A Mobile Robot Navigation Planning in a Human Populated Environment

Fernando Carreira, J. M. F. Calado and Carlos Cardeira

Abstract— **In recent years, the introduction of mobile robots in populated environments like industry, houses and services, created new challenges for robots, who must consider the emotional reactions shown by humans when faced with unexpected moving robots in their field of view. In particular, it is necessary that path planning algorithms have in consideration the presence of humans and their feelings of safety and comfort. Actually, avoidance of human obstacle should not be based in the same techniques as avoiding classic rigid obstacles. In this paper is described the implementation of a path planner that takes into consideration the localization, orientation and different comfort distances of humans. The robot motion through the generated path planner was simulated in a virtual reality scenario based in CAD and VRML objects. The virtual reality is integrated in the Matlab/Simulink model providing integration of the robot in the environment. This leads to very realistic views of the robot paths allowing a better perception of the motion in the human populated environment.**

I. Introduction

Navigation to a certain goal does not only mean to find and follow the shorter path to there, but essentially to know and decide what is the better way to get there. In fact, finding a path between two places that guarantees safety navigation is not always easy because environments normally have many obstacles that increase the collision risk if the robot does not have the ability to achieve a good-quality path [1].

The introduction of robots in humans daily life [2] creates new challenges that did not exist in industrial environments, where they are usually physically separated from humans [3]. In a populated environment with robots, the accident risk caused by a robot hitting a person is constant and this is one of the most common accidents [4], which must be minimized.

Thus, it is important that robots adopt their behaviour according to the humans activities [5], in order to avoid conflicts, provide courtesy [6], and guarantee a safe, reliable, effective and socially acceptable motion [3].

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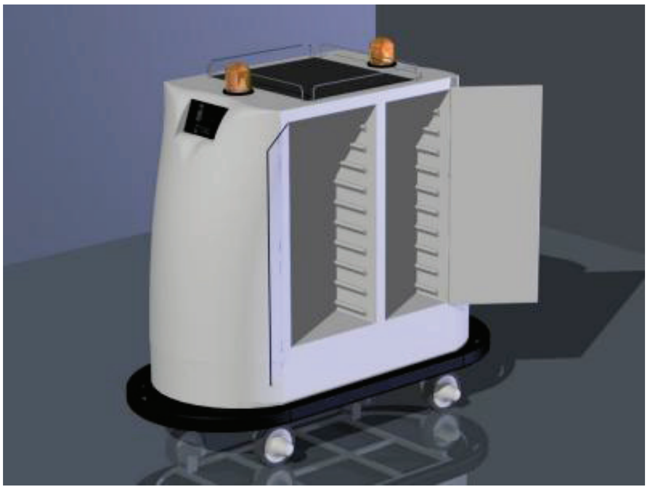

Fig. 1. 3D virtual prototype of i-MERC

For instance, [7] has developed the concept of an automatic vehicle - i-MERC (Fig. 1), in two versions: mobile robot and power-assisted, for the transport of meals, with an omni-directional locomotion system, temperature control and management of food hospitals [8-10] drift.

Considering such a system implemented in populated hospital environments, it is very important that its motion could be friendly, safe and socially acceptable. This problem led the authors to develop a mobile robot planner to a human populated environment combining a potential fields path planning method [11] and the safety issues defined in [3]. The scope of this planner is obtaining a safer and more reliable robot path planning in the presence of humans.

This paper is organized as follows: section two describes the proposed mobile robot planner based on a potential field's method and the details concerned with the human repulsion forces. The third section describes the implemented model and the virtual reality scenario which allows the simulation of the robot movement in a populated virtual environment. The simulation conditions and the different scenarios as well as the results will be described in the fourth section; this section will address several operating conditions that include different initial poses of the robot and humans. The fifth section will present the virtual reality results of the path planning method and the trajectory control simulations when the robot meets humans in different poses. Finally, in the sixth section, some conclusions about the present navigation planning method and a discussion about near future tasks that should be undertaken are presented.

II. Mobile Robot Planning in a Human Populated Environment

Traditionally, path planning with potential fields aims driving the robot through a potential field that gives rise to attractive and repulsive forces created by higher and lower potentials. This path planning methodology represents obstacles as higher potential points that repel the robot being the goal to reach a lower potential location that attracts it.

However, potential fields methods consider that obstacles are all of the same type and the only goal is to avoid the collisions with the obstacles [11]. The path to avoid the obstacle does not take into account different possible reactions that may occur if the obstacle is a human. In our approach, it has been considered that obstacles are humans, which have repulsive forces around them. However, instead common potential fields methods where a repulsive force is uniform around obstacles; the repulsive force in our methodology is based on the human pose, in order to provide a safe and reliable mobile robot path (Fig. 2).

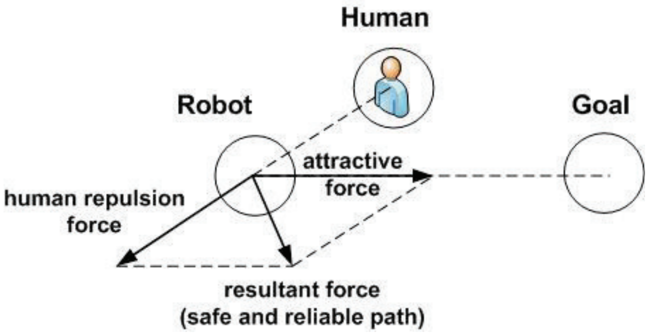

Fig. 2. Potential fields with humans

A. The Humans Repulsive Forces

Usually, the path planning based on potential fields considers a repulsive force caused by obstacles, which repel the robot, but the different nature of objects and humans is disregarded.

In the proposed method the repulsion field is not uniform around the humans since they perceive differently their surrounding areas. In [3], the authors identify two important aspects in the definition of a safe and reliable path planning in a robot-human interaction situation: the safety and visibility criterions.

The proposed method borrowed inspiration from these criteria for the definition of a repulsive field around humans. Thus, it has been considered that the human repulsion forces are a function of two repulsive forces, namely "repulsive safety force" and "repulsive visibility force", which improve the safety and the comfort of the human, respectively.

1) Repulsive safety force

Unlike objects, where security distance should be the minimum necessary to prevent accidents, humans need a personal distance to possible harming equipment that assures a feeling of safety. This distance is a function of the personality and culture of each person but, for a public zone, the minimal personal distance will be about 3m [12].

This safety distance should be adapted to humans states: standing up, sitting, etc., since humans normally have less mobility when sitting than when standing up [3].

Thus, a repulsive safety force define by a 3D Gaussian shape around the human which output is a function of xy robot coordinates, as described in the equation 1.

$$SF_R(x,y) = \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{1}{2\sigma^2}\left((x-h_x)^2+(y-h_y)^2\right)} \tag{1}$$

where h_x and h_y stands for the human position, σ is a parameter given by the following equation, $\sigma = d/3$, being d the human-robot safety distance that should be parameterized according to humans states, culture, age, etc.

In Fig. 3, the repulsive safety field for a personal safety distance of 3m.

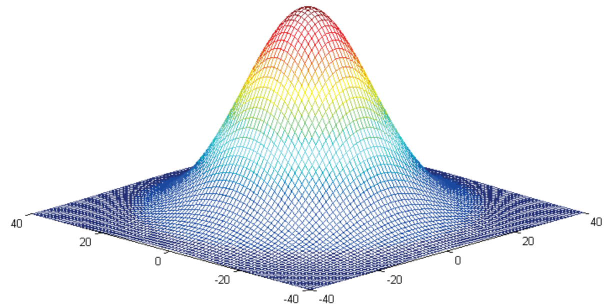

Fig. 3. The repulsive safety field around a human (in cm)

1) Repulsive visibility force

However, beyond the safety criterion presented, when humans are in a bustling area with moving machines, normally, they feel more comfortable when the machines are in their field of view. Sisbot *et al.* [3] call this feeling as "mental safety – comfort". This means that the humans comfort when the robot is in the field of view because they can follow its motion with them own eyes and can react to any endangering movement.

In order to meet this human notion of comfort and safety, a repulsion field based on the human visibility of the robot, has been defined. Once that humans can see (with both eyes) approximately 180 degrees in horizontal [13], following this criterion, the area behind the human is very uncomfortable since humans cannot see the robot and predict its motion. Thus, the proposed methodology consider that the repulsive visibility force is a 3D Gaussian function in the area behind the human and null in the front of him, as it is described in the equation 2,

$$VF_R(x,y) = \begin{cases} \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{1}{2\sigma^2}\left((x-h_x)^2+(y-h_y)^2\right)}, & \text{if } \theta \in [90;270]^{\circ} \\ 0, & \text{if } \theta \notin [90;270]^{\circ} \end{cases} \tag{2}$$

where θ is the angle between the direction of the human to the calculation point and the one for which he faces, defining if the point is ahead or behind human:

$$\theta = tan^{-1}\left(\frac{y-h_y}{x-h_x}\right) \tag{3}$$

Like the repulsive safety force, the repulsive visibility force should be adapted to different scenarios, through the safe distance parameter. In Fig. 4 the repulsive visibility field for the same safety distance as in fig 3 (3m), is shown.

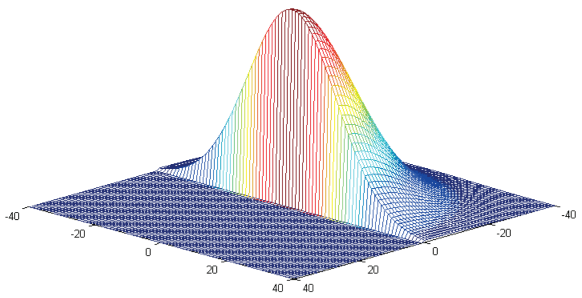

Fig. 4. The repulsive visibility field around a human (in cm)

2) The human repulsive force

Once the safety and visibility repulsive forces are available, the human repulsive force is computed as a weighted sum of the both forces [3]. This approach allows, not only to combine the different aspects, but also to assign different relevance to each one, as is represented by equation 4. For example, for different situations or persons, in some cases, it can be given more importance to safety and, in others, to the visibility comfort.

$$F_R(x,y) = w_1 \cdot SF_R(x,y) + w_2 \cdot VF_R(x,y) \tag{4}$$

where *w1* and *w2* are the weighing factors of security and visibility repulsive force.

In Fig. 5, the human repulsive field, considering an equal weighted sum of both repulsive fields, is depicted.

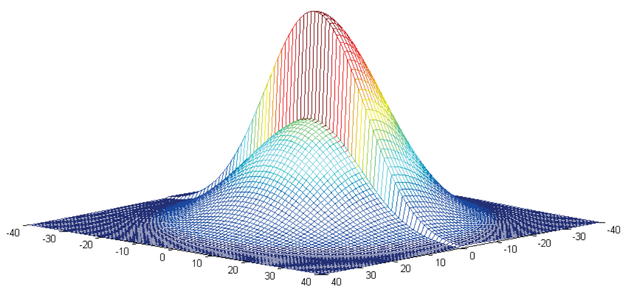

Fig. 5. The human repulsive field (in cm)

3) The attractive force

For the attractive field, the method proposed in [11] has been followed, which defines such a field as the inverse of the distance between the robot position and the goal being described by equation 4,

$$F_a(x,y) = \frac{1}{\sqrt{(x-g_x)^2+(y-g_y)^2}} \tag{5}$$

where g_x and g_y are the goal coordinates.

III. Simulations and Results

In order to test the mobile robot navigation planner when the robot passes through humans, different orientations and configuration was performed and analysed. In the simulations, it was expected to see the robot moving towards the goal point while maintaining a safety and comfortable distance from humans when passing near them.

First, it has been conducted tests with the path planner parameterized with a safety distance of 1m without the addition of the visibility criterion. With this configuration, the path planner, with the classical obstacles avoidance (without being human aware), has been simulated. Fig. 6 shows that with two persons near the robot, it has been chosen the shorter path, ignoring the humans comfort distance.

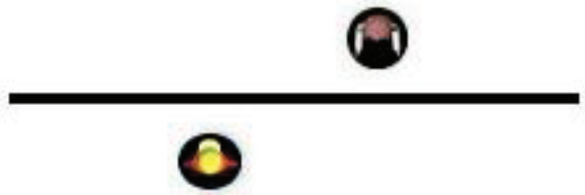

Fig. 6. Robot passes in front of humans (no safety criterion was taken into account)

The second test was concerned with only one person in four different poses: two 0.5m above the start-target line (Fig. 7 and 8) and two 0.5m below it (Fig. 9 and 10).

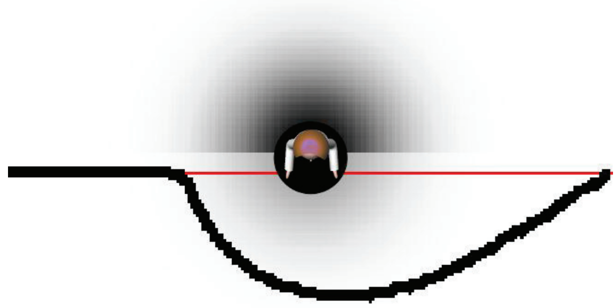

Fig. 7. Robot passes in front of human (short path) when he is above the line (robot find him on its left)

In this test, the robot moves from left to right and the results show that when the robot finds a human on its left avoids him by turning to the right and to the opposite side when it finds him at its right.

However, contrarily to what would happen with the traditional potential fields method, the path is shorter when the human is facing to the robot path (Fig. 7 and 8) than when the robot is folowing a path on the human back (Fig. 8 and 10).

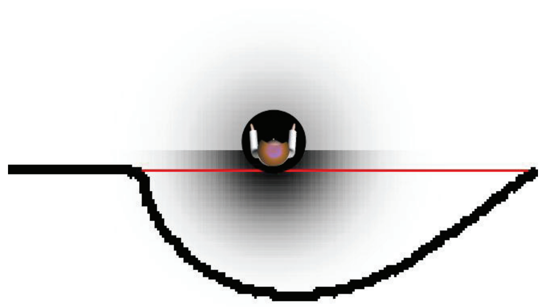

Fig. 8. Robot passes behind of human (longer path) when he is above the line (robot find him on its left)

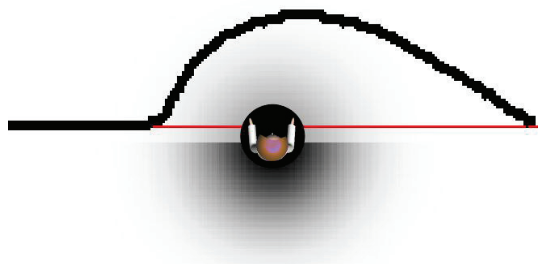

Fig. 9. Robot passes in front of human (short path) when he is below the line (robot find him on its right)

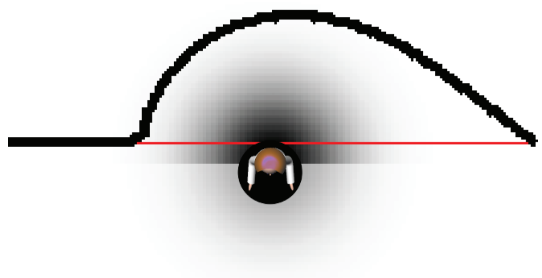

Fig. 10: Robot passes behind of human (long path) when he is below the line (robot find him on its right)

Further tests have been performed considering the path planner with 2 persons facing the start-target line, and different safety parameters (Fig. 11-14).

With 4m of distance and 40% to the safety criterium, the robot avoids both humans leaving more distance when getting close to the second person (Fig. 11).

Fig. 11. Robot passes around humans

When the safety distance has been decreased to 3m (Fig. 12) and 2.5m (Fig. 13) the robot began to pass between humans. As expected, the path with 3m of safety distance present a route with a greater bend than with 2.5m.

In the last test, a distance of 4m around humans in the same pose, but without consider the safety criterium, has been considered. As the humans are facing the shorter robot path, the robot follow it, doing the same way than in the fisrt simulation, in other words, doing the same when the traditional obstacle avoidance methods (Fig. 14) are used.

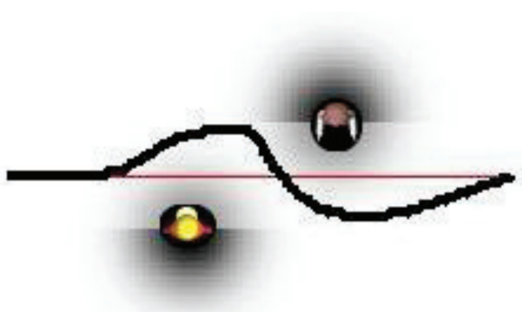

Fig. 12. Robot passes between humans with great bends

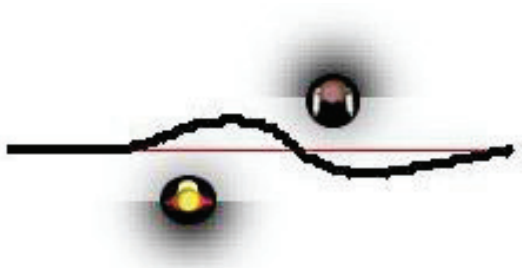

Fig. 13. Robot passes between human with smooth bends

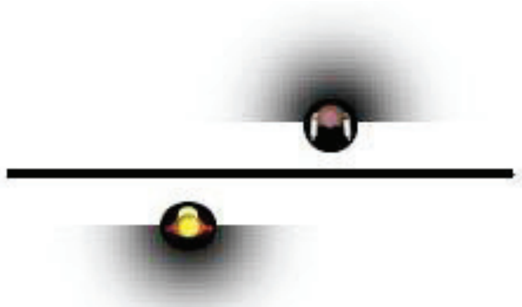

Fig. 14. Robot passes trough he shorter path

IV. Virtual Reality Simulation

To implement the mobile robot navigation planner, we developed a specific tool in MATLAB®/SIMULINK® (Fig.

15) where we can configure the simulation parameters as human and robot pose in map, safety criterions, or analyze the generated path before the simulation.

To increase de reality of the simulation of mobile robot navigation in an environment with humans it has been developed virtual reality scenery where the humans (shape and pose) were included by the developed tool,

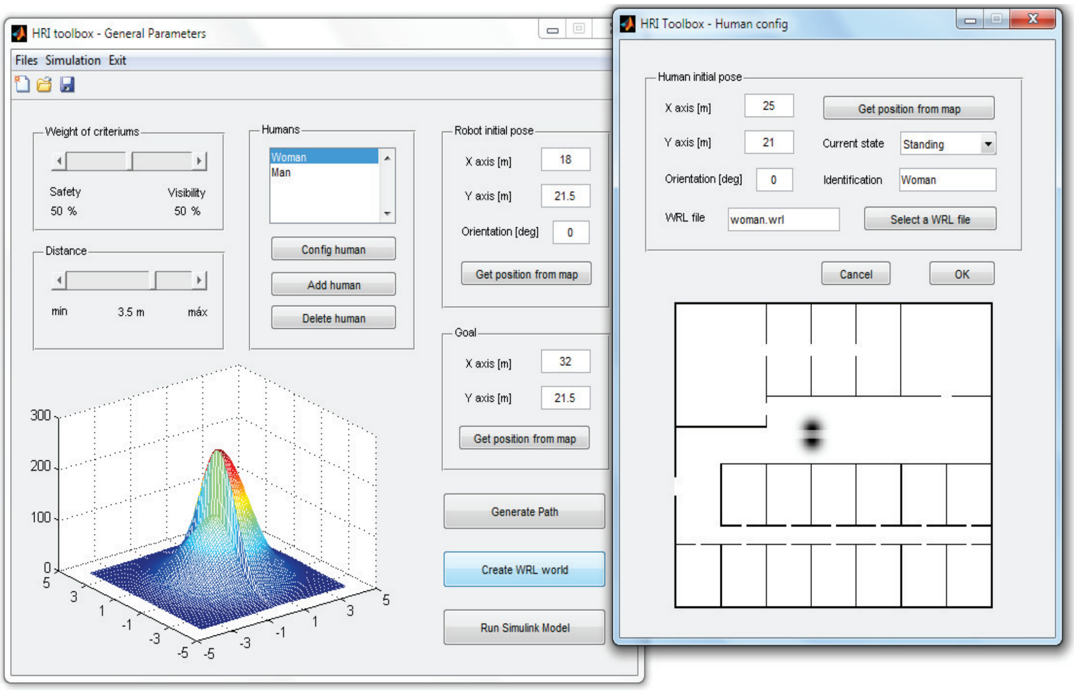

Fig. 15. MATLAB® tool to config the humans

The animation in virtual reality environment aside the simulation were implemented with the blocks of Simulink 3D Animation Toolbox. With this animation, we can have a better perception how i-MERC moves through humans in a hypothetical hospital, but also could be played to show the concept of mobile robot human aware navigation planner's researches or potential customers of robots working in environments with humans.

The robot and the hospital scenery were modelled in Solidworks® (3D CAD software), being the 3D model of the robot, the same that could be used by a design engineers on its concept development or process production. Nevertheless, the human avatars were chosen from the 3D ContentCentral® [14] public dataset. The 3D models were converted to VRML (Virtual Reality Modelling Language) format and several viewpoints were defined in order to assess the global and human level perception of the resulting paths (Fig. 16).

To simulate motion, the coordinates and orientation of robot and humans were parameterized. Thus, the xy translation and the rotation considering z have been used as the inputs to the VRML virtual world.

During simulation, these values are sent from the robot model to the VRML world, through the Simulink 3D Animation Toolbox, thereby producing an animation of the simulated situation.

V. Virtual Reality Results

Simulations were also performed using the Virtual Reality Scenarios providing a better perception of the robot path around humans.

Thus, Fig. 17 shows that in the first (Fig. 6) and last (Fig. 14) simulation, the robot effectively passes very close to humans may causing some discomfort or insecurity. The Fig. 18 shows the simulation when the path planner defines a route around both humans (Fig. 11). The Virtual Reality Scenario shows that this, effectively, is the more comfortable and safe path. However, the robot not always has enough free area to follow this path, requiring a shorter path.

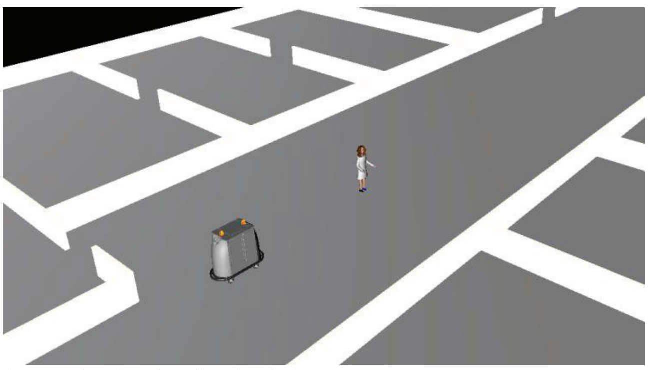
Fig. 16. The virtual reality simulation

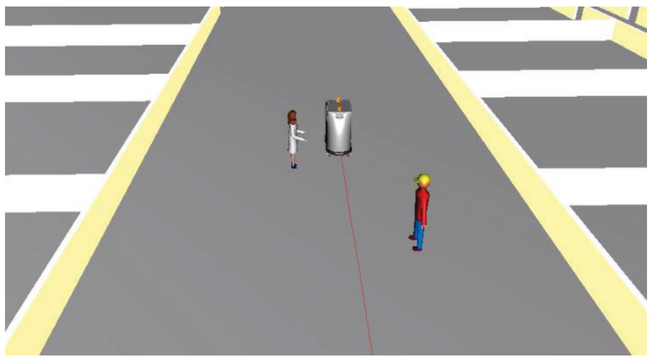
Fig. 17. Robot passes in front of human (Virtual Reality)

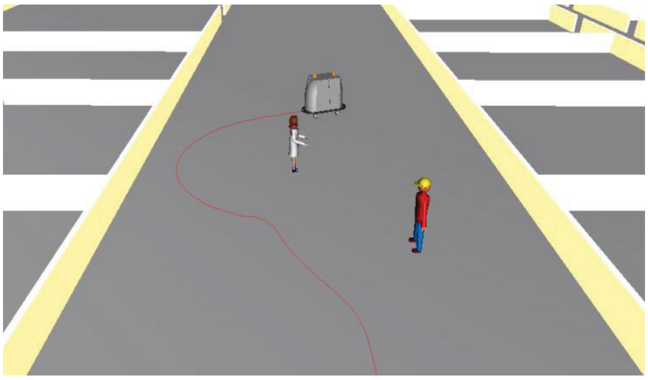

Fig. 18. Robot passes around humans (Virtual Reality)

In fact, when the safety distance has been decreased to 3m the robot followed a shorter path between humans, while keeping a safety distance to them (Fig. 19 and 20).

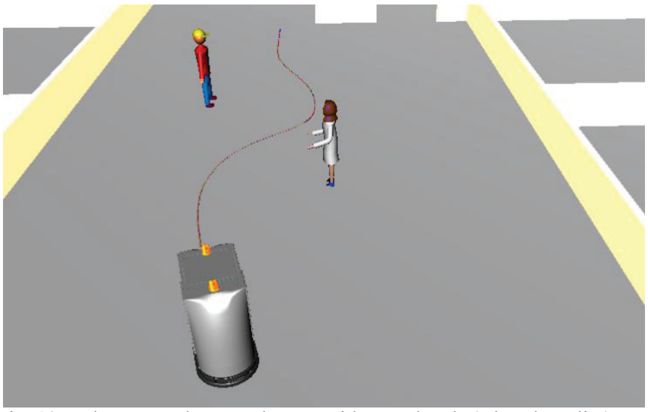

Fig. 19. Robot passes between human with great bends (Virtual Reality)

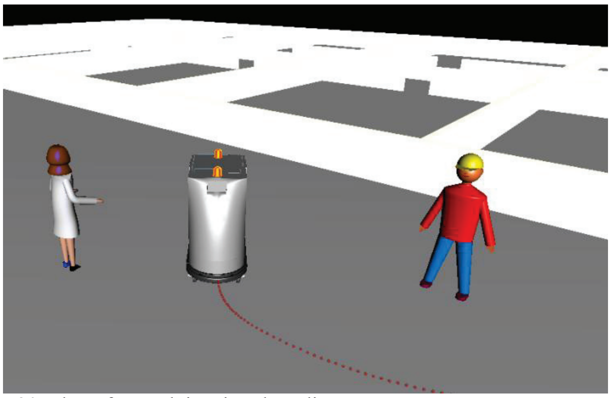

Fig. 20. The safety path in Virtual Reality

A video of virtual reality simulations can be found in http://www.isel.pt/dem/investigacao/moronau/index.html

VI. Conclusions and Future Work

A path planner human aware using the potential fields methods, have been developed. Instead of the traditional potential field's methods, the approach followed in this paper uses a potential field being a function of the human "mental safety" distance and considering the existence of safety and visibility criterion. Thus, the generated path not only depends on the distance to humans but takes into account the humans' orientation.

Furthermore, the developments of a tool enable to configure easily different sceneries and create virtual reality scenarios which allowed a better understanding of the robot movement in a populated environment.

As future work, we will optimize the algorithm trying to eliminate the discontinuities of the function when the robot passes from front to back of a human, but keeping the "mental safety" criterions.

Since the robot has an omni-directional kinematic structure, the corresponding advantages will be explored to increase the comfort of humans and minimize the robots movements along its path.

After these steps, it has been performed simulations considering the motion of humans, creating different and more realistic scenarios. To implement these simulations, an on-line path planner human aware should be implemented becoming the robot sensible for the dynamic of the environment.

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