PATH PLANNING FOR ELECTRICAL WHEELCHAIR, ACCESSIBILITY AND COMFORT FOR DISABLED PEOPLE

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Abstract

In today's residential and industrial environment, adapting the space to handicapped persons is an important condition that has to be fulfilled. The accessibility of space to wheelchairs is a subject that has gained extensive attention. The problem that has to solved is similar to that of the mobile robot path planning case. In this case, the conditions are more stringent than the mobile robot path palnning. However, the planner has to produce trajectories of better quality. In this work, the authors address this problem and start from the mobile robot case to benefit from the experience in this field. A large number of techniques has been developed. Nowadays researchers are improving new techniques in order to carry out efficient robot path planning. Avoiding obstacles is a basic requirement present in almost all mobile robots planning methods. In the second stage, these trajectories are used as initials solutions for functions to evaluate and improve accessibility and comfort for disabled people. A study on different path planning methods such as, roadmaps, cell decomposition, mixed integer linear problem model, potential field and medial axis was done. A potential field method (directed potential field) is developed in order to improve this category of methods. The result of the various path-planning methods produced an initial trajectory. This trajectory is used as input to the second stage: 'Evaluation and Improvement of Accessibility and Comfort'.

Keywords: Accessibility, Disabled people, Comfort, Path planning, Potential field, Wheelchair.

Presenting Author's Biography

Fadi Taychouri is a PhD student at the University of Versailles Saint Quentin in Yvelines, Systems Engineering Laboratory of Versailles (LISV). His thesis subject is "Evaluation and improvement of accessibility for disabled persons based on modelling tools and Virtual Reality". This work is carried within the Assistance and Handicap (AH) team of LISV. This team aims to develop evaluation methodology and adaptation processing of assistive technology for the disabled.

1 Introduction

In this paper the authors main concern is the qualification accessibility and improvement the displacement of a wheelchair user. This user is a person who, due to significant and persistent incapacity, encounters many difficulties in the achievement of every day's various activities. So using the wheelchair to replace walking should be as complete as possible. The displacement is characterised by the ability to perform the basic actions within the available space: forward movements, backward movements and rotations. This is simply referred to as accessibility.

There are many definitions to accessibility. One definition is given by Canadian ministry of Transport [1], where the term "accessible" means that most types of wheelchairs can be accommodated, and that customers can remain in their own wheelchairs while travelling. The term "partially accessible" means that most persons with a physical, mental, or medical disability, can be accommodated. Purpose-built buses, rail cars, and taxis are accessible. Other accessibility definition is given by the French Agence "Agence nationale pour l'amélioration de l'habitat" (ANAH) [2]: to study the accessibility, several conditions have to be satisfied. These conditions include checking the easiness of essential daily gestures and movement through doors.

From the various definitions of accessibility, it may be considered that the study of accessibility consists of the generation and evaluation of trajectories within the evolution space. This may be based on the extensions of the path planning methods. In this work, the authors are mainly concerned in the evaluation of accessibility and comfort within vehicles and within dwellings.

For dwellings, scenarios for the displacement from one point to another have to be defined. Such a scenario would be moving from a point in the bedroom to another in the bathroom. Another example (see figure 1) is moving from the entrance to the bedroom. These scenarios have to be defined in advance. Each displacement is then to be evaluated. The overall scenarios are then used to evaluate the level of the accessibility. This problem is an extension of the robot path planning case, which concerns moving from an initial point to a target while avoiding obstacles.

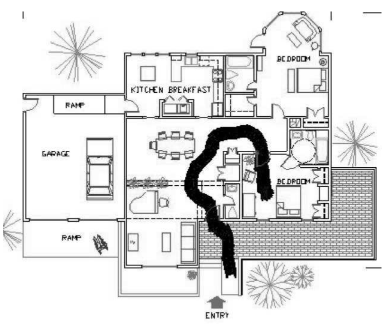


Fig. 1 Trajectory generated for the accessibilty evaluation

Unlike the case of dwellings, in the vehicle accessibility problem, the displacement possibilities are quite different. This displacement may be divided into phases: initial approach phase (1), transfer phase (2) and final positioning phase (3) (see figure 2).

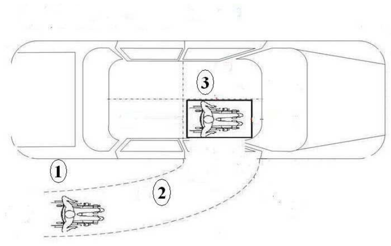


Fig. 2 Example of vehicle transfert phase

The path planning methods may be divided into two main categories: global and local. Global approaches, such as the Road Map method [3] and the Mixed integer quadratic and linear programming base method [4], assume that the wheelchair's environment is completely known. In the global approaches, a complete trajectory from a wheelchair initial position to its goal is computed. Their main advantage is the globality of the generated trajectory. However, these methods are not appropriate for fast obstacle avoidance computation. In addition, the global environment model is inaccurate or not available. On the other hand, local approaches such as potential field methods and gradient methods use only a small fraction of the world model to generate the wheelchair control. Thus, the obvious disadvantage of such methods is their incapacity to produce optimal solutions. Local approaches are easily trapped into local minima. However, the key advantage of local techniques over global ones lies in their low computational cost, which is particularly important when the world model is updated frequently based on sensor information.There is a large number of methods for solving the basic planning problem. Different methods are studied in the section 3.

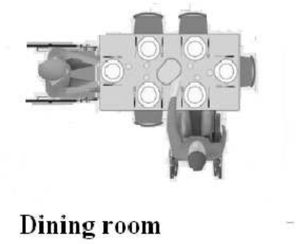
This paper is organised as follows. In section 2, the accessibility and comfort problem is considered. The trajectory generation problem is then addressed in section 3. In section 4, potential field methods used for trajectory planning are discussed in detail and a contribution of the authors to this field is detailed. In section 5, the comfort evaluation problem is discussed and an evaluation function is proposed and analysed. Finally, in section 6, the authors give some concluding remarks.

2 Accessibility and Comfort

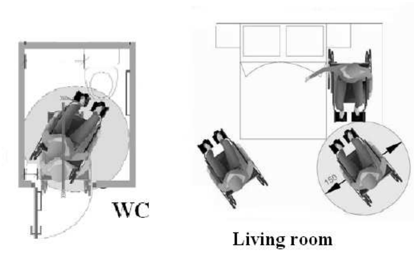
Disability is part of everyday life varying in degree, diversity and distribution and will more than likely affect most people to a greater or lesser extent at some point in their lives.

The problem of accessibility for disabled people is very complicated because it is related to the everyday situations and to the person's specific activities which require the execution of many tasks: horizontal circulation, vertical and interior circulations (entering houses, going through interior doors, moving around rooms, bathrooms, toilets,). Full access means more than just being able to get through the front door and use the toilets. It means being able to make a full use of the facility as a participant, spectator or as a member of staff in the commercial or industrial sector. Enabling full access does not, in most cases, mean inflated costs. If integrated into the design and development process, it can be achieved easily and then produce a better facility for everyone [5].

From the various definitions of accessibility, the one considered in this work is that of the capacity of a person to reach and use facilities and to move easily within a given space (see figure 3).



(a) Dinning room



(b) Toilet (c) Living room

Fig. 3 Various positions of a wheelchair: kitchen, toilet and living room

It is difficult to define comfort since this criterion varies from one person to another and depends on the geometry of space, energy spent by the person and other parameters. In this work, an attempt will be made to give a first answer to this problem.

3 Generation of trajectories

To classify spaces (dwellings and vehicles) according to their accessibility and degree of comfort and qualify the accessibility of installations, the need arises for the definition of evaluation parameters. These have to be applied to the various displacement scenarios. Each scenario gives a starting and arrival points for the displacement. To each displacement a trajectory needs to be generated. These trajectories are then used to evaluate and classify the accessibility and comfort of the space. The accessibility of a space to wheelchairs is a subject that has gained extensive attention. The accessibility problem that needs to be solved is similar to that encountered in the mobile robot path planning case. The conditions, in this case however, are more stringent and the planner has to produce trajectories of better quality. This approach requires adding constraints to the trajectories generated for the robots to adapt them to the wheelchairs' case. While generating trajectories for the robots, the space available around to robot (front, left, right) is of no interest as long as the robot may move within this space. In the case of the wheelchair, however, this is of prime importance. Another important parameter for wheelchair trajectories is the quality of curves. Again, in this case, the curves along wheelchair trajectories are much more important than in the mobile robot's case. The mobile robot trajectory generation is necessary in real time. In the case of the electric wheelchair, this is not necessary since the driver solves the real time problem. The interest is mainly in the analysis of the evolution space at the design stage in order to determine the quality of the design. In section 5, the evaluation problem is addressed. In order to deal with this problem the trajectory planning problem is first considered. There are different path planning methods: roadmap [3] mixed integer quadratic and linear programming approach [4] cell decomposition [6] potential field [7]..[10] and medial axis methods [11]. Many methods of path planning and avoiding obstacles are based on the principle of the potential fields. A potential field method called directed potential field is developed in this work in order to improve their performance. The outputs of the various path planning methods give the initial trajectories of the wheelchair in order to deal with the 'Evaluation and Improvement of Accessibility and Comfort' problem next.

4 Potentiel field methods

In this section, the various potential field methods available in the literature are first presented. A new directional potential is then proposed and simulations are done to compare it to other existing methods.

4.1 Artificial potential field

An important aspect of all potential methods is the representation of obstacles. The majority of the proposed methods use the minimal distance to obstacles to calculate the value of repulsive forces. In this work, obstacles are represented by several points as shown in figure 4.

Using this principle, and adding the effect of the proposed directed potential a variable effect of each obstacle is obtained. There are two methods to represent the obstacles:

1. **Minimal distance representation**
   For each position k of the robot, calculate the minimal distance d_{oj} between the robot and the obstacle j, then the repulsive force of the obstacle j will be of the form:

$$F_k^j = \frac{C_r}{d_{oj}^2} \qquad (1)$$

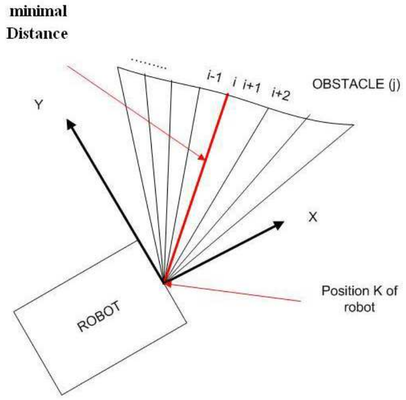


Fig. 4 Robot and obstacle represention

where
F_k^j is the value of repulsive force,
C_r is a constant,
d_{oj} is the minimal distance between the obstacle and the robot.

2. **Multiple distance representation**

For each position k of the robot, calculate all the distances from points i of the obstacle j and the robot, then the repulsive force of the obstacle j is obtained as follow:

$$F_k^j = \sum_{i=1}^{N_p} \frac{C_{ri}}{d_{oji}^2} \tag{2}$$

where
F_k^j is the value of repulsive force,
C_{ri} is a constant for point i of obstacle j,
d_{oji} is the distance between point i of obstacle j and the robot
N_p is the number of points representing the obstacle j.
The value of the repulsive force (APF) derived from the potential field is inversely proportional to square of the distance between the robot and the obstacle i [7]:

$$F_{rj} = \frac{C_r}{d_{oj}^2} \tag{3}$$

where
F_j is the value of repulsive force for obstacle j,
C_r is the constant,
d_j is the distance between the robot and obstacle j.

The value of the attraction force is proportional to the distance between the robot and the goal point [7]:

$$F_a = C_a.d_a \tag{4}$$

where
F_a is the value of attractive force,
C_a is a constant,
d_a is the distance between the robot and the goal point.

Figure 5 shows a robot moving from its initial position to the goal point subject to the sum of forces (attractive and repulsives).

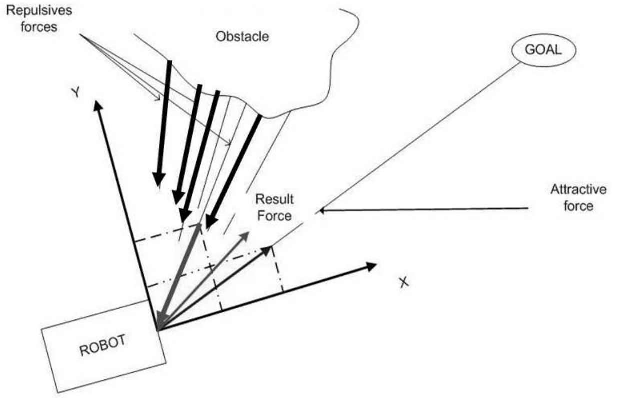


Fig. 5 Robot moving subject to the sum of forces

4.2 The potential functions of Ge and Cui [14]

One of the problems of the artificial potential field methods is related to Non-Reachable Goals in the vicinity of Obstacles (GNRON). In most of the previous studies, goal positions were set relatively far away from obstacles. In such cases, when the robot is near its goal position, the repulsive force due to obstacles is negligible. The robot is thus attracted to the goal position by the attractive force. If the attractive and repulsive potentials are defined as commonly used [7] [8] [9], the repulsive force will be much larger than the attractive force. In another word, the goal position is not the global minimum of the total potential. Therefore, the robot cannot reach its goal due to nearby obstacles. Thus the artificial potential field is multiplied by the distance to the power δ between the robot and the goal point as follows:

$$U_{rep} = \begin{cases} \frac{1}{2}\eta(\frac{1}{d} - \frac{1}{d_o})^2 d_g^\delta & \text{if } d < d_o \\ 0 & \text{if } d \geq d_o \end{cases} \tag{5}$$

where
U_{rep} is the repulsive potential field,
η is a gain constant,
d_g is the distance between the robot and its goal,
δ is an integer,
d is the distance between the robot and the obstacle,
d_o is the distance of influence of the obstacle. In this manner *Ge and Cui* guarantee that the goal point is a global minimum and the robot can approach the obstacle.

4.3 Extended potential field (EPF)

This method proposes two extensions to the traditional method that take into account the robot's orientation with respect to the obstacles on the one hand and the objective of the motion (the goal point). on the other hand the objective is to filter out obstacles that would otherwise induce an unnecessary avoidance behaviour. The extended approach is then applied to sensor-based motion such as wall following and tracking. The artificial repulsive force is multiplied by two functions: one function depends on the angle between robot and obstacle and the second function depends on the angle between the robot and the goal point [8].

4.4 A Proposed Method :Directed potential field

This proposed approach is based on the creation of a repulsive potential field. This potential is maximal when the robot moves directly in the direction of the obstacle and it is negligible when the robot moves parallel to the obstacle. This method is similar to the extended potential field developed by [8]. However, in the proposed scheme, each part of the obstacle acts in a different way according to the directed field. In what follows, these differences will be described.

4.4.1 Formulation and equations

The position of the robot, its direction of movement and the angles made with the various obstacles create the robot's repulsive field. Consider the following directed field function r:

$$r = m(\cos(\alpha_i))^n \tag{6}$$

where
m is a constant and n is a integer.
in the interval

$$\alpha_i \in [-\pi/2, \pi/2] \tag{7}$$

The field is maximal for α equal to zero, and zero for α equal to $+\pi/2$ and $-\pi/2$. Figure 6 represents the variation of r according to variation of α between $-\pi/2$ and $+\pi/2$ and for $n = 1, ..., 4$. The axis X represent the direction of the robot. Notice that in figure 6 the larger is n the larger is r. This function is then used to create the directed potential field. Figure 7 represents the variation of r for α varying between $-\pi/2$ and $+\pi/2$, for $n = 2$ and constant gains m=2,4 and 6.

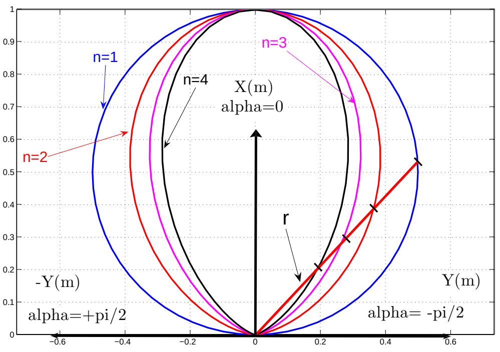


Fig. 6 Variation of r according to α for different values of n

Returning to the equation of the repulsive forces, the equation (2), and multipling by r from equation 6, the following equation is obtained:

$$F_{rj} = \sum_{i=1}^{N_p} \frac{m(cos(\alpha_i))^n}{d_{oji}^2} \tag{8}$$

where
F_{rj} is the repulsive force created by the obstacle j,
m is a constant,
d_{oji} is the distance between the robot and the point i of each obstacle j
and α_i is the angle between the direction of robot and point i of the obstacle j.

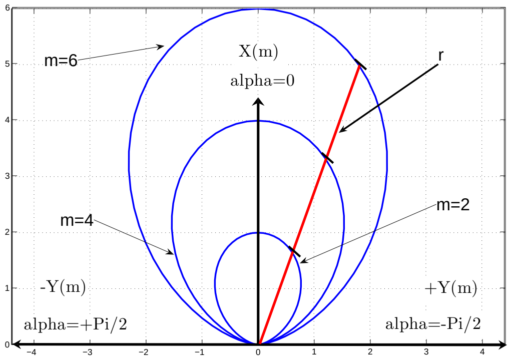


Fig. 7 Variation of r according to α for different values of m

Figures 8 and 9 give a comparison between the directed fields and the artificial field.

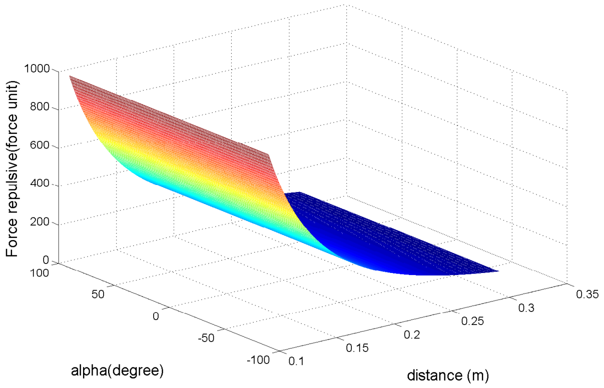


Fig. 8 APF-Artificial Potential Field

It may be noted that the value of repulsive force increases for small distances and the zero angle between the robot and the obstacle. Whereas for the artificial potential field the forces depend only on the distance. In this manner, a variable effect of each obstacle is obtained. Each part of the obstacle acts in a different way from the other parts.

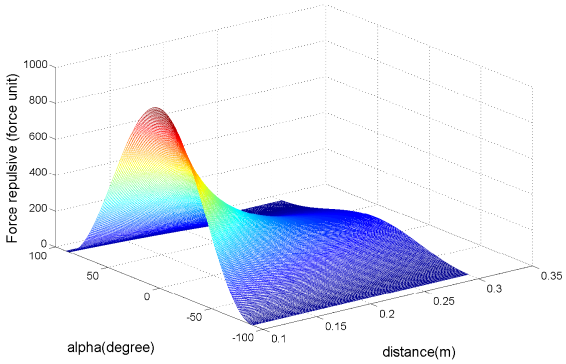


Fig. 9 DPF-Directed Potential Field

The proposed approach, the Directed Potential Field (DPF), was compared to the other methods proposed in the literature extensively. These comparisons show the effectiveness of the DPF in reaching goals in the vicinity of obstacles and eliminate the robot oscillation in vicinity of obstacles. It is able to displace the robot between narrowly aligned obstacles in configurations where the traditional method fail (see figure 10). The proposed scheme overcomes the drawbacks of other path planning methods such as navigating through narrow pathways and oscillations in the neighbourhood of obstacles.

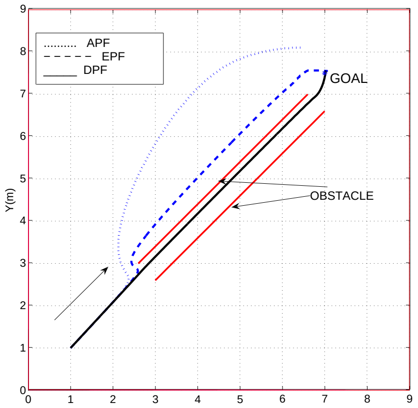
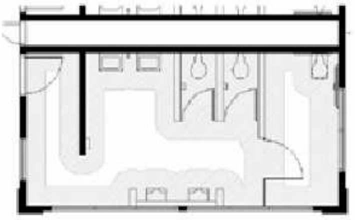


Fig. 10 Robot moving between two near obstacles, comparison between APF, EPF and DPF

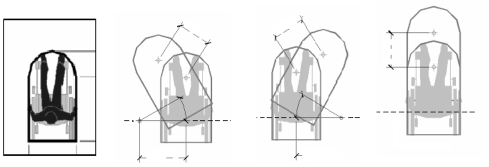
5 Evaluation parameters and functions

Various parameters may be used to evaluate accessibility and comfort:

- **Trajectory:** This concerns the quality of the trajectory including the distance between the wheelchair and obstacles and trajectory curves [12].
- **Time and energy:** This includes the time necessary to execute task as well as the velocity and the user interface actions.
- **Accessibility and Comfort:** This is a cost function of the available space such as open spaces in front of the wheelchair, accessible surfaces (horizontal or vertical), possibility of turning left and right and the capacity of gripping and touching objects (frontal and lateral).



(a) Appartment and Accessible space



(b) (c) (d) (e)

Fig. 11 Parameters of the Wheelchair (a) (b) (c) (d) (e)

In the following part a function is proposed based on the above parameters. The trajectories obtained by the path planning are used as initial solutions. The trajectories are then optimised to maximise the comfort criteria (minimise discomfort).

5.1 The evaluation function

Before defining the evaluation function, a primary evaluation of the space is considered. Consider the division of the space into the following zones:

- **Free Zone** (Z_f): This is the zone without obstacles. It covers the total area reduced by the space occupied by obstacles. Notice that this does not correspond to the space where the wheelchair may move freely.
- **Comforts Zones** (Z_c): This corresponds to the zones where the wheelchair user can reach the various goals with comfort (example: minimum effort, minimum time,...). This zone will be defined after the evaluation phase.
- **Accessible Zones** (Z_a): This corresponds to the zone where the wheelchair user can reach the various goals with limited comfort. A grid is first superposed on the free zone. This zone is obtained by choosing from the grid the accessible points.
- **Inaccessible Zones** (Z_i): These are zones that the wheelchair user can not access. (see figure 12).

The evaluation is performed using several subfunctions. In what follows these criteria will be defined.

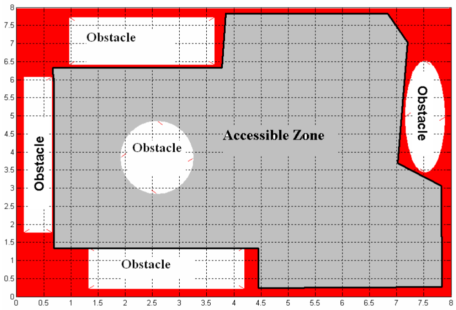


Fig. 12 Wheelchair's accessibility zone

5.1.1 Accessible to free zone ratio criterion

Consider first the simple classification criterion: the primary evaluations A_1 criterion. This corresponds to the relationship between the accessible zone and the free zone as follows:

$$A_1 = \frac{S_a}{S_f} \tag{9}$$

where:
S_a is the area of the accessible zone,
S_f is the area of the free zone
A_1 is the accessible to free zone ratio.

This criterion allows a first classification of our space.

5.1.2 Mobility Criterion

The second proposed criterion is related to maneuverability. It will be referred to the mobility criterion. It summarizes various conditions such as the possibility of rotating left, right and also surface accessibility. To obtain this criterion we consider the representation of the wheelchair by a circle [13] of minimum, 150 cm, diameter (see figure 13).

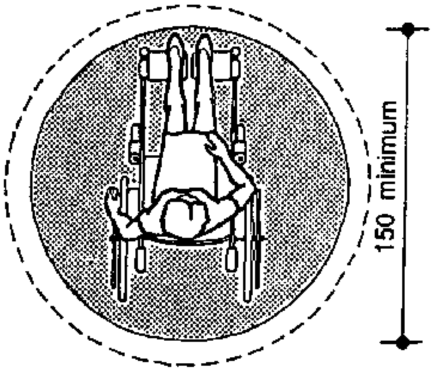


Fig. 13 The wheelchair's mobility space

This circle gives the surface necessary for the wheelchair user to make a half turn to the left or to the right and make a full rotation. This is in brief, having the freedom of movement at each point of the evolution space (see figure 14).

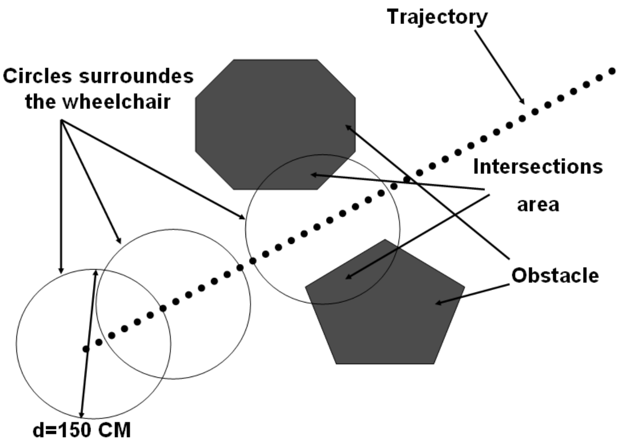


Fig. 14 Illustration of the wheelchair mobility criterion

The trajectory is represented by coordinates of the points (x_i, y_i) along this trajectory. At each point (x_i, y_i) the intersection area between the circle i and various obstacles j is calculated.

$$I_1 = \sum_{i=1}^{n_t} \sum_{j=1}^{N_o} \left(\frac{Ain_{ij}}{A}\right)^2 \tag{10}$$

where
Ain_{ij} is the intersection area between the circle in position i and obstacle j,
A is the area of the circle (normalisation factor),
N_o is the number of obstacles,
n_t is the number of points along the trajectory.

5.1.3 Distance criterion

The third criterion is related to the distance realised by the wheelchair. It makes it possible to compare the trajectories according to their length. Consider the relationship:

$$D_c = \sum_{i=1}^{n_t} (D_i) \tag{11}$$

where
D_c is the covered distance,
D_i is the distance between points $(i-1)$ and point i of trajectory,
n_t is the number of points along the trajectory.

Thus a shorter trajectory could be considered to be more comfortable.

5.1.4 Curvature criterion

It is considered here frequent orientation angle variations of wheelchair lead to uncomfortable driving and, thus, to lower quality trajectories. For this reason, the fourth criterion used corresponds to the sum of squares of rotation angle variations of the wheelchair between along the trajectories. This may be expressed as

$$D_\beta = \sum_{i=1}^{n_t-1} (\beta_{i+1} - \beta_i)^2 \tag{12}$$

where
D_β is the sum of squares angle variantions,
β_{i+1} is the wheelchair orientation angle at point $i+1$ of trajectory,
β_i is the wheelchair orientation angle at point i of trajectory,
n_t is the number of points considered along the trajectory.

5.1.5 The comfort function

The function used to represent discomfort is obtained by weighing the above criteria. The lower the value of this function is higher is the comfort of the configuration of the trajectory. Consider the function:

$$F(I_1, D_c, D_\beta) = p_i.I_1 + p_{Dc}.D_c + p_\beta.D_\beta \tag{13}$$

where
F is the evaluation function,
p_i, p_{Dc}, p_β are the weights corresponding to the mobility, the distance and the curvature criteria respectively.
This function is then minimised to obtain the optimal trajectory corresponding to all displacements in each configuration.

5.2 Simulation and comparison of trajectories

In this part of the paper, trajectories are evaluated and compared for simple examples. A first trajectories manually generated are compared. This is followed by computation of optimal trajectories. The question of optimality and evaluation of space configurations is then addressed.

5.2.1 Comparison of trajectories

Consider a 14×14 meters space with a starting point and an arrival point and three obstacles (as shown in figure 15).

Three trajectories are compared for their comfort (T_1, T_2 and T_3). The results obtained for the three trajectories are given in table 1.

Tab. 1 The values of the criteria and evaluation functions for three trajectories

T_i	$F(T_i)$	I_1	D_c	D_β	p_i	p_{Dc}	p_β
T_1	54.30	0.003	51.0	3.3	1	1	1
T_2	67.72	0.028	62.8	4.9	1	1	1
T_2	57.60	0.003	54.0	3.6	1	1	1

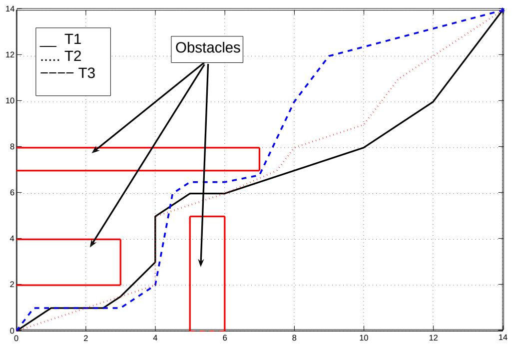


Fig. 15 Comparison of three trajectories

The values in table 1 show that the trajectory T_1 (54.3) is more comfortable than the others. This depends, of course, on the weights given to each criterion. These weights are very important in the computation of the optimal trajectory.

5.2.2 Optimization of the evaluation function

In this subsection, the trajectory minimising the evaluation function is considered. One of the trajectories compared above (trajectory T_1) is used as an initial solution. The optimal and initial solutions are compared in Table 1. The trajectory optimising comfort is then computed. The results are shown in Table 2 .
The trajectories are compared graphically in figure 16.

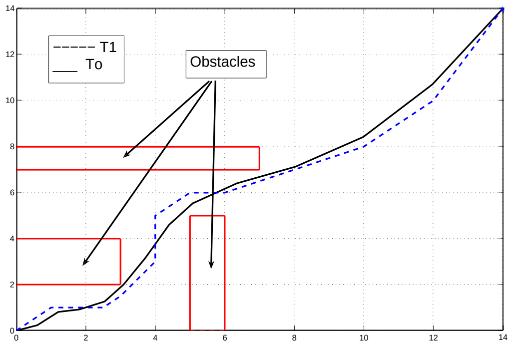


Fig. 16 Comparison of the initial T_1 and optimal T_o trajectories

This figure shows that the optimised trajectory is more comfortable.

Tab. 2 Comparison of the initial trajectory T_1 and the optimal trajectory T_o

T_i	$F(T_i)$	I_1	D_c	D_β	p_i	p_{Dc}	p_β
T_1	54.33	0.003	51	3.3	10	1	1
T_o	45.70	0.050	44	1.2	10	1	1

5.2.3 Accessibility

In the previous sections the problem of the evaluation and optimisation of trajectories was considered. This was the first step towards the evaluation of the accessibility. In order to evaluate the accessibility within dwellings, the following steps must be taken:

1. From the architectural drawings define the space for the evolution of the wheelchair.

2. Define the various options for the installation of the furniture and equipment within this space.

3. Define the displacement scenarios. This corresponds to the enumeration of the displacements within the household and their frequency.

4. For each installation, calculate the optimal trajectory using the evaluation function. Using the frequency of each displacement, calculate the overall accessibility quality of the configuration.

5. Compare the above-obtained results select the best configuration and hence qualify the overall accessibility of the architecture.

The authors define the above accessibility index as a first proposal to qualify numerically installations and compare them. It is subjective and depends on the choice of the criteria and their weight. It is, though, a first step towards the numerical estimation of the accessibility. Although in this paper, it has been applied to households, its application within the professional environment is quite the same. Furthemore, the application to the accessibility of vehicles is much simpler in term of trajectory.

6 Conclusions and perspectives

The accessibility of installations to persons on wheelchairs is an important issue for the wellbeing of persons with physical handicap. In this paper, the authors make a first contribution towards this important issue. Work in this field is essentially related to regulations. These regulations give the conditions to be fulfilled for accessibility. They do not, however, give the means for the numerical comparison of installations. In this work, a first step has been accomplished. To do so, the authors proposed evaluation functions and applied them to calculate trajectories that optimise these trajectories. Further work is presently underway to confirm the evaluation functions by applying them to multiple situations.

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