Proceedings of the International Multiconference on
Computer Science and Information Technology pp. 711–718

ISBN 978-83-60810-14-9
ISSN 1896-7094

Multilevel Localization for Mobile Sensor Network Platforms

Jae Young Park, Ha Yoon Song
Department of Computer Engineering, Hongik University, Seoul, Korea
pjyooungs@hotmail.com, hayoon@wow.hongik.ac.kr

***Abstract*—For a set of Mobile Sensor Network, a precise localization is required in order to maximize the utilization of Mobile Sensor Network. As well, mobile robots also need a precise localization mechanism for the same reason. In this paper, we showed a combination of various localization mechanisms. Localization can be classified in three big categories: long distance localization with low accuracy, medium distance localization with medium accuracy, and short distance localization with high accuracy. In order to present localization methods, traditional map building technologies such as grid maps or topological maps can be used. We implemented mobile sensor vehicles and composed mobile sensor network with them. Each mobile sensor vehicles act as a mobile sensor node with the facilities such as autonomous driving, obstacle detection and avoidance, map building, communication via wireless network, image processing and extensibility of multiple heterogeneous sensors. For localization, each mobile sensor vehicle has abilities of the location awareness by mobility trajectory based localization, RSSI based localization and computer vision based localization. With this set of mobile sensor network, we have the possibility to demonstrate various localization mechanisms and their effectiveness. In this paper, the preliminary result of sensor mobility trail based localization and RSSI based localization will be presented.**

I. Introduction

THE researches on Mobile Sensor Network (MSN) have been plenty worldwide. For MSN, there could be a lot of valuable application with attached sensors as well as capabilities such as locomotion, environmental information sensing, dead-reckoning, and so on. For such applications, usual requirements have been acknowledged with localization of each sensor node and formation of the whole sensor network. In this research, we are going to discuss about a Mobile Sensor Vehicle (MSV) which can compose MSN. We will discuss a construction of MSN as well as required functionalities of each MSN.

This paper is organized as follows. In section II we will discuss localization method that have been researched. The following section III we will analyze the requirement for MSV, the hardware design of MSV, and equipments for localization, and we will discuss software capabilities of MSV software and will show software components to fully control our MSV including software for MSN itself, monitoring program, map building features, and other related topics. In section IV, our approach and methodology for mobility trajectory based localization for medium distance localization will be discussed. Section V we will demonstrate one of the localization feature of our MSV. RSSI (Radio Signal Strength Identification) based localization will be presented based on 802.11 devices with software modification. We will show the merits and demerits of RSSI based localization. Finally section VI will conclude this paper with possible future research topics.

This work was supported by 2006 Hongik University Research Fund.

II. Related Work

There have been a lot of researches regarding mobile sensor localization. In this section, we will discuss past researches concentrating RSSI based localization, and dead-reckoning based localization. This works are not restricted on mobile sensors only but also related to robot technology.

A. RSSI based Localization

Radio Signal Strength Identification is one of the known solutions for distance measure. It requires wireless network device for mobile sensors and extra features.

We use 802. 11 network devices which have wide popularity. In addition we need communication between mobile sensors thus 802.11 networking devices are popular solutions for us. RSSI features for 802.11 device networks are required features in order to implement physical layer of CSMA/CA networking [12]. However RSSI based distance measure is very prone to radio signal attenuation and thus has low accuracy. And it has some restriction that once it is a data transfer modes, it cannot switched to API mode instantly. It implies the restricted realtimness for RSSI based localization. There are no defined standards for 802.11 RSSI and manufactures of 802.11 device usually provide their arbitrary method [11]. This is another restriction.

In this paper, we will demonstrate our MSV successfully does long distance, low accurate localization only with commercial 802.11 devices and networking software embedded on MSVs.

B. Computer Vision Based Approach

There are very few researches on localizations by use of computer vision technology. There have been the previous results regarding mobile sensor vehicle control, obstacle detection and so on.

Matsummoto et al. [13] used multiple camera in order to control mobile robots. In their research, cameras are installed on their working space instead of mobile vehicle itself. Their whole system is consisted of mobile robots and multiple cameras and this helps the search of proper path of robots.

Their initial experiments were done with 3 pan-tilt cameras. Keyes et al. [14] researched various camera options such as lens type, camera type, camera locations and so on. They also used multiple cameras to obtain more precise information. In this paper we will provide MSV with multiple cameras in order to accomplish short distance, high accurate localization.

C. Autonomous Driving Robot and dead-reckoning

This sort of localization is usually due to military area. For example DARPA, USA invests on unmanned vehicle, and their aim is about 30% of army vehicle without human on board controller. Stanley by Stanford university [15], which earned first prize in competitions, are equipped with GPS, 6 DOF gyroscope and can calculate the speed of driving wheels. Those sensors information can be combined to locate the position of their unmanned vehicle. They used computer vision system with stereo camera and single camera, and laser distance meter, radar in order to get environmental information. Sandstorm from CMU [16] is equipped with laser distance meter as a major sensor. Topographical model can be obtained by laser lines and the speed of car can be calculated by the density of laser line. Gimbal on their vehicle can install long distance laser scanner with seven laser sensors. Shoulder-mounted sensors can calculate height information of topography. Two scanners on bumpers can obtain obstacle information. Long distance obstacles can be identified by radar.

Our MSV are equipped with RSSI devices, stereo cameras and other sensors for dead-reckoning. Apart from the examples of locomotive robots, these equipments are for accurate localization.

III. Mobile Sensor Vehicle

We developed MSV in order to experiment our localization method in real environment. Various versions of MSV are designed and implemented. The localization functions implemented on MSV are as follows:

- Long distance low accuracy localization by RSSI
- Medium distance medium accuracy localization by dead-reckoning tracking
- Short distance high accuracy localization by Stereo camera with computer vision.

In the following subsection we will discuss hardware and software of MSV respectively.

A. Hardware

MSV is actually a mobile sensor node for MSN. Each MSV can move autonomously and can identify obstacles. They can communicate each other by 802.11 networking devices. The chassis of MSV are composed of aluminum composite with high durability and lightweight. The main driving mechanism is caterpillar composed of three wheels, L-type rubber belt, gears as shown in figure 1. The adoption of caterpillar is for minimization of driving errors. There are a lot of rooms to install additional sensor hardware. With digital compass equipped on the top of MSV, the accurate vehicle location can be sensored. This angular information can help exact localization of MSVs. The design concepts of MSV are as follows.

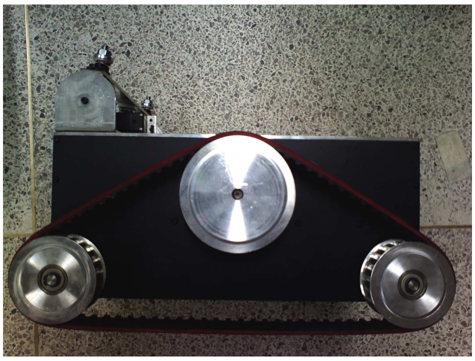

Fig. 1. Driving Mechanism Outlook

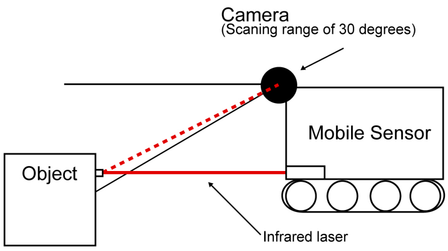

Fig. 2. Obstacle Detection Mechanism

- Autonomous mobility
- Extensibility of equipped sensors
- precise movement and mobility trail

And MSV characteristics as a node of mobile sensor network are as follows:

- Self identification and colleague identification
- Wireless communication
- Computing power

For autonomous driving, MSV must identify obstacles and avoid them. We use an infrared laser and cameras with infrared filter. IR laser is constantly lighting in parallel to round. Camera looks down grounds in a degree of 30 which is determined by experiments. The concept of this obstacle detections is depicted in figure 2. Obstacle reflects IR laser and sensed by camera [3], [5]. The obstacles with reflected IR will be detected as white lines. For short distance obstacles within the dead angle of camera, ultrasonic sensors are located under the MSV and in front of MSV. For computer vision based localization, MSVs are equipped with stereo eyes as shown in figure 3. Three servo motors can control two cameras independently. This stereo camera system can be used not only for localization but also for obstacle detection with diminished dead angle. There are three infrared LEDs mounted in the front of MSV. These LEDs are for computer vision based localization.

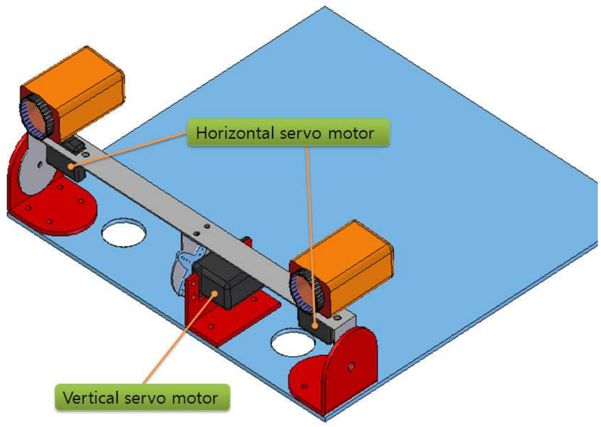

Fig. 3. Stereo Eye System

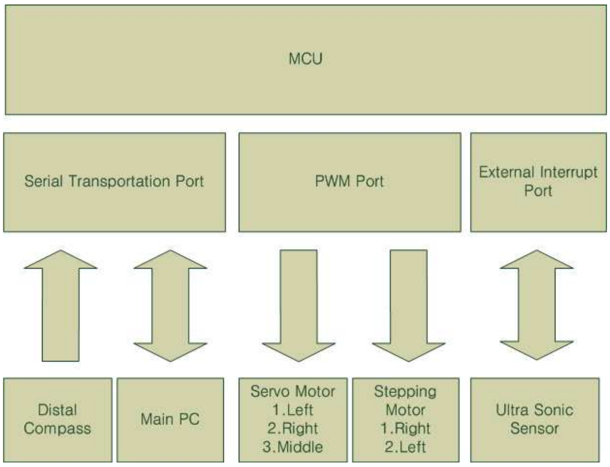

Fig. 4. Hardware Structure

For hardware construction, we need micro controller unit, a serial communication port, a PWM port, an interrupt port in order to control motors and communicate with sensors. Figure 4 shows the conceptual structure of MSV hardware.

B. Software

Software for MSV operations are required in a form of embedded software. Figure 5 shows required facility and their structure for MSV software.

Total part of software can be divided into five categories. One of the role of software is to convert sensor information into driving information. Information for driving can be obtained via serial communication from T-board (MCU) with driving information and angular information.

The location of MSV is constantly updated with the moving distance and updated angle. Camera class provides obstacle information as well as basic information for map building. Map building class builds a map with the information from T-board class and camera class. These maps are required for autonomous locomotion and localization. Network class provides networking functionalities between MSVs.

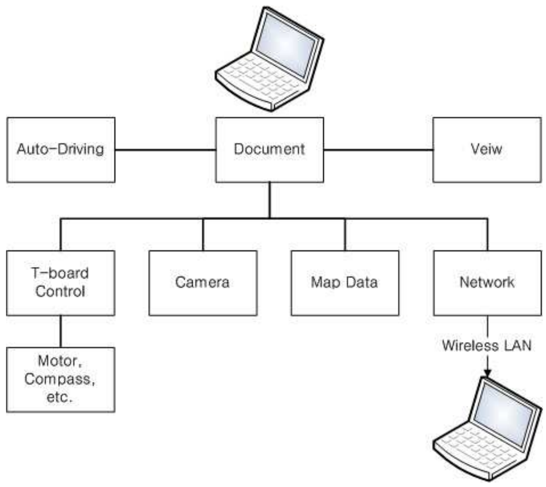

Fig. 5. Software Structure

1) Core Software: We implement core software based on multi threads. There is document class, which provides organic data flow between classes. Thus the major role of MSV software is as follows.

- Autonomous driving
- Motor control and driving distance identification
- Communication with MCU (T-board)
- Obstacle detection
- Map building
- Internetworking
- User interface dialog (Monitoring Program)

2) Monitoring Program: Monitoring program is a user interface between MSV and user. Monitoring program shows MSV condition, camera view, driving information, map built, and other sensor information. It also provides manual operation functionality of MSV. Figure 6 shows outlook of monitoring program. A mouse click on local map can drive MSV into dedicated location on the map.

Subdialog box in figure 7 shows the map built during the navigation of each MSV. It shows a result of localization based on dead-reckoning.

3) Map Building: Map building is one of the core parts of localization. The result of localization must be presented on local map and therefore be transferred to global map. MSVs communicate with each other in order to combine local maps into global maps. The following information will be shown on a map.

- White : Untapped territory
- Red : Territory with obstacle
- Blue : Territory with MSV
- Green : Tapped territory
- Undefined : Totally unknown territory

For map building we must consider relative coordinate and absolute coordinate. For example, obstacle information identified by MSV is in a form of relative coordinate. In relative coordinates, the very front of MSV is in angle 0 as shown in figure 8. This coordinate must be transformed into

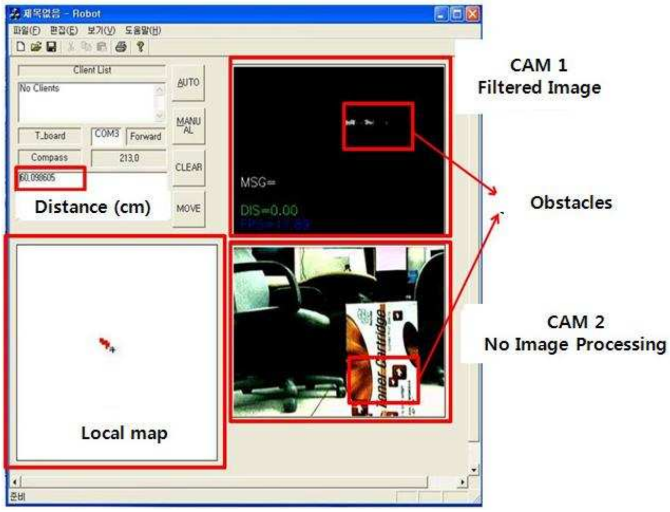

Fig. 6. Monitoring Program Screen

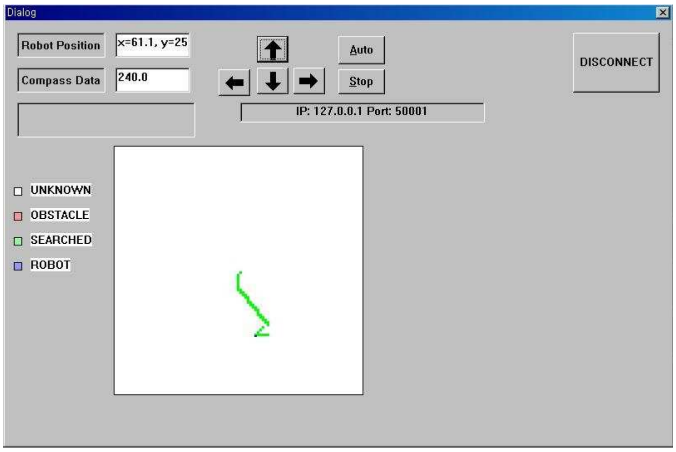

Fig. 7. Subdialog Program

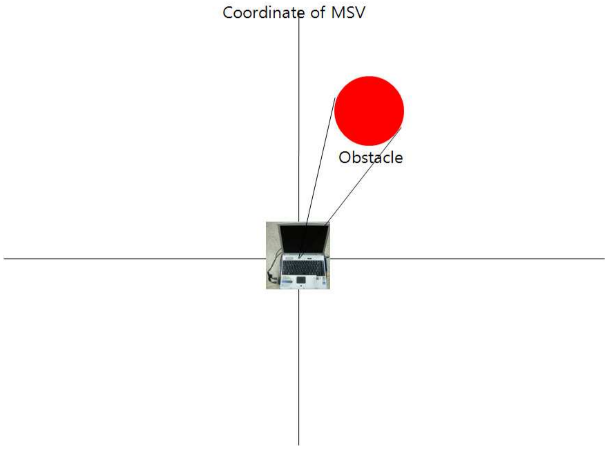

Fig. 8. Relative Coordinate

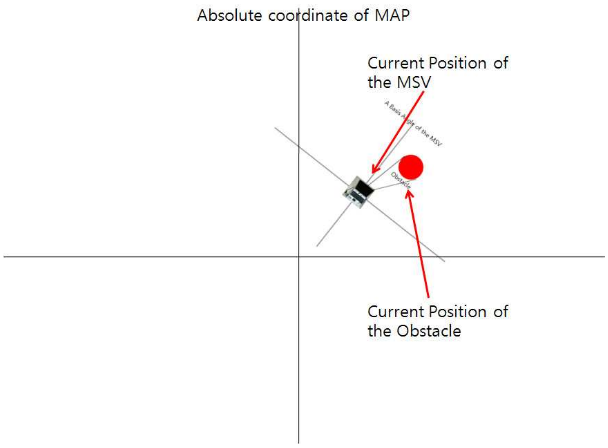

Fig. 9. Absolute Coordinate

absolute coordinate as shown in figure 9 and therefore can be a part of map.

Local map is usually in a form of grid map. However in case of global map with huge capacities, grid map is very inefficient. Therefore we will use topological map for global map as presented by Kuipers and Bynn [4]. Thrun [6] presented a hybrid approach of both maps and we will consider it as our ultimate format of global map. Table I compares advantages and disadvantages of grid and topological map.

IV. Sensor Mobility Trail based localization

A. Dead-Reckoning

For the medium distance localization, we decided to utilize mobility trail. We define the range of medium distance between 4 meters and 40 meters since our vision based short distance localization covers within the range of 5 meters and RSSI based long distance localization is effective outside the range of 30 meters. Our aim is to trail the mobility of MSV and to record the trail on the local map with reasonable accuracy for medium distance localization. Every driving mechanism for mobile sensors or even mobile robots has mechanical errors and it is impossible to avoid such errors practically. We can summarize the cause of driving errors as followings:

- The difference between the sizes of two (left and right) wheel
- The distortion of wheel radius, i.e. the distance between average radius and nominal radius
- The wheel misalignment
- The uncertainty about the effective wheelbase
- The restricted resolution of driving motors (usually step motors)

Usually those errors are cumulated and final result will be void without proper error correction technique. However, in order to cope with those location errors due to mechanical errors, a method of dead-reckoning have been widely used and we also adopt such technique as well. Dead-reckoning is a methodology that calculates the moving distance of two wheels of MSV and derive the relative location from the origin of MSV.

Among the various versions of Dead-reckoning techniques, we used UMBmark technique from University of Michi-

TABLE I
COMPARISON BETWEEN GRID MAP AND TOPOLOGICAL MAP

MAPS	Grid MAP	Topological MAP
Advantages	• precise presentation of geography of environment • ease of algorithm design : environmental modeling, path finding, localization by map-matching	• simple presentation of environment and simple path planning • tolerance of low accuracy mobile sensors • natural interface to users
Disadvantages	• difficulty in path planning • requirement of large memory and computation • poor interface to symbolic problem solver	• impossibility of large map building with inaccurate, partial information • difficulties in map-matching : difficulties in calculation of pivot sensor value • difficulties in dealing complex environment

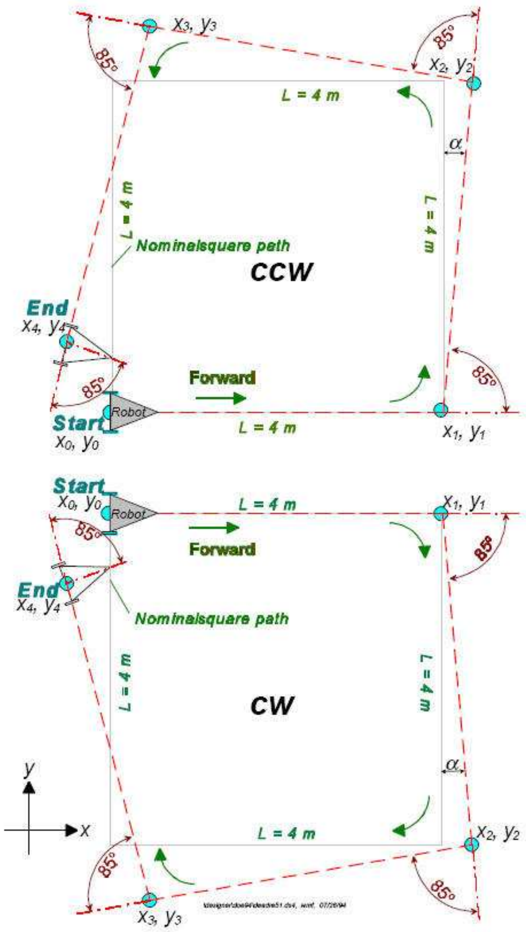

Fig. 10. Rotational Angle Error

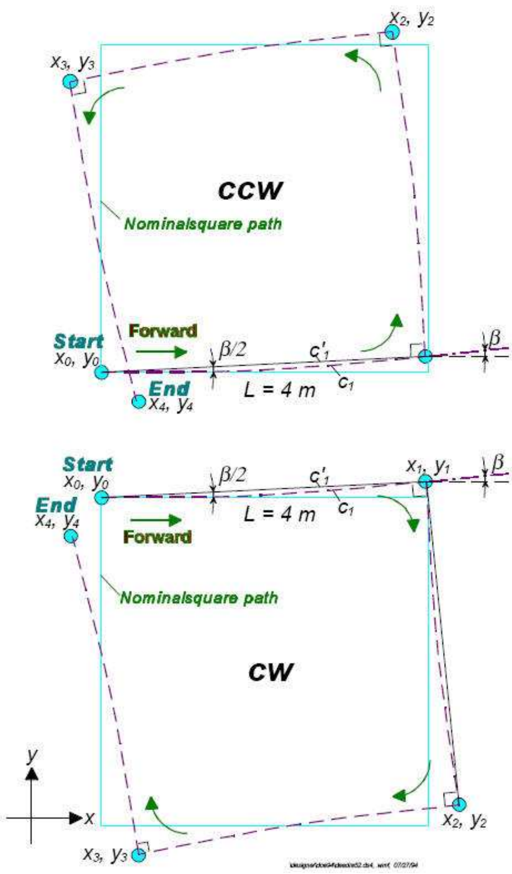

Fig. 11. Wheel Mismatch Error

gan [2]. UMBmark analyzes driving mechanism errors and minimized the effect of driving errors. UMBmark analyzes the result of MSV driving in a certain distance and compensates mechanical errors of MSV driving mechanism. The driving results of rectangular course, both in clockwise(CW) and counter-clockwise(CCW), and then analyzed.

Two error characteristics are classified in Rotation angle error and Wheel mismatch error. Rotational angle errors are for the difference between actual wheel sizes and theoretical design sizes of wheels. Due to rotational angle errors, CCW driving after CW driving shows larger errors as usual. For example, actual wheel size bigger than designed wheel size results in insufficient rotation at corners and then rotational angle errors are cumulated for the whole driving. The following equation summarizes the rotational angle error which is depicted in figure 10.

$$E_d = \frac{D_R}{D_L}$$

where D_R is diameter of left wheel and D_R is diameter of right wheel. In short, E_d is a ration between diameters of left wheel and right wheel.

Wheel mismatch errors are from wheelbase mismatch. This error causes skews in straight driving. With wheel mismatch error, the error characteristics of CW driving is opposite to CCW driving. The following equation summarizes the wheel size error which is depicted in figure 11.

$$E_b = \frac{90°}{90° - \alpha}$$

where α is a value of rotational angle error. E_b stands for a ration between ideal and practical errors in rotation, i.e. wheel base error.

Equations above and figures 10 and 11 have been reprinted from [2].

Mechanical errors are systematical errors and therefore can be predicted and analyzed, while non-mechanical errors cannot be predicted because non-mechanical errors are due to the driving environment. Non-mechanical errors are classified as follows:

- Uneven driving floor or ground
- Unpredicted obstacle on driving course
- Slipping while driving

We applied UMBmark to our MSV and the following subsection shows the result.

B. Driving Error Correction of MSV

We composed a set of experiment for MSV driving in order to apply UMBmark. The driving experiments have been made on the flat and usual floor with the rectangular driving course of 4 × 4 meters. As shown in figures 10 and 11, both CW and CCW driving have been made and error values have been measured. These error values are incorporated in our software system and MPU controllers.

With the following equations from [2] we can find the error value for error correction.

$$b_{actual} = E_b \times b_{nominal}$$

where b_{actual} is an actual wheelbase and $b_{nominal}$ is a measured wheelbase.

$$\Delta U_{L,R} = c_{L,R} \times c_m \times N_{L,R}$$

Where U is actual driving distance, N is the number of pulses of the encoder, and c_m is the coefficient to convert pulse per centimeters.

Our experimental result with driving location correction by UMBmark dead-reckoning mechanism is shown in figure 12. Circled dotes are result from CCW driving and rectangular dotes are from CW driving. Empty dotes are of uncorrected driving results while filled dotes are of driving results with UMBmark in 16 meter driving experiment. Note that the origin of MSV (starting point) at the coordinate (0,0) are at the upper right part of the figure. Without dead-reckoning technology, MSV returns to erroneous point than the origin point, at the left part of the figure. This MSV tends to show more errors with CW driving. With the application of UMBmark technique, we achieved faithful result within 10 centimeters of error range in total. Directional errors are within the range of 3 centimeters from the origin. Since our approach is for mechanical driving errors, non-mechanical errors can be avoided and thus we will introduce real-time correction of driving with the help of digital compass for the future researches. Thus it is possible to mention that the trail of MSV in figure 7 is in the correct location within the errors of 10cm in our experimental environments.

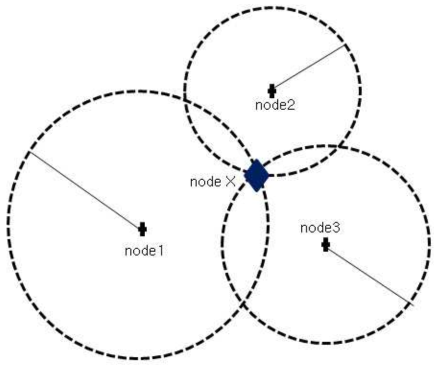

Fig. 13. Triangulation With RSSI Measurement

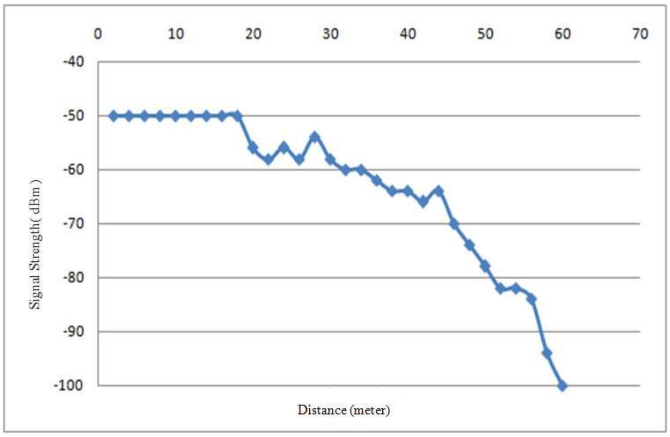

Fig. 14. RSSI values According To Distance

V. RSSI BASED LOCALIZATION

Our MSV are equipped with homogeneous 802.11 networking devices with RSSI facilities. With distance information we can do triangulation with at least three nodes and one anchor. Our monitoring station with monitoring program can act as an anchor. The 802.11 networking devices can be switched to AP (Access Point) mode so that each MSN can act as AP. With software modification that utilizes 802.11 device RSSI features, we can achieve RSSI based localization for our MSN.

The unit of RSSI is in dBm (-50dBm ∼ -100dBm) and it designates distances between specified MSVs. As already mentioned, the RSSI value is very affective by environments, and we obtain error rate of 10 ∼ 15% in specific distance. The RSSI value is very sensitive with hardware vendor and the direction of AP [7]. Our experimental environment is as follows.

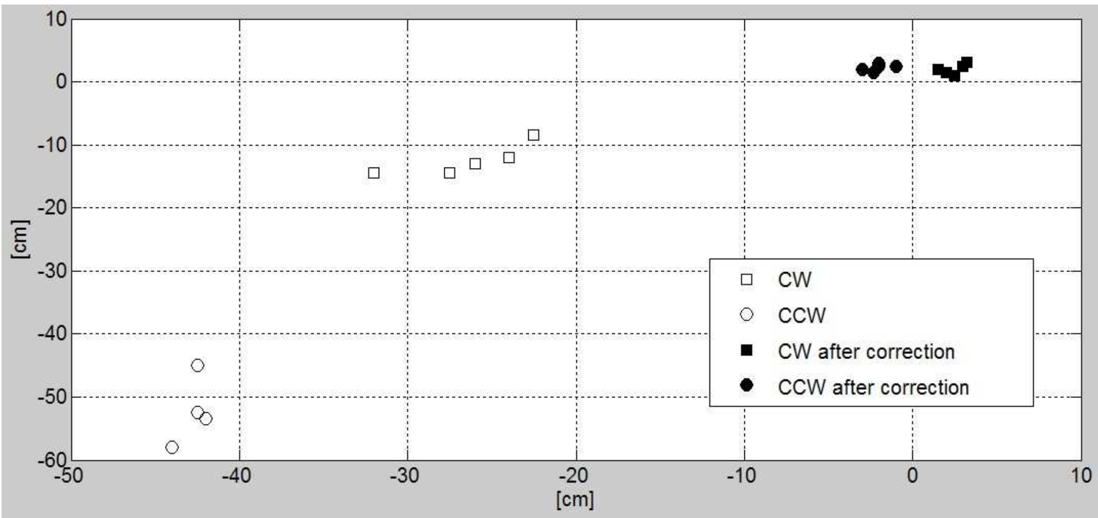

Fig. 12. Result of UMBmark

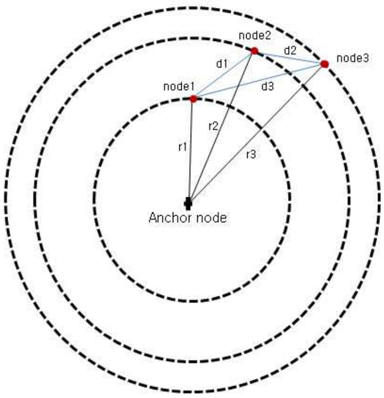

Fig. 15. Relation Between One Fixed Anchor And Mobile Sensor Vehicles

- Wide open area
- Intel Wireless LAN 2100 3B Mini PC Adapter
- WRAPI software model [11]
- One fixed anchor as monitoring station

For the calibration of our RSSI device, a set of experiment has been conducted and the results are shown in figure 14.

We can find within the distance of 20 meter, RSSI is no more useful for distance measure since the signal strength is too high. Our experiments shows RSSI based localization is useful more than 35m distance. The values are within error range of 15% by experiment. This is the main reason why we choose RSSI based localization for long distance, low accuracy localization.

From the distance information from RSSI sensing, we can do triangulation as shown in figure 13. For actual implementation, we have one fixed anchor and can do more precise localization with a known anchor coordinate as shown in figure 15. The figures show three mobile nodes one anchor node. The distance obtained from circle $r1, r2, r3$ can be obtained from RSSI values. Thus with this environment we can triangulate the coordinate node X from the intersection of circles drawn by node 1, node 2, and node 3 [9][10].

Thus from the distance which can be obtained from RSSI values, let the distance be di from radius of circle ri The following algorithm 1 shows a procedure to find coordinates of each MSV with provided distance information by RSSI.

Figure 16 shows a final result in RSSI based localization. The x-axis stands for actual distance between MSVs and y-axis shows a distance calculated by algorithm 1. As we predicted the RSSI based localization is useful with the distance more than 30 meters. On the range where RSSI based localization is effective, we can see errors between actual distance and calculated distance. We believe it is tolerable since we have another method of localization with more accuracy within the distance of 30 meters. Of course, the distance information is not a sufficient condition for localization. The other information of direction of MSV can be obtained by digital compass on each MSV. Thus we implemented long distance, low accuracy localization.

VI. Conclusions

For the localization methodologies for mobile sensor network, we proposed three different categories of localization methodology. In addition for the experiment, we implemented mobile sensor vehicle as a node of mobile sensor network. We showed brief description of mobile sensor vehicle including hardware and software functionalities. The driving mechanism hardware and software cooperate with each other and naturally achieve localization based on dead-reckoning, which is a medium distance and medium accuracy localization. The result of localization can be presented on local maps and eventually be merger into global maps. In addition we showed RSSI based localization. The long distance, low accuracy localization can be implemented by 802.11 networking devices

Algorithm 1 Localization of Sensor Nodes with RSSI Measurement

```
Input : d1, d2, d3, r1, r2, r3
//Distance d1, d2, d3
//Circle r1, r2, r3
Output : SolutionList
LinkedList SolutionList
//Mobile Sensor Node Coordinates

for (each (x1,y1) on Circle r1)
{
 for (each (x2,y2) on Circle r2)
 {
  if (d1 ==
   distance between (x1,y1) and (x2,y2))
  {
   for(each (x3,y3) on Circle r3)
   {
    if (d2 ==
     distance between (x2,y2) and (x3,x3))
    {
     if (d3 ==
     distance between (x3,y3) and (x1,y1))
     {
      SolutionList =
       Coordinate (x1,y1),(x2,y2),(x3,y3)
}}}}}}
```

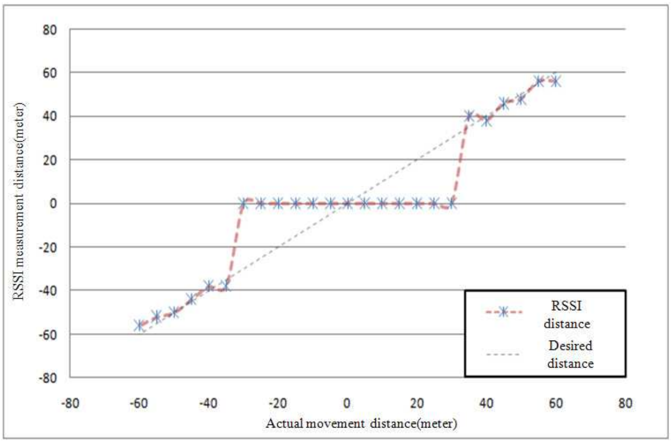

Fig. 16. Actual and RSSI based Distance

and algorithms based on triangulation. For short range, high accuracy localization, a stereo camera system is utilized. The detailed result of this computer vision based approach can be found in [18]. From these three levels of localization, we believe that we implemented useful localization system and will do more research using this platform. For example multiple MSV can cooperate and communicate each other and then a formation based on localization can be made. Also, a digital compass is also equipped in each MSV. Our medium accuracy localization can be more precise with more error correction mechanism with digital compasses.

REFERENCES

[1] Localization for Mobile Sensor Networks, Lingxuan Hu and David Evans, Tenth Annual International Conference on Mobile Computing and Networking (MobiCom 2004). Philadelphia, 26 September – 1 October 2004.

[2] J. Borenstein, L. Feng, D. K. Wehe, Y. Koren, Z. Fan, B. Holt, B. Costanza, UMBmark—A Method for Measuring, Comparing, and Correcting Dead-reckoning Errors in Mobile Robots 1995.

[3] R. B. Fisher, A. P. Ashbrook, C. Robertson and N. Werghi, A low-costrange finder using a visually located, structured light source. "3-D Digital Imaging and Modeling", 1999. *Proceedings. Second International Conference on 4-8 Oct. 1999* Pages: 24–33.

[4] B. Kuipers and Y.-T.Byun, "A robot exploration and mapping strategy based on a semantic hierarchy of spatial representations," Journal of Robotics and Autonomous Systems, 1991.

[5] J. Ollero Gonzalez and A. Reina, "Map Building for a Mobile Robot equipped with a 2D Laser Rangefinder," Proc. of the IEEE Int. Conf. on Robotics and Automation, pp. 1904–1909, 1994.

[6] Zhengyou Zhang , "A Flexible New Technique for Camera Calibration." *IEEE Transactions on pattern analysis and machine intelligence,* Vol. 22, No. 11, November 2000.

[7] Martin A. Fischler and Robert C. Bolles, SRI International. "Random Sample Consensus: A Paradigm for Model Fitting with Applications to Image Analysis and Automated Cartography." Communications of the ACM, June 1981.

[8] J. Borenstein and Y. Koren, "Histogramic In-Motion Mapping for Mobile Robot Obstacle Avoidance, IEEE TRAN." *Robotics and Auto,* Vol. 7, No. 4, 1991.

[9] Anastasia Katranidou, "Location-sensing using the IEEE 802.11 Infrastructure and the Peer-to-peer Paradigm for Mobile Computing Applications," Heraklion, February 2006.

[10] P. V. Bahl and Padmanabhan, "Radar: An In-Building RF-based User Location and Tracking System," in *Proceedings of the Conference on Computer Communications (IEEE Infocom),* (Tel Aviv, Israel), March 2000.

[11] WRAPI, http://sysnet.ucsd.edu/pawn/wrapi

[12] IEEE Std. 802-11.1997, "IEEE Standard for Wireless LAN Medium Access Control(MAC) and Physical Layer(PHY) Specification," June 1997.

[13] Kohsei Mstsumoto, Jun Ota and Tamio Arai, "Multiple Camera Image Interface for Operating Mobile Robot," Proceedings of the 2003 IEEE lnternational Workshop on Robot and Human Interactive Communication Millbrae, California, USA, Oct. 31 – Nov. 2, 2003.

[14] Brenden Keyes, Robert Casey, Holly A. Yanco, Bruce A. Maxwell, Yavor Georgiev, "Camera Placement and Multi-Camera Fusion for Remote Robot Operation," IEEE Int'l Workshop on Safety, Security and Rescue Robotics, Gaithersburg, MD, August, 2006.

[15] Sebastian Thrun, Mike Montemerlo, Hendrik Dahlkamp, David Stavens, Andrei Aron, James Diebel, Philip Fong, John Gale, Morgan Halpenny, Gabriel Hoffmann, Kenny Lau, Celia Oakley, Mark Palatucci, Vaughan Pratt, Pascal Stang, Sven Strohband, Cedric Dupont, Lars-Erik Jendrossek, Christian Koelen, Charles Markey, Carlo Rummel, Joe van Niekerk, Eric Jensen, Philippe Alessandrini, Gary Bradski, Bob Davies, Scott Ettinger, Adrian Kaehler, Ara Nefian, Pamela Mahoney, "Stanley: The Robot that Won the DARPA Grand Challenge." Journal of Field Robotics 23(9), 661–692 (2006).

[16] A. Elfes, "Occupancy grids: A Probabilistic Framework for Robot Perception and Navigation," PhD thesis, Department of Electrical and computer Engineering, Carnegie Mellon University, 1989.

[17] Magnus Lindhe, Karl Henrik Johansson, "Communication-aware trajectory tracking," IEEE International Conference on Robotics and Automation, 2008, , pp. 1519-1524, 2008, IEEE.

[18] Kwansik Cho, Ha Yoon Song, Jun Park, "Accurate Localization in Short Distance based on Computer Vision for Mobile Sensors," First International Symposium on Multimedia—Applications and Processing (MMAP'08), Oct. 2008, IEEE.