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DVZ-based Obstacle Avoidance Control of a Wheelchair Mobile Robot

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Abstract— This paper addresses the control problem of unicycle mobile robot evolving in unknown environments using reactive behaviours. The deformable Virtual Zone (DVZ) principle is used to resolve this problem through defining a safety zone around the vehicle. This approach presents fast control laws that react depending on the presence of an obstacle in the safety zone. Experimental tests are carried out on a wheelchair mobile robot and proved the effectiveness of the studied method.

I. INTRODUCTION

During the last years, researchers have been interested in the problem of reactive behaviours for collision avoidance in the domain of mobile robotics. Many researches have investigated the control of land autonomous vehicles, underseas robots, manipulators and walking machines. Many experiments have been carried out on real robots (wheeled mobile robots, legged robots and an AUV) and on simulated ones. The most famous reacted approach is the potential method developed by O.Khatib [1]. It consists in building an arbitrary positive potential field functions attached on obstacles that repels the robot and an attractive field located on the target. This technique was been ameliorated by Borenstein researches [2] through making a vector field histogram attached on proximity information. The main problem of these behavioral methods is to design a reactive function without undesired local minima. Elnagar, in [3], propose to model the potential field with Maxwell's equations that eliminates the local minima problem depending on the environment knowledge availability.

Miniguez et al in [4] proposes a reactive navigation method for non holonomic robots using the ego-kinematic space. This method is based on a proximity diagram attached to obstacles updated during the robot navigation. Another approach based on a reflex behavior reactive, is using the Deformable Virtual Zone (DVZ) technique, that allows to control the reactive behaviours of a mobile robot in [5] and [6]. This method is based on defining a risk zone surrounding the robot which can be deformed due to the proximity information. The system reaction is made to drive the robot to contour the obstacles in order to reform the risk zone to his initial form.

In this paper we propose an extension of this method to the case of wheelchair for handicapped persons by underlying two different parts:

- the obstacle detection
- the computation of the system reaction

The obstacle detection is an important topic and in this paper we have considered a wheelchair equipped with a laser sensor able to measure the distance between the robot and its environment during 240 degree. The system reaction computation is based on the DVZ technique. This paper is organized into five sections. In section 2 the mathematical formulation for obstacle detection system is presented. In section 3 the basic algorithm for system reaction applied on wheelchair for handicapped persons is reviewed. The experimental results are discussed in section 4. Finally, section 5 presents the conclusion and further works for this study.

II. OBSTACLE DETECTION SYSTEM

Several types of mobile robots with driving wheels and encoder system have been studied in the literature [7], [8] and [9]. The most studied types are those of the steering angle commanded vehicles. However, our experiments will be carried up onto a wheelchair for handicapped persons. In fact, many researchers [10], [11] and [12] have proposed innovations to improve wheelchair automation and disabled persons assistance.

A. Kinematic equations

The wheelchair is a unicycle robot with two steering wheels and two independent driving wheels, which can be oriented and commanded by acting on the speed of each wheel, as shown on the schematic model (Fig.1).

The kinematic model is given by:

$$\begin{cases} \frac{dX_R}{dt} = \frac{V_R + V_L}{2} \cos\theta_R \\ \frac{dY_R}{dt} = \frac{V_R + V_L}{2} \sin\theta_R \\ \frac{d\theta_R}{dt} = \frac{V_R - V_L}{L} \end{cases} \quad (1)$$

where V_R and V_L are the robot's right and left wheel's velocities, respectively; $\dot{\theta}_R$ is the robot's angular velocity, L is the distance between two wheels and θ_R is the angle between

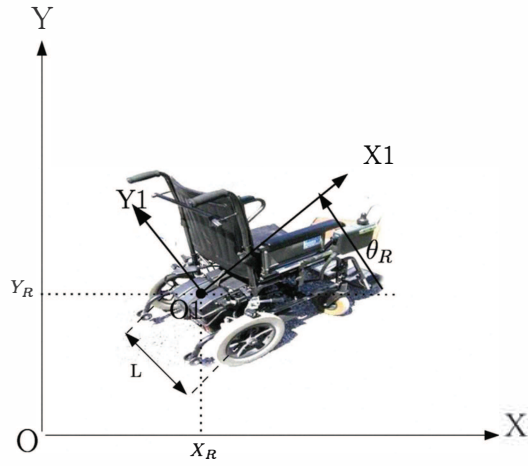


Fig. 1. The schematic model of a wheelchair

the robot's direction and the X -axis. By discretization of the system (1) using Euler method, it becomes:

$$\begin{cases} X_R^{new} = X_R^{old} + T \frac{V_R^{old} + V_L^{old}}{2} \cos\theta_R^{old} \\ Y_R^{new} = Y_R^{old} + T \frac{V_R^{old} + V_L^{old}}{2} \sin\theta_R^{old} \\ \theta_R^{new} = \theta_R^{old} + T \frac{V_R^{old} - V_L^{old}}{L} \end{cases} \quad (2)$$

where T is the sampling time.

B. Proximity system

The exteroceptive sensor we have used is a scanning laser range finder HOKUYO URG-04LX connected to the robot either with serial connection RS232 or USB port. The communication is ensured through a protocol developed by the constructor. This section presents briefly the laser specifications and the acquisition programs.

1) *Laser Sensor Specifications*: URG-04LX is a laser sensor for area scanning. Scan area is 240 degree with maximum radius 4000mm. This sensor outputs the measured distance every 0.36 degree. Figure 2 shows the detectable area for white Kent sheet (70mm * 70mm).

2) *Distance Data Acquisition*: The maximum measurable distance of the sensor is 4095mm with 1mm resolution. Each data are expressed with 12 bits (0 4095 range). In order to reduce the data volume, 6-bit binary code is converted to 1-byte character codes. The encoding process is described in figure 3.

The distance acquisition program is developed in C platform. Figure 4 presents distance measured with a cylindrical obstacle surrounding the robot.

III. SYSTEM REACTION

This section presents the obstacle avoidance algorithm based on the Deformable Virtual Zone concept (DVZ) as described

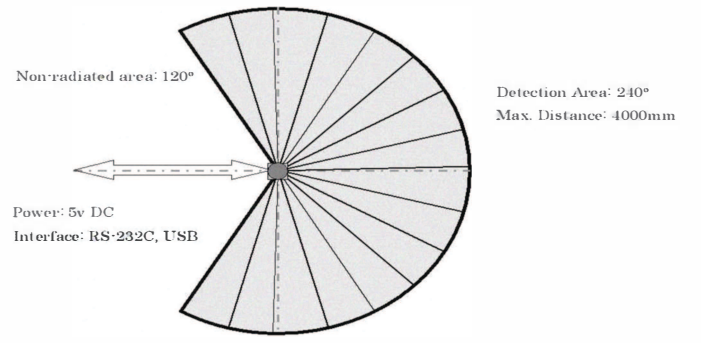


Fig. 2. Hukoyo detectable area

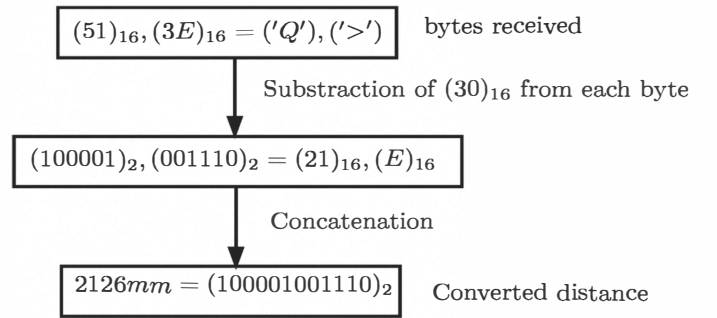


Fig. 3. Conversion data algorithm

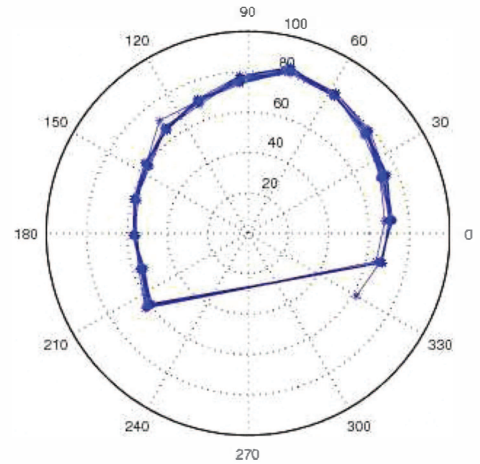


Fig. 4. Distance measurements with cylindric obstacle

in [6]. The main issue is to define a risk zone surrounding the robot as a DVZ depending on the robot/environment interaction (Fig. 5). The risk zone deformation is due to the proximity information. The system reaction drives the robot velocities (linear and angular velocities, V and ω) function of this deformation calculation. In general, the risk zone deformed by an obstacle can be reformed by reacting on the robot velocities.

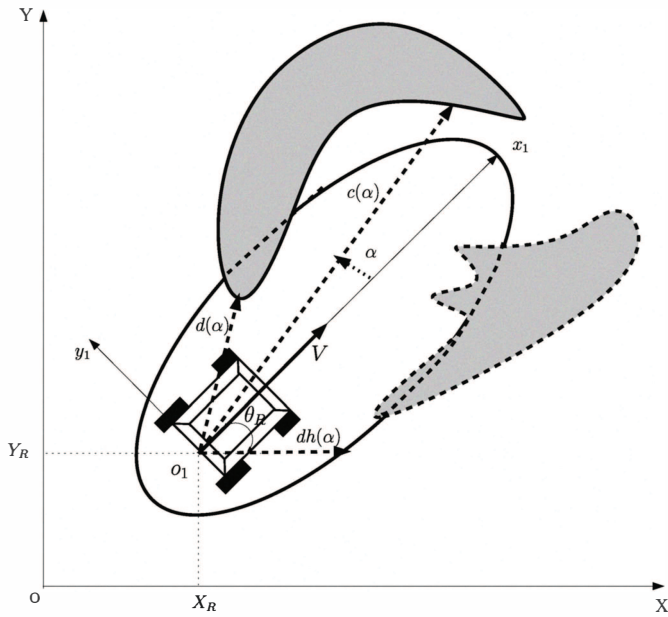


Fig. 5. Obstacle pose problem

A. The Undeformed Risk Zone

We have considered a risk zone with elliptic shape in order to obtain a DVZ polar expression as described in figure 6. The risk zone expression can be described as follows:

$$d_h(\alpha) = \frac{-B + \sqrt{(B)^2 + 4AC}}{2A} \quad (3)$$

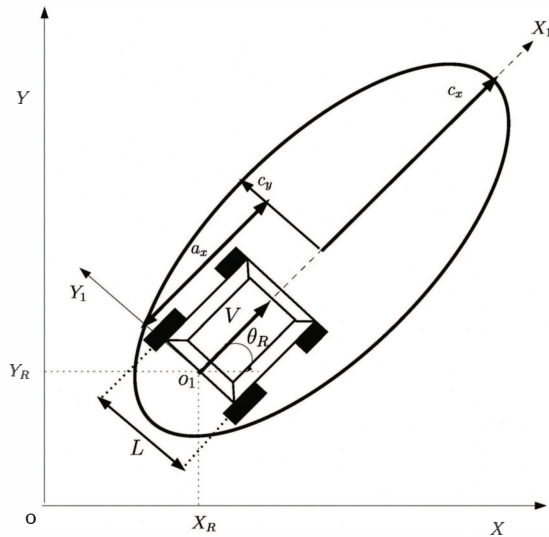


Fig. 6. The undeformed risk zone.

With:

$$\begin{cases} A = (c_y \cos(\alpha - \gamma))^2 + (c_x \sin(\alpha - \gamma))^2 \\ B = 2.(a_x \cos(\alpha - \gamma)c_y^2 + (a_y \sin(\alpha - \gamma)c_x^2) \\ C = (a_x c_y)^2 + (a_y c_x)^2 - (c_x^2 c_y^2) \end{cases} \quad (4)$$

The undeformed risk zone is expressed function of robot velocities, so we have choose to use the control function described in [6].

$$\begin{cases} c_x = \lambda_{cx} V^2 + c_x^{min} \\ c_y = \frac{\sqrt{5}}{3} c_x \\ a_x = \frac{-2}{3} c_x \\ a_y = 0 \end{cases} \quad (5)$$

With :

- c_x and c_y are the parameters defining respectively the elliptic length and width.
- a_x and a_y are the robot coordinates in the c_x and c_y axis.

We have supposed that the risk zone is rigidly attached to the robot, so we have considered the angle $\gamma = 0$. Besides, we have limited the laser detected area to 180 degree due to the PC processing time with a measure every 7 degree. The stayed 180 angle is supposed without deformation.

B. The deformed risk zone

The deformed risk zone is obtained based on distance measured by the laser sensor. These distance information are noted $c(\alpha)$. As the most important measures needed for the robot control are those inside the undeformed risk zone, a preliminary test on the measured distances is necessary. We have noted $d(\alpha)$ the obtained test result.

$$\begin{aligned} d(\alpha) &= c(\alpha) \text{ if } c(\alpha) < d_h(\alpha) \\ &= d_h(\alpha) \text{ else} \end{aligned} \quad (6)$$

Figure 7 shows detected obstacles while the robot is not navigating. Black dots indicate dynamic objects detected inside of the risk zone. While the green ones are distances measured (when obstacles are outside of the risk zone). We have considered 24 measures every laser range during 5 minutes.

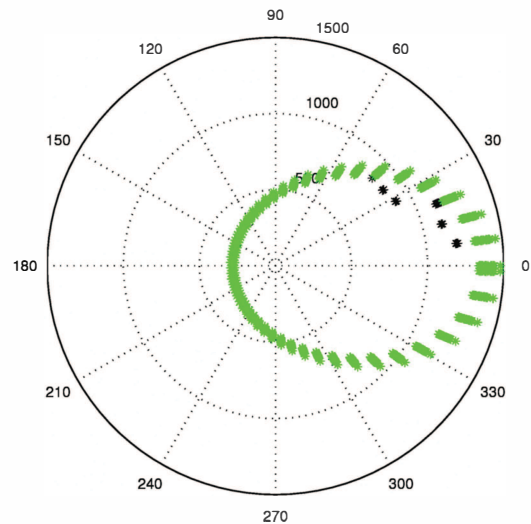


Fig. 7. The deformed risk zone.

C. The deformation

We have considered with I the intrusion information expression.

$$I = \int_{\alpha=0}^{2\pi} \frac{d_h(\alpha, V) - d(\alpha)}{d(\alpha)} d\alpha \quad (7)$$

The derivation of the intrusion expression yields the following results.

$$\dot{I} = J_I^V \dot{V} + J_I^{\theta_R} \omega + F^{\text{Rob.vel}} V + F^{\text{Obst.vel}} \quad (8)$$

With $J_I^V, J_I^{\theta_R}, F^{\text{Rob.vel}}$ and $F^{\text{Obst.vel}}$ are presented in [6].

D. The control system

We have used the wheelchair kinematic model, described in the previous section, in order to concept the velocities to be applied on the robot wheels. We have choosed by $L_I = \frac{I^2}{2}$ a Lyapunov condidate. The derivation of this expression yields the following result:

$$\dot{L}_I = I(J_I^V \dot{V} + J_I^{\theta_R} \omega + F^{\text{Rob.vel}} V) \quad (9)$$

Our contribution consists on verifying the control system applied on a wheelchair platform and described by the following system 10.

$$\begin{cases} \dot{V} = -K_V J_I^V I - \frac{F^{\text{Rob.vel}}}{J_I^V} V \\ \omega = -K_\omega J_I^{\theta_R} I \end{cases} \quad (10)$$

With K_V and K_ω are positif gains yielding $\dot{L}_I \leq 0 \forall t$

IV. EXPERIMENTAL RESULTS

The experimental tests are carried out with the C software. The navigation environment is a research laboratory presenting dynamic persons, tables and chairs. We have implemented the algorithm on a wheelchair for handicapped persons mounted on the ICOS laboratory. This robot has two driving wheels and two steering wheels with : the tread between driving wheels is $L = 750mm$ and the wheel radius is $160mm$. Proximity information are carried out with a laser range finger sensor. We have fixed the sensor detectable area to 180 degree.

- **Experiment 1:** The purpose of the first experiment is to show the application of the obstacle avoidance algorithm in the mobile robot using both the laser sensor data (to generate velocities to be applied on the robot) and the encoders measurement(to calculate the real robot position). In this experiment, the robot have to navigate in the above described environment while avoiding obstacles. The result of this experiment is presented in figure 8. It shows that the robot avoids clearly the obstacles and this validate our approach. However we detected an approximately 25cm deflection along the x axis and 35cm along the y axis between the real and the estimated robot position due to the encoders errors. Figure 9 shows the evolution of the left and right linear velocities. The black and red curves are the desired velocities generated by

the obstacle avoidance algorithm, and the blue ones are the real wheelchair speeds. Some differences between the two measures are detected due to the robot response time which is 0.7 second.

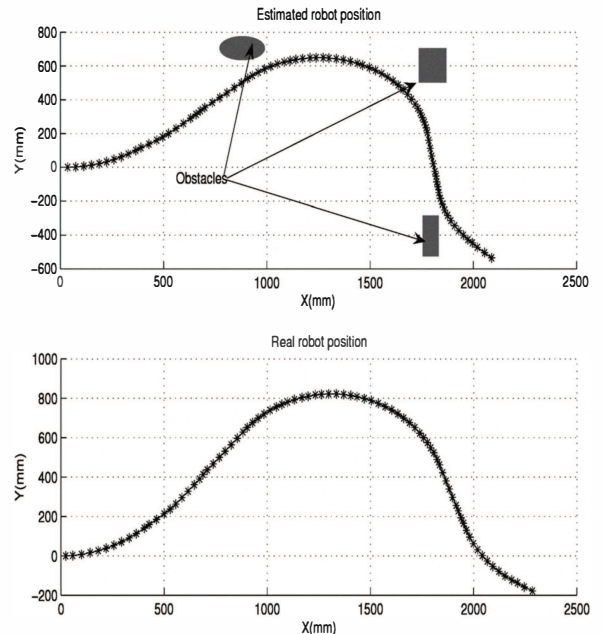


Fig. 8. Arbitrary experimental trajectory.

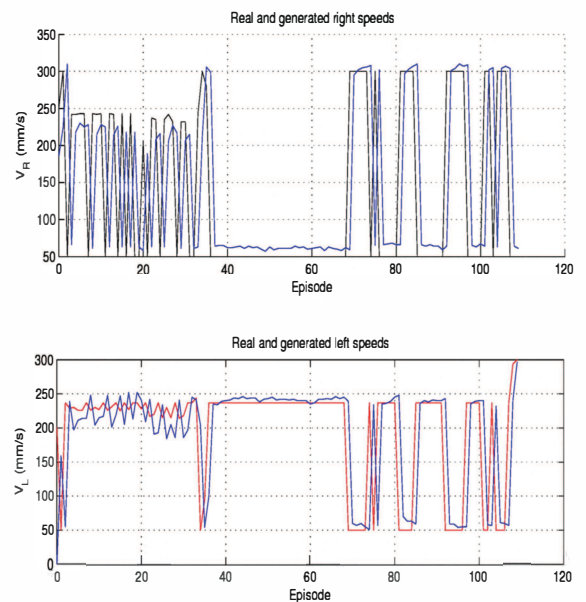


Fig. 9. Real and generated speeds.

- **Experiment 2:** The purpose of the second experiment is to show the effectiveness of the new method in a goal seeking trajectory. Different trials are carried out by adopting three paths and two start points. In figure 10, the robot have to attempt a target defined by the coordinates

($X_T = 3000mm, Y_T = 3000mm$) while in figure 11 the robot have to achieve a longer distance defined by the coordinates ($X_T = 9000mm, Y_T = 9000mm$), having a more complicated route and with obstacles on both sides. In the last test presented in figure 12, the starting point is defined by the coordinates ($X = 5000mm, Y = 10000mm$ and $\theta = 90$) while the target coordinates are ($X_T = 8000mm, Y_T = 0mm$). We noticed that by adopting the DVZ approach in different trials, the robot attend the target while avoiding obstacles.

- **Performance evaluation:** The obstacle avoidance method is applied with different trajectories. During this courses, we calculated the robot position. These functions make it possible to still evaluate the obtained performances by the DVZ method.

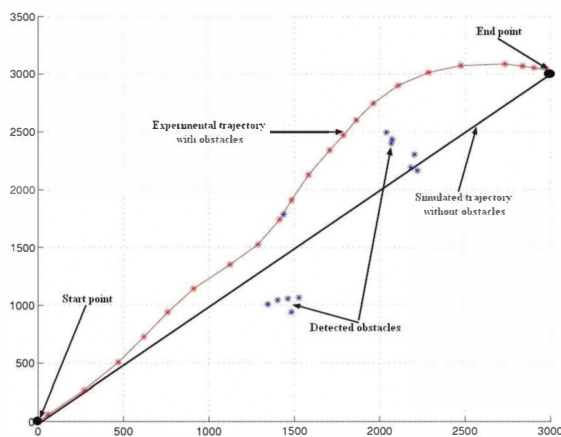


Fig. 10. Goal seeking experimental trajectory.

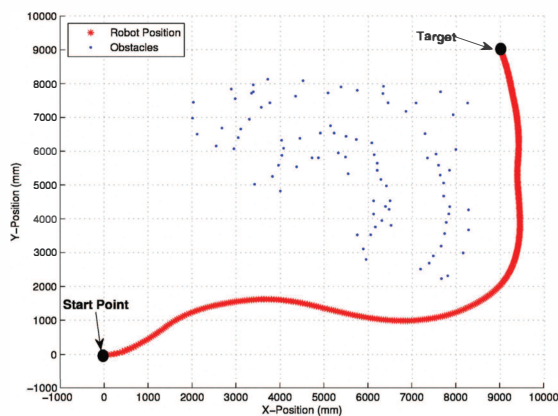


Fig. 11. Goal seeking simulation with longer trajectory.

V. CONCLUSION

We have designed an obstacle avoidance control for a wheelchair based on the DVZ approach. The implementation of the algorithm demonstrate the effectiveness of the proposed

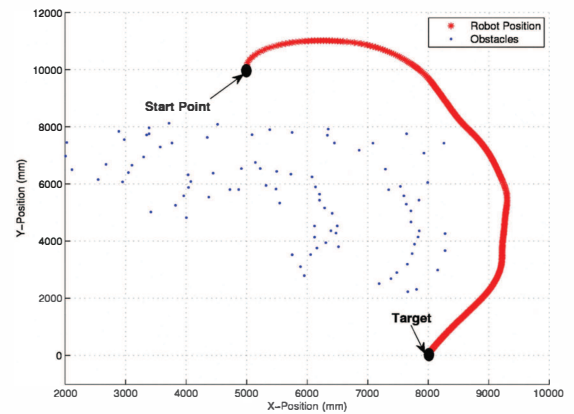


Fig. 12. Goal seeking simulation with different start point.

method in order to avoid some obstacles even in corner situation. In this way, we control the robot despite his inertia and response time. To further improve the obtained results we propose to combine reactive behaviours with some local methods (as fuzzy logic).

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