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Multi-Robot Visual Navigation Structure based on Lukas-Kanade Algorithm

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Résumé This paper presents an efficient control structure of two mobile robots based-visual navigation methods in an indoor environment. The proposed navigators are based on decision systems employed the necessary values estimated by a Lukas-Kanade (LK) algorithm of optical flow (OF) approach. The robots control systems use the generated motion values in order to detect and estimate the positions of the nearest obstacles and objects around each mobile robot. The multi-robot system task is to navigate autonomously in their environment safely without collisions. Obstacles are identified and detected with the employed cameras of each robot based on video acquisition and image processing steps. The efficiency of the proposed approach is verified in simulation using Visual Reality Toolbox. Simulation results demonstrate that the visual based control system allows autonomous navigation without any collision with obstacles..

Keywords Lukas-Kanade algorithm · Multi-Robot · Visual · Camera · Decision · VRML toolbox

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1 Introduction

Robotics is a vast and multidisciplinary field of science, starting with mechanical aspects, going through the automatic and going up to higher-level aspects such as perception, environmental modeling and decision-making. Research in the field of mobile robotics focuses on the design of intelligent systems based on efficient control techniques allowing the mobile robot to move around its environment without assistance or human intervention to achieve a goal desired [1]. The task of autonomous navigation of a mobile robot must be able to take decisions to carry out movements according to the information on the position and the environment that it bypasses by endowing it with a capacity of perception, decision. Many sensors may be utilized in robot applications (localization, interception, impediment avoidance or navigation) [2]. Vision structures are very effective and appealing sensors utilized in robotics [3]. The digital camera mimics herbal beings' imaginative and prescient to outline visible homes of the environment (colorings and shapes). For their use, pc imaginative and prescient is a thrilling device in lots of applications : photo registration and enhancement, matching for stereo imaginative and prescient, sample recognition, and movement estimation and analysis [5, 6].Behavior-based navigation methodology presents a made tool to subdivide the world navigation task into tiny sub-tasks [3, 7]] : obstacle avoidance, wall following, goal seeking, target pursuing, and so on. Different strategies are projected for obstacle shunning task. Visual-based navigation technique is a beautiful approach utilized in robotic applications. The vision system will increase the utility of mobile robots in numerous domains. [8, 9, 10]. Optical flow estimation is used in many applications. Vehicles navigation, video image reconstruction and object tracking are some examples. Moving vehicle detection is an important part of Intelligent Transport System (ITS). [4, 11]. This method is a pace calculation approach hired specially in movement estimation, video compression-reconstruction, picture segmentation [11, 12] , detection and fending off obstacles[5, 12, 13]. In papers [6] and [7], surveys of visual navigation techniques are bestowed for robotic applications in indoor and outside environments. For the problem of avoiding obstacles, the author of [14] proposed real-time robot navigation based on the task of tracking objects and avoiding obstacles. The robot uses a stereo vision system to locate the desired target, while using a laser viewfinder to avoid collisions. The author of [13] studied the optical flow method based on the balance strategy to avoid obstacles. Calculate the depth from two consecutive images. In [2], the author used monocular vision based on color segmentation and edge detection to check the obstacle avoidance task of the robot in a dynamic and changing environment. In the paper [15], Wang et al. Since 2015, they have been studying the problem of avoiding obstacles for quad copters using monocular cameras based on improved optical flow methods. The use of optical flow methods in robotic applications is outlined in [12]. The main objectives of this work are the development of avoid collision of the robot with mobile or fixed barriers and Decisions by robots are made by only one controller. After applying optical flow calculation for detecting motion vectors. Analysis is employed to identify the mobile or fixed barriers for the tracking process. This paper is prepared as follows. Section 2 discusses an optical flow. Section 3 provided THE MOBILE ROBOT .Section 4 discusses the CONTROL STRUCTURE. Section 5 the experimental consequences are provided. Finally, end is drawn in Section 6.

2 BREIF ON OPTICAL FLOW APPROACH

2.1 Definition

The optical flow describes the direction and time rate of pixels in a time sequence of two consequent images. A two-dimensional velocity vector, carrying information on the direction and the velocity of motion is assigned to each pixel in a given place of the picture. For making computation simpler and quicker we may transfer the real world three-dimensional (3D+time) objects to a (2D+time) case. Then we can describe the image by means of the 2-D dynamic brightness function of location and time I(x, y, t). Provided that in the neighborhood of a displaced pixel, change of brightness intensity does not happen along the motion field, we can use the following expression [1].

$$(x, y, t) = I(x + \delta x, y + \delta y, t + \delta t) \tag{1}$$

Optical flow estimation is computationally demanding. At present there are several groups of methods for its calculation All the methods come from (1) and consequently the presumption of conservation of brightness intensity. The optical flow determination is solved by the calculation of partial derivatives of the image signal. There are two most used methods, namely :

— Lucas-Kanade
— Horn-Schunck

2.2 Lucas-Kanade

The Lucas-Kanade algorithm makes a "best estimate" of a neighborhood's displacement by examining changes in pixel intensity that can be explained from the known intensity gradients of the image in that neighborhood. For a single pixel, we have two unknowns (u and v) and an equation (that is, the system is under-determined). We need a neighborhood to get more equations. By doing so, the system is over determined and we must find a least square solution. The Lucas-Kanade algorithm is ancient method of observing optical information at interesting points in an image (i.e. those with sufficient information on the intensity gradient). It works for moderate object speeds. In Lucas-Kanade algorithm, we have an equation with two unknowns :

$$I_x u + I_y v + I_t = 0 \tag{2}$$

In order to calculate (u, v) for a pixel, we can follow the following steps :
— If we use a 5x5 window, this gives us 25 equations per pixel.

$$\underbrace{\begin{bmatrix} I_x\,(P_1) I_y\,(P_1) \\ I_x\,(P_2) I_y\,(P_2) \\ \vdots\vdots \\ I_x\,(p_{25}) I_y\,(P_{25}) \end{bmatrix}}_{\substack{A \\ 25\times 2}} \underbrace{\begin{bmatrix} u \\ v \end{bmatrix}}_{\substack{d \\ 2\times 1}} = - \underbrace{\begin{bmatrix} I_t\,(P_1) \\ I_t\,(P_2) \\ \vdots \\ I_t\,(P_{25}) \end{bmatrix}}_{\substack{b \\ 25\times 1}} \tag{3}$$

Now we have more equations than unknowns

$$\underset{25\times 2}{A}\,\underset{2\times 1}{d} = \underset{25\times 1}{b} \rightarrow \min imize\,\|Ad - b\|^2] \tag{4}$$

Solution : solve the problem of least squares - minimum solution of least squares given by the solution of :

$$\underset{2\times 2}{(A^T A)}\,\underset{2\times 1}{d} = \underset{2\times 1}{A^T b} \tag{5}$$

$$\underbrace{\begin{bmatrix} \sum I_x I_x & \sum I_x I_y \\ \sum I_x I_y & \sum I_y I_y \end{bmatrix}}_{A^T A} \begin{bmatrix} u \\ v \end{bmatrix} = - \underbrace{\begin{bmatrix} \sum I_x I_t \\ \sum I_y I_t \end{bmatrix}}_{A^T b} \tag{6}$$

The summations are on all pixels in the K x K window.

2.3 Focus of expansion (FOE)

For translational motion of the camera, image motion everywhere is directed away from a singular point corresponding to the projection of the translation vector on the image plane. This point, is called the Focus of Expansion (FOE), it is computed based on the principle that flow vectors are oriented in specific directions relative to the FOE. Additionally, the FOE represents the projection point in the image allowing to obtain information about the depth of some pixels and the FOE. This information is called Time To Contact (TTC) (Arnspang et al. 1995). In a situation where the camera is moving forward, the Focus of Expansion point is shown as in the Fig. 1(b) (red circle).

2.4 Time to contact (TTC)

The time-to-Contact (TTC) can be computed from the optical flow which is extracted from monocular image sequences acquired during motion. The image velocity can be described as a function of the camera parameters and split into two terms depending on the rotational (Vt) and translational components (Vr) of camera velocity (V) respectively. The rotational part of the flow field can be computed from proprioceptive data (e.g. the camera rotation) and the

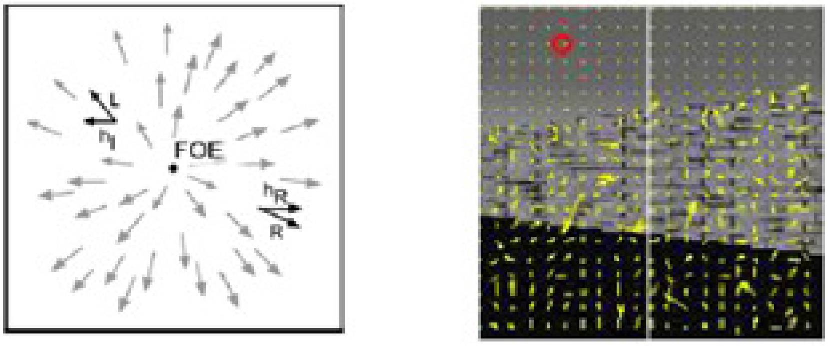


Figure 1 a FOE calculation. b Results of FOE (color figure online).

focal length. Once the global optic flow is computed, (Vt) is determined by subtracting (Vr) from (V). The TTC is computed as follows :

$$TTC = \frac{-z}{dz/dt} \tag{7}$$

Where Z is the distance camera-obstacle, and dZ/dt is the velocity of the robot camera.

3 THE MOBILE ROBOT

In this section, we present the simulated mobile robot in its environment using Virtual Reality Modeling Language (VRML). The used mobile robot is a cylindrical platform with two motorized wheels. . In order to perceive its environment, the robot is endowed by a virtual camera, where the objective is to navigate autonomously. The simulated mobile robot is illustrated in Fig. 2a. Using VRML library, we have created a virtual navigation environment that imitates the real space in 3D containing obstacles at the form of boxes, floor, walls and the goal. The designed 3D environment is depicted in Fig. 2. 2b. The robot motion is based on the nonholonomic kinematic model described as follows :

$$x_r = v * \cos(\theta_r) \tag{8}$$

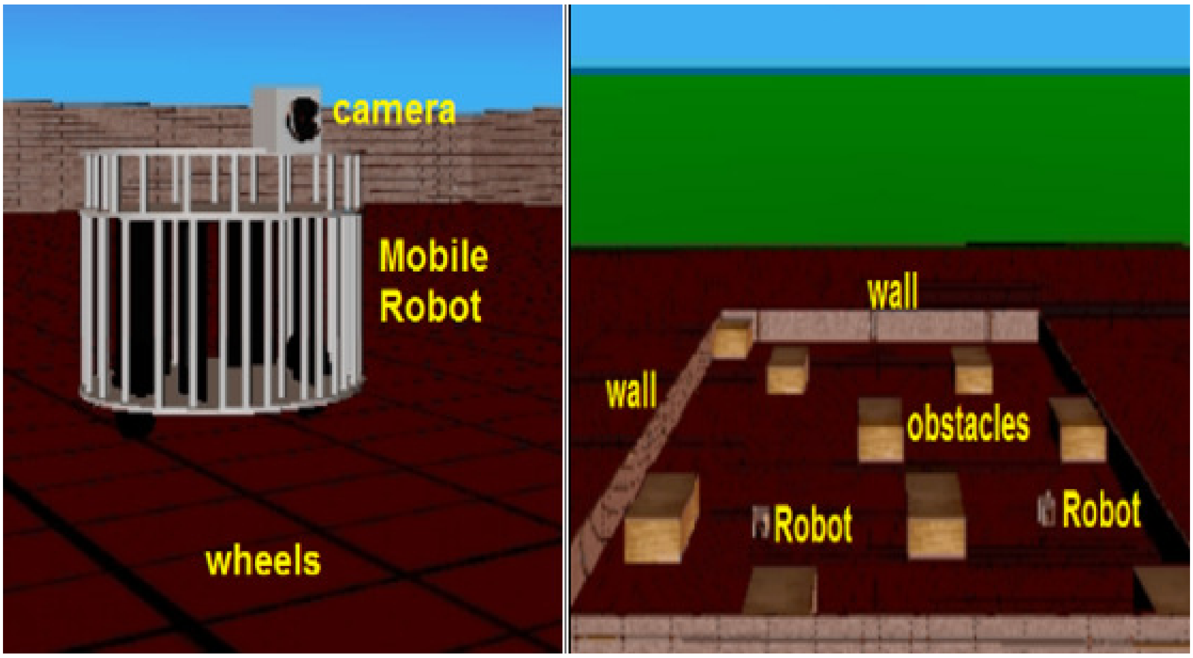
$$y_r = v * \sin(\theta_r) \tag{9}$$

$$\theta_r = w \tag{10}$$

Where :

— (x_r) and (y_r) are the robot coordinates.

— (θ_r) is the heading angle.



(a) (b)

FIGURE 2 Structure of the simulated robot environment.

— v is the linear velocity.
— w is the angular velocity calculated from the steering angle (α_r).

4 CONTROL STRUCTURE

In this section, we present the proposed control structure for the multi-robot system in an indoor environment. Using the acquired images by the robots cameras, the elaborated control system must infer the appropriate control action for the two mobile robots. In our application, we assume that :

— The robot and the goal move on the same plane.
— The simulated environment is static.
— We haven't considered pan-tilt motions.

The block diagram of this control strategy is presented in Fig 3.

5 SIMULATION RESULTS

In this section we show the experimental results using VRML. In VRML, we design environment and the wall and two robots without obstacle (boxes) in first experience and with obstacle in second experience. Before applying optical flow estimation on frames, the image format is converted from RGB to

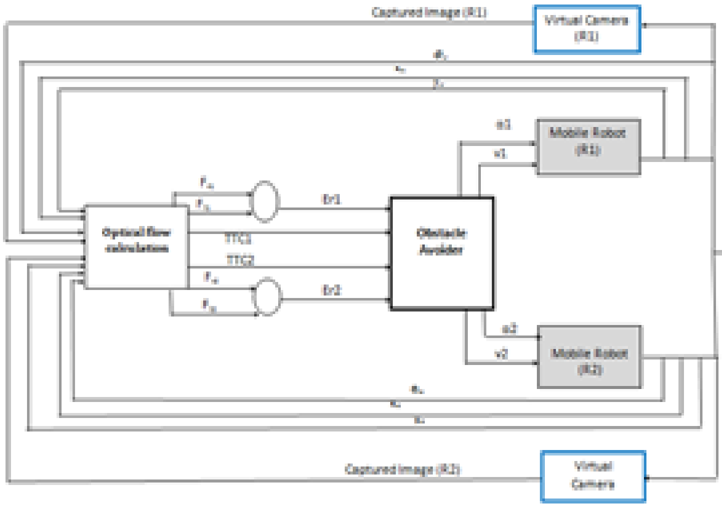


Figure 3 Visual Navigator

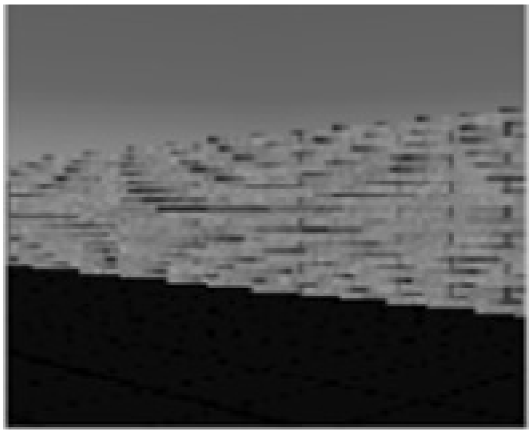


Figure 4 Gray image

gray (Fig. 4) ; because Intensity measurements act well on gray-scale frames. Depends on methodology steps, the proper optical flow estimation (Locus-Kanade) has been applied. To test the studied the visual obstacle avoidance task, we consider the following assumptions :

- if the robot environment is free of obstacles, the mobile robot moves forward.
- else, the robot turns left or turn right to avoid collisions.

Examples of the camera view in colour and the calculated optical flow vectors are given in the top left and right corners, respectively. At any time-step, the robot perceives the surrounding environment using the virtual camera. The acquired image indicates the state of the environment on the robot front side. Then, optical flow values are calculated to detect obstacles in the two parts. The detected and the nearest obstacle are defined by the flow vectors (in yellow color) in the top right. In this last one, we indicate the focus of expansion (FOE) as a red circle (Fig 1.b). To illustrate the robot's ability to detect and avoid obstacles.

5.1 Experiment 1

For this experiment, we have 2 robots in an obstacle-free environment, each robot having the same 1st experiment parameter. The results of the simulation of this task are presented (Fig.5). This example shows the scenes of navigation by 2 mobile robots from a given position (x_0, y_0) in order to move freely in its environment without collision with obstacles.

Figure 6 shows the executed paths by the mobile robots in the 2D environment. The two robot positions are shown (The red path for the 1st robot , and the black path for the 2nd robot).

This navigation system is effective to accomplish this task with good performances. To present the moments of avoidance, the Time-To-Contact (TTC) is computed from the optical flow values as shown in Figure 7 (a. for the 1st robot, b. for the 2nd robot).

5.2 Experiment 2

In this experiment, we will set the same conditions as first Experiment but increase the obstacles (boxes) in the environment. The results of the simulation of this task are presented Figure.8. This example shows the navigation scenes by 2 mobile robots from a given position (x0, y0) in order to move freely in its environment without collision with obstacles.

Figure 9 shows the path taken in the 2D environment. The two robot positions are shown with obstacles (The red path for 1st robot, the black path for the 2nd robot, Yellow squares represent obstacles).

This navigation system is effective to accomplish this task with good performances. To present the moments of avoidance, the Time-To-Contact (TTC) is computed from the optical flow values as shown in Figure 10 .a. for the 1st robot, b. for the 2nd robot).

6 CONCLUSION

In this paper, we have introduced an Optical Obstacle Avoidance Control Module for two mobile robots using a common controller. The proposed navigation system was simulated in a three dimensional environment using the VRML library. In this proposed control strategy, the acquired image in each time step is divided into two parts right and left to guarantee the robot's motion in the two directions. The efficiency of the proposed approach is verified in simulation using Virtual Reality Toolbox. Simulation results demonstrate that the visual-based control systems allow autonomous motions without any collision with obstacles for the controlled mobile robots In next work, the interest will be given to increasing numbers of robots in the same area by a single controller. Then, we can propose a multi-agent system to coordinate actions between the used mobile robots in a crowded environment.

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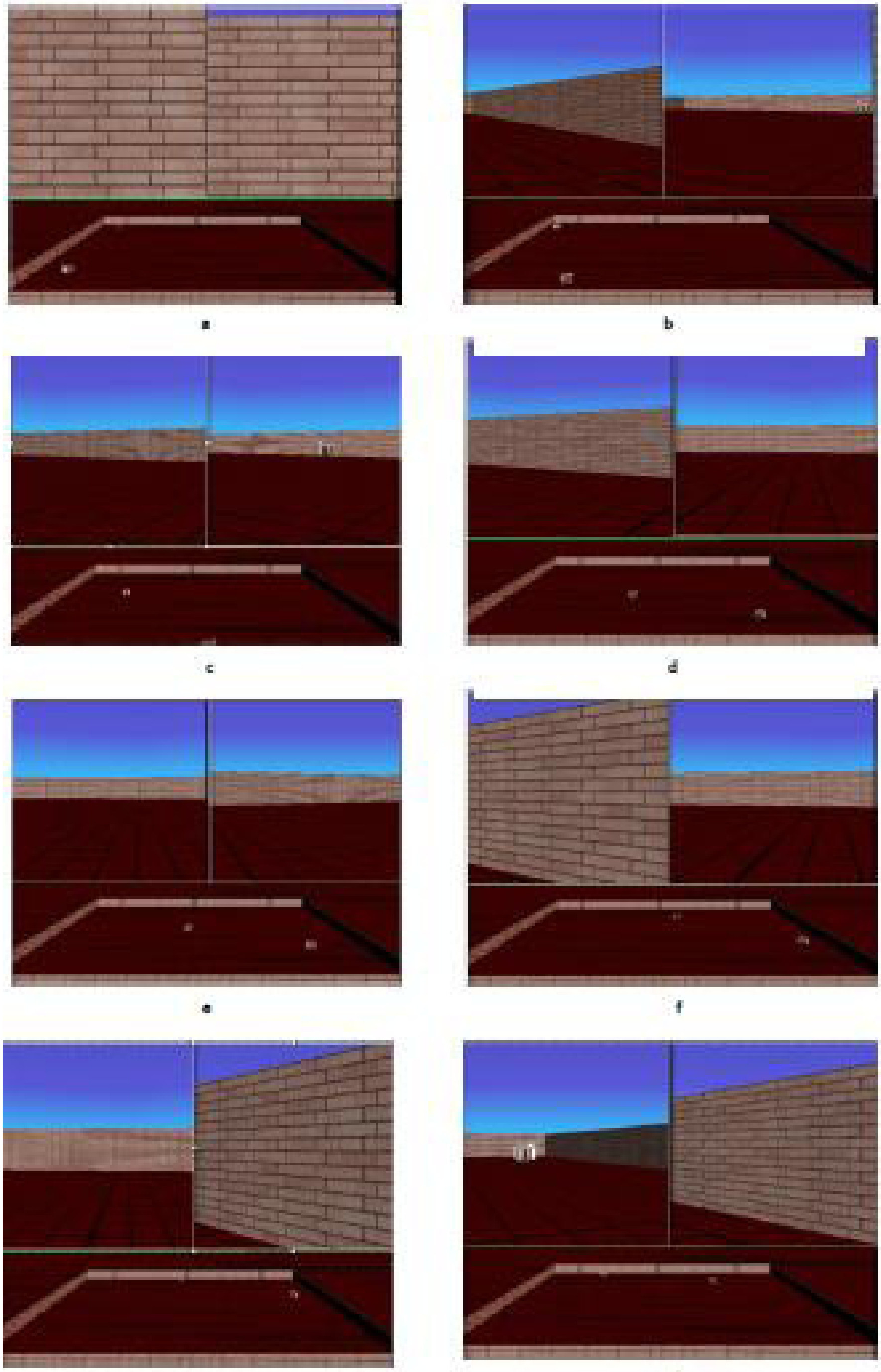


a b c d e f g h

Figure 5 Navigation frames of the 2 robots without obstacles (captured image of 1st robot in top left, captured image of 2nd robot in top right)

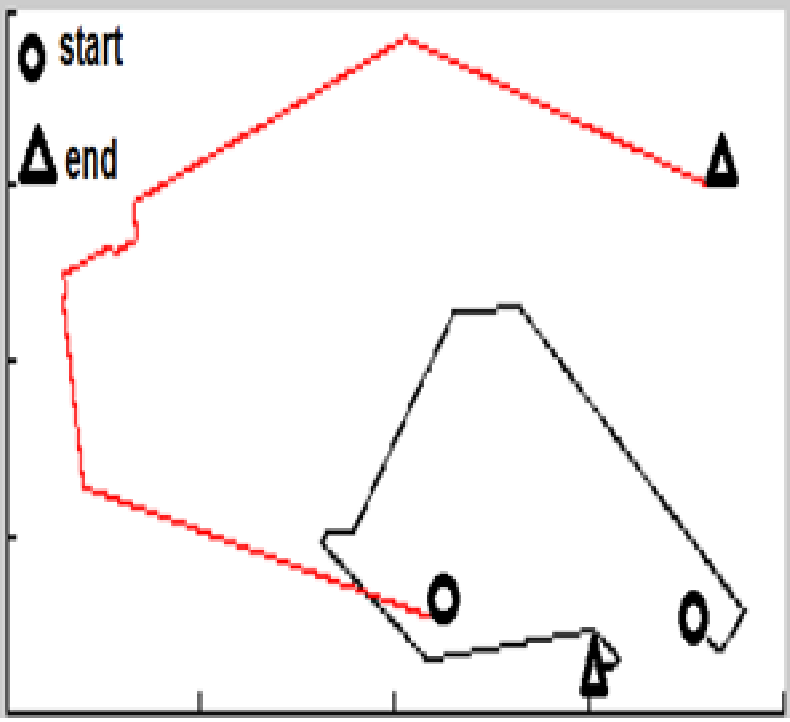
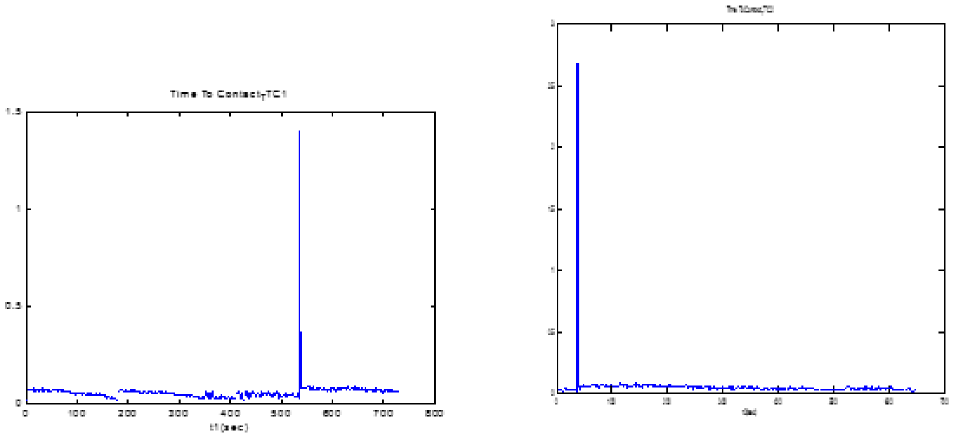


Figure 6 Path of the 2 robots (without obstacles)



(a)

(b)

Figure 7 Time To Contact (A for 1st robot and B for 2nd robot).

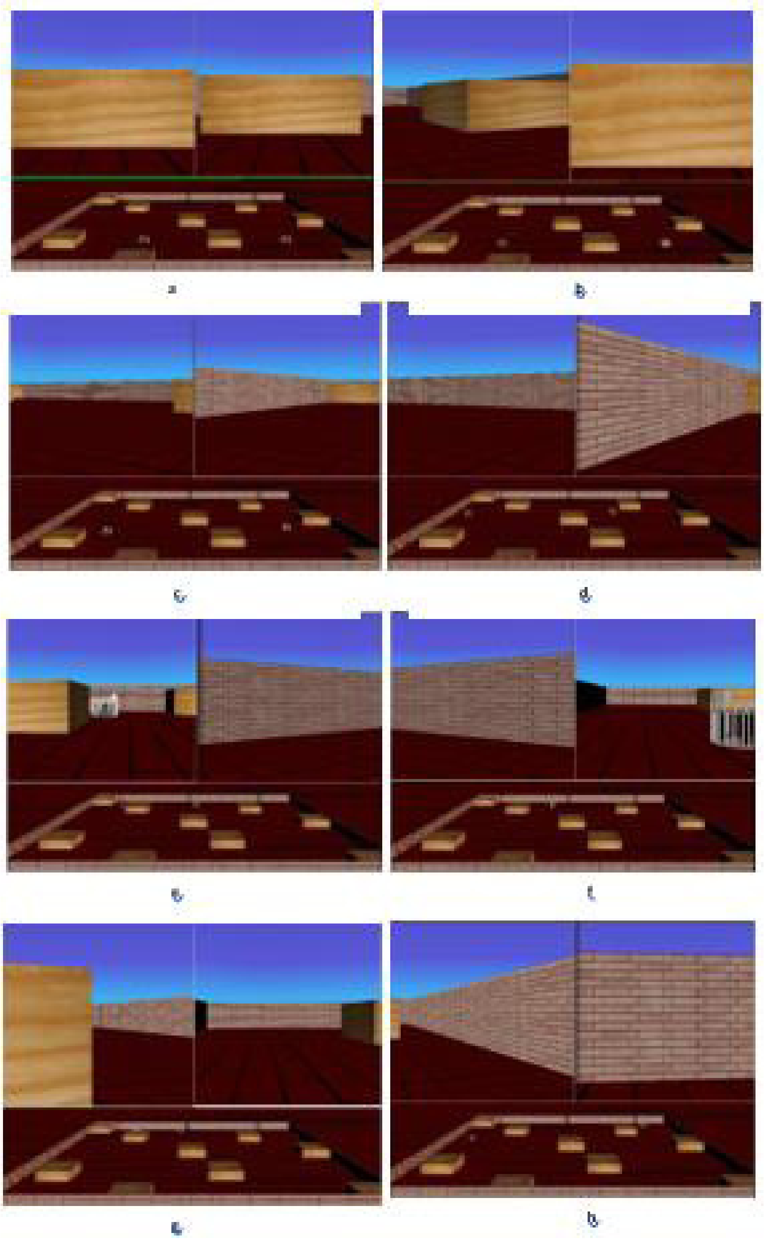


Figure 8 Navigation frames of the 2 robots with obstacles (captured image of 1st robot in top left, captured image of 2nd robot in top right)

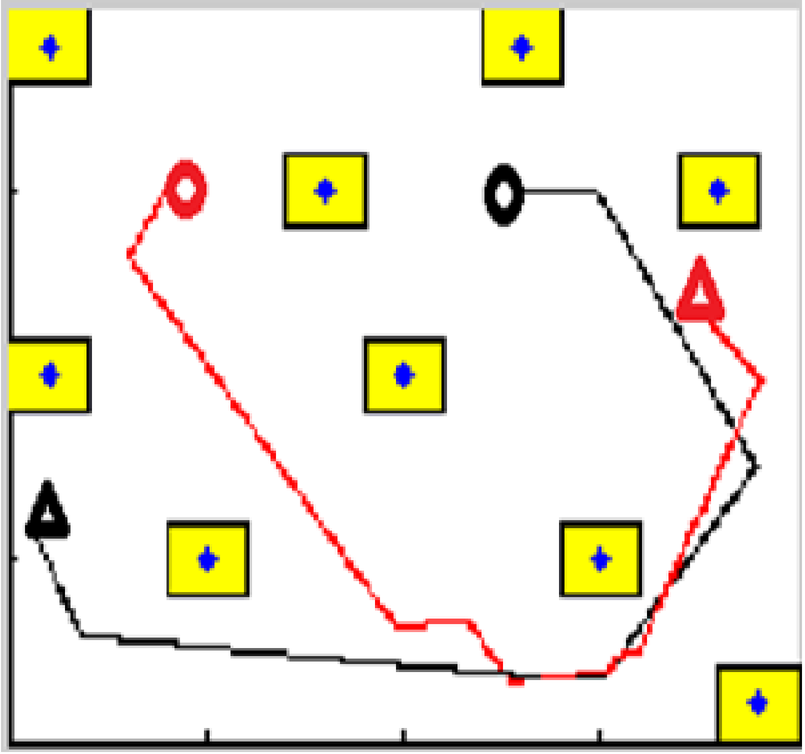
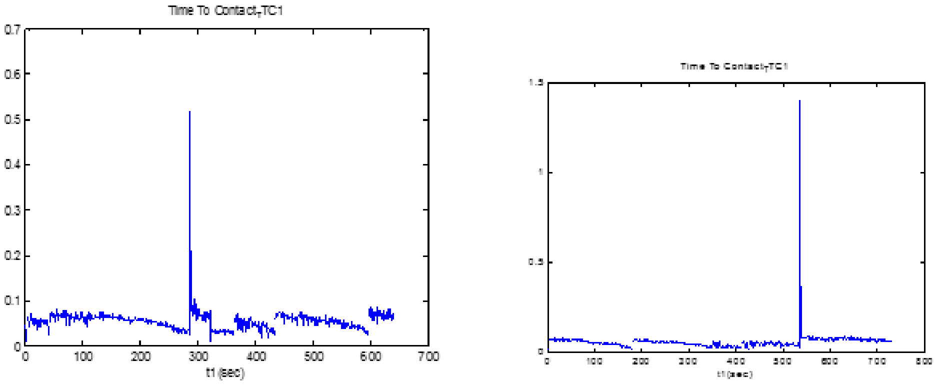


Figure 9 Path of the 2 robots with obstacles.



(a) (b)

Figure 10 Time To Contact (A for 1st robot and B for 2nd robot).