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IMPROVING THE LOCALIZATION OF ELECTRIC WHEELCHAIR BY USING PARTICLE FILTER

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Abstract- The electric wheelchair for handicapped is used to improve the displacement of disabled persons. An automatic navigation system is needed to ensure greater autonomy and security for the disabled person. Automatic control system is added to a manual control for autonomous displacement. Initial system composed of two DC motors installed at the rear of used electric wheelchair, power module for the motors control and joystick to select speed and moving direction. We include an automatic control system composed by two electronic cards, based on microcontrollers CB405 and PIC16F877 for the signal acquisition from the encoders and distance measurements from ultrasonic sensors (SRF08 and SRF04). The ultrasonic sensors used to improve the localization when we use an automatic control system. Several techniques exist for sensors fusion solves the problems of mobile robots localization. Among these methods, we can quote the particle filter that use data from the encoders and measures from the ultrasonic sensors.

Index terms: electric wheelchair, encoder, ultrasonic sensors, particle filter, power module, microcontroller, CB405, PIC16F877.

I. INTRODUCTION

Each Mobile robot is primarily designed to perform a number of tasks. The task depends on the scope for which the robot has been designed as the medical field which is the case for our work.

So that the robot can work, it is necessary to develop systems of perception, localization, path planning or control. The architecture of the robot can be summarized by two tasks (the task of navigation and of localization).

There are several techniques used to aid disabled people and move the wheelchair. In the work of Razali Tomari and al. [1] they propose a method of navigation in indoor environments with presence of humans based on the observation of head information obtained from color and range images. We cited other proposed works in literature, we note The “AGENT-BASED” system proposed by Chung-Hsien-Kuo and all [13]. This control system of electric wheelchair navigation use fuzzy logic. This method composed by different part, then goal-seeking to join the target, obstacle-avoidance and wall-following. Also we cited the "Hephaestus system" developed by Richard C. Simpson and all is mounted on the wheelchair "Everest and Jennings Lancer 2000" [15]. This intelligent wheelchair system uses the Mobility aid to allow an individual to have more mobility and independence when moving.

Several methods of localization give the mobile robot position. Then the relative localization [11] is based by using odometers or the inertial sensors. The current robot position is calculated from the knowledge of the initial point, by the integration of information from sensors of displacement, velocity or acceleration. Also the absolute localization used in other works [4], then the principle of this method is based on the use of active or passive tags which are placed in the environment. Usually the active tags are of transmitters (infrared, Laser) and/or receptors (photodiode, camera, ultrasound transducer, radio antenna). Then we cite the method of an indoor localization proposed by Yan Bingbing and al. [2] based on RFID.

Also, in the work of Kum Qian and al. [6] they use a unified and probabilistic method for simultaneously localization of a mobile service robot and states estimation of surrounding objects and co-existing people.

The data fusion appeared in order to manage very large quantities of multi-source data. For a few years, methods of data fusion have been adapted and developed for applications then the research of S. C. Mukhopadhyay et al. [14,16,20] and other research using data fusion [4,8,9,17,19].
Particle filters, also known as methods of sequential Monte Carlo (SMC) are techniques of estimate based on simulation. The Monte-Carlo methods are present in very broad fields of science. Used in mobile robotics for localization, path planning and vision, this technique is also more widely in physics, engineering, statistics or economics.
Particle filtering has been used to solve many complex problems [4,9,12]. The particle filter, used in this paper is a numerical method to approximate the conditional probability distribution of the state knowing the observations, using the empirical distribution of a particle system.
This paper describes the use of particle filter and fusion used for the localization of an electric wheelchair for handicapped. At first, the simulation is performed. As a second step, we proceed with practical experimentation. The goal is to have a better estimation of the wheelchair position.

II. CONTROL SYSTEM FOR THE ELECTRIC WHEELCHAIR

The electric wheelchair for handicapped is monitoring by a manual system. The manual systems composed by joystick to manipulate the electric wheelchair [23]. The joystick is connected with the power module [22] using CAN bus to send and receive information.

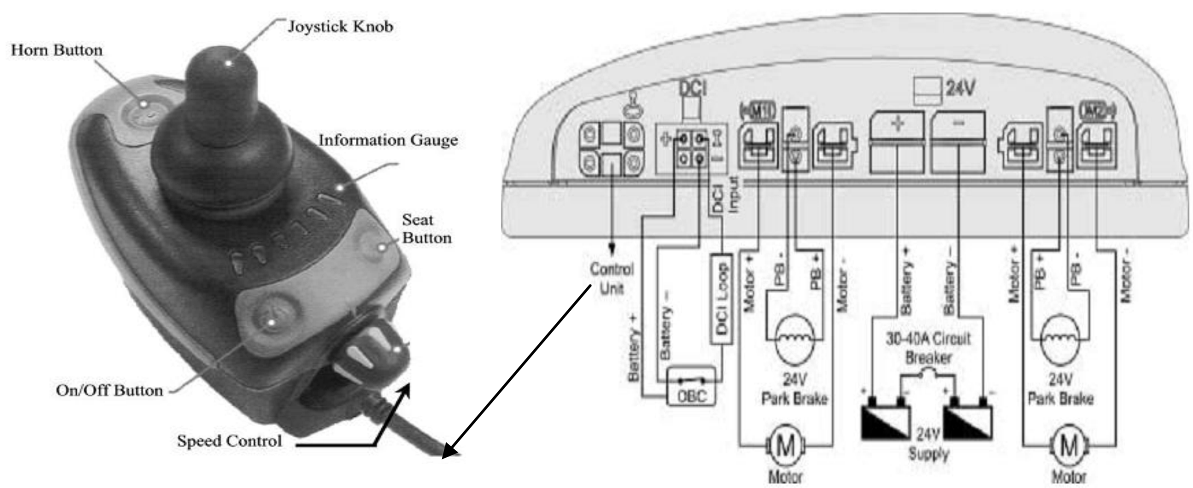

Figure 1. Manual control system of the electric wheelchair

The power module controls the motor speed. The connection between these components is given in figure 1.

In order to make the disabled more independent, we have added a controller to attend a desired position. Then we have added an obstacle detection system and an obstacle avoidance controller. In this context the electric wheelchair has been equipped with two control unit. The first unit based on micro-controller CB405 for manage the motors velocity and acquisition of signal from the encoders [7]. The second based on PIC16F877 for explore the ultrasonic sensors SRF08 and SRF04 [3]. All information is sent to the computer for calculation of new speed control. The data transmission between the control unit and the computer is through the MAX232 circuit providing a serial link with a rate of 9600 bit/s.

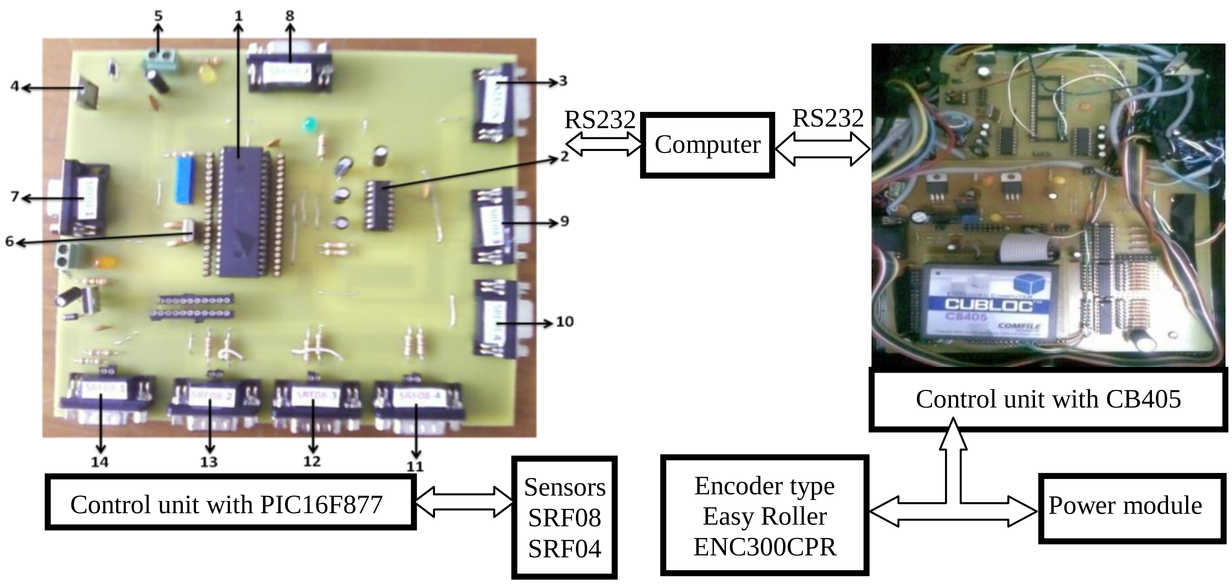

Figure 2. Automatic control system of the electric wheelchair

The wheelchair's automatic control system architecture is represented by Figure 2. In this system the distance measurement separating the electric wheelchair and obstacles obtained by the control unit with PIC19F877. This distance measured by two types of ultrasonic sensors SRF08 and SRF04.

a. Ultrasonic sensors SRF04

SRF08 and SRF08 are based on measuring the elapsed time between emission and return echo [24]. When the ultrasonic wave is emitted it propagates at the speed of sound in the air, it approximate to 343m/sec. Once an obstacle is encountered, the echo returns to the transducer, which then calculates the time between transmission and reception of the ultrasonic waves. The connection of SRF04 sensor and the control unit is presented in Figure 3.

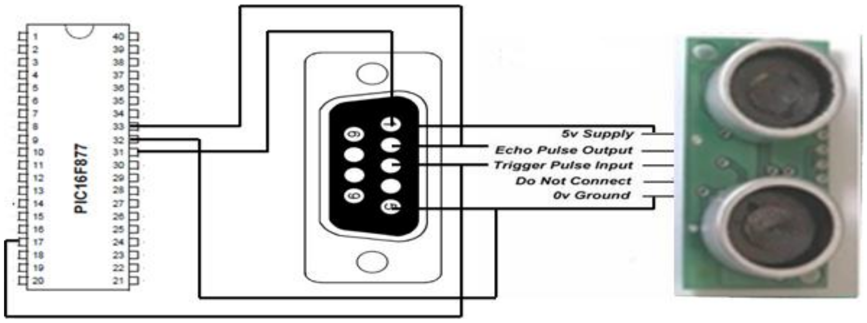

Figure 3. Connection of SRF04 with microcontroller PIC16F877

b. Ultrasonic sensors SRF08

This sensor analyzes the ultrasonic wave using an integrated microcontroller. The control unit with PIC16F877 uses the I2C (Inter Integrated Circuit) bus to manage the ultrasonic sensors SRF08 [25]. The I2C is a serial bus using three wires that uses only two signal lines and the corresponding masses. The advantage of this bus is to connect multiple sensors on the same wire. The connection of SRF08 sensor and the control unit is presented in Figure 4.

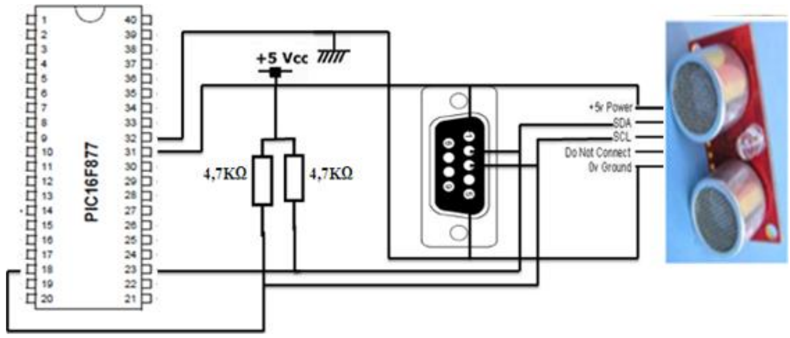

Figure 4. Connection of SRF08 with microcontroller PIC16F877

c. Placement of sensors on the electric wheelchair

Eight ultrasonic sensors are located on forward and backward of the electric wheelchair. Also the incremental encoders installed on the DC motors shown on figure 5. These measures are very useful for obstacle avoidance algorithms. The navigation system require speed measurement and sensors reliability in view to obtain accurate real distance.

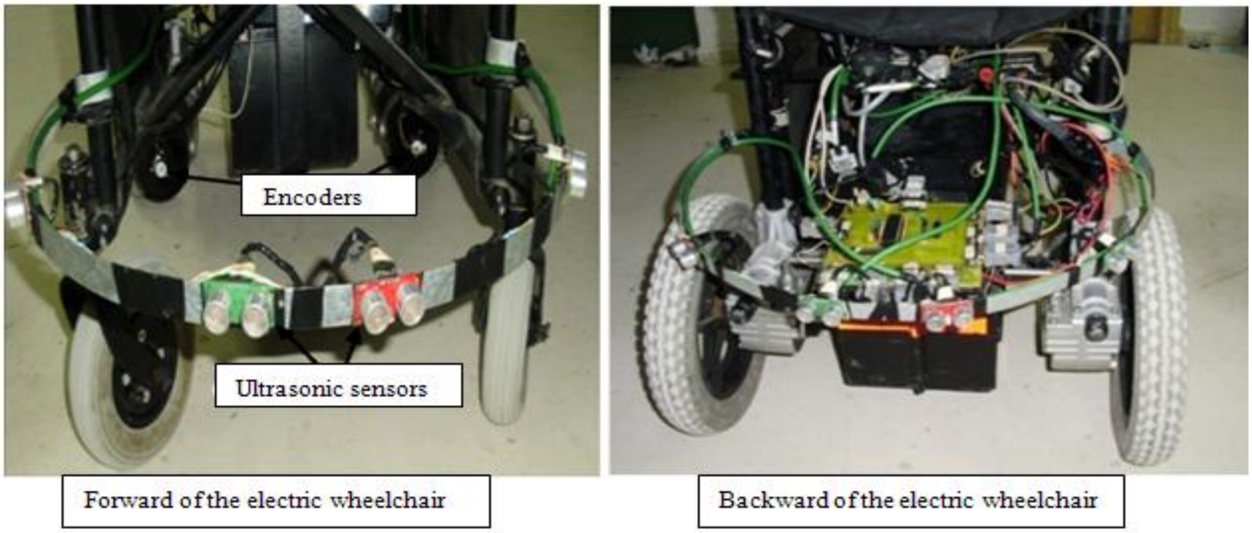

Figure 5. The automatic control system installed on the electric wheelchair

In this electric wheelchair we use a fuzzy controller which generates a wheel speed command in order to reach desired position with the least effort. This fuzzy controller use the information delivered by the encoders and kinematic model for localization [7]. We have used an electric wheelchair designed for medical applications and precisely for handicapped that cannot support high speeds. The results of this fuzzy controller are presented in reference [7, 10].

In the other hand we developed a fuzzy controller to ovoid obstacle for increase security of the electric wheelchair users [3].

The fuzzy controller to join the target and the fuzzy controller to avoid obstacle use the encoder for the localization. In this method of localization we confront a large error margin mainly in practice, because the initial start condition are always flawed and principally made for the angle of rotation. Many other external condition increases the error of localization then the orientation of free rotating wheels placed forward that ensure static stability. Also the sliding wheel driving provides false measurement of displacement. In consequence these fuzzy controllers don't work properly that in ideal condition.

In this context, we tried to improve the localization using the particle filter in order to achieve the desired places with more precision.

In the following paper we will detail the principle of the particle filter and the various equations used by this method. Also we describe the experimental result obtained by the particle filter applied on the electric wheelchair for handicapped.

III. PARTICLE FILTER

Particle filter are a sequential version of Monte Carlo methods to solve the problems of filtering. The conditional distribution of the state is represented by a weighted Dirac finite number are mentioned particle. Each particle represents a weighted probable system state. Its weight is in particle confidence degree function to represent the system state.

The particle filter is currently experiencing strong growth in many fields of science and information technology and communications, or engineering sciences, then localization, navigation, tracking, continued multi targets, vision, robotics, audio signal processing and digital communications.

We start by describing the basic algorithm, historically the first contain a redistribution step, introduced as the particle filter with interaction or condensation algorithm (conditional density propagation) [12].

We consider now a Markov discrete nonlinear system:

$$x_{k+1} = f_k(x_k, u_k, v_k), \quad k = 0,1,\ldots \quad (1)$$

$$y_k = h_k(x_k, w_k), \quad k = 0,1,\ldots \quad (2)$$

Where f_k and h_k are known functions, x_k is the vehicle previous configuration at the time k, u_k is the control vector calculated using proprioceptive sensors noisy information between the time k and k+1. y_k is the vector obtained by observation and exteroceptive sensors. v_k and w_k are the state noise vectors and observation noise.

The necessary conditions for the implementation of the particle filter algorithm are generating $p(x_{k+1}|x_k, u_k, v_k)$ according to the state transition law and be able to assess the likelihood function $p(y_k|x_k, w_k)$ at any point in the space state.

The algorithm of the particulate filter is based on Monte-Carlo sampling. We note $x_{0:k} = (x_{0,\ldots,}x_k)^T$, the path from the initial state x_0 in the final state x_k. It is assumed that the state k, was an approximation of the conditional density $p(x_{0:k}|y_{0:k-1})$ state x_k knowing measures $y_{0:k-1} = y_{0,\ldots,}\, y_{k-1}$.

1- For i=1 to N, particles evolve $x_{k+1}^i = f_k(x_k^i, u_{k+1})$. (3)

2- For i=1 to N, to evolve the weight of the particles $w_{k+1}^i = w_k^i \frac{p\left(x_{k+1}^i \middle| x_k^i\right) p\left(y_k | x_{k+1}^i\right)}{q\left(x_{k+1}^i | x_{0:k}^i, y_{0:k}\right)}$. (4)

3- For i=1 to N, normalizing the weight of the particles $w_{k+1}^i = \frac{w_k^i}{\sum_{j=1}^N w_k^j}$. (5)

a. Degeneration of particle weight

The previous algorithm has a serious defect: in a few iterations k, almost all weight w_k^i are zero. Ideally the weight should stay around $\frac{1}{N}$, the particles are of equal importance in the approximation.

We can consider the following criteria [18]:

$$N_k^{eff} = \frac{1}{\sum_{i=1}^N (w_k^i)2} \in [1, N] \quad (6)$$

This represents the effective number of particles. When N_k^{eff}nearly N then particles are same importance. There is weight degeneration when N_k^{eff} nearly 1.

In the next section we present a protection method against degeneration by redistributing particles.

b. The particles resampling

The particles propagation by sequential importance sampling algorithm causes the degeneration of the filter due to the particle error. To solve this problem, we will generate another particle system of the same size by promoting particles larger weight. Some particles will be duplicated and others eliminated. Then a new sample of particles is obtained.

IV. Localization of electric wheelchair using particle filter

In this paper we use the electric wheelchair for handicapped is composed of two independent driving wheels presented in figure 5. The movement of the electric wheelchair is obtained by acting on the wheels speed. We use the kinematic model for calculate the displacement and localization in the environment.

a. Kinematic model of the electric wheelchair

The displacement of the electric wheelchair is given by the kinematic model defined with equations 7 which V_d is the linear velocity of the right wheel, V_g is the linear velocity of the left wheel, and ω is the angular velocity of the wheelchair. The position of the electric wheelchair is given by three parameters which are the x-coordinate, the y- coordinate and θ the orientation.

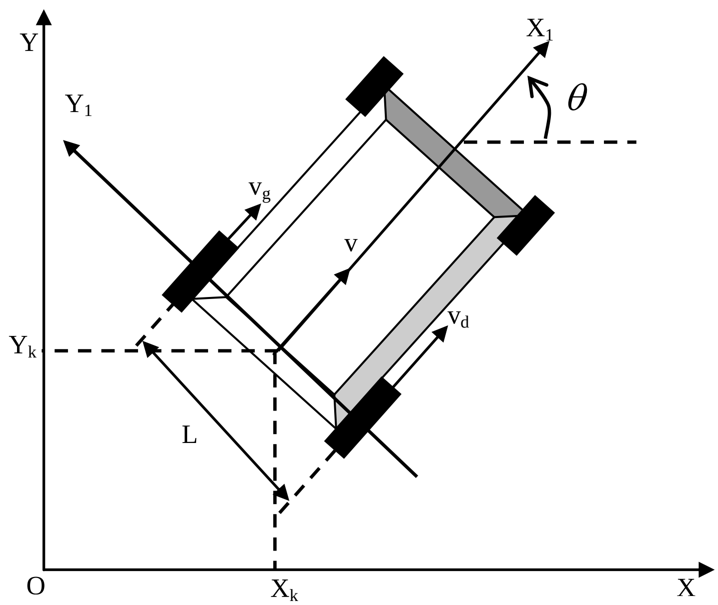

Figure 6. Kinematic scheme of a two-wheeled mobile electric

L: the distance between the driving wheels.

$$\begin{cases} \frac{dx}{dy} = \frac{V_d + V_g}{2} \cos\theta \\ \frac{dy}{dt} = \frac{V_d + V_g}{2} \sin\theta \\ \frac{d\theta}{dt} = \omega = \frac{V_d - V_g}{L} \end{cases} \qquad (7)$$

For the simulation and practice we use a discrete model defined by the system of equation 8.

T : The sampling period.

$$\begin{cases} x_k = x_{k-1} + T\,\frac{V_{dk}+V_{gk}}{2}\cos\theta_k \\ y_k = y_{k-1} + T\,\frac{V_{dk}+V_{gk}}{2}\sin\theta_k \\ \theta_k = \theta_{k-1} + T\,\frac{V_{dk}-V_{gk}}{L} \end{cases} \qquad (8)$$

b. The use of particle filter for data fusion

Each particle represents a configuration of the electric wheelchair. This particle is associated with a weight representing the consistency between the configuration of the particle and the configuration of the electric wheelchair in its environment from observations.

First step: Initialization

$$p^i = (x^i, w^i) \qquad (9)$$

Where w^i the weight associated to the particle i of the configuration x^i.

$$P^i = \begin{pmatrix} x_{init} + \epsilon_x^i \\ y_{init} + \epsilon_y^i, \frac{1}{N} \\ \theta_{init} + \epsilon_\theta^i \end{pmatrix} \qquad (10)$$

Where $(\epsilon_x^i, \epsilon_y^i, \epsilon_\theta^i)$ are random variables.

Second step: Prediction step

During this stage, the data from the odometer (v_d, v_g) will be used to move the particles.

The evolution of the particle is given by:

$$P_{k+1}^i = \begin{pmatrix} x_k^i + T\,\frac{V_{dk}+V_{gk}}{2}\cos\theta_k^i \\ y_k^i + T\,\frac{V_{dk}+V_{gk}}{2}\sin\theta_k^i\ , w_k^i \\ \theta_k^i + T\,\frac{V_{dk}-V_{gk}}{L} \end{pmatrix} \qquad (11)$$

Third step: Estimation step

We have n=8 ultrasonic sensors. For each particle i and for each sensor j we evaluate the error

$$e_y^i = y^j - y_m^j(x^i) \qquad (12)$$

Where y^j is the distance returned by the sensor number j and $y_m^j(x^i)$ is the distance computed by our simulator ultrasonic sensors depending on the configuration x^i. We consider a Gaussian error $N(0, \sigma_d)$, that is to say, the probability of measuring y^j at the configuration x^i is given by

$$p(y^i|x^i) = e^{\frac{-1}{2}\times\frac{(e_y^i)^2}{\sigma_y^2}} \qquad (13)$$

The new coefficient of the particle is computed by using the following relationship:

$$w_{k+1}^{i} = w_{k}^{i} \times \sum_{j=1}^{n} p\left(y^{i} | x^{i}\right) \qquad (14)$$

The weights of the particles are adjusted using the equation:

$$w^{i} = \frac{w^{i}}{\sum_{j=1}^{N} w^{j}} \qquad (15)$$

Fourth step: Re-sampling

Re-sampling is performed when the inequality $N_{eff} < N_{th}$ is verified [18].

Initially, we create $[Nw^{i}]$ copies of the particle x^{i}, $[Nw^{i}]$ is the integer part of Nw^{i}. With this approximation, the number of particles generated is less than N. It is therefore necessary to add additional particles $\overline{N}$, $\overline{N}$ is given by [21]:

$$\overline{N} = \sum_{i=1}^{N}\left(Nw^{i} - [Nw^{i}]\right) \qquad (16)$$

$$w^{i} = \frac{\left(Nw^{i} - [Nw^{i}]\right)}{\overline{N}} \qquad (17)$$

VI. SIMULATION AND EXPERIMENTAL RESULTS

The navigation of the electric wheelchair occurs by the fuzzy controller to join the target and avoid obstacle. The localization of the electric wheelchair made in the first by the kinematic model using the information received by the encoders. In this paper we accurate the localization by using the particle filter.

The dimensions of the electric wheelchair for handicapped used in this application are as followings:

Length = 1000 mm

Width = 530 mm

Wheel radius = 150 mm

The sampling period used in all this paper is T=1 second. This time is necessary to get information with sensors and turn the control program.

We proceed in the first time by simulation using MATLAB. In the second step we implement the developed program using automatic control system described in section II.

a. Simulation results

We focus now on the simulation results obtained by the particle filter for the mobile electric wheelchair localization. The first simulations consist of a linear displacement of 3000 mm the initial start point coordinates are $(x_0 = 0 \; et \; y_0 = 0)$ and the end point are $(x_f = 3000 \; et \; y_f = 0)$. Two obstacles are placed on y=750mm and y=500.

We performed the simulation of the particle filter with 1000 particles. Figure 7 shows us the result obtained by applying the fuzzy controller to join target and localization method with particle filter. The black cross on the curve position, show particles having the highest weights .We notice the decrease of the particle's cloud which is due to the resampling. When a large number of particles deviate from the path, the estimated data may be incorrect.

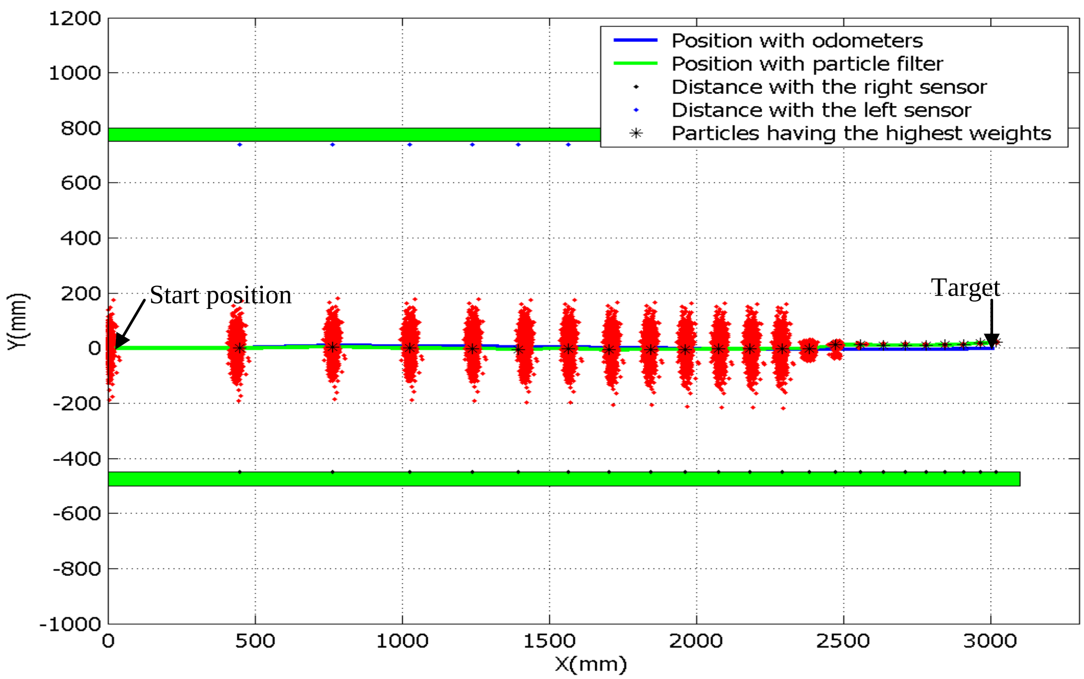

Figure 7. Simulation of particle filter with target (x=3000mm, y=0 mm)

The role of resampling is to overcome this problem by removing the particles with low weight and duplicating those with high weight. Therefore the number of particles must be sufficient to avoid the divergence of the filter. But by increasing the number of particles the calculation time increase too. Therefore, it's necessary to have compromise between the number of particles to perform filtering and the calculation time.

Figure 7 represent the simulation result using the ideal initial condition and the measure of displacement not affected by the error. The fuzzy controller permits to electric wheelchair to join the target. The localization by the particle filter is the same with odometers.

The purpose of this second simulation is to evaluate the performance of particle filter using data from ultrasonic sensors and odometers. We consider now the start position(x=0mm , y=0mm), but in reality it is (x=0mm, y=100mm). The real information obtained only by the ultrasonic sensors. The result shows a good localization using the particle filter. Indeed, the particle filter could correct the odometer’s errors especially during wheel rotation. The green curve represents the position obtained with particle filter. The blue curve represents the position obtained with odometers.

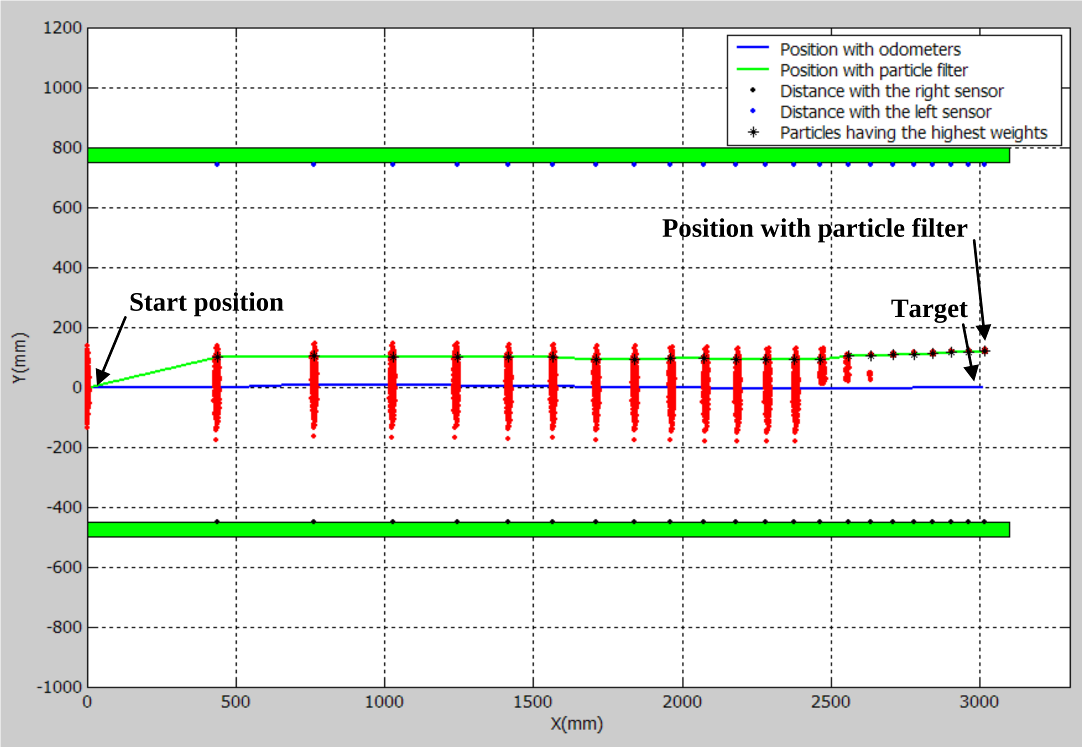

Figure 8. Simulation of particle filter with real start position (x=0mm, y=100 mm).

The third simulation represented by figure 9. We consider now the start position (x=0mm , y=0mm), but in reality it is (x=0mm, y= -100mm). In these simulations we managed to apply the data fusion using data from exteroceptive sensors and odometric information. The simulation results show that the particle filter method improves the localization. The results are more precise.

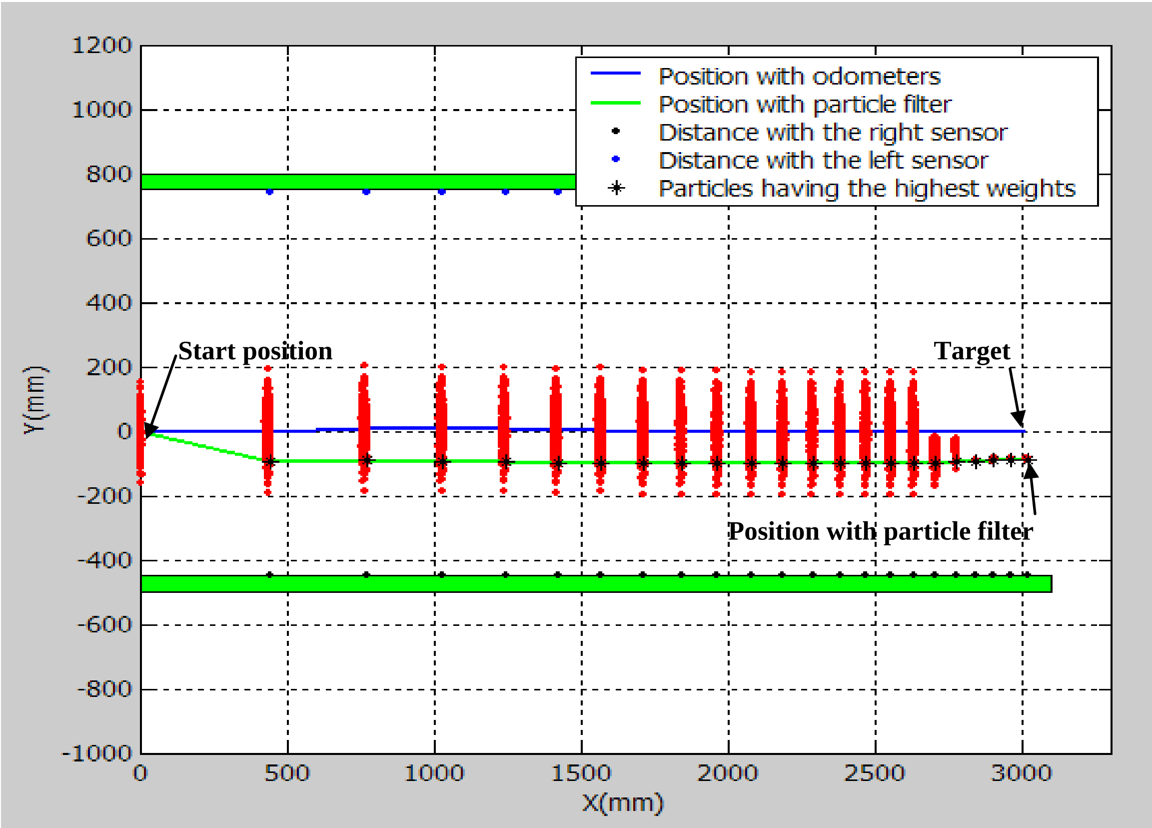

Figure 9. Simulation of particle filter with real start position (x=0mm, y=-100 mm).

b. Particle filter for electric wheelchair localization

The electric wheelchair is equipped with an automatic control system. The software MATLAB compiles the developed program. Information from the sensors is received with a serial communication. The command is sent to the control unit by the serial link.

The test environment of the electric wheelchair is a hallway. At first, we placed the electric wheelchair in a hallway as the right wall is located at 500 mm from the wheelchair and the left wall is located at 750 mm figure 10.

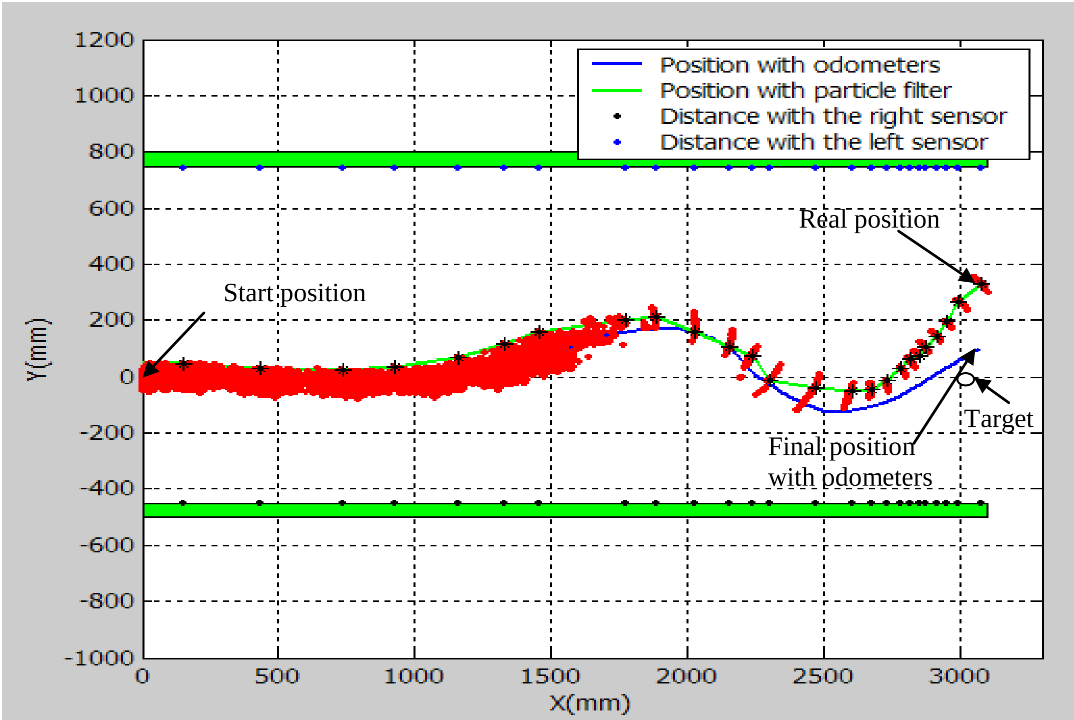

Figure 10. Practice of particle filter with start position (x=0 mm, y=0 mm)

In a second case in practice, we move the electric wheelchair 200 mm to the left, in order to verify filter capacity to correct the initial position.

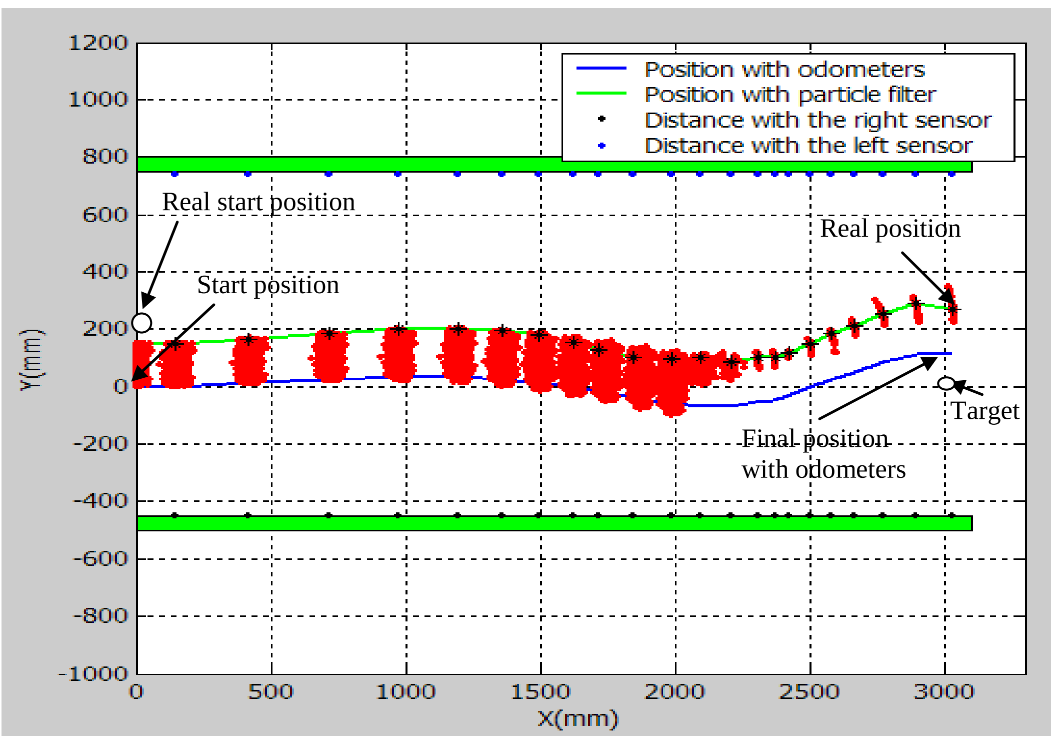

Figure 11. Particle filter practice with start position (x=0mm, y=200 mm)

The results show an improvement in the position estimation. There was a decrease of the difference between the estimated position and the actual position. The results obtained by this method are satisfactory. This method supplies results quickly. We can notice that throughout the trajectory traversed by the electric wheelchair, the points group which describes the position of the wheelchair rest small which shows the precision of the results. In addition the filter localized the electric wheelchair even by changing its starting position.

y(mm)				
Odometric	Position error	Estimated by particle filter	Position error	Real position
0	200	182	18	200
16	194	192	18	210
34	183	203	14	217
12	176	180	8	188
-57	168	100	11	111
-4	170	150	16	166
117	167	268	16	284

Table 1. Comparative table of measurement

The table shows the measurements obtained in the experimental test presented in Figure 11.

The first column shows the measurements obtained by odometric. The second and fourth columns give the calculated errors relative to the real position. The third shows the position estimated by particle filter. This result shows the improvement in localization and minimizing the positioning error. The particle filter serves to improve the performance of the navigation system to reach a target.

We consider another real case. The figure 12 shows the result of locating the electric wheelchair by particle filter in a real environment. The navigation system includes the doorway and the displacement in a hallway.

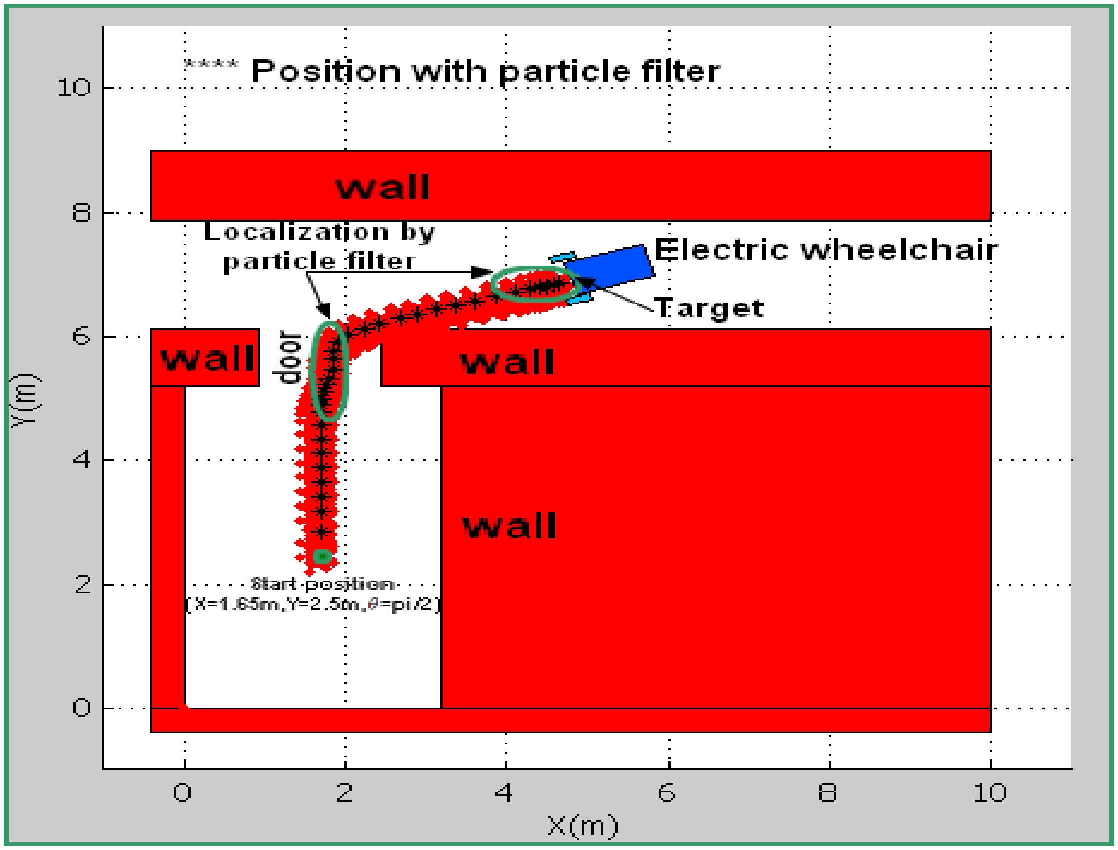

Figure 12. Navigation system includes the doorway and the displacement in a hallway

The start position in this case is considered (X=1.65m, Y=2.5m, θ=*Π/2*). The localization with particle filter begins with the generation of the initial particles. They represent the probable positions of the wheelchair. During navigation, the wall detected by an ultrasonic sensor is an obstacle to avoid. At the same time, the measurement of this sensor is useful for localization. The estimated actual positions by the particulate filter are represented by black stars. In figure 12, the localization of the wheelchair by the particulate filter is shown when passing through the door and when detecting wall by the left sensor.

Upon detection of an obstacle, the particulate filter gives the estimated. The navigation to achieve the target location is performed by the fuzzy controller associated with the obstacle avoidance algorithm. Improving the accuracy of the location was used to reach a target location with greater precision.

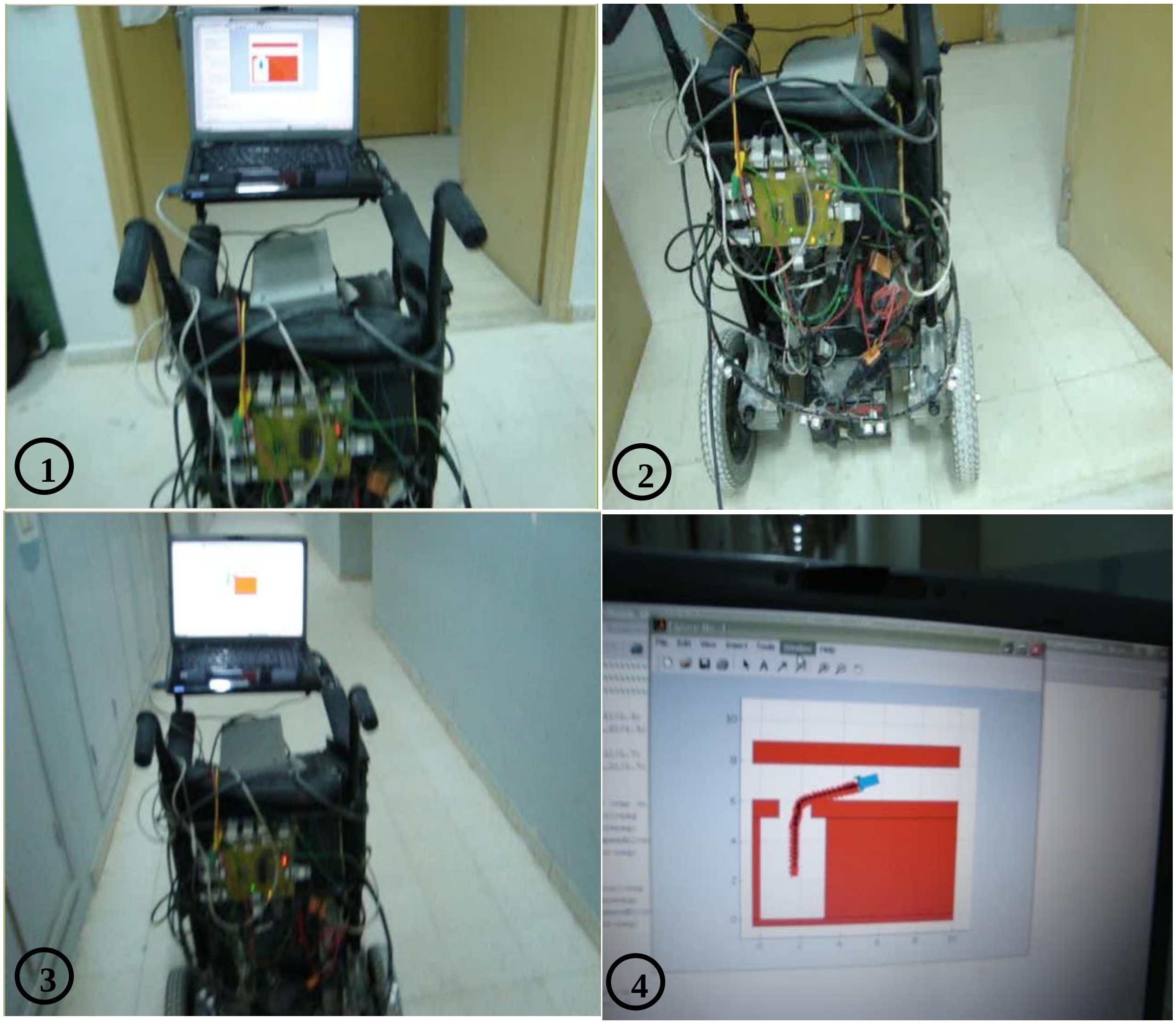

Figure 13. Real navigation includes the obstacle avoidance and localization

Figure 13 represents the picture of the experimental test. The picture 1 represents the start of navigation. In progress the electric wheelchair pass throw the door (picture 2). The picture 3 shows the wheelchair oriented by the navigation system to join target. Finally, the trajectory obtained with navigation system and localization presented in picture 4.

VII. CONCLUSIONS

This article treats the problem of sensor's data fusion for the localization of a mobile robot main issue is to use a localization algorithm which must correct the errors of the sensors in order to return the estimated configuration close to the actual one. After verifying the correct functioning of the particle filter in the simulation part we preceded with experiments to evaluate the performance of this filter. The particle filter is an efficient method for resolving the problem of localization. Finally, the particle filter gives the accepted result and improves the performance of the fuzzy controller to join a real target position and the obstacle avoidance.

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