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FUZZY LOGIC CONTROL AND HMI INTERFACES OF AN INTELLIGENT WHEELCHAIR SYSTEM

Mohamed Slim Masmoudi, Imen Klabi, Mohamed Masmoudi

METS Research Group National Engineers School of Sfax, Tunisia
med_slim_mas@yahoo.fr, Klabi_imen@yahoo.com, mohamed.masmoudi@enis.rnu.tn

ABSTRACT

In this paper an obstacle avoidance system and a Fuzzy Logic Controller (FLC), together with a distributed system of embedded microcontrollers, are presented. The Fuzzy logic algorithm is a powerful solution among Soft computing techniques, which deals with certain control problems especially when the situation is undefined and ambiguous. One of the main problems faced by conventional control systems is the inability to operate when information is incomplete and imprecise. As the complexity of the system increases, a traditional mathematical model will be difficult to implement. The paper detailed the FLC algorithm controlling the Wheelchair system. The controller enables the wheelchair movement by avoiding and encountered obstacles. The wheelchair can make brake in dangerous environment by the infrared and ultrasonic sensors. We focus the study on non conventional control algorithm implemented using a PC interfaced with an embedded microcontroller platform. Voice and face recognition algorithm have been also tested on the system to facilitate the control of the wheelchair for disabled person. Simulation and experimental results are carried out on a wheelchair platform.

Index Terms— FLC; Path following; obstacle avoidance; voice recognition; face tracking; Wheelchair; embedded microcontrollers; Simulation; disabled person.

1. INTRODUCTION

Wheelchairs are medical devices. For many disabled person these devices are essential to their mobility, social and professional life. In case of long path the wheelchair control task requires training and a certain concentration. In case of

severe disable mobility, wheelchair control seems very difficult and sometimes even impossible task. These kinds of patients are not able to use standard wheelchair which needs muscular strength to move the wheelchair. At the same time, they can't use the electrically powered wheelchair which is controlled by joystick. Therefore, many researchers have been interested to improve the control of the wheelchair either by implementing advanced soft computing algorithm or adding a new HMI interfaces.

Many research literatures used soft computer algorithm to control wheelchair system in academic field as well as in the industrial area.

Tyagi et al. designed and implemented a Fuzzy logic smart wheelchair system using a finger tip control for guiding the process. Ultrasonic Sensors have been used to avoid obstacle [1].

Seki et al. used fuzzy controller to drive an electric wheelchair on disturbance roads. The designed fuzzy controller is expected to be widely used as a mobility support system for elderly or disabled people. The algorithm has been implemented on a high-performance CPUs [2].

Songmin et al. developed a fuzzy control method of smart tennis wheelchair based on seat pressure sensors and omnidirectional wheels. The wheelchair could be controlled in manual with joystick device or in automatic mode [3].

Various interfaces to get the user's intension by voice, breath, eyes movement, head movement, feet, brain signals, and touch screen are proposed.

Akira Sasou (2009), proposed a method of acoustic head orientation estimation (AHOE) using a microphone array mounted on a wheelchair, and apply it to a novel interface for controlling a powered wheelchair [4].

Akira Murai et al. (2009), proposed a new functional voice activated wheelchair. Also, he proposed the collision

avoidance function CAF to prevent the wheelchair to take incorrect movement by false recognition.

The system is based on a commercial electronic wheelchair, it equips two ultrasonic sensors and eight infrared sensors, grammar based voice recognition system and laptop with seven Peripheral Interface Controller (PIC). So the complexity and cost of this system will be high [5][6].

Youhong Zhu (2011), proposed a novel intelligent wheelchair control method by simple voice commands. This method includes a health diagnosis function to find the disease paroxysm of users, to distinguish psychological and physical state, and to avoid abnormal operation risk by disease and emotion [7].

Berjón R. et al. (2011), proposed a new Human-Machine Interface (HMI) systems which controls the movement of a powered chair, by using a RGB camera attached to a laptop to track the face's movements of the person sitting on the wheelchair [8].

Rini Akmeiliawati et al. (2011), replaced the popular joystick controlled wheelchair with a hand-glove control system for easier maneuvering by bending the fingers. This method is not useful for the patient who has amputee or paralyzed arm [9].

The presented work is innovative in the sense, it uses different methods to control the wheelchair by voice, face tracking and path following computed with obstacle avoidance using ultrasonic sensors and fuzzy logic control. This application is an HMI system that aims those severe disabled people who have amputee or paralyzed arm, and tries to help them and make them as independent as possible. This paper is organized into six sections. In section 2 the model of the robot and its equipments are presented. In section 3 the path following fuzzy control and obstacle avoidance are described. Also, it contains the results of the simulation and experimental tests. Section 4 describes the voice recognition module. In section 5 the behavior of the head tracking system to control the wheelchair is described. Conclusion is summarized in Section 6.

2. KINEMATIC MODEL OF THE WHEELCHAIR SYSTEM:

The wheelchair is a vehicle based on two independent coaxial drive wheels to each other. They are mounted on the left rear and right rear sides. In addition to two front idlers to ensure static stability, as shown on the schematic model (Figure 1). It is therefore uni-cycle or differential platform [10].

The modeling assumptions are:

- Contact wheel / ground point.
- The wheels are dimensionally stable, of radius r .

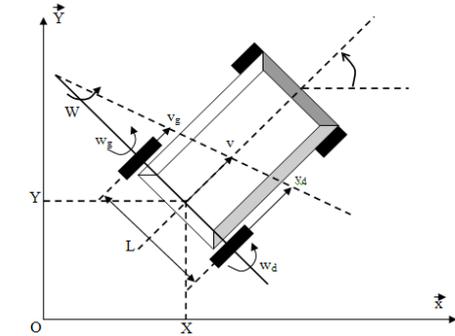


Figure 1. The schematic model of a wheelchair

The kinematic model is given by:

$$\begin{cases} \frac{dX}{dt} = \frac{V_g + V_d}{2} * \cos \theta \\ \frac{dY}{dt} = \frac{V_g + V_d}{2} * \sin \theta \\ \frac{d\theta}{dt} = \frac{(V_d - V_g)}{L} \end{cases} \quad (1)$$

Where,

- L : is the distance between the tow back drive wheels
- V_g, V_d : are the wheelchair's left and right wheel's velocities, respectively.
- r : is the radius of the drive wheel.
- V : is the average of the two velocities $V_d = r \times w_d$ et $V_g = r \times w_g$
- θ : is the angle between the wheelchair's direction and the X-axis.
- w_g and w_d are the wheelchair's left and right wheel's velocities, respectively.

By discretization of the system (1), it becomes:

$$\begin{cases} X_{k+1} = X_k + \frac{V_{gk} + V_{dk}}{2} * \cos \theta_k * T \\ Y_{k+1} = Y_k + \frac{V_{gk} + V_{dk}}{2} * \sin \theta_k * T \\ \theta_{k+1} = \theta_k + \frac{(V_{dk} - V_{gk})}{L} * T \end{cases} \quad (2)$$

Where,

X_{k+1} and Y_{k+1} represents the position of the center axis of the wheelchair; T is the sampling time.

3. AUTOMATIC NAVIGATION OF THE WHEELCHAIR

In order to ensure the robot autonomy during its navigation in different paths, we have to specify the coordinates of the initial position (x_0, y_0) and the desired position in the path. These two parameters are used to generate the whole point of the path that the wheelchair must follow to achieve its objective.

The distance between the robot and a desired point in the path (d) and the angle between the orientation of the robot and the target (φ) are the input parameters of the Path Following Controller (PFC).

Against, the distance between the robot and an obstacle measured by the ultrasonic sensors SRF08 are the inputs parameters of the Obstacle Avoidance Controller (OAC).

Both controllers produce outputs robot's right and left wheel's velocities (V_d, V_g) . In fact, one controller must operate at a given time, and this via a switch for switching from one controller to another depending on whether the obstacle is very close (OAC) or away (PFC). These velocities will be sent to the robot, and it is from its actual speed and model we can calculate its position (x, y) which will be used again to calculate the trajectory, as shown on the following figure (figure 2).

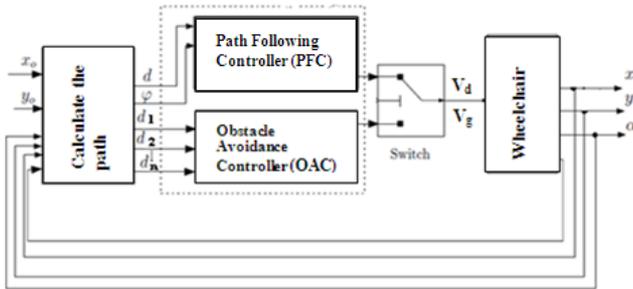


Figure 2. The schematic illustration of the wheelchair automatic navigation

3.1. Path Following Controller (PFC)

To allow the chair to achieve a target point in the path from a given position, we have used Fuzzy logic algorithm that present a powerful solution among Soft computing techniques. The chair position is calculated in real time by the encoders. The fuzzy Controller outputs are the speeds $(V_g$ and $V_d)$ that will be applied respectively to the left and right wheelchair in order to orient it to reach a desired position.

In order to ensure the robot autonomy during its navigation in different paths, we have to generate the robot polar coordinates.

Figure 3 described the polar coordinates between the robot and a desired point in the path.

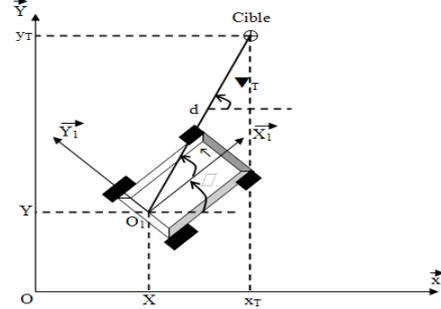


Figure 3. Robot polar coordinates

The fuzzy controller has as inputs the polar coordinates of the target point calculated relative to a reference related to the chair. The actual output variables of the fuzzy controller are the reference values for the speed V_g, V_d of each drive wheel, as shown on the figure 4. The terms of the input variables is given by the following equations:

$$d = \sqrt{(x_T - x)^2 + (y_T - y)^2}$$

$$\varphi = \arctan\left(\frac{y_T - y}{x_T - x}\right) \quad (3)$$

Where,

(x, y) : wheelchair position

(x_T, y_T) : target position

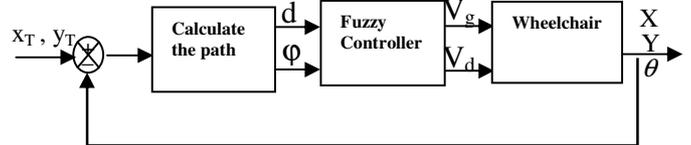


Figure 4. Block diagram of the path control loop

Table 1. Rule base for the Fuzzy controller

		Angle (φ)													
		NG		NM		NP		Z		PP		PM		PG	
		V_g	V_d	V_g	V_d	V_g	V_d	V_g	V_d	V_g	V_d	V_g	V_d	V_g	V_d
Distance (d)	TP	G	F	M	F	F	Z	Z	Z	Z	F	F	M	F	G
	P	TG	M	G	F	M	F	F	F	F	M	F	G	M	TG
	M	TG	G	TG	M	G	F	M	M	F	G	M	TG	G	TG
	G	TG	G	TG	G	TG	M	G	G	M	TG	G	TG	G	TG
	TG	TG	G	TG	G	TG	G	TG	TG	G	TG	G	TG	G	TG

By defining five membership functions TP, P, M, G and TG for the variables d and seven membership functions NG, NM, NP, Z, PP, PM and PG for the variable φ , it is easy to define a set of linguistic rules to describe the desired behavior of the fuzzy controller.

The entire “rule base” describing the fuzzy controller is presented in Table 1. Each cell of table 1 contains a logic sentence.

To simulate the path following of the wheelchair, our fuzzy controller must be programmed under Matlab. The first step is to insert the fuzzy rules in the toolbox of Matlab by using the command “fuzzy”. The membership functions used to encode the angular error input, distance error input and velocity outputs of the FLC module are respectively shown in the following figure 5, figure 6 and figure 7.

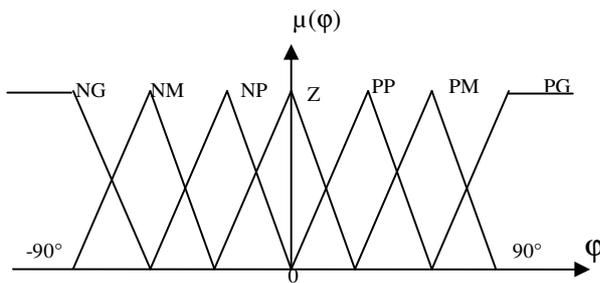


Figure 5. Angular error input

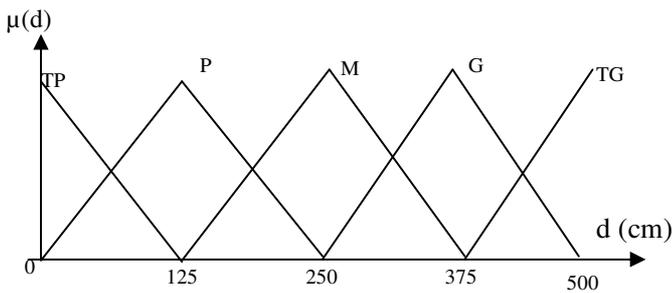


Figure 6. Distance error input

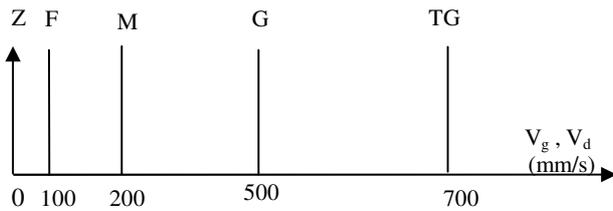


Figure 7. velocity outputs

3.1.1. Simulation results

The simulation tests are validated using Matlab software. The purpose of the first simulation (figure 8) is to show the application of path following fuzzy algorithm in the wheelchair.

We have choose $x_T = 300$ and $y_T = 3000$, the position of the target point in the path.

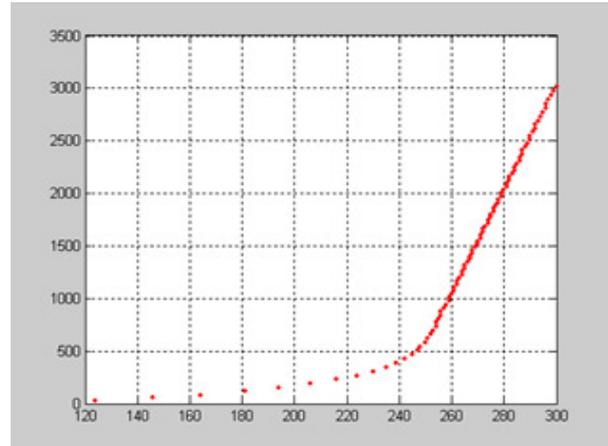


Figure 8. Path following of the wheelchair without obstacle

Figure 8 showed that the robot reached the desired target. In the second simulation, we will introduce an obstacle in the path of the chair.

The wheelchair will move from the point (0,0) to the point (1200,2000). The beginning of the obstacle is (100,100), as shown on the following figure (figure 9).

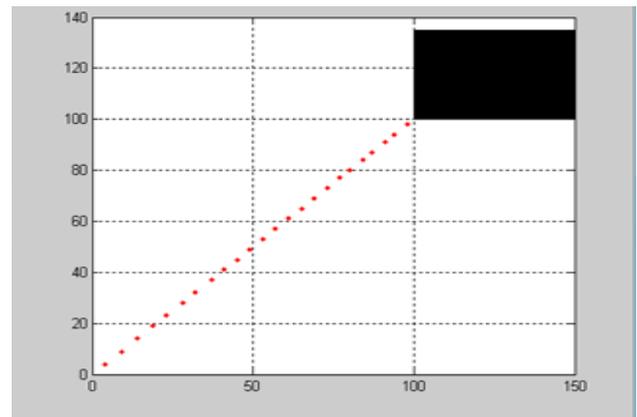


Figure 9. Path following of the wheelchair with obstacle

Figure 9 showed that the wheelchair can't reach the desired target (1200,2000) because of the obstacle. So we need to introduce an intelligent obstacle avoidance system.

3.2. Obstacle Avoidance Controller (OAC)

In the first time, we have implement an obstacle avoidance algorithm under Matlab in order to show the effectiveness of the computation between the path following and the obstacle avoidance. The trial showed the success of the adopted strategy, as shown on the following figure (figure 10).

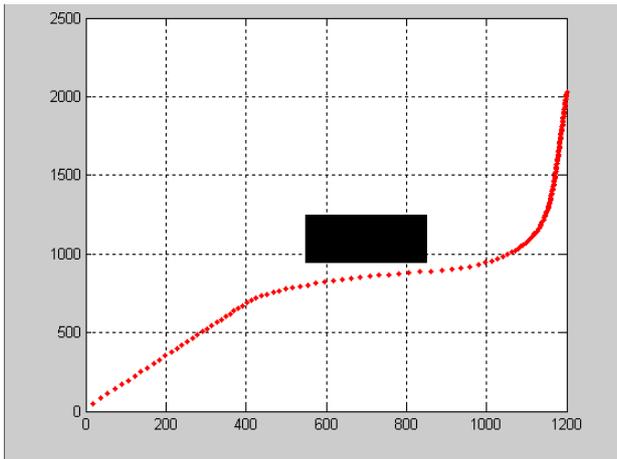


Figure 10. Path following and obstacle avoidance

3.2.1. Obstacle Avoidance with ultrasonic sensors

The obstacle detection is done by SRF08 ultrasonic sensors. The SRF08 sensor detects objects by emitting a short ultrasonic wave (40 kHz) and receiving the reflected echo. It is characterized by a wide range of detection (about 45 °). The wheelchair used in this experiment have four SRF08 ultrasonic sensors (D1, D2, D3 and D4) located on the front panel of the wheelchair, as shown in figure 11, for the most efficient reading distances.



Figure 11. Four SRF ultrasonic position sensors on the wheelchair

The sensors D1, D2 are intended for detecting the obstacle is in front right and front left. We set the limit (100 cm) to trigger the obstacle avoidance controller.

In this case if $(D3 > D4 < 50)$, the chair will deviate to the right, if the distance $(D4 > D3 < 50)$ the chair will turn left, as shown in the chart (figure 12).

When the obstacle avoidance was made the chair gets its way until it reaches its goal.

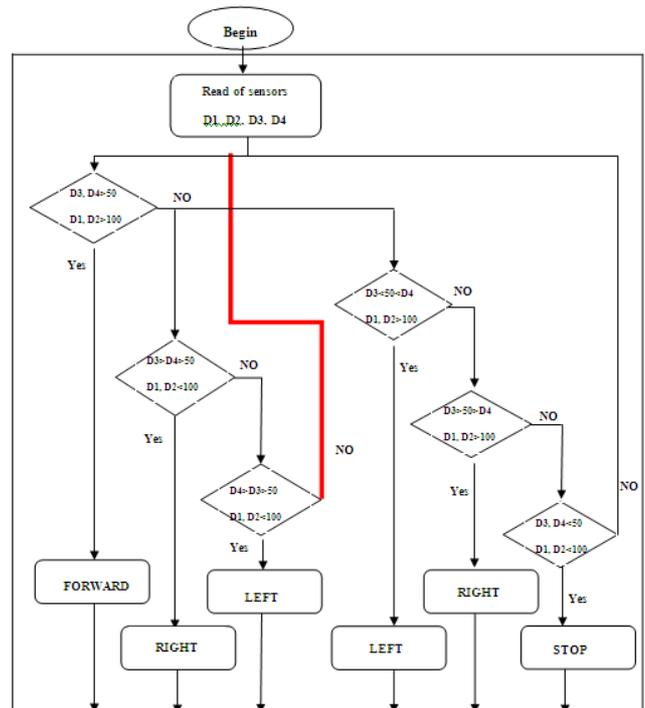


Figure 12. Obstacle avoidance chart with SRF sensors

3.2.2. Experimental Results

The different equipments used in this application are shown in the figure 13.

The Command card presents the receiving part of the commands sent by the fuzzy controller. This card is composed of a PIC16F877 a microcontroller with 33 I/O lines covers all the requisites for this wheelchair.

The main function of this unit is to receive the data from the ultrasonic sensors SRF08 on the I2C bus and sends it via a serial connection RS232 in order to determine the right command to be given to the driver circuit.

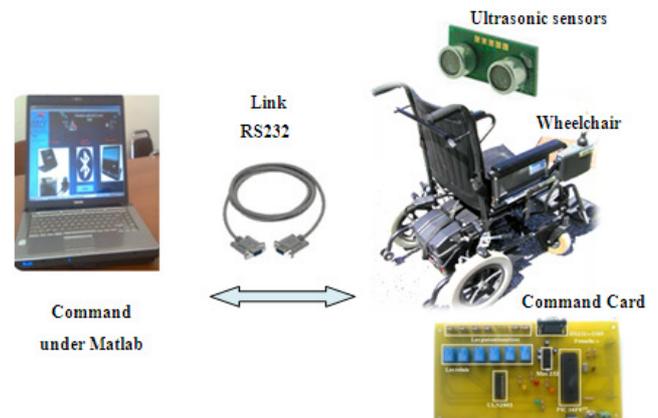


Figure 13. Synoptic diagram of the project

The obstacle avoidance method computed with path following is finally implemented on the wheelchair. During this course (step 1 to step 6) showed in the figure 14, we noticed that the wheelchair avoid the obstacle.



Figure 14. Real avoidance of a Wall

4. VOICE RECOGNITION

Windows 7 computer is used to get the voice translated into commands. This way use the library “Microsoft Speech Object Library.dll”, bundled inside Windows 7. It allows us to continuously get audio from a microphone and translate that audio into plain text readable by a machine, without any need to send the audio to any server. This way is faster because the audio stream is converted locally, and not in a server. And when we are talking about a wheelchair, and that someone could get harmed, quickness becomes a critical factor.

Table 2. show the list of commands that the system can understand, and the corresponding action.

Table 2. Voice commands and corresponding action

Command	Action description
Avant	Makes the chair go forward
Arrière	Makes the chair go backward
Gauche	Makes the chair move left
Droite	Makes the chair move right
Stop	Makes the chair stop moving

To enable the voice command of the electric wheelchair, you need to validate two main parts: a hardware part and a software part. The hardware bloc manage the serial connection between the wheelchair and the PC. The software part is composed of three main parts: configuration, programming and creating a GUI (Figure 15).



Figure 15. The voice recognition developed GUI

5. FACE MOVEMENT TRACKING

We manage to move the chair by tracking the face’s movements of the person sitting on the wheelchair. To track objects, like faces, with a camera, Haar-like features [11] suit our purposes.

Haar-like features take a detection window (an area of an image) and consider adjacent rectangular regions; it sums all of the pixel intensities in these regions and calculates the difference between them. This difference is used to categorize subsections of an image.

In our system we use Haar-like features supplied by the Open Source Computer vision Libraries created by Inel [12].

With Haar-like features we detect the position of the face at a specific time, and the changes of the position of that face inside the entire image (figure16). The algorithm that permits to track the face movement in order to commanding the wheelchair is shown on the following figure (figure 17).

The detection step can decide only the existence or not of a face in an image. To detect a face, it is necessary to follow the following steps:

- Configuration of the serial link.
- Check the image
- Detection of facial contour (Figure 16)
- Capture of the nearest webcam face
- Run the algorithm for detecting facial movement (Figure 17)

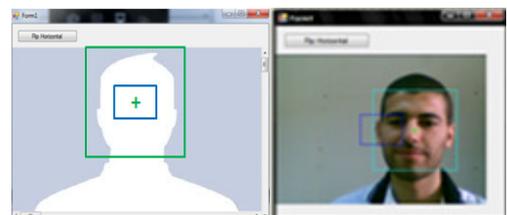


Figure 16. Face detection interface

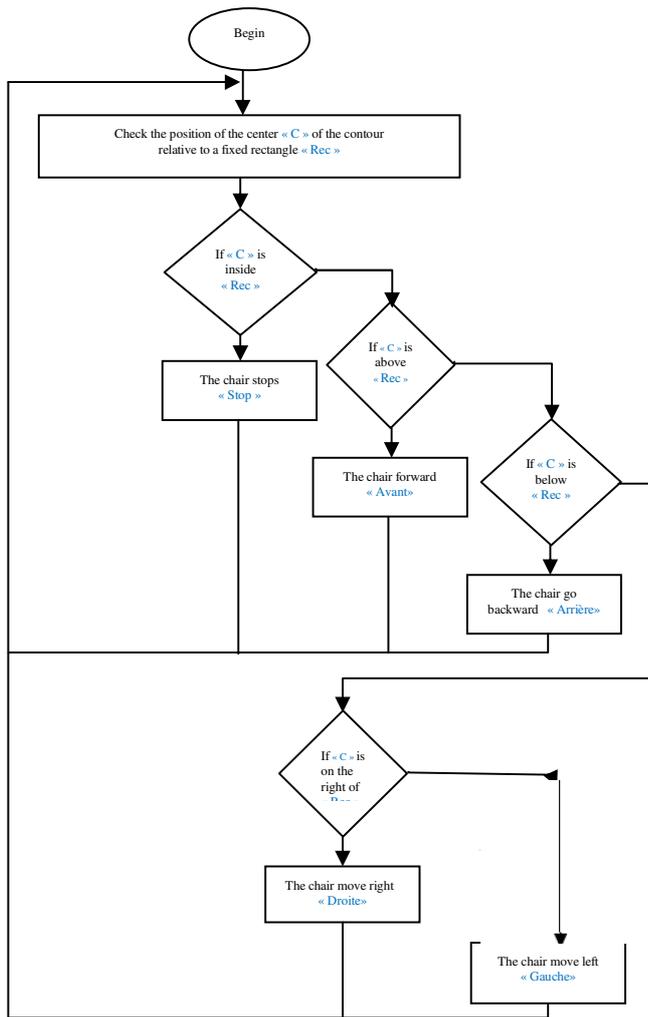


Figure 17. Flowchart for detecting facial movement

6. CONCLUSION

In this paper, an intelligent wheelchair with ultrasonic obstacle detection computed with path following fuzzy control, voice control system and face tracking is developed.

The results of the simulation and experimental tests in a real environment, showed the success of the FLC algorithm and the provided HMI interfaces for controlling the wheelchair.

This intelligent wheelchair can help the elderly or severe disabled people who have amputee or paralyzed arm to perform the complex operation.

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