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Design and Implementation of Cricket-based Location Tracking System

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***Abstract*—**In this paper, we present a novel approach to location system under indoor environment. The key idea of our work is accurate distance estimation with cricket-based location system using A* algorithm. We also use magnetic sensor for detecting obstacles in indoor environment. Finally, we suggest how this system can be used in various applications such as asset tracking and monitoring.

***Keywords*—**Cricket, Indoor Location Tracking, Mobile Robot, Localization.

I. INTRODUCTION

LOCATION aware services are very useful and widely used in everybody life such as smart home system, context-aware system for health care and silver care, asset tracking, public safety, and personal safety. As far as we know, the key solution of location tracking is Global Positioning System (GPS) [1]. Although adequate for outdoor positioning, GPS receivers do not usually function indoors. To support indoor location tracking, lots of indoor location systems over the years are devised. Each approach solves a bit different problem or supports different applications, location sensing mechanism works in a variety of ways. The most preferred and proven approach for location systems is to use infrared signal, ultrasonic, and scene analysis mechanism. There is a large and growing list of works related to location system, including Active Badges[2], Active Bats[3], Cricket[4], RADAR[5], UWB[6], and RFID(Radio Frequency Identification)[7]. However, this approach has not been efficient, since individual location sensing technology has a trade-off between location systems. The category of the trade-off is scalability, ease of deployment, cost, precision, and limitations.

In this paper, we propose cricket-based location tracking system that provides efficient indoor navigation and integrates additional magnetic sensor for recognizing obstacles that should be avoided, and finally completing navigation. With this approach, we can integrate several location systems simultaneously and combines multiple sensory data. The benefits of our approach are more accurate, more complete, or more dependable result. In order to yield higher accuracy of navigation, in this paper, a novel pass finding algorithm is also proposed. The rest of the paper is organized as follows. Section 2 surveys various well-known location tracking systems. Then in Section 3, we cover the design and implementation of cricket-based location system, especially, distance estimation algorithm, path search algorithm, and robot movement mechanism. In Section 4, we present development environment and the result of experiment and then conclude in Section 5.

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II. RELATED WORKS

Active Badges[2] is a indoor sensing system which transmits a unique infrared signal every 10 seconds and central server collects signal through fixed sensors. Active Badges has several limitations when applied to practical use of location tracking. The main limitations are difficulty in locations with fluorescent light or sunlight, which generates infrared emissions and ranges over some meters, for larger areas, uses multiple infrared beacons. Active Bats[3] and Cricket[4] use ultrasonic pulse for 3-dimensinal positioning in indoor environment. Active Bats is attached to the objects or persons whose location has to be determined and the Bat can monitor and display the movement of object wearing a badge. Bat emits ultrasonic pulse when requested and receivers calculate time-of-flight. The key design philosophy of Active Bats focuses on low power, low cost and accuracy, however, Active Bat is known for drawbacks in scalability, ease of deployment, and cost. Cricket makes use of proximity-based lateration technique for providing location information. Cricket gives a decentralized scalability and no grid of ceiling sensors as mobile receivers perform the timing and computation functions. However, Cricket requires many manual pre-configuration, so cricket technology has a limitation in large scale deployment because of setup and management const.

Lots of previous researches target structured environment that requires fixed sensing nodes. However, in STAM[9], location tracking system tracks mobile robots and maps an unstructured environment, using up to 25 wireless sensor nodes in an indoor setting. These sensor nodes form an ad hoc network of beacons, self-localize with respect to three anchor nodes, and then track the locations of mobile robots in the field. MoteTrack[10] also deploys wireless sensor networks for accurate location tracking of mobile users. MoteTrack is based on low-power radio transceivers coupled with a modest amount of computation and storage capabilities, and mobile node location is computed using a received radio signal strength signature from beacon nodes. Although RFID technology is not designed for indoor location sensing, RFID is also good alternative for location tracking in indoor environment. LANDMARC[11] is RFID-based location sensing technology which improves the overall accuracy of locating objects by utilizing the concept of reference tags. Ferret[12] is RFID localization for pervasive multimedia which combines location tracking technology with pervasive multimedia applications.

III. System Overview

Here we describe the architecture of proposed system which composed of three main components (Sensor, Robot, and Mobile Device).

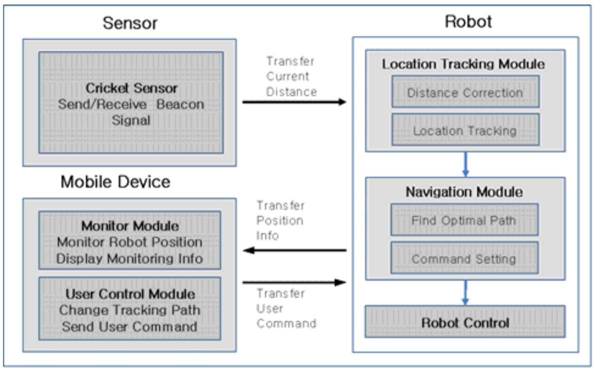


Fig. 1 Location tracking system architecture

Cricket has multiple senders (Tx, Beacon) and a receiver (Rx, Listener). Sender periodically transfers ultrasonic signal (beacon) to receiver. The receiver accepts ultrasonic signal and then transfers the data to location tracking module. The magnetic sensor can detect obstacles in map, whose position is not known to navigation module. So, we must find the obstacles in real-time manner. The mobile robot calculates the distance between sender and receiver. Current position of mobile robot can be calculated by the data transferred from sensor device. Navigation module finds optimal pass between current mobile robot position and destination. In this works, we adapt A* algorithm to calculate optimal path. The mobile device receives robot position and displays monitoring information such as routing path, robot status and communication status. For user controlled navigation, mobile device transfers control commands that change robot movement.

A. Mobile robot module

Fig. 2 shows the behavior diagram of the mobile robot. When robot is in booting sequence, it first checks if all modules are in normal status. After hardware/software integrity checks, location tracking module is activated. Periodically, robot gets destination information from the mobile device, and robot controls the movement device. If there is no user information for movement, the robot moves to target point based on A* algorithm.

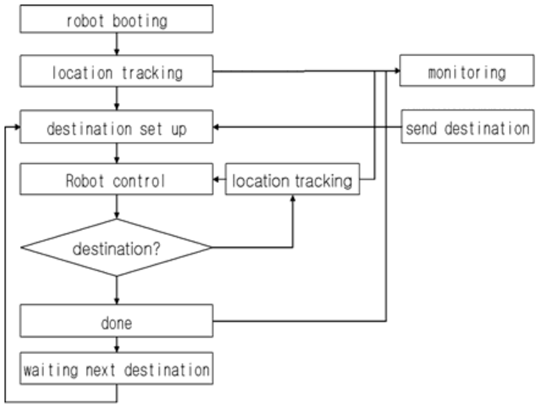


Fig. 2 Robot behavior diagram

B. Distance Estimation Mechanism

To estimate distance, we used the location information from cricket sensor data. Cricket system use TDOA (time-difference-of-arrival) of RF and ultrasonic signal to compute distances. TDOA methods record the differences between the arrival of the same beacon at different sites, and the sender's position can be inferred.

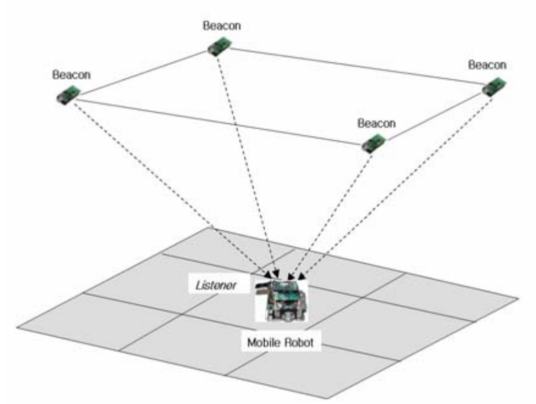


Fig. 3 The mechanism of distance estimation. Robot calculates current position with ultrasonic sensing

When mobile robot is running on the map, ultrasonic sensing data is the primary source of location information. In real world, there exist many obstacles around robot, so we must support obstacle detecting mechanism and obstacle position information. To address this problem, magnetic sensing data can be used for obstacle detecting purpose. In this work, whenever we detect obstacles, we record the position in the map. We record all the information on the map includes obstacles such as road, target point, etc. Fig. 4 shows the navigation map which is used for testing the proposed system. For example, R_n is a wall, B_n is a bridge, and M_n is a obstacle.

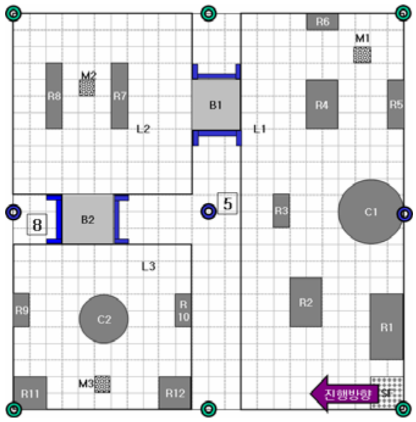


Fig. 4 Navigation map example

C. Navigation Algorithm

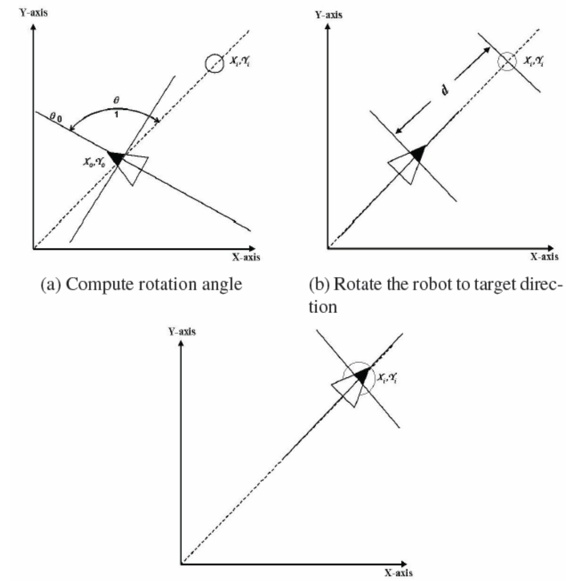
To move target position, the mobile robot have to search optimal path in the map. With the intension of easy solution, we converted the map into two dimension array. In order to search optimal path, we adapted A* algorithm. Fig. 5 shows the path search algorithm in two dimension array map.

```
FindPath(StartNode, GoalNode)
SelectNode ← ∅
CloseList ← ∅
OpenList ← ∅
PathList ← ∅
OpenList ← OpenList ∪ StartNode
while
  do SelectNode ← MinimumCost(OpenList)
    CloseList ← SelectNode
    for NearNode ← North to NorthWest of SelectNode
      do if (NearNode = Wall) or (NearNode = ∅) then continue
        else if (NearNode ∈ OpenList) and (NearNode·G > SelectNode·G)
          then NearNode·ParentNode ← SelectNode
        else if (NearNode ∉ OpenList)
          then OpenList ← NearNode
               NearNode·ParentNode ← SelectNode
               NearNode Compute F, G, H cost
    if (GoalNode ∉ OpenList)
      then return fail
PathList ← PathList ∪ GoalNode
SelectNode ← GoalNode
while
  do PathList ← PathList ∪ SelectNode·ParentNode
    if (SelectNode·ParentNode = StartNode)
      then return PathList
    SelectNode ← SelectNode·ParentNode
```

Fig. 4 Path search algorithm

D. Robot Movement

In previous section, target position can be obtained by the path search algorithm. When the target position is determined, the robot must rotate to target direction and move to target position. To complete robot movement, we first decide the direction to turn the mobile robot, and the distance to move is calculated. As Fig. 5 shows, robot movement action divided into three steps.



(a) Compute rotation angle (b) Rotate the robot to target direction (c) Move to target position

Fig. 5 Three step of robot movement

(x_0, y_0): current mobile robot position
(x_i, y_i) : target mobile robot position
θ_0 : current mobile robot direction
θ_1 : target mobile robot direction
d : distance between current and target position

The mobile robot computes the size of rotation angle θ_1 with previous movement information. In Equation 1, Ψ is yielded by the gradient difference between current robot direction and target direction.

$$\psi = atan\left(\frac{y_i - y_0}{x_i - x_0}\right) / \pi \times 180 \quad (1)$$

However, Ψ cannot be used as is because it only means the size of rotation angle between current position and target position. Therefore additional calculation is needed to decide target direction. Equation 2 describes how we can obtain θ_1 from Ψ .

$$\theta_1 = \begin{cases} 90 - |\psi| & y_i > y_0,\ x_i > x_0 \\ 90 + |\psi| & y_i < y_0,\ x_i > x_0 \\ 270 - |\psi| & y_i < y_0,\ x_i < x_0 \\ 270 + |\psi| & y_i > y_0,\ x_i < x_0 \\ 90 & y_i = y_0,\ x_i > x_0 \\ 180 & y_i < y_0,\ x_i = x_0 \\ 270 & y_i = y_0,\ x_i < x_0 \\ 360 & y_i > y_0,\ x_i = x_0 \end{cases} \qquad (2)$$

With Equation 3, we can transform rotation angle to rotation command, such as *turn left* or *turn right*.

$$x = \theta_0 - \theta_1$$
$$\phi = \begin{cases} turnleft(|x|) & x < -180 \\ turnright(|x|) & x > -180,\ x < 0 \\ turnleft(|x|) & x > 0,\ x < 180 \\ turnright(|x|) & x > 180 \end{cases} \qquad (3)$$

The distance between current position and target can be derived by Equation 4.

$$d = \sqrt{(x_i - x_0)^2 + (y_i - y_0)^2} \qquad (4)$$

E. Communicate with a Mobile Device

To communicate with mobile device, we used wireless LAN technology. The robot accepts TCP/IP socket data from wireless LAN modules in embedded board, and checks if a user sends control data with mobile device. If control data is received, the robot decodes control data and executes command.

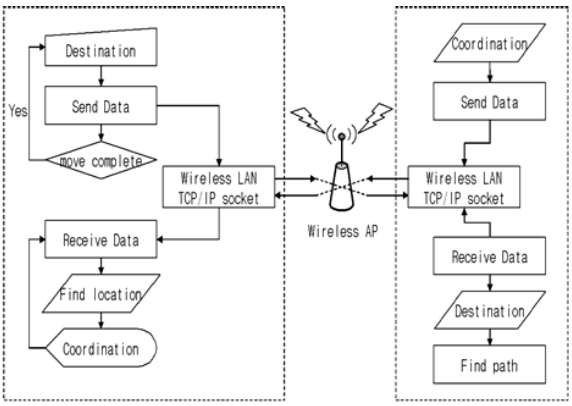


Fig. 6 Communication model

IV. DEVELOPMENT ENVIRONMENT AND RESULT

Our approach described above has been implemented and tested using a mobile robot that manufactured by the Meritech Corporation in Korea. It is equipped with wireless LAN module, sensor module, ESTK 2440 board, and two wheels. The detailed hardware specification is described in Table I.

TABLE I
HARDWARE SPECIFICATION

Type	**Hardware Specification**
Mobile client	- Intel PXA 270 312 Mhz - CF type 2 slot - 3.5Inch TFT Display - 64MB RAM, 128MB Flash ROM
Robot (ESTK 2440)	- S3C2440A MCU - SDRAM 64MB - AMD Flash 1MB(NOR Type) - NAND Flash 32MB - USB Device Connector - UART 1 Port for Debug - Ethernet 1 Port - JTAG Port for Multi-ICE
Crossbow MCS410CA Cricket Mote	- Ultrasonic 433.1 ~ 434.8MHz - Atmega128L - Chipcon CC1000 - 512KB Flash Memory

Fig. 7 shows the development tools which were used in implementing the proposed system. We used Qplus operating system and Esto development environment, Qplus/Esto is very famous embedded system software in Korea[13].

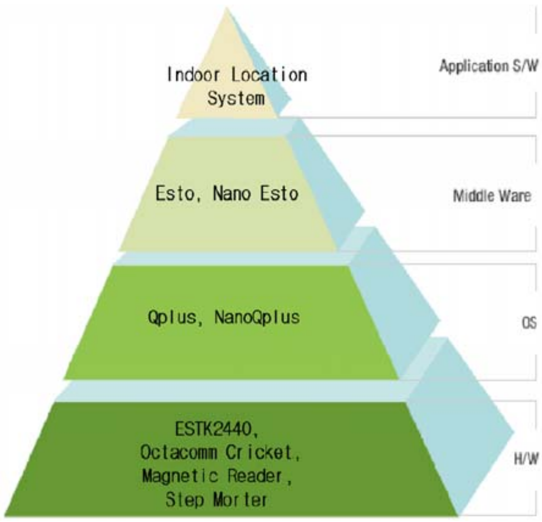


Fig. 7 Development tools

The experiments described here were carried out in the map offered by the 4th Embedded Software Contest in Korea. The size of the environment is 240cm by 240 cm. We installed 14 magnetic markers and 9 beacons in the environment. The nine small circle in the map is a cricket beacon and other squares and big circle is reference object which attaché magnetic marker. The experiment is designed to illustrate the localization error during navigation. Fig. 8 shows testing environment for the proposed system.

Fig. 8 Test environment

In this paper, we have described the design and implementation of cricket-based indoor location tracking system. We discussed the key issues for designing an indoor navigation system such as navigation algorithm, integrating multiple sensors, and robot movements. In ubiquitous world, location tracking service will be challenging theme. We believe the proposed system is more efficient and widely used in real environment, because the design is very simple and supports good error resilience. In our experiments, the deviation of error is under 10 CM.

V. CONCLUSION

This paper has presented a novel approach to location system under indoor environment. We have deployed cricket-based location system and adapted obstacle detecting mechanism. Although mobile robot has no hardware system which determine direction and position, proposed system can control direction and position precisely. The key idea of our work is accurate distance estimation with cricket technique that converge the location information from two different sources. The one is magnetic sensing module and the other is ultrasonic sensing module. In our system, ultrasonic sensing data is the primary source of location information and magnetic sensing data is used for obstacle detecting purpose only.

We have a plan to investigate the suitability of our approach for several practical purposes (e.g. unmanned vehicles for amusement park, patients tracking in a indoor environment, and parking management system). We are also planning to extend our works to outdoor environment with multiple sensors.

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