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Intelligent Visual Robot Navigator via Type-2 Fuzzy Logic and Horn-Schunck Methods

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Résumé The aim of this paper is to propose a visual navigation control system for a wheeled mobile robot using a type-2 fuzzy logic controller (T2FLC) and Horn-Schunck algorithm (HS) of optical flow (OF) approach. The obstacle avoidance task for an autonomous mobile robot is studied using Takagi-Sugeno fuzzy logic controller based on video acquisition and image processing algorithm. The horn-Schunck algorithm is applied to extract information about the environment and estimate the positions of the surrounding obstacles. The captured image is divided into two parts right and left in order to facilitate the robot motion. Simulation is done using Visual Reality Toolbox in 2D and 3D. The obtained simulation results demonstrate the effectiveness of this autonomous visual navigator.

Keywords Horn-Schunck algorithm · Mobile Robot · type-2 fuzzy logic · VRML toolbox · visual navigation.

1 Introduction

Obstacle avoidance is one of the most important task for mobile robot applications. In unknown and complex environments, robots must have powerful

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control systems and precise perception parts [1]. Many sensors can be used in robotic applications. Vision systems are very powerful and attractive sensors used in robotics [2]. The camera mimics natural beings vision to define environmental visual properties (colors and shapes). For their use, computer vision is an interesting tool in many applications : image registration and enhancement, matching for stereo vision, pattern recognition, and motion estimation and analysis [3]. Different methods have been proposed for obstacle avoidance task. Visual-based navigation method is an attractive approach used in robotic applications [4,5]. However, Optical flow (OF) is an interesting method for visual mobile robot navigation [6,7,9]. OF is a velocity calculation strategy in image, used mainly in motion estimation, video compression-reconstruction, image segmentation detection and avoiding obstacles [8]. In paper [10], authors have studied the ability of obstacle avoidance task for a mobile robot in dynamic environment using monocular vision based on colour segmentation and edge detection. Authors in paper [11], have studied the obstacle avoidance task using a balancing strategy based optical flow method. The depth is calculated from two consecutive images. Authors in [12] have proposed real-time robot navigation based on object tracking and obstacle avoidance tasks. The robot uses a stereo vision system to detect the desired target while the laser finder is used to avoid collision. On the other hand, fuzzy logic controllers (FLCs) have the ability to handle and treat the detected robotic uncertainties [13,14,18]. Where, type-1 fuzzy logic system uses crisp and precise fuzzy sets. However, type-2 fuzzy logic system presents a new generation of fuzzy logic controllers based on the extension principle of Zadeh [15]. Type-2 FLCs offer an opportunity to model the increasing uncertainties and give a better representation in robotic fields [16,17]. The three basic robot behaviours : goal seeking, obstacle avoidance and wall-following have been studied using type-2 FLCs in paper [17]. Authors in [19], have studied the navigation task in dynamic environments with a hierarchical structure using Type-2 fuzzy logic controller. In the paper [18], the authors have proposed a comparison between Type-1 and Type-2 Takagi-Sugeno FLC for controlling a mobile robot. They have studied and compared the performances of the three main behaviors : goal seeking, obstacle avoidance and wall-following. The hybridization of optical flow approach and fuzzy logic method is an interesting research area. In [20], type-1 fuzzy systems have been used to estimate the depth and the rotation angle fast moving object tracking. In [21], the authors proposed a vision system based type-1 fuzzy logic control for unmanned aerial vehicle (UAV) navigation in real-time. They have tested different functionalities : landing, object following and obstacle avoidance. Authors in [22] proposed visual robot navigation based on bio-inspired approach for optical flow data interpretation and fuzzy inference system. A vision based obstacle avoidance system is proposed in paper [3] using Scale Invariant Feature Transform (SIFT) and type-1 fuzzy logic system. Hybrid systems for different robot functionalities using type-1 fuzzy logic controllers and Horn-Schunck algorithm are proposed in our previous paper [23]. The objective of this paper is the hybridization of Takagi-Sugeno type-2 fuzzy logic controller with Horn-Schunck algorithm

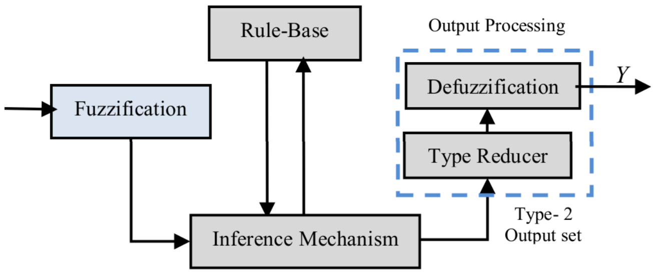


Figure 1 Type-2 fuzzy Logic System (T2FLS).

of optical flow method for mobile robot motion with obstacle avoidance. The paper is organized as follows : in Section 2, we present briefs on type-2 FLCs HS methods. The proposed type-2 fuzzy visual navigator is introduced and explained in Section 3. Simulation results are presented and discussed in Section 4. Section 5 concludes the paper.

2 TYPE-2 FLC AND OPTICAL FLOW METHODS

In this section, we will present briefly the two used approaches in this work : type-2 fuzzy logic controllers (T2FLC) and Horn-Schunck (HS) optical flow algorithm. The first method is used as a controller to generate the steering angle for mobile robot motion, and the second is applied to detect the surrounding obstacles and objects in the environment based on a virtual camera.

2.1 Type-2 Fuzzy Logic Controllers

The main advantage of type-2 fuzzy logic control is the introduction of human experience in the form of If-Then rules about how to control systems with increasing uncertainties. The structure of a Type-2 fuzzy logic controller is same as the structure of a type-1 controller, the difference between them is in the block of output processing [15,17]. The membership functions of type-2 fuzzy sets are three dimensional functions. Type-2 FLC is composed of the five elements as depicted in 1 [16,18] : Fuzzification, Rule-Base, Type reducer and Defuzzification.

2.2 Horn-Schunck Algorithm

The HS algorithm is a differential technique of optical flow. It was proposed by Horn and Schunck [24]. HS algorithm is used to adjust the kernel model using the density of velocity [6]. This method is used to calculate the pixel motion [8,24]. It is based on the velocity vectors in the image as follows :

$$I_x u + I_y v + I_t = 0 \tag{1}$$

Where I_x, I_y and I_t represents the derivatives of the image intensity values in three dimensions spatiotemporal x, y and the time respectively. u and v represent horizontal and vertical optical flow vectors. The Horn-Schunck method computes the estimation of the velocity field that minimizes the following criteria :

$$E = \iint (I_x u + I_y v + I_t)^2 \, dxdy + \alpha \iint \left\{ \left(\frac{\partial u}{\partial x}\right)^2 + \left(\frac{\partial u}{\partial y}\right)^2 + \left(\frac{\partial v}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial y}\right)^2 \right\} dxdy \quad (2)$$

where : $\frac{\partial u}{\partial x}$ and $\frac{\partial u}{\partial y}$ are the spatial derivatives of the optical velocity component. u and v are scales of the global smoothness term. HS algorithm minimizes eq. 2 to obtain the velocity field $[uv]$ for each pixel. Velocity values are given by the following equations :

$$u_{x,y}^{k+1} = \bar{u}_{x,y}^{k} - \frac{I_x \left[I_x u_{x,v}^{-k} + I_y^{-\hat{k}} v_{x,y} + I_t \right]}{\alpha^2 + I_x^2 + I_y^2} \quad (3)$$

$$v_{x,y}^{k+1} = \bar{v}_{x,y}^{k} - \frac{I_y \left[I_x u_{x,v}^{-k} + I_y^{-\hat{k}} v_{x,y} + I_t \right]}{\alpha^2 + I_x^2 + I_y^2} \quad (4)$$

In these equations,$[u_{x,y}^k, v_{x,y}^k]$ is the velocity estimate for the pixel at (x, y), and is the neighborhood average of $\left| \begin{matrix} -k & -k \\ u_x, y, & \mathcal{V} x_n y \end{matrix} \right]$ .For $k = 0$, the initial velocity is 0. In this paper, we have used the optical flow approach to detect objects and obstacles in robot environment. In optical flow algorithms, there are two basic informations. The projection of the translation vector in the image plane defines the point called focus of expansion (FOE) [9]. The coordinates of this point give information about the direction of the 3D translation of the camera [8]. Figure 2 presents the simulated focus of expansion. Secondly, the depth of the pixels defined by the FOE is represented using the projection point in the image. This information is called Time To Contact (TTC) [12]. The objective is to estimate the necessary time to collision with the captured object in the image. The TTC is expressed by the speed and the distance of the detected obstacles [23].

3 PROPOSED CONTROL SYSTEM

This section discusses the proposed obstacle avoidance navigator for mobile robot. The control structure is presented in Figure 3. The controlled robot perceives its environment using a virtual camera with high resolution. Horn-Schunck algorithm (HS) of optical flow is used to estimate the velocity vectors of the image (optical flow calculation). The image is divided in two parts :

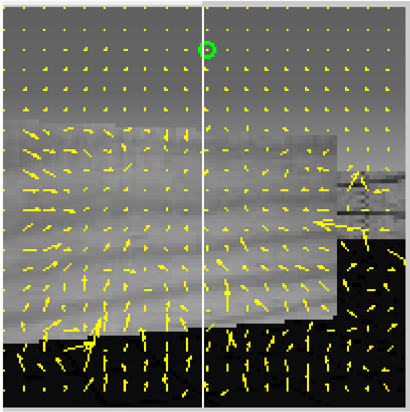


Figure 2 Focus Of Expansion.

right and left. It is treated, resized and subdivided in two parts in order to generate the appropriate control actions. The designed control system allows the robot to avoid collisions with the nearest obstacles. For each part of the image, the algorithm calculates the mean value of optical flow (F_r and F_l). In each time step, the error flows (E_r) and their variations (ΔE_r) are computed using the following equations :

$$E_r(t) = F_l(t) - F_r(t) \tag{5}$$

$$\Delta E_r(t) = Er(t) - \mathrm{Er}(t-1) \tag{6}$$

These two variables are used by the designed type-2 fuzzy logic controller to infer the motion actions : the steering angle α and the robot velocity v. The robot motion is defined by the kinematic model shown in eq. 7 [23].

$$\begin{aligned} \dot{x}_r &= v\cos(\theta_r) \\ \dot{y}_r &= v\sin(\theta_r) \\ \dot{\theta}_r &= w \end{aligned} \tag{7}$$

where : - x_r and y_r are the robot coordinates ; θ_r is the heading angle ; v is the linear velocity ; and w is the angular velocity. The proposed controller is a Takagi-Sugeno type-2 fuzzy logic controller [26]. It uses two inputs : E_r and ΔE_r and one output (steering angle). We consider the robot moves with a constant velocity. Inputs are fuzzified using the membership functions (T2MFs) illustrated in Figures 4− 5. The output action (steering angle) is represented by singletons as in Figure 6. The used fuzzy labels are : ZZ : Zero, PS : Positive Small, PB : Positive Big, NB : Negative Big, NS : Negative Small. Using these variables, the type-2 If-Then fuzzy rules are given in Table 1. The rule-base is used to characterize the relationship between type-2 fuzzy inputs and type-2 fuzzy output as follows :

$$\text{IF Er is } A_1^i \text{ and } \Delta Er \text{ is } A_2^i \text{ THEN } \alpha = B^i \tag{8}$$

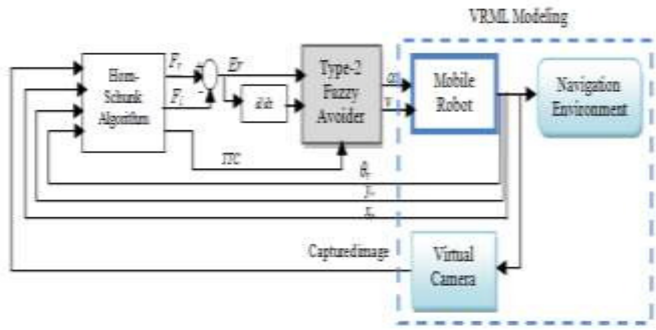


Figure 3 Visual Obstacle Avoidance Navigator.

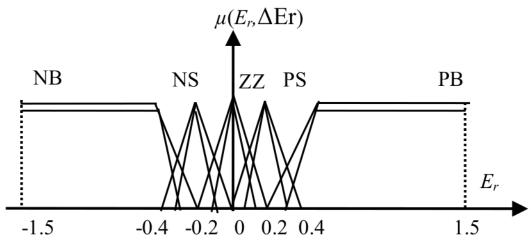


Figure 4 Membership Functions of E_r.

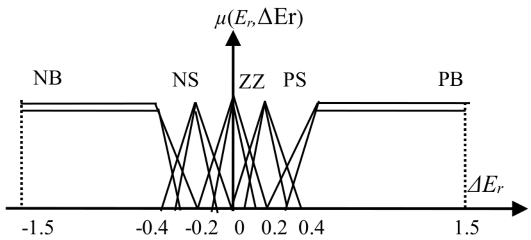


Figure 5 Membership Functions of ΔE_r.

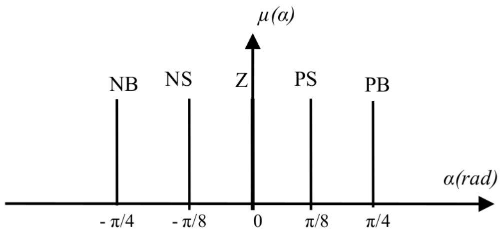


Figure 6 Membership functions of α.

Where $i = 1 \ldots N$, and N is the number of fuzzy rules in a given fuzzy rule-base, $A^i \ldots A_2^i$ are the input type-2 fuzzy sets, B^i is the output fuzzy set.

Table 1 TYPE-2 FUZZY RULE-BASE

ΔE_r	E_r				
	PB	PB	PS	NS	NB
NB	PB	PB	PS	NS	NB
NS	PS	PS	PS	NS	NB
ZZ	PS	PS	NS	NS	NS
PS	PS	PS	NS	NP	NS
PB	PB	PS	NS	NB	NB

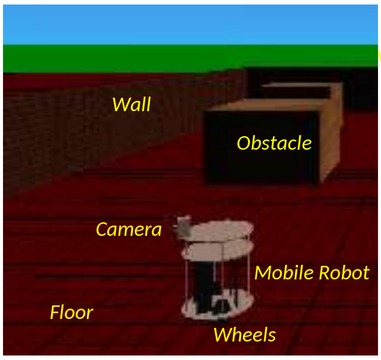


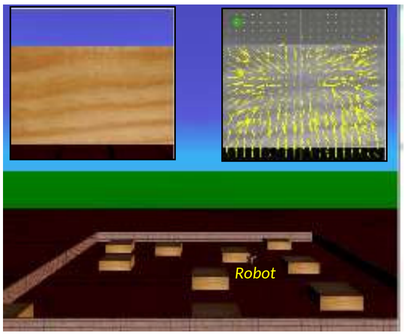
Figure 7 Simulated Mobile robot using VRML.

4 SIMULATION RESULTS

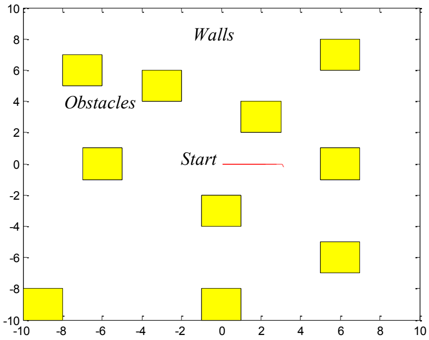
In this section, we will present examples of mobile robot navigation using the proposed hybrid Takagi-Sugeno type-2 fuzzy logic controller and HS algorithm. In our work, the simulation is done using VRML library (Virtual Reality Modeling Language) to define the navigation environment in 2D and 3D forms. The simulated mobile robot is a cylindrical platform with two motorized wheels as depicted in Figure 7. To perceive the environment and to navigate autonomously, the robot is equipped with a virtual camera. To test the studied visual obstacle avoidance task, we consider in simulation the following assumptions :

- If the robot environment is free of obstacles, the mobile robot moves forward.
- Else, the robot executes the generated control action by the elaborated type-2 fuzzy logic controller to avoid collisions (turn right or turn left).

The simulation results of the obstacle avoidance are presented in Figures 8(a)−13(a). They present the robot positions during movement with obstacle avoidance starting from initial point (start) to the final destination (end). For each position, the captured image in colour and the calculated optical flow vectors are given in the top left and right corners, respectively. The current position in 2D is depicted in Figures 8(b)−13(b). 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

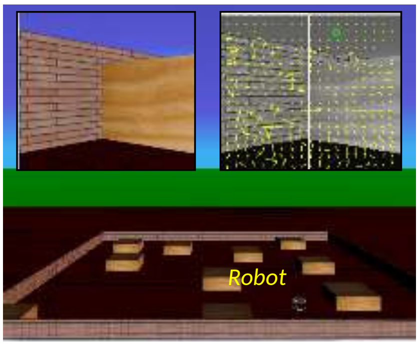


(a)

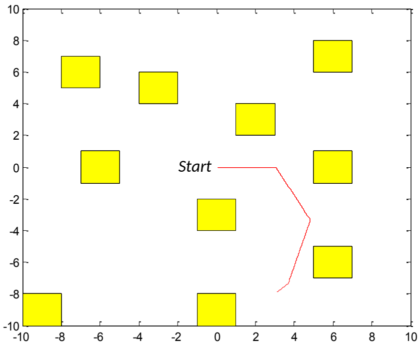


(b)

Figure 8 3D Frame of Robot in Position 1 with its 2D path.



(a)



(b)

Figure 9 3D Frame of Robot in Position 2 with its 2D path.

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 green circle. The final robot path is illustrated in 13(b). As it can be seen from the presented results, the proposed type-2 fuzzy controller is able to generate the appropriate control action for obstacle avoidance task. The robot moves freely and autonomously without collisions. This navigation system is effective to accomplish this task with good performances. Figures 14 a−b−c give the variation of right-left flow values, the difference between them as errors and the time-to-Contact (TTC) respectively. For each graph, as example, the moment of obstacle avoidance is indicated in dashed lines (turn left or right).

5 CONCLUSION

In this paper, hybrid type-2 fuzzy logic visual obstacle avoidance controller is proposed for mobile robot. The proposed navigator is a Takagi-Sugeno type-2 Fuzzy logic controller combined with Horn-Schunck algorithm of the

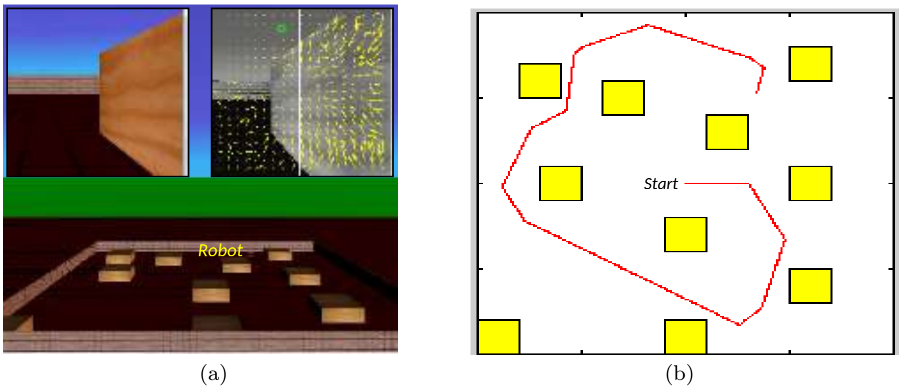


FIGURE 10 3D Frame of Robot in Position 3 with its 2D path.

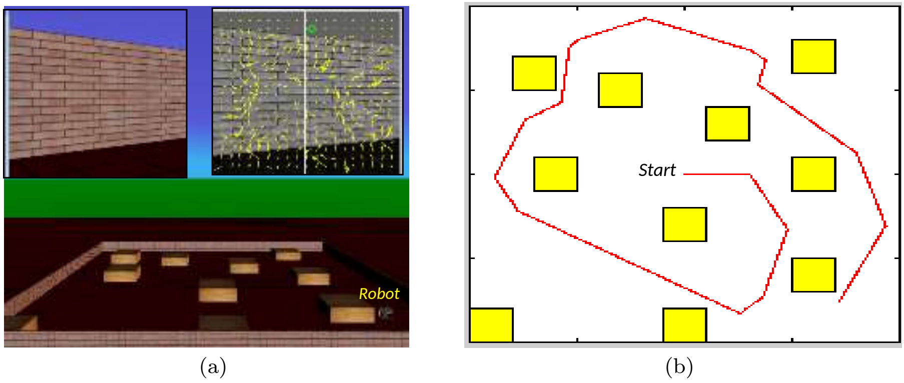


FIGURE 11 3D Frame of Robot in Position 4 with its 2D path.

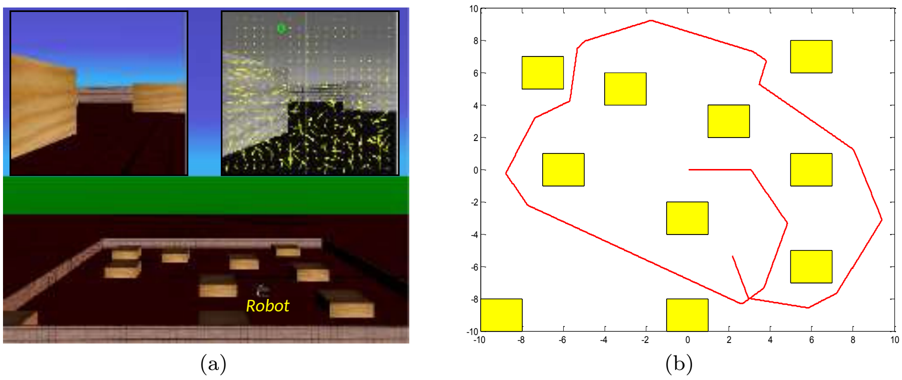
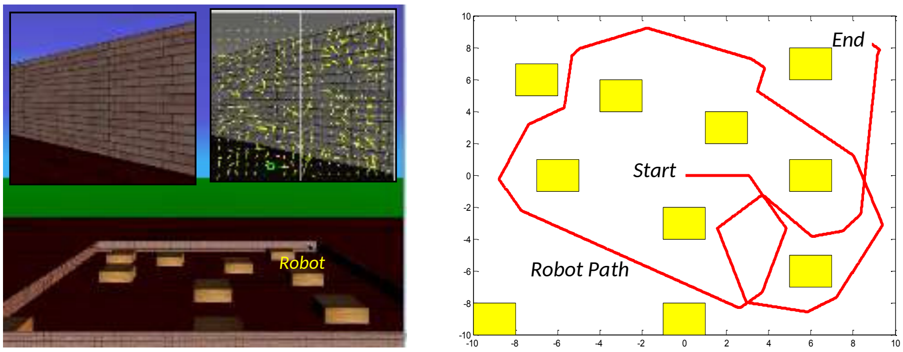


FIGURE 12 3D Frame of Robot in Position 5 with its 2D path.

optical flow method. The acquired image is divided in two parts (right and left) and treated in order to generate the correct control action to steer the robot around the nearest obstacles autonomously. Simulation is done in 2D



(a) (b)

FIGURE 13 Final Obtained 2D Robot Path.

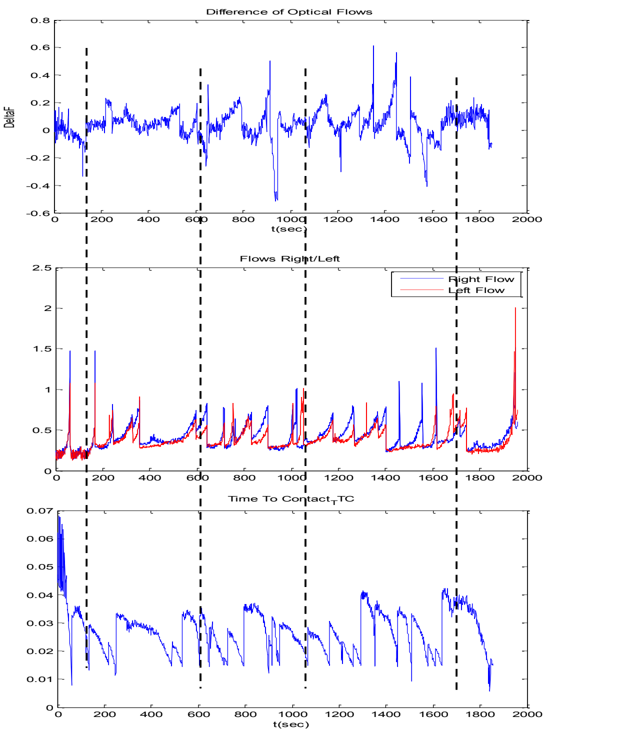


FIGURE 14 Right and Left Flows, Error and Time To Contact

and 3D environment using a VRML library. The obtained simulation results demonstrate the efficiency of the proposed control strategy based type-2 FLC for mobile robot navigation and obstacle avoidance. We will propose nextly, the application of Lukas-Kanade algorithm with type-2 FLC, and the development of other robot sub-tasks as pursuing a moving target, avoiding moving obstacles.

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