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Implementation of Fuzzy Controller for Mobile Robot Navigation on NI's Embedded- FPGA Robotic Platform

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Abstract— Autonomous mobile robots in the field of modern automation technology have gained interest in the last decades. A navigation system of an autonomous mobile robot in a cluttered (with static or dynamic obstacle) environment is one of the interest areas. This paper presents Fuzzy logic controller based obstacle avoidance approach for National Instruments (NI)'s embedded robotic platform which to host the SBRIO (Single-board Reconfigurable Input-Output) that includes a powerful real-time controller, and a field programmable gate array (FPGA). The robot platform used here has an ultrasonic sensor located at the front of the robot and rotatable from -65 to 65 degrees. To construct the proposed system, it has used twelve (12) sensors information as input parameters. The design and software were implemented using LabVIEW modules. In order to provide better insight into the experiment's objectives, the proposed methods compared with the VFH algorithm. The experimental results verified in simulation modes which are simplicity and quicker reacting to sudden changes in sharp-edged shapes. It is cleared that the fuzzy logic approach was successfully applied to the DaNI mobile robot to navigate in the safest direction.

Keywords : *Mobile Robot, Obstacle Avoidance, DaNI, LabVIEW, Fuzzy Logic*

1.Introduction

The autonomous robot navigation system has been significant interest in the robotic research field. This system is used in land, underwater, and in the air for various missions such as search, rescue in disaster areas, and environmental mapping. These robots normally perform for sequences of procedure in unpredicted states or new situation with enable to control functions as a pre-programmed. There are several troubles that mobile robot able to encounter in unknown and unstructured environments [1]–[6]. The detection of an obstacle in motion environment based sensor fusion is the right method to handle the navigation strategy. Various algorithms have been established in literature for analysis to navigation problems incorporated with mobile robots including vision-based fuzzy logic[7][8][9][1], Artificial Potential Field[10][11], Genetic Algorithm[12][13], Neural Network[14], Type-2 Fuzzy Logic[15][4] and Vector Field Histogram[16],[2]. Fuzzy logic is known to be an effective tool in the management of situations caused by unclear situations such as uncertainties and sudden movement management in robot navigation. It is a well-known fact that the mobile robot is effective in gaining intelligent behavior for stable navigation by avoiding irregular movements. The number of input sensors is important in order to avoid the local minimum and high maneuverability. There are various studies that take in to account the three input sensor information for intelligence soft computing structure [3]. The fast and complexity of the real-time hardware implementation of intelligent robots have great importance. Many hardware advanced techniques directly affect the process of fast processing and complex calculations. Field Programmable Gate Array (FPGA) has become an important alternative in this progress. FPGA is proven by complex engineering applications that it is an effective tool for real-time hardware implementation [17], [18] [19]. The introduction of the SBRIO card developed by NI is seen as an important development in this regard. All the embedded devices required for reconfigurable FPGA, analog, digital input-output ports, and real-time operations are grouped together on this board [20] [21]. The NI-SBRIO-based platform offers a powerful graphical development solution for prototyping and designing embedded system engineering within the LabVIEW software. The NI platform has enabled the user to expand their hardware application as well as to design and implement the FPGA-based module [18], [22]–[27]. The objective of this paper is designed a fuzzy logic sensor fusion model, compare the controllers for optimum obstacle avoidance and evaluate the effectiveness of using sensor fusion model in order to achieve smoothness in the motion of DaNI mobile robot keeping a safe distance from the obstacle.

This paper is organized as follows. In section 2 we describe the methodology. In section 3, we handled the fuzzy logic controller approach and its implementation. The experimental simulation results and system implementation are presented in Section 4. Finally, the conclusion is summarized in section 5.

2. Methodology

LabVIEW Robot simulation model builder consists of Graphical User Interface to create environment, obstacle and robot module. The robot used in this environment is a differential drive DaNI mobile robot module [28]. The hardware component block diagram interface of this robot is shown in Figure 1. This robot has an ultrasonic sensor mounted on a servo motor and has a scanning capability of between 65 and -65 degrees from the front of the robot. The twelve ultrasonic sensors information were taken into account as controller inputs which are used for each scanning 12^0 angle, thus able to cover approximately 130^0 scan for obstacles. The ultrasonic sensor mounted on a servo motor in the front side of the mobile robot and its arrangement is shown in Figure 2. According to these sensors, the corresponding fuzzy control rules are activated. The outputs of activated fuzzy rules were used to control the speed of the robot's wheels.

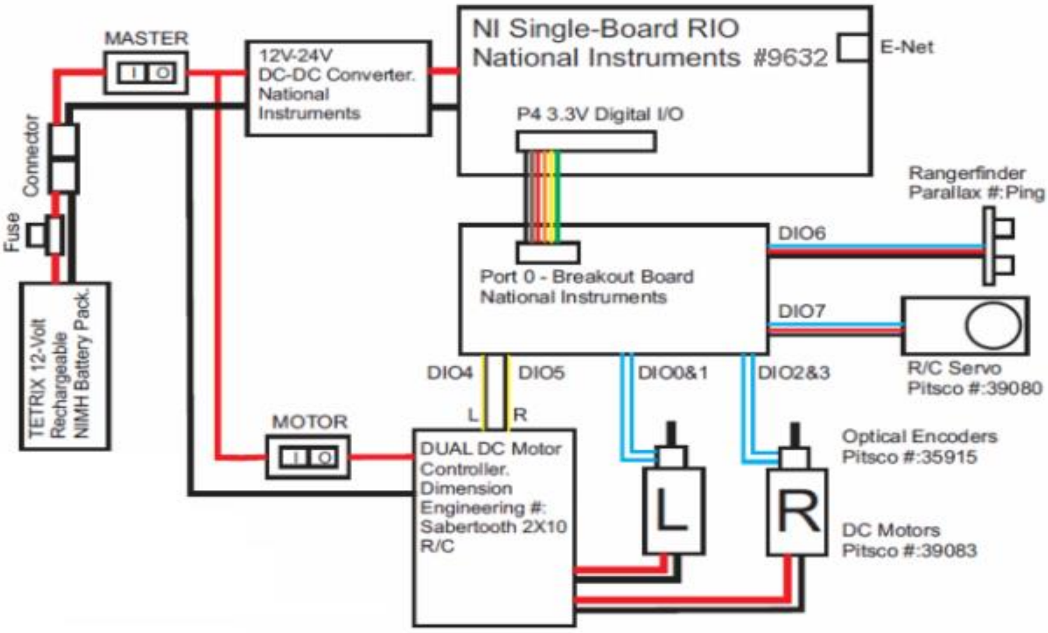

Figure 1. DaNI 2.0 Hardware Component Block Diagram

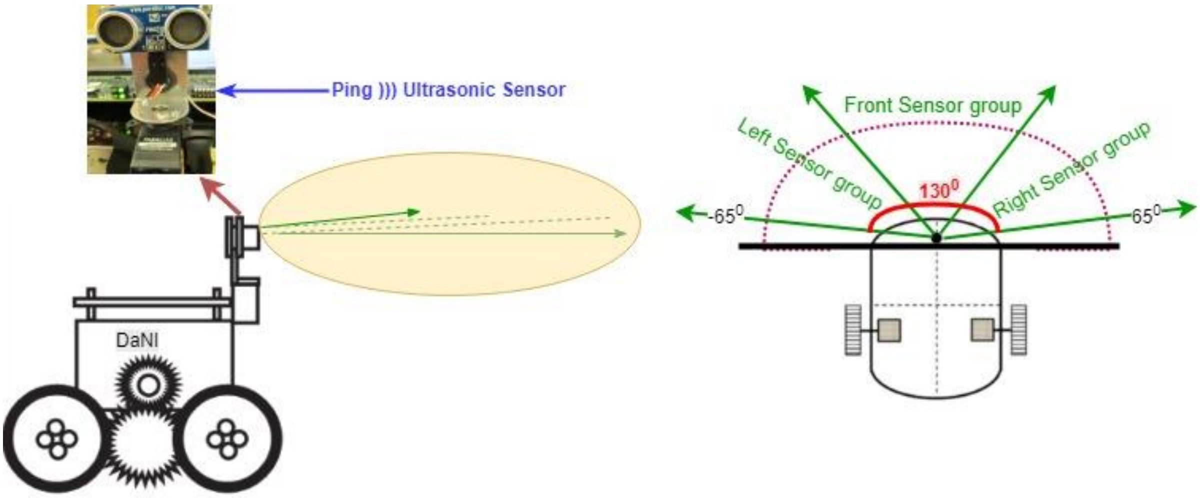

Figure 2. Ultrasonic sensor arrangement

3. Fuzzy Control

The design and theoretical basis of the fuzzy model for the mobile robot navigation and obstacle avoidance have presented in this section. This is intended to provide the basic concepts needed to understand the algorithm inputs corresponding outputs with rule base determination. Fuzzy logic includes a Fuzzifier, rule base, fuzzy inference engine, and defuzzifier processor.

3.1. Fuzzifier

The inputs of the fuzzy set converts into suitable linguistic variables. These variables are distances between the robot and obstacles with relevance to the left, right and front sensors described by d_l, d_r and d_f. The Fuzzifier is called linguistic definitions that are appropriate for determining the functions of the input variables. Each fuzzy set takes values ranging from 0 to 1, which represent the degree of belonging of the fuzzy cluster. In this experiments we consider 3 inputs linguistic values as inputs corresponding to the obstacle distance start at -65 degrees up to +65 degrees' angles which is rotates continuously and senses the distances from obstacle on left (d1, d2, d3, d4), front (d5, d6, d7, d8) and right (d9, d10 d11, d12) sides. The velocity of the left and right wheels are calculated after the application of fuzzy rules and defuzzification. Figure 3 illustrated the block diagram of the controller architecture.

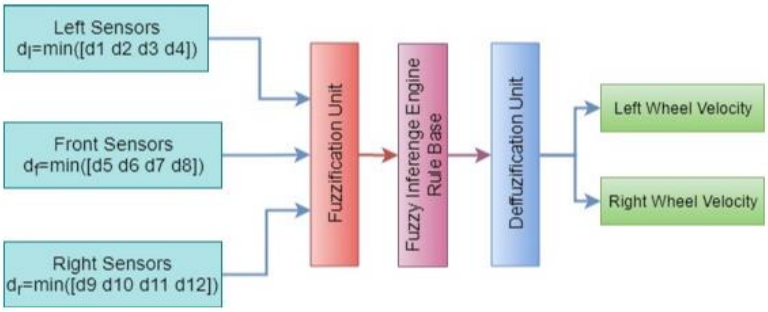

Figure 3. Controller architecture (d1, d2, …, d12 these are distance sensors)

To decrease the complexity of the fuzzy logic controller (fuzzy rule base and inputs), all twelve ultrasonic sensors together was not used. Therefore, the nearest distances to the obstacle taken in to account. This is expressed by the following equations.

$$Left(d_l) = \min([d_1, d_2, d_3, d_4\ ]) \quad (1)$$
$$Front(d_f) = \min([d_5, d_6, d_7, d_8\ ]) \quad (2)$$
$$Right(d_r) = \min([d_9, d_{10}, d_{11}, d_{12}\ ]) \quad (3)$$

In order to ensure that the mobile robot reacts effectively to the unknown environment in real time, the control algorithm must be based on the design of the fast response philosophy. With this in mind, fuzzy logic controller data were combined to simplify the controller and information from the sensor closest to the obstacle was addressed. These inputs and outputs are fuzzified using the arbitrarily selected membership functions given in Figure 4.

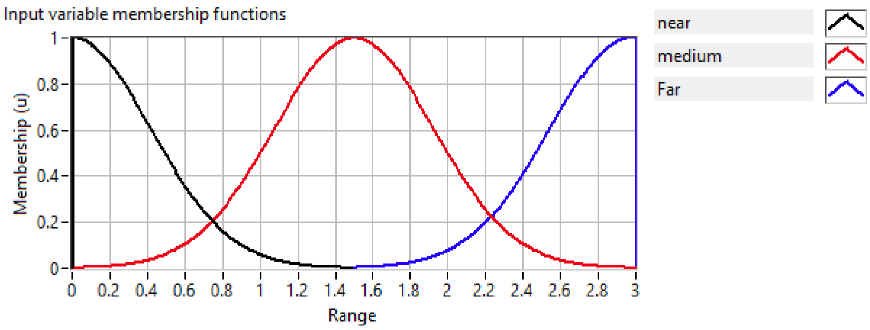

Figure 4. Membership functions of obstacle distance (d_l, d_f, d_r)

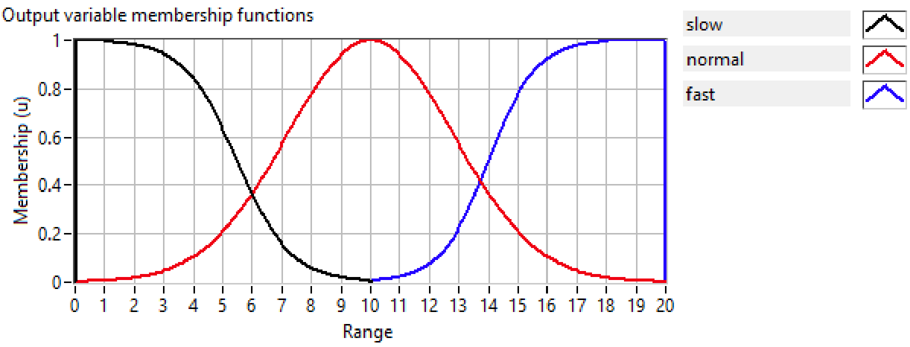

Figure 6. Membership function of wheel velocity

3.2. Fuzzy Inference Engine

The inference engine combines rules and gives a mapping from input to output fuzzy sets. It is necessary to compute the intersection and union of fuzzy sets and implements compositions of fuzzy relations. The desired behavior defined by a set of linguistic rules. It is necessary to set the rules adequately for the desired result. For instance, a fuzzy logic with p inputs (inputs ($x_1 \in X_1$, ... $x_p \in X_p$) and one output (y ∈ Y) with M rules have the following form.

$$R^\ell\text{: IF } x_1 \text{ is } \tilde{F}_1^\ell \text{ ...and } x_p \text{ is } \tilde{F}_p^\ell \text{ THEN } y \text{ is } \tilde{G}^\ell ,\ \ell = 1 \dots M$$

The knowledge bases for each controller consists of 27 rules related to the robot wheel velocity. The input/output relationship fuzzy rules are demonstrated in Figure 7.

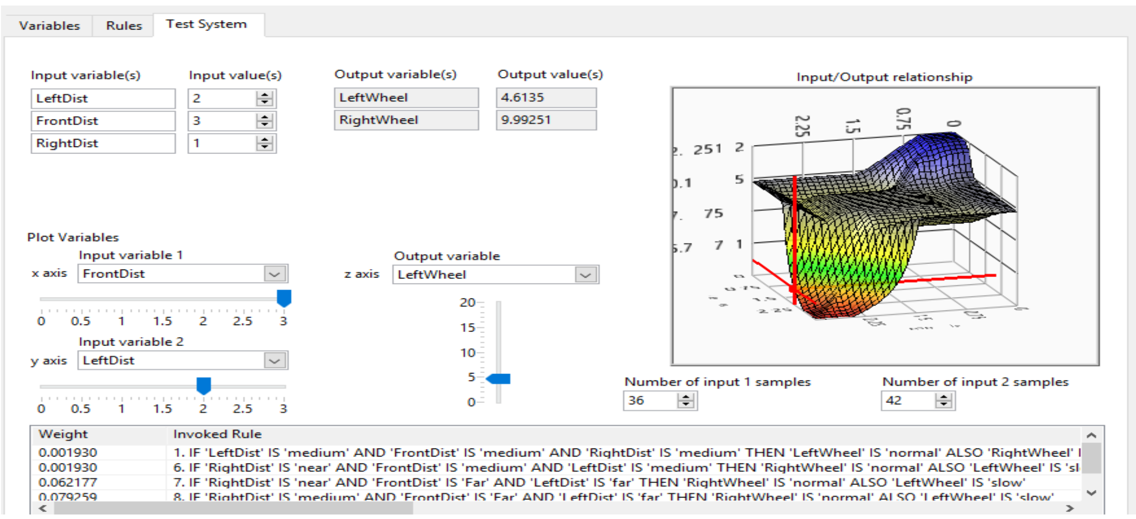

Figure 7. Fuzzy rules defined for proposed method and the weights of the invoked rules.

3.3. Defuzzification

The converting a fuzzified output into a single crisp value with respect to a fuzzy set process is defined as defuzzification. Many defuzzification methods have been used. There are several common methods, such as Center of Sums, Center of gravity, Center of Area, Weighted Average, Maxima Methods and etc. We applied the Center of Sums method. It is one of the most popular methods for defuzzification because of easy implementation and giving good result.

4. Experimental Results

The main contribution of this work is to develop a Type-1 fuzzy logic controller based obstacle avoidance approach for National Instruments (NI)'s embedded robotic platform. Many experiments have been done to verify the algorithm and to ensure that the simulation is really applicable based on the experimental results obtained from a real map. We have shown that this algorithm can be easily implemented on a real robot for the purpose of obstacle avoidance. The overall algorithms are implemented and tested on a 2.40 GHz dual-core system with 16GB RAM by using LabVIEW. To fully test the behavior of the algorithm we used Figure 8 program block diagram. The graphical design developed in LabVIEW using various modules.

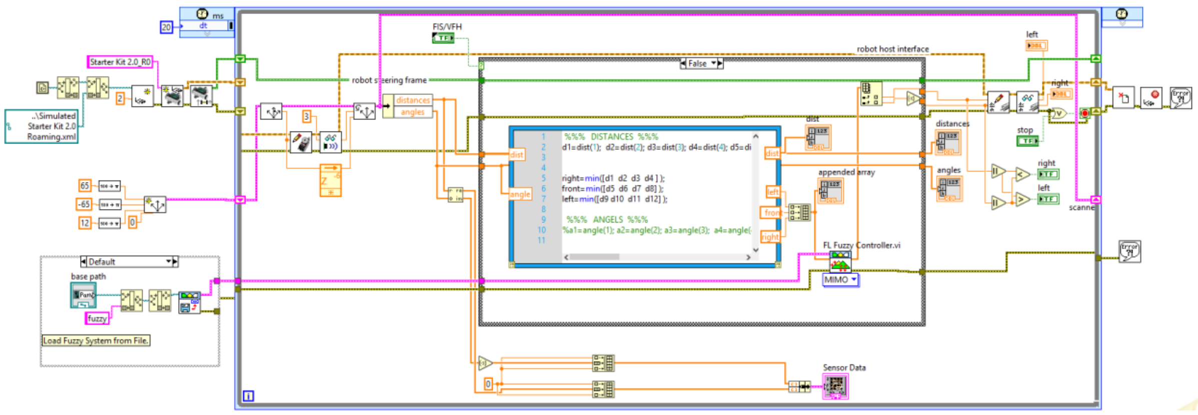

Figure 8. Graphical Design in LabVIEW for Fuzzy controllers.

The system has been tested under different variable maps; The main purpose of this test is to control the robot wheel velocity based on the ultrasonic sensor variable. Figure 9 shows the mobile robot (DaNI) wheel velocity. As seen in this graph, the velocities vary between 0 and 13. The right and the left wheel movements are influenced as forwarding movement. The generated robot wheels' velocity has shown from its initial position to destination point in this graph.

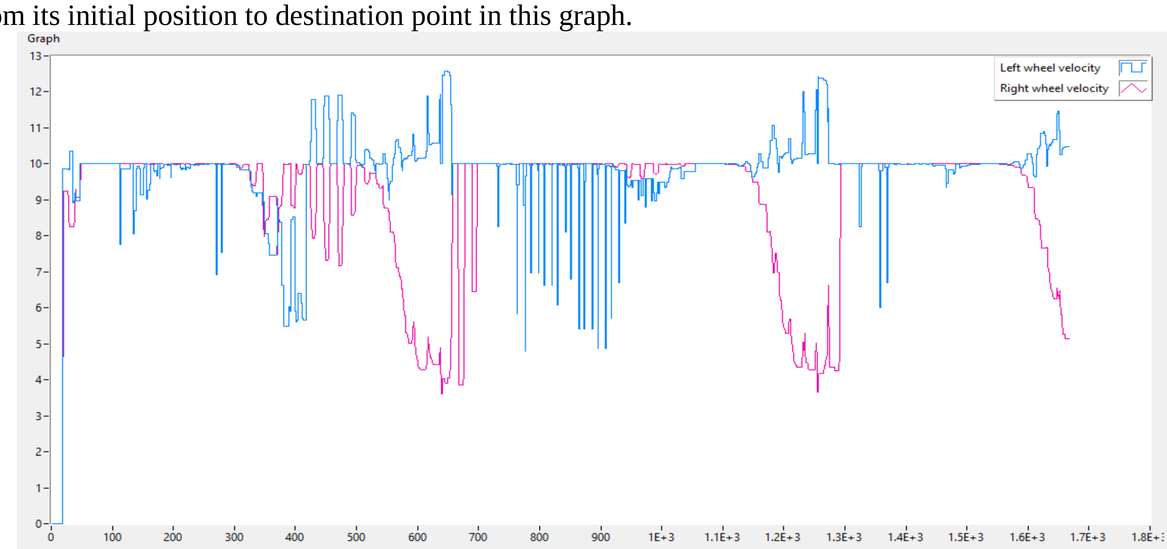

Figure 9. Graphical representation of the mobile robot wheels' velocity

The graph of the ultrasonic sensor data which is effective in the formation of the graphic above (see fig.9) is shown below (fig.10). The sensors' data obtained during the robot navigation in all direction (from d1 to d12) are shown graphically in Figure 10. The sensing distance of the ultrasonic sensor is 3 meters.

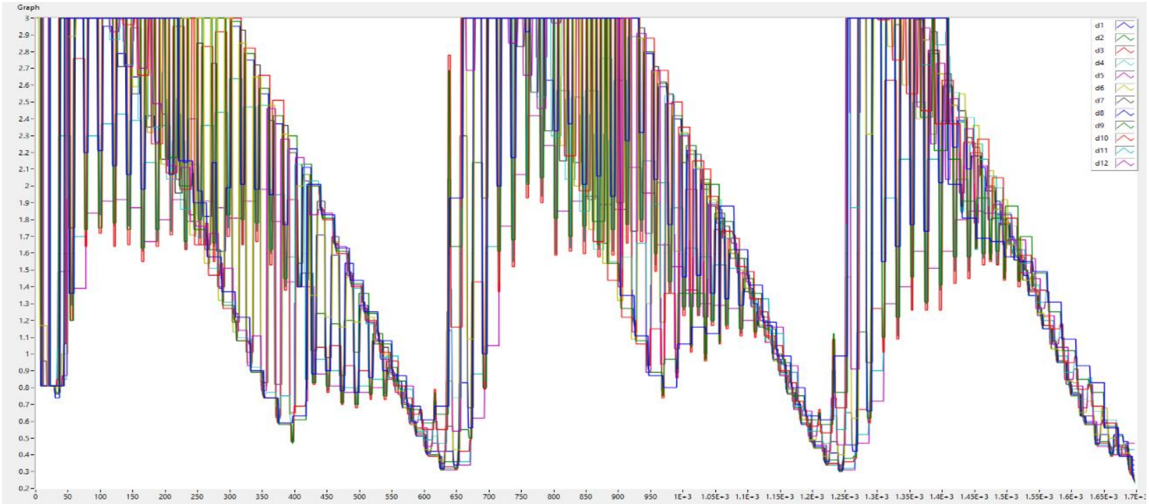

Figure 10. Ultrasonic sensor sensitivity in all direction (d1, d2, …, d12)

The processing time is very important in real-time applications and experimental studies. In this study, a large number of sensor data was used to obtain the obstacle avoidance behavior of the robot with smoother movements and design a robust control. These sensors are divided into three groups to reduce the complexity of the controller design. So that three sensor data is used as if control is designed. By using the sensor data which is closest to the obstacle, the minimum value of the sensors that are grouped in order to prevent the bump and provide smooth passage is used. It is observed that the robot's motion is easily oriented towards the destination point without collision. It's managed to overcome the obstacle of all the dimension and shapes that were on its way. The robot motion algorithm is quite convenient the data obtained during the navigation is shown graphically in Figure 11.

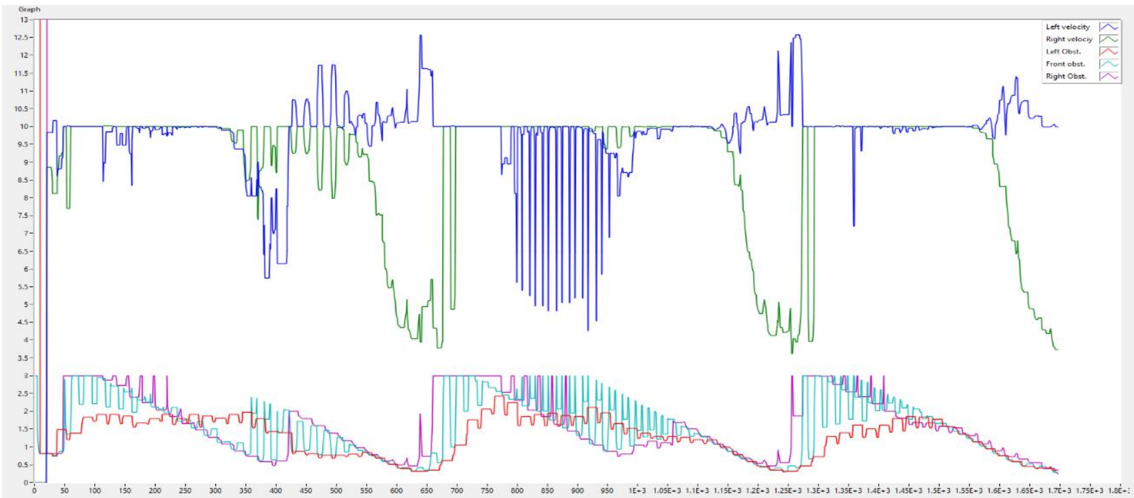

Figure 11. Graphical representation of control inputs (min distances in grouped sensor) and outputs (right and left wheel velocity)

From the simulation results, it is understood that the proposed method is suitable for mobile robot obstacle avoidance. The method is simple and gives good results than VFH. The proposed method is easier to be executed than VFH obstacle avoidance method. The VFH approach uses all the vectors in the range of -65 to 65 degrees of the obstacles in 2-degree steps. It then finds the largest gap from these values and moves the robot in the direction of the largest gap. The comparison of the proposed algorithm with VFH has shown that the robot is smoother and more stable using fuzzy control. Since the closest sensor data is used, the obstacle avoidance behavior is not executed suddenly. The fuzzy logic approach is understood to be an effective way of dealing with uncertainty by implementing simple linguistic logic rules without intensive mathematical models. The effectiveness of the proposed algorithm is proven by the simulation design approach where the robot achieves all the desired results.

5. Conclusion

This paper presents a Fuzzy logic controller based obstacle avoidance approach for National Instruments (NI)'s embedded robotic platform. In this platform, many static obstacles are located. The fuzzy controller enables the robot navigation in this static environment that should provide smoother motion and instant reaction to sudden changes. The robot platform used here is the DaNI mobile robot and has ultrasonic sensors that can be turned 130 degrees in front. Sensors that make a measurement at 12 degrees are used in robot instruction. The design and software were implemented using LabVIEW modules. In order to provide better insight into the experiment's objectives, the proposed methods compared with the VFH algorithm. It is observed that the VFH algorithm is not very accurate and sometimes the robot does not take into account the obstacles close to it to reach the largest gap. In this study, we tried to overcome this shortcoming. According to the VFH algorithm, it was observed that the fuzzy controller gave better results against such problems. With the fuzzy logic-based controller, it has been found that the robot has a more stable response to the smoother and sudden changes. The effectiveness of the proposed algorithm has been proven by the simulation design approach. It has shown that our proposed approach works successfully and that the outputs of the controllers enable a smoother and remarkably faster speed.

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