Robot Localization with Ultrasonic Position System

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Abstract— The robot localization problem is a key problem in making truly autonomous robots. In this work we provide thorough discussions of Ultrasonic Positioning System can be applied to the localization problem. First, we look at the use of Kalman filters and basic concept and the equation involved in Kalman filters. Secondly, we create understanding of how the Kalman filters can be implemented in robot localization. We show our discussion and experiments how Kalman filters applied to the localization problem. Lastly, we perform simulations using Usat Wheel Chair robot in our own general Kalman filters robot monitoring software.

Index Terms— Ultrasonic Positioning System (UPS), Kalman filter, Robot, indoor location.

I. INTRODUCTION

When an autonomous robot perform action such as free path tracking and reactive navigation, the capability to estimate its position with respect to a reference frame is very important. A rough estimation of the robot location (position and orientation) is possible with odometric data. In this paper, we will focus on how the mathematics derivation and formulation of Kalman filter, how to apply Kalman filter and its extensions into robot localization, and the simulation and experimental result of using Kalman filter on an autonomous driving robot system. A general factor that complicates some of the difficulties is the existence of noise and errors. The general localization problem could be described as Bayesian estimation problem. We formalized the uncertainty and beliefs of localization problem into a probabilistic point of view and look at different solutions to the localization problem that implement this framework.

The kinematics model of the robot is never accurate. The sensor models also suffer from inaccuracies and can become very complicated. The sensor readings are corrupted by noise. Besides, the motion of the robot involves external sources of error that are not observable by the sensors used. Due to the above reasons, there is error in the calculation of robot's position and orientation which generally grows unbounded with time. Many methods have been used accordingly to estimate mobile robot's pose.

Many studies have been presented to solve this localization problem. The GPS system which is widely used in automobiles has large error range and is not available indoors.

UPS (Ultrasonic Positioning System) is an absolute positioning system using ultrasonic sensors. It used direct ultrasonic waves method to measure the distance between the transmitters and receiver. Ultrasonic ranging sensors have proved to be very useful, economical external sensing system for localization of mobile robots. The numerous ultrasonic locations method can be divided into two groups of technical methodologies. The first one is that the robot measures time of flight (TOF) data from itself to its surrounding by using several ultrasonic sensors mounted on it and processes this information to obtain its spatial location by means of barrier tests, extended Kalman filtering with environment models. In this method, four ultrasonic transmitters are attached on the ceiling in the fixed positions whose coordinates are known and the ultrasonic receiver is attached on a specific object. Ultrasonic receiver receives ultrasonic waves signal from four ultrasonic transmitters and calculates its position real time with respect to the (x,y,z) coordinates. [2]

In this work, we will show the implementation of the Kalman filter on an autonomous driving robot system using ultrasonic positioning system. The system architecture will be displayed and we will formulate the equations which have been used in determining the location of the autonomous driving robot together with the Kalman filter equations and we summarize the presented work with concluding remark, we will also present ideas and possibilities for future research.

II. THE IDEAS BEHIND UPS [8]

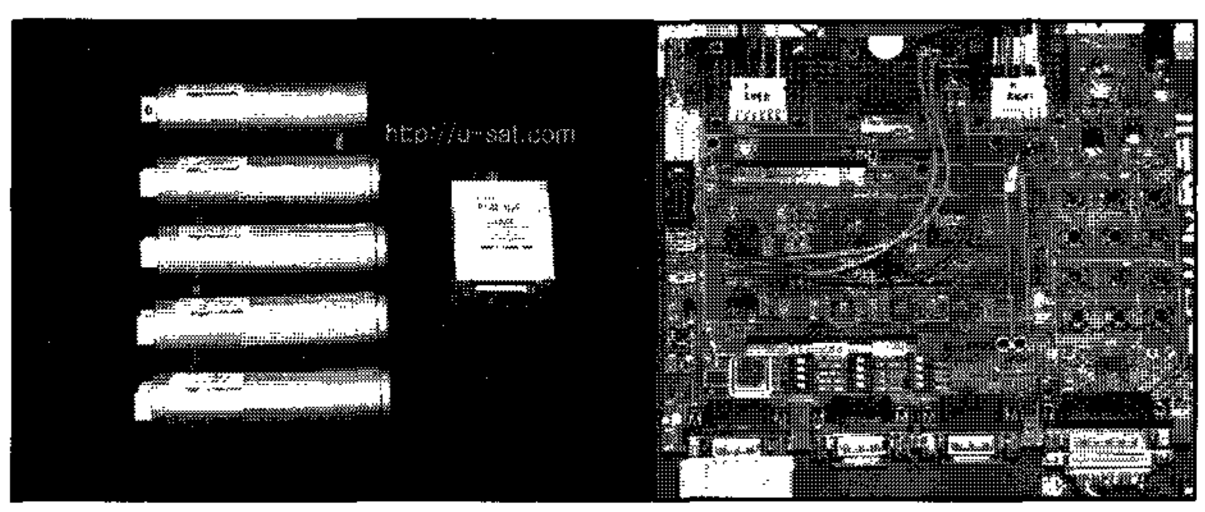

Fig.1 Ultrasonic Positioning System (U-SAT)

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Generally, UPS consists of four ultrasonic satellites and one receiver as shown in Figure 1, 2, 3.

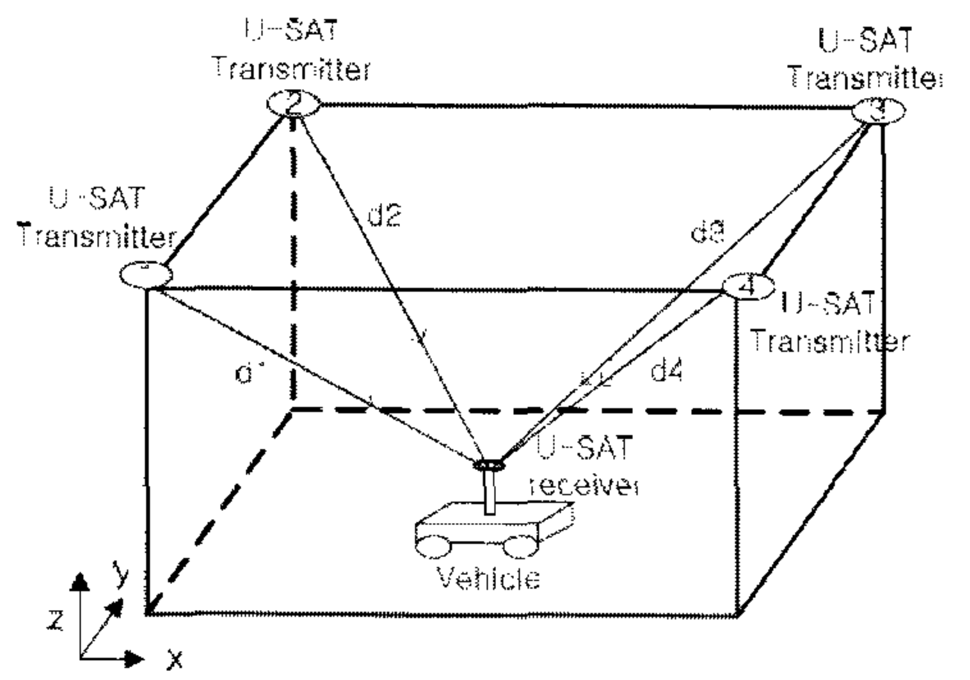

Fig.2 Hardware Configuration of U-SAT

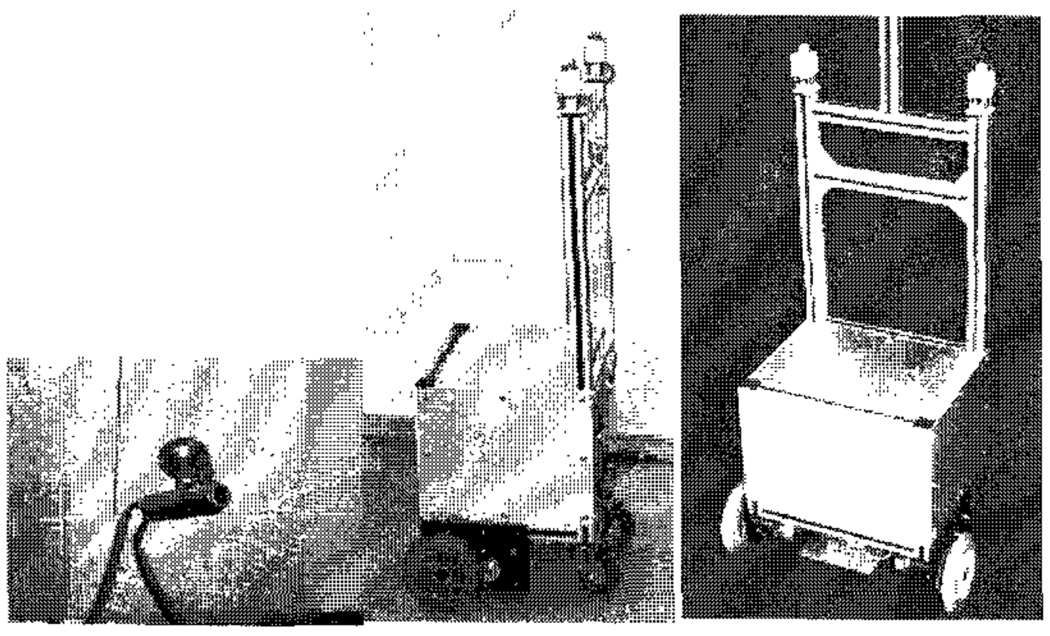

Fig. 3 Ultrasonic Satellite & U-SAT Wheel Chair Robot

III. UPS and Kalman Filter as Robot Localization [6]

A. Kalman Filter

The Kalman Filter is an optimal estimator for linear system. The problem of filtering non-linear systems is however more difficult. The Extended Kalman Filter addresses the problem by linearizing about the filters estimated trajectory. Figure 4 shows the resulting trajectory of the real and estimated states of a representative run. Due to the system noise and the difference between the real and noise-free trajectory, the robot could perform a perfect square. Besides that, the trajectory of a perfect square path increases over time. During the starting phase, the EKF does not receive any reading in the real state. Therefore, the EKF is not able to differentiate between the noise-free and real trajectory. After EKF obtaining the average the system noise is zero, eventually makes the predictions of the EKF decide to follow the noise-free path. Thus, whenever there is no incoming reading, the estimated state trajectory is far difference with the real trajectory, and it follows the trajectory as modeled by the system model.

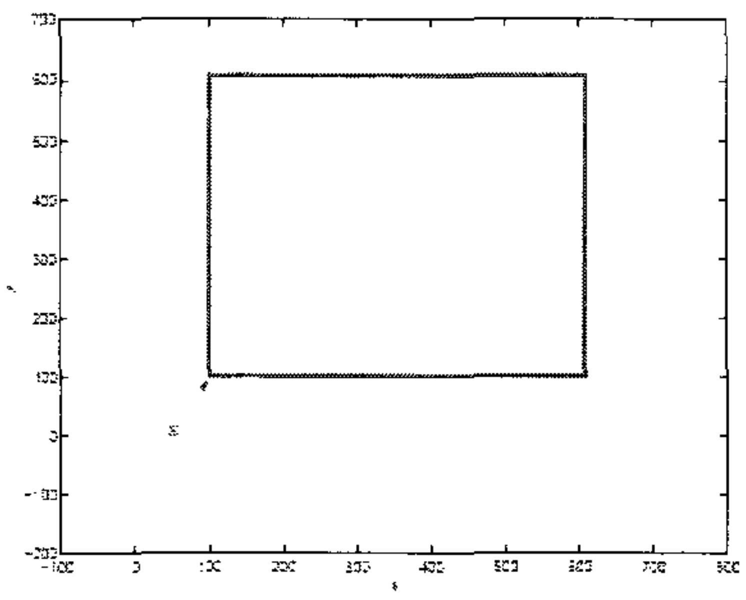

Fig. 4 Robot starts at point S and moves in counter-clockwise

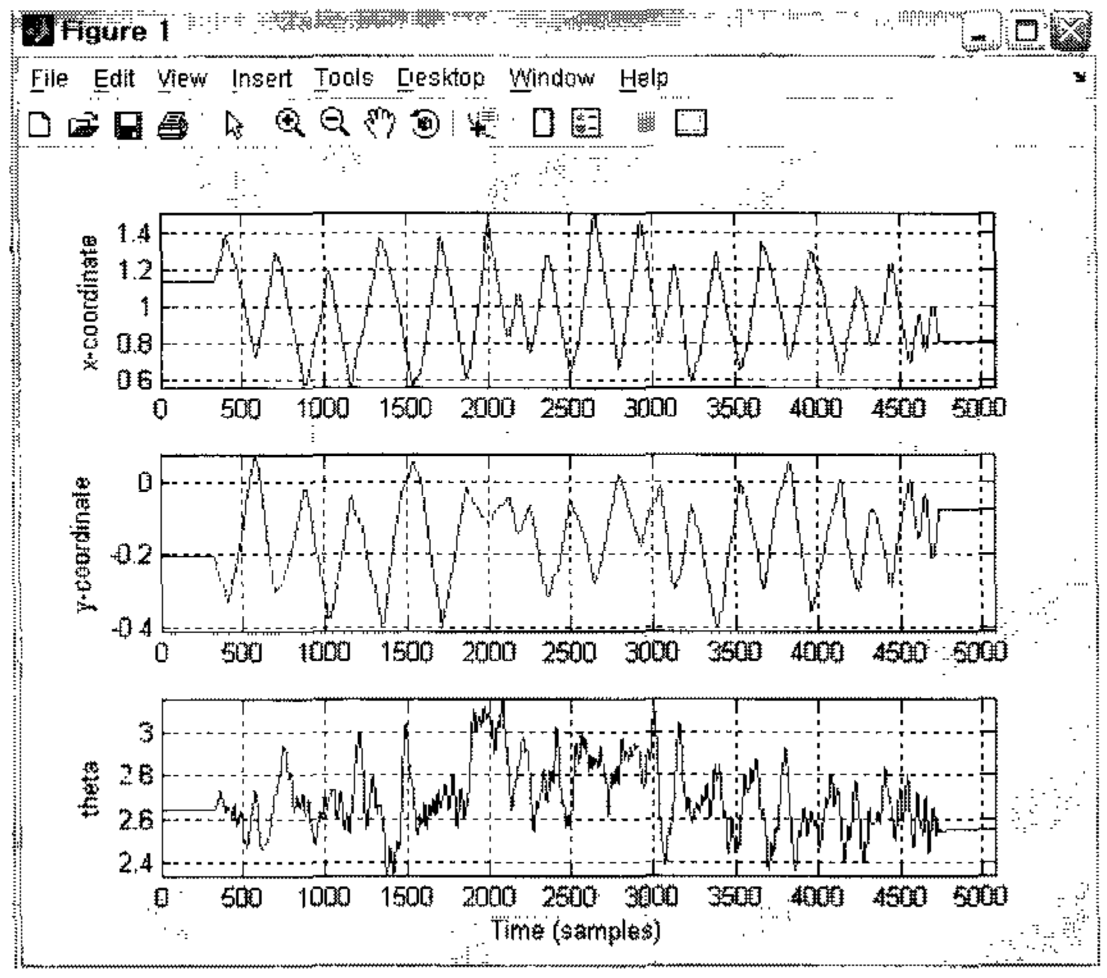

Fig. 5 EKF results of the driving mobile robot from initial location to final location in the x, y coordinate and the orientation

Figure 5 shows the result of the driving mobile robot from initial location to final location in the x, y coordinateand the orientation. From the results showing in three different graphs, we take the maximum samples of 5072 units. The mobile robot receives the measurement data fromthe ultrasonic positioning system and corrects its state estimation from time by time. The initial state of the robot is the first observation data obtained from the sensor in x, y and orientation coordinates. The EKF filter will estimates the states for nonlinear system written in the general form, x(k+1) = f[x(k),u(k),v(k)] and y(k) = g[x(k),w(k)].

At the experiment, the ultrasonic sensor made use of an integrated receiving and transmitting model at 40 KHz that could detect rear side of the robot shown in Figure 6.

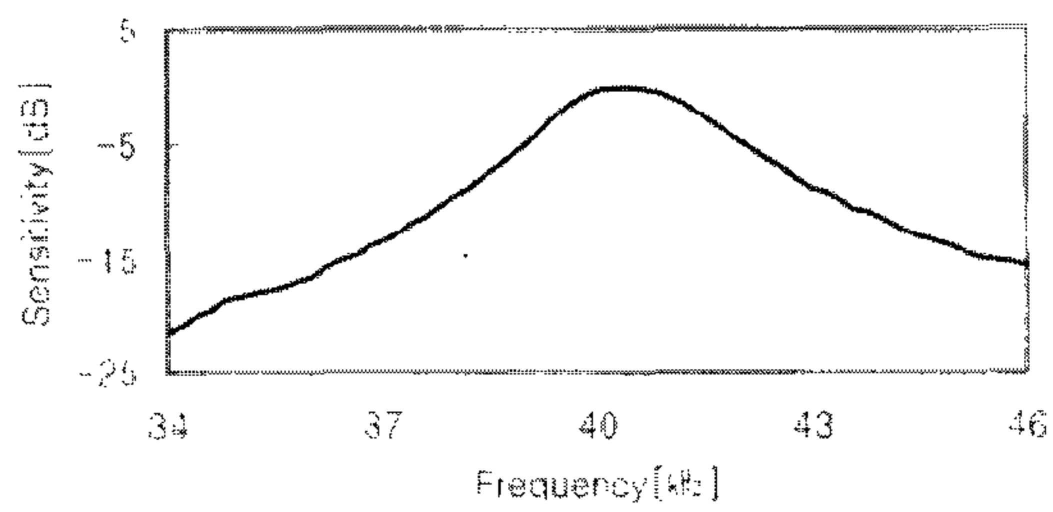

Fig. 6 Ultrasonic Sensor Frequency

B. DD1 & DD2

The paper presents two filters: the DD1 filter, which is based on first-order approximations and the DD2 filter, which is based on second-order approximations. In term of accuracy, the DD1 filter is said to be comparable to the EKF in tems of expected error. The superior DD2 filter, however, outperform the EKF in accuracy and is claimed to be comparable to a fourth order filter (for "one-dimensional" systems, i.e. z is one dimensional).

The simulation result of Figure 7 and Figure 8 are identical. The main differences are the filtering time and the Jacobians are replaced by divided differences. The difference between DD1 and EKF mainly relate to the update of the various covariance matrices.

The operation of the DD1 adopts a form of feedback control in estimation: the filter estimates the process state at some time and then obtains feedback in the form of measurement. As such, the equations for the DD1 iterations fall into two groups: correction equation and measurement update equations.

State prediction computation:

$$\bar{z}_{t+1} = f(\hat{z}_t, 0)$$

Covariance prediction computation:

$$\bar{P}(t+1) = S_{z\hat{z}}(t)(S_{z\hat{z}}(t))^T + S_{zv}(t)(S_{zv}(t))^T$$
$$\bar{S}_z(t+1) = [S_{z\hat{z}}(t)\ \ S_{zv}(t)]$$
$$\bar{y}_t = g(\bar{z}_t, 0)$$

The DD1 filters update the Cholesky factors of the covariance matrices directly. The DD2 filter use the same concept as what the DD1 filter do and it define four additional matrices containing divided differences. Figure 9 is the right and left wheel radius and the wheel distance according with time.

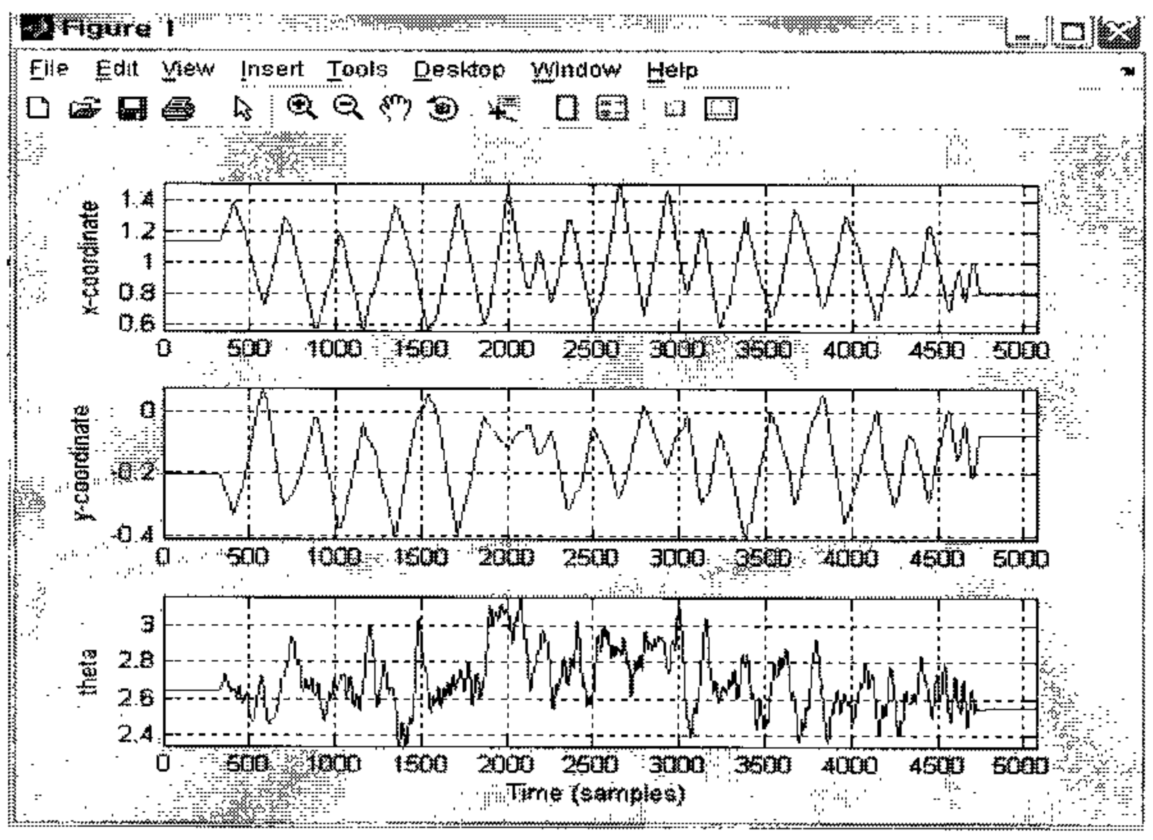

Fig. 7 DD1 results of the driving mobile robot from initial location to final location in the x, y coordinate and the orientation

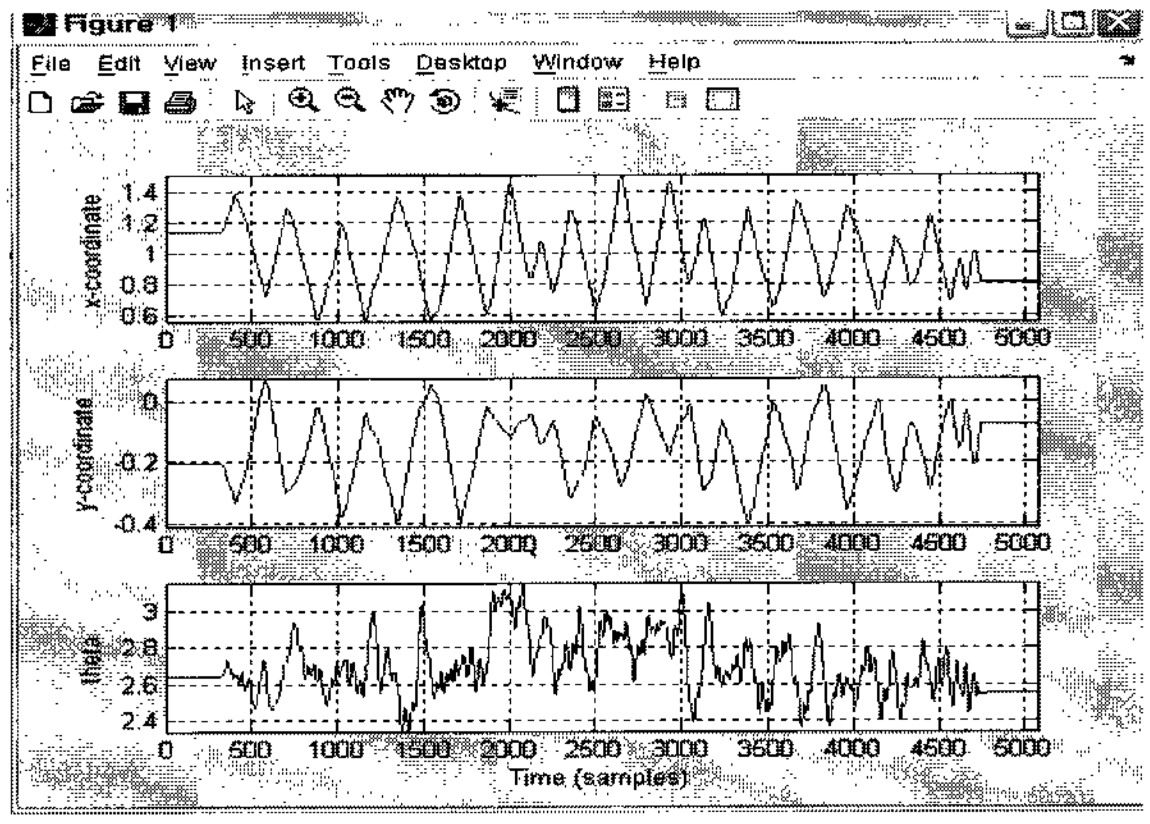

Fig. 8 DD2 results of the driving mobile robot from initial location to final location in the x, y coordinate and the orientation

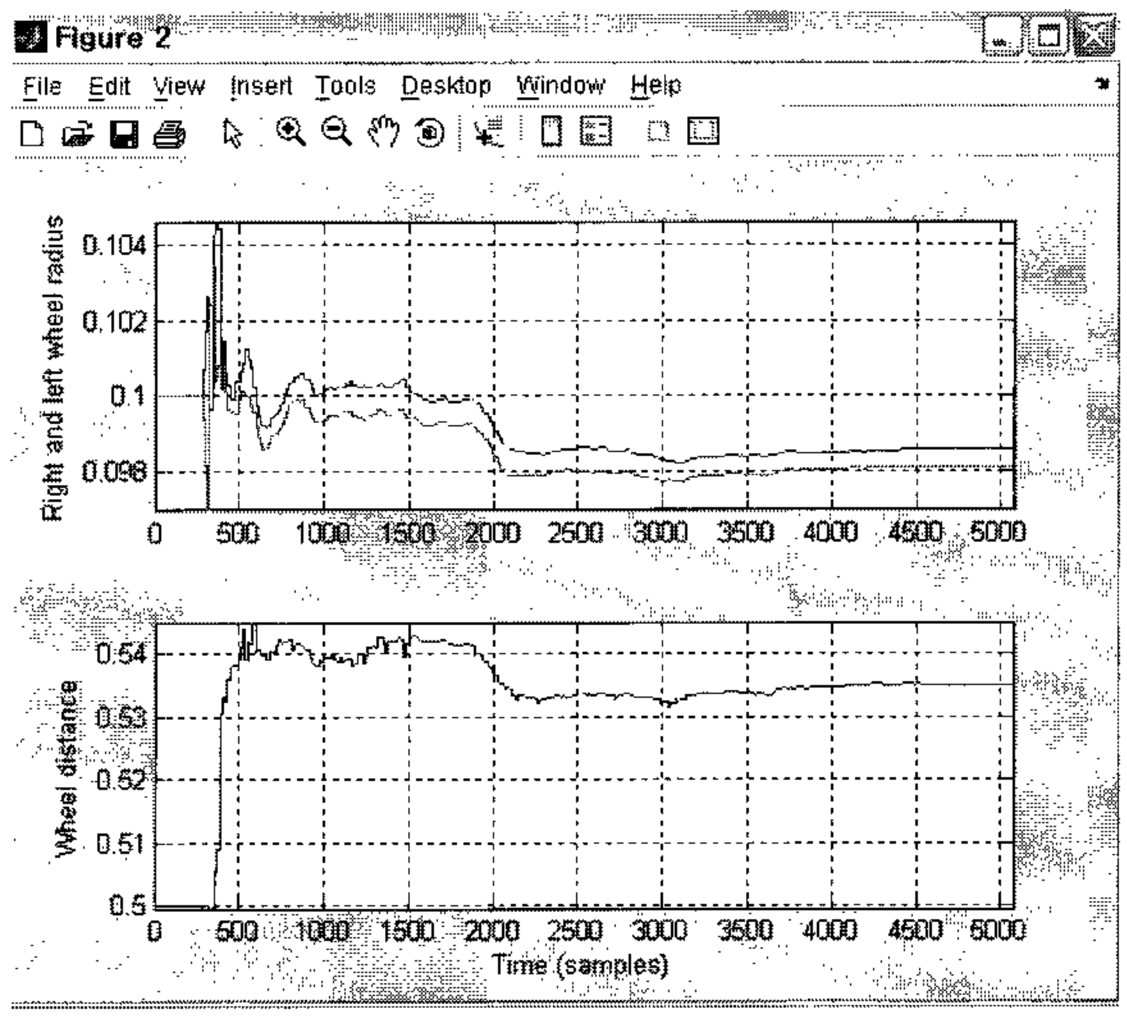

Fig.9 Result of the wheel distance & right and left wheel radians with 5072 samples

C. Robot Localization

At the starting of the experiment, a connection needs to be established with personal computer and the robot via RS232. The current position of the robot will be displayed on the blank graph on the computer by using the ultrasonic position system. The software show in Figure 10 written in C++ used to monitor, control, and setting up the properties of the mobile robot. With these software, user able to control the mobile robot movement to the user desired destination. By pressing the buttons on the software, robot can move in the path that user assigned. All the path and movement of the robot are calculated by the software. The software will clearly display the current location of the robot and the location of the robot will be updated from time to time.

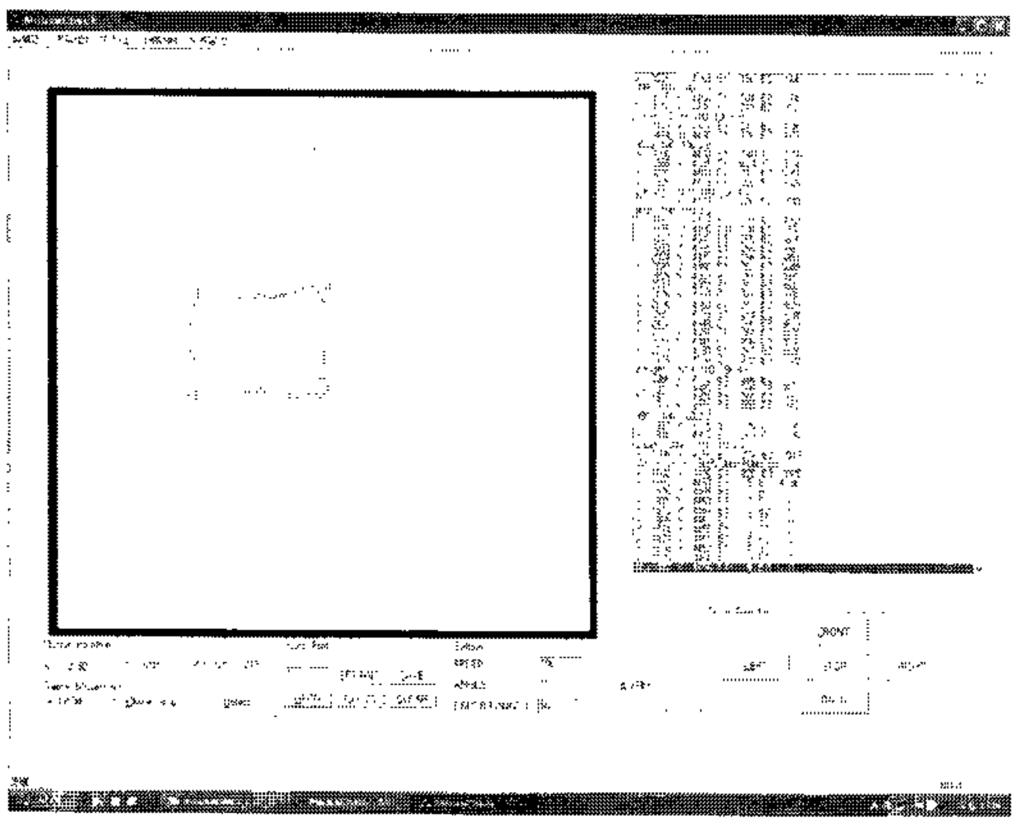

Fig. 10 Robot Software Controller in C++

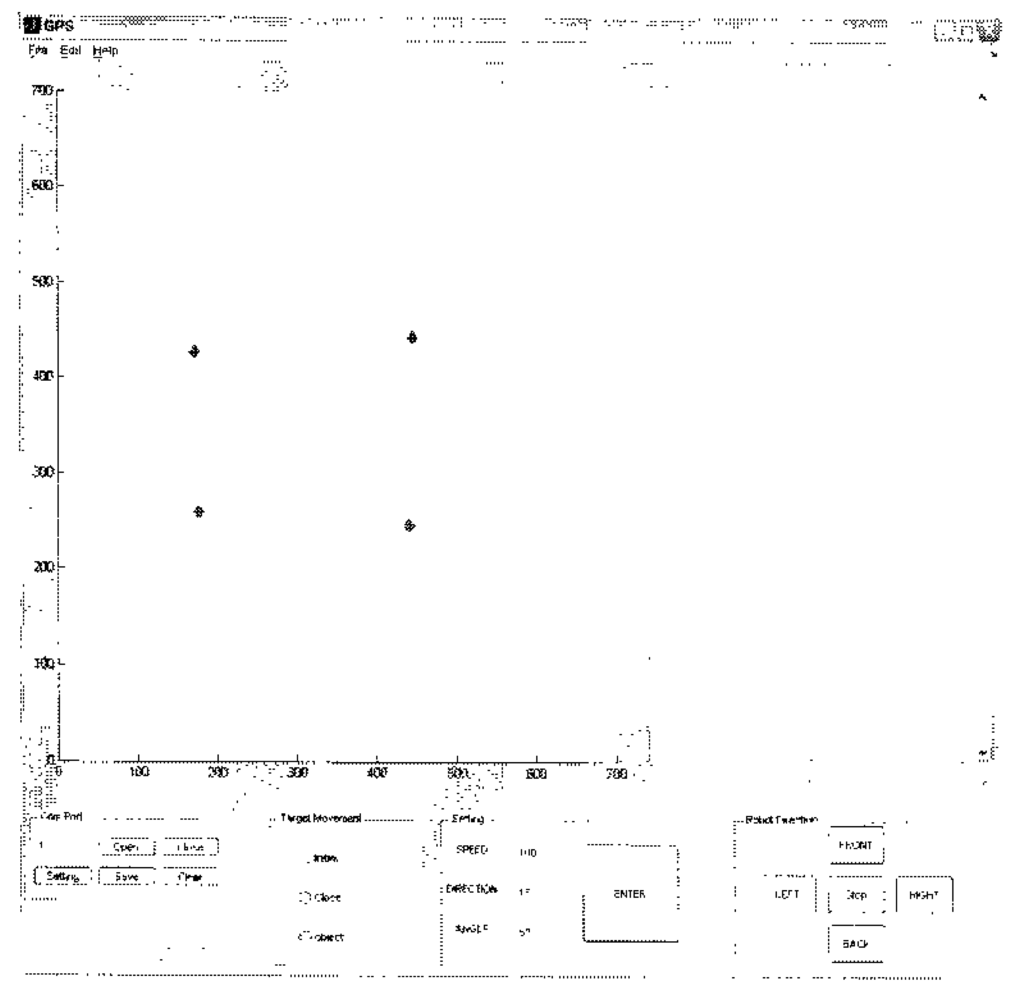

Fig.11 Robot Software Controller in matlab

Eventually, we applied the Kalman Filter for the robot localization in Matlab. The software written in Matlab has similar functionality as the software written in C++. Figure 11 show the window of the software written in Matlab.

IV. CONCLUSIONS [6]

This project has demonstrated that the Kalman Filter can be effectively applied to robot localization and world modeling and significantly enhances the operation over other methods. It is possible to obtain and estimate of a stationary robot position using a Kalman Filter accurately to within a few centimeters with reasonable consistency. We have described an ultrasonic sensor localization system for autonomous mobile robot navigation in indoor environment, based on the modeling of the ultrasonic sensor sensing process and a genetic iterative refinement method. The proposed algorithm is based upon an iterative extended Kalman Filter, which utilizes matches between observed geometric beacons and an a priori map of beacon locations to correct the position and orientation of the robot. This method is applicable to mobile robot localization and proved to achieve solutions with computational time less than those search methods which provide precision of the same order. From a particular point of view, it is very important for the robot to know where it has been located with related to the environment in order for it to determine the next action to be carried out. The location or pose of a robot could be represented in x, y and heading direction of a robot in a global coordinate system. In order to show how we can use Kalman Filters in the Robot localization context, we derived models for acting and sensing and discussed the true behavior of these systems in the light of noise. In the predictive position tracking section, we displayed the three different kinds of simulation results of three different filtering which include the Extended Kalman Filter, DD1 and DD2. We do the same thing again by showing the simulation resulted in matlab on how robot use the measurement information it obtained from the sensor to correct its state estimation.

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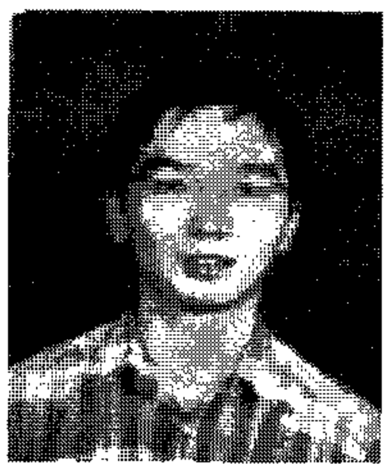

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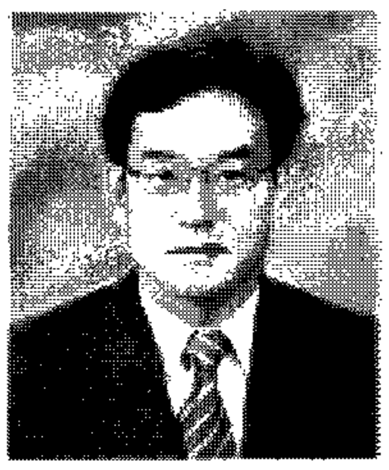

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