leonard, J.J. and Durrant-Whyte, H.F., "Mobile robot localization by tracking geometric beacons," *IEEE Transactions on Robotics and Automation*, Vol. 7, No. 3, pp. 376–382, 1991.
2. Negenborn, R., *Robot Localization and Kalman Filters*, MASc. thesis, University of Utrecht, September 2003.
3. Bemis, S., Riess, B. and Nokleby, S., "Design and Control of an Omnibot Autonomous Vehicle," *Proceedings of the 2008 ASME International Design Engineering Technical Conferences*, Brooklyn, USA, August 3–6, 2008.
4. Singhal, A., *Issues in Autonomous Mobile Robot Navigation*, Technical Report, University of Rochester, May 1997.
5. Borenstein, J., Everett, H.R., Feng, L. and Wehe, D., "Mobile Robot Positioning: Sensors and Techniques," *Journal of Robotic Systems*, Vol. 14, No. 3, pp. 231–249, 1997.
6. Cox, I.J., "Blanche- An Experiment in Guidance and Navigation of an Autonomous Robot Vehicle," *IEEE Transactions on Robotics and Automation*, Vol. 7, No. 2, pp. 193–204, 1991.
7. Thrun, S., "Finding Landmarks for Mobile Robot Navigation," *Proceedings of the 1998 IEEE International Conference on Robotics and Automation*, Leuven, Belgium, pp. 958–963, May 1998.
8. Kleeman, L., "Optimal Estimation of Position and Heading for Mobile Robots Using Ultrasonic Beacons and Dead-reckoning," *Proceedings of the 1992 IEEE International Conference on Robotics and Automation*, Nice, France, pp. 2582–2587, May 1992.
9. Chenavier, F. and Crowley, J.L., "Position Estimation for a Mobile Robot Using Vision and Odometry," *Proceedings of the 1992 IEEE International Conference on Robotics and Automation*, Nice, France, pp. 2588–2593, May 1992.
10. Soo-Yeong Yi and Byoung-Wook Choi, "Autonomous navigation of indoor mobile robots using a global ultrasonic system," *Robotica*, Vol. 22, No. 4, pp. 369–374, 2004.
11. Goel, P., Roumeliotis, S.I. and Sukhatme, G.S., "Robust Localization Using Relative and Absolute Position Estimates," *Proceedings of the 1999 IEEE/RSJ International Conference on Intelligent Robots and Systems*, Kyongju, South Korea, pp. 1134–1140, October 17–21, 1999.

12. Bemis, S., Riess, B. and Nokleby, S., "Control of a novel omni-directional platform," *Canadian Conference on Electrical and Computer Engineering*, pp. 761–766, May 4–7, 2008.
13. Priyantha, N., *The Cricket Indoor Location System*, Ph.D. thesis, Massachussets Institute of Technology, June 2005.
14. Miu, A.K.L., *Design and Implementation of an Indoor Mobile Navigation System*, Master's thesis, Massachussets Institute of Technology, January 2002.
15. MIT Computer Science and Artificial Intelligence Lab, "Cricket v2 user manual," On the WWW, January 2005, URL http://cricket.csail.mit.edu/.