Fuzzy - Arduino Based Control Strategy for Human Safety in Industrial Robots

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***Abstract*— There are many industries which uses various industrial robots for their production tasks like painting, wielding etc. In the majority industries human and robots shares the same work environment which results chances of accidents between human and robots if robots are not equipped with proper protection. In this paper, a new method is proposed to avoid such collisions between human and robot in automation industries. Most of time while externally adding this safety feature in the industrial robots you have to change either its programming or internal structure. The industrial robots like ABB robots which are widely used in industrial environment don't accept such changes. So this paper uses proximity IR sensors which are applied on ABB's IRB1200 pick and place robot. A controller is demonstrated using fuzzy algorithm implemented in MATLAB Simulink and Ardiuno. Finally RAPID based program helps robot to take proper action based on controller output.**

Keywords— ABB IRB 1200 robot; human-robot collision; Infrared Proximity Sensors; Fuzzy-Arduino controller

I. Introduction

Industrial robots are considered as one of the most efficient way to perform tasks in industries like painting, welding, soldering etc. without human concern. These robots are known for their speed of work and better performance. There are many industries where human-robots share the same platform. It is very risky to allow robots and human work together because there will be chances of collision between human and robot. So to avoid such situation there various ways which are generally studied under the area of physical human robot interaction.

Generally [1] Industrial robots are fabricated for static environment. Most of the time while programming it is expected that work area is isolated from any physical intervenes generally from humans. So to make work area safe, it should be demarcated and need sensor based systems. In many cases robot speed is reduced to avoid the risk of collisions; that situation makes the system less accurate and non-cooperative.

Q. Kun, J. Niu, and H. Yang [2] presents real time human recognition system which can be implemented for human robot interaction. This approach consists of Kinect sensors which sense human gesture to operate industrial robots from distance.

A specially designed compliant wrist [3] is developed which supports human-robot interaction. They implemented proximity sensor based network which supports contact feedback. The designed compliant wrist structure allows arm to adapt the colliding surface. The object search algorithm locates external object and activates close proximity interaction. This maintains safe distance from object. For this operation a SISO fuzzy controller is designed to allow desired safe distance.

This sensor based approach[4] consists of three dimensional image sensors which creates volumetric evidence grid representation of workspace. This workspace is divided into background space of robot and humans. The space surrounded by robot is danger zone and neighbouring human having safety zones. Both zones are adaptive according to their respective movements. When robot and human approaches very closely, intersection of zones occurs and it stops slowdown until violation is cleared.

In this collision detection method[5] is reported which uses robotic sensors and provides directional information for safe robotic reaction after collision. In the hardware a rigid robot arm extended to the case of robots with elastic joints, proposing different reaction strategies.

This paper presents[6] safety methods for ABB industrial robots. Author designed proximity/contact- force sensor which consist of a couple of infrared Light Emitting Diode(LED) and Photo-Detector(PD) to detect both contact force and proximity sensing elements. The robotic tasks are developed in RAPID language which follows during execution. The sensors are interfaced with ABB robot using standard control unit. Robot reduces its speed as soon as obstacle is detected and stops when contact occurs which are detected by contact force sensing element.

P. A. Lasota presents[7] inherent human robot safe design capable of allowing human robot interactions at small distance of separation. In this paper, Motion caption system is used to identify recent position of the human with respect to end effector of the robot. So by leveraging robotic joint angles and real time measurement of human positioning, a precise robotic speed adjustment is achieved.

With the development of embedded system and communication technology, robot can be advanced in smaller platform and human to control from distance location. In this paper [8] mobile robot is monitored through live video streaming and controlled by web browser over Wi-Fi network. Here robot is considered as server and remote human operator as client. The paper discusses project of building the robot made by compact embedded system board(Mini2440), video streaming to remote client and internet based communication to transfer control signal. The Mini2440 board consist of PIC microcontroller board connect to system by UART interface. The outcome of this paper demonstrates that human can monitors robot remotely over the Wi-Fi network by scanning robotic environment and controlled from client side computer.

The majority of the work under human robot interaction is bringing robots and humans under same workspace and allowing them for close proximity interaction. But the development of framework describes without considering human response to these technologies. So in this paper [9] author conducted case study to investigate human response to robot adaptation at motion planning level by allowing human participants work co-operatively with robot in the shared workspace. A PhaseSpace motion capture system is used to track human motion within workspace and to capture the actions performed. Team efficiency evaluated by set of quantitative metrics and human responses like safety and comfort collected through questionnaires. From these set of experiments author concluded that response of the majority of the peoples well to the motion level robot adaptation and significant advantages can be achieved from terms of fluency and satisfaction.

The ideas which are presented above shows various methods to avoid human robot interactions but in most of the solutions they have suggested to modify the internal hardware and software of the industrial robot, or adding new costly technology or both which are not possible to implement. So this paper proposed cost effective method which doesn't modifies architecture of industrial robot. We are going to use proximity IR sensors which are applied on ABB's IRB1200 pick and place robot. The space around robot is divided into three zones; far zone, close zone and safe zone which are shown in figure 1. The closer zone is a region around robotic workspace while safe zone is region around close zone far from manipulator workspace. In normal condition robot performs their normal operations like pick and place, painting, welding etc within reachable workspace. It stops working when proximity sensor senses human stands in safe region, but when human approaches towards robot and appears in close zone, it starts moving backward to avoid collision. So to perform this controlling action (moving backward) proximity sensors are connected to some controller to take proper action according to proximity sensor output. The controller part demonstrated using fuzzy algorithm implemented in MATLAB Simulink and Arduino. Finally RAPID based program helps robot to take proper action based on controller output.

II. HARDWARE DESCRIPTION

ABB IRB1200 industrial robot consists of robotic manipulator intended for industrial tasks like welding, painting etc. The controller for the ABB IRB robot is IRC5, which is separate cabinet consists of Drive Module and Control Module[10]. Drive module consist of power electronics circuits and drive.

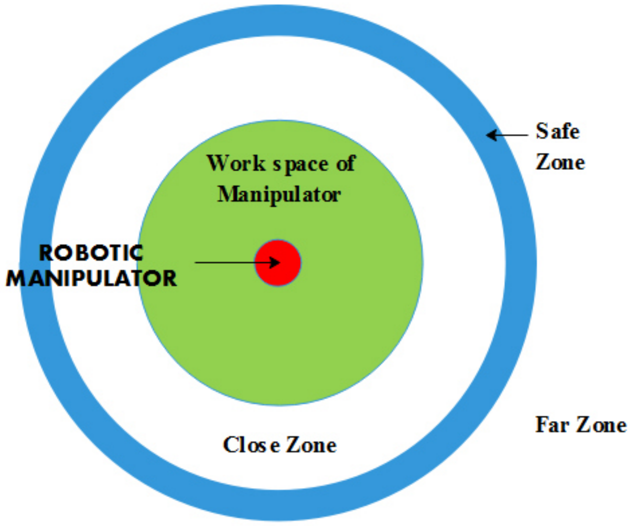

Figure1. Zone distribution around Robotic Manipulator (top view)

In case of Multi-Move system many drive modules will be used. Control module consists of central controller with electronic control a device which performs control of a robotic system. FlexPendant is handheld controller with touch screen, a joystick and eight buttons for robot control. Flexpendant has provision of manual programming and control. RobotStudio is a computer application which provides offline programming and simulation of robotic manipulator. IRC5 controller consists of I/O units where we can provide and take signal from external device. There are various types of I/O units which are categorised according to the nature of signals. When signals from proximity sensors is in analog form then DSQC 652 I/O unit used otherwise DSQC 651used for digital signals.

This paper describes a different type of strategy for controlling ABB's industrial robot. The close proximity interaction can be achieved by either fuzzy algorithm or Arduino based programming. The proximity sensors are applied on fixed reference frame to detect humans in the surroundings. The arrangement of proximity sensors on robotic arms are as shown in figure 3.

III. CONTROL STRATEGY

A. Design of Fuzzy Logic

The proximity sensor continuously sends signals to the controller to indicate position of the human with respect to end effector's reference frame. When human is very far (not reachable) from sensors it will send signal to fuzzy controller such that no action will be taken by controller. Whenever human enters in safe zone, according to the direction; sensor's output will increase which takes action to stop. As when human crosses safe zone and approaches closer to robotic end effective it will move backside. The fuzzy membership function for the above logic is shown in figure 6. The

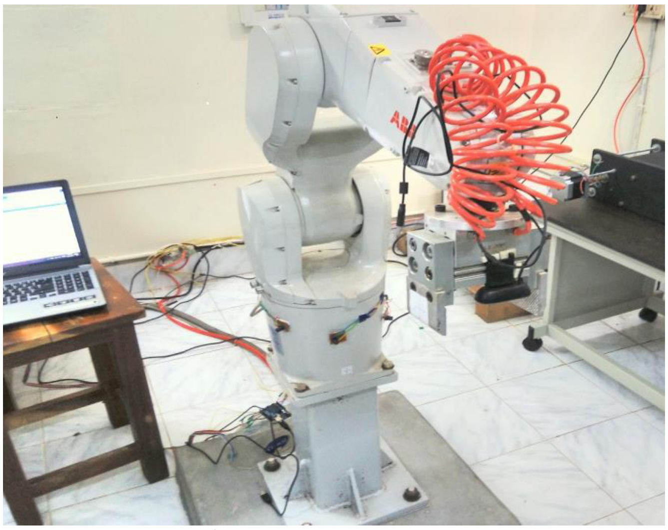

Figure 2. ABB IRB 1200 setup

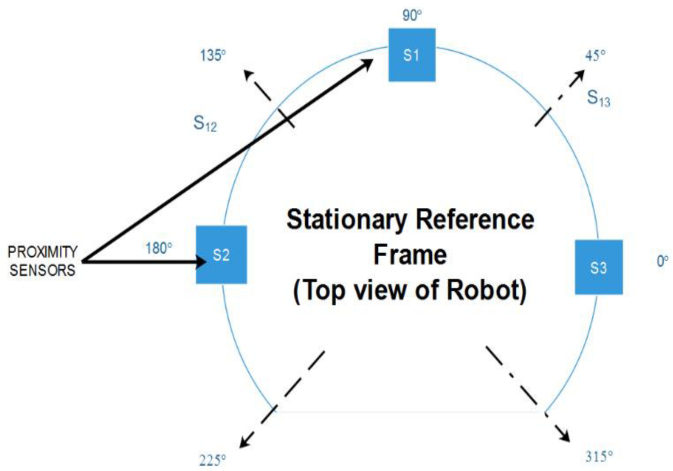

Figure 3. Sensor arrangement on robot(top view)

directions of the end effector of the robot are defined with respect to the end effector's reference frame and can be either -X, -Y, +X, +Y or any combinations of Table 1. For example, if human approaches closer to end effector from a direction such that sensor S_1 and S_3 senses then it will take control action such that it will move in the direction in between –Y and –X. This combination is forwarded to Fuzzy controller[3] designed in the MatLab Simulink.

In the above case the average output of two proximity sensors S_1 and S_3 is input the fuzzy controller(D_z) . The output fuzzy controller(M_d) is depends upon input and fuzzy inference rules. The input membership function is divided into three categories close, safe and far as shown in upper half figure while action taken by controller also divided into backward, stop and execute as shown in the figure.

$$\mathbf{D_Z} = \sum_{i=1}^{3} \boldsymbol{Si}\,/2 \qquad (1)$$

The centroid defuzzifier formula used to calculate output is

$$\mathbf{M_d} = \frac{\sum_{i=1}^{N} \mu\boldsymbol{i}.(\boldsymbol{ai}.\mathbf{Dz}+\boldsymbol{bi})}{\sum_{i}^{N} \mu\boldsymbol{i}} \qquad (2)$$

Where μ_i is output membership function a and b are design parameters varies according to user. The output of the fuzzy controller depends upon the distance between end effector and human. The fuzzy controller can be tuned up according to required distance[3].

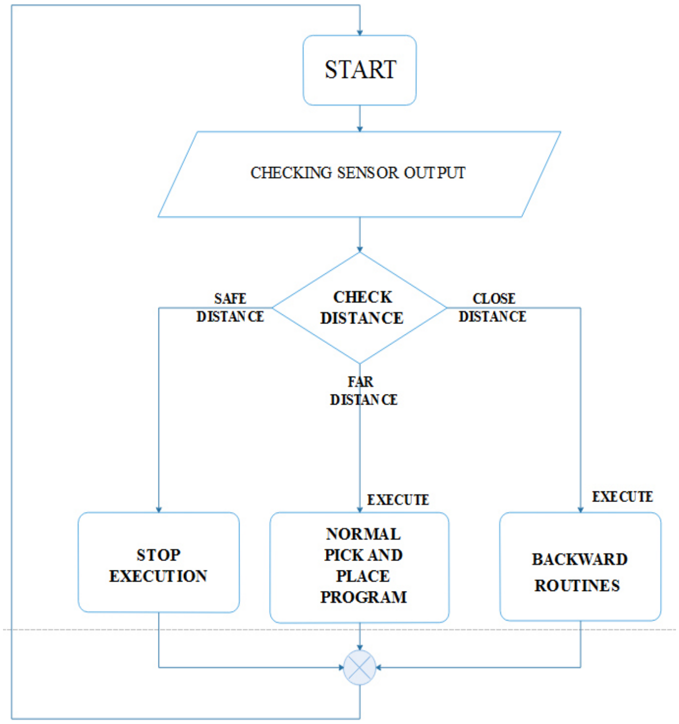

Figure 4. Flowchart for complete setup

TABLE I. IF THEN RULES FOR OBJECT SEARCHING

	If	*Then*	*direction*
1	S_1		-Y
2	S_2		+X
3	S_3		-X
4	S_1 AND S_2		-Y AND +X
5	S_1 AND S_3		-Y AND -X

The fuzzy rules for the given interaction are:

- *If* distance is very less (CLOSE) *then* output is BACKWARD
- *If* distance is in safe zone (SAFE) *then* output is STOP
- *If* distance is very large (FAR) *then* output is FORWARD

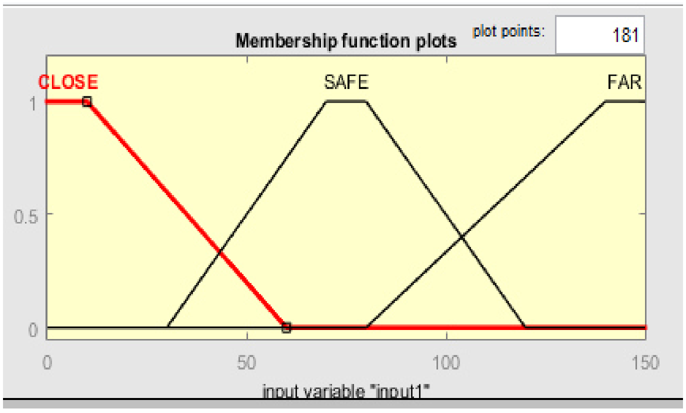

Figure 5(a). Fuzzy definitions for input variable

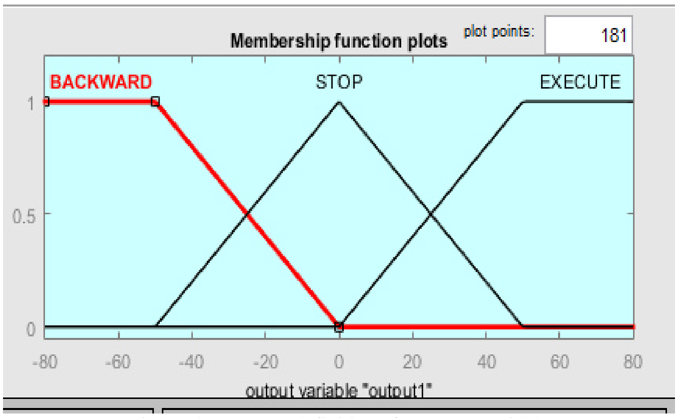

Figure 5(b). Fuzzy definitions for output variable

1) Implementation of Fuzzy controller in Arduino board

The outputs from sensors are given to Arduino Mega 2560 analog input ports. According to fuzzy inference rules it will give fuzzy output across defined Arduino output pins. The nature of output is PWM signals. As shown in fuzzy Simulink model for different combination of signal we have assigned different output pins. For example, if arduino board receives output from only sensor S_1 it will give corresponding PWM signals on defined output port 1 and similarly for S_2 output is taken across output port 2 etc.

The Arduino Mega 2560 is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins out of which 15 can be used as PWM outputs, 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with an AC-to-DC adapter or battery to get started. Arduino Mega 2560 has open source software that is why it's quiet easy to implement control logics on this microcontroller board.

2) Interfacing of Fuzzy controller and IRC5

According to the distance measured by sensors, fuzzy controller will take action and will give corresponding PWM output signal, this action is mentioned above. The output pins of Arduino Mega 2560 are connected input port of robotic controller IRC5. The algorithm is already developed in RAPID language defines movements in different directions.

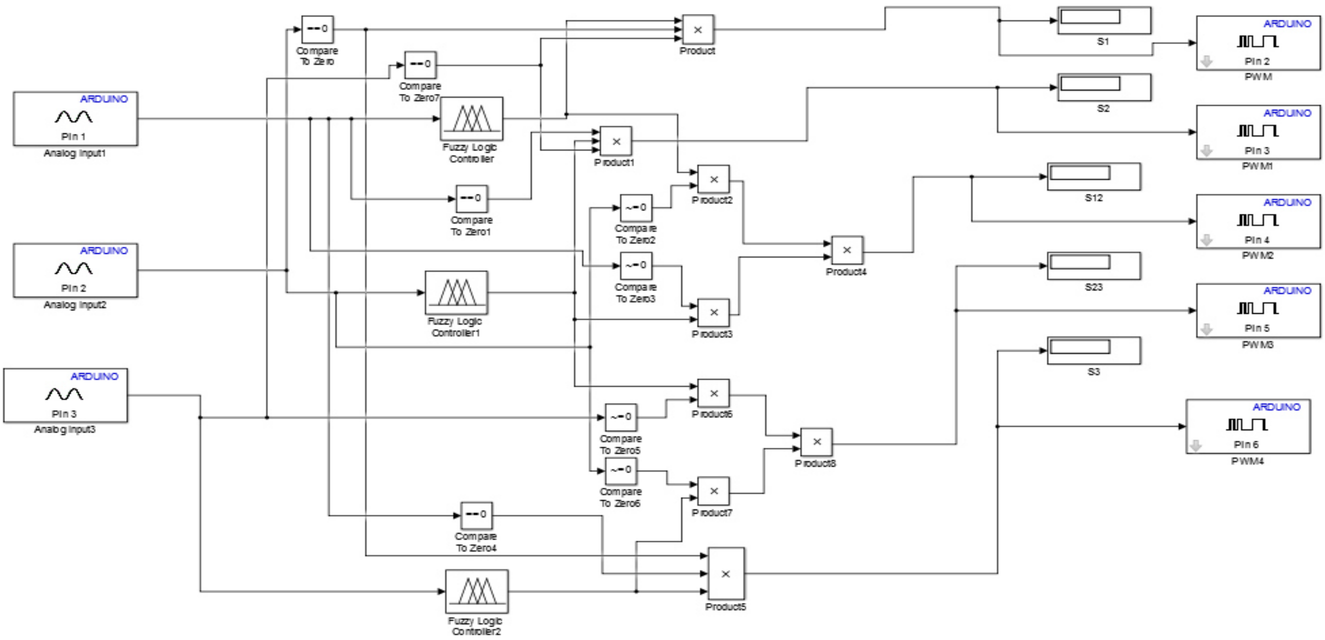

Fig. 6: Fuzzy Strategy for collision avoidance

So program is developed in such a way that it will execute routine corresponds to the activation of sensors. The logic for simulation is shown in flowchart figure 4. This arrangement helps robot to move precisely according to human positions.

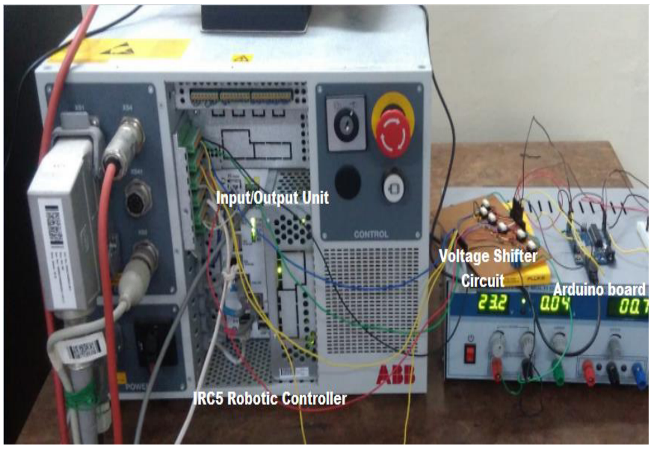

Fig 7. Interfacing of Fuzzy- Arduino with IRC5

3) Simulation Results for Fuzzy Controller

The fuzzy controller is designed in such a way that it should correctly respond to sensor output and its combinations given above. The output of the fuzzy controller will decide corresponding action to be taken. For the given arrangement, a model is designed in MATLAB-Simulink in order to achieve desired objective. According to object distance, sensor will respond by corresponding analog voltage. This analog voltage is given to the Simulink model shown in fig 7 through input port of arduino and we get corresponding output in the form of PWM signals as shown in fig 8, 9, 10. This signal is given to the IRC5 robotic controller to take corresponding control action. The results are in shown below for different sensor outputs.

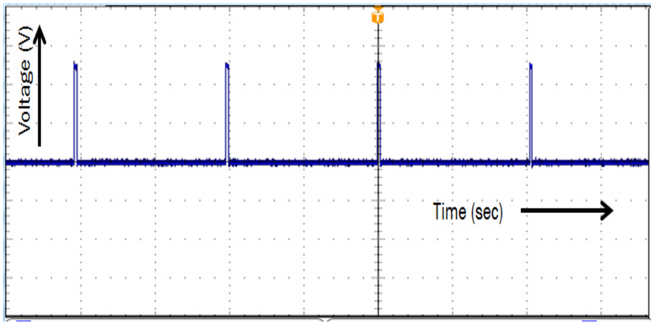

Fig. 8: Fuzzy-arduino output when sensor output is 0.5V
(Human just crosses safe zone and at a distance approx. 2m from robot workspace)

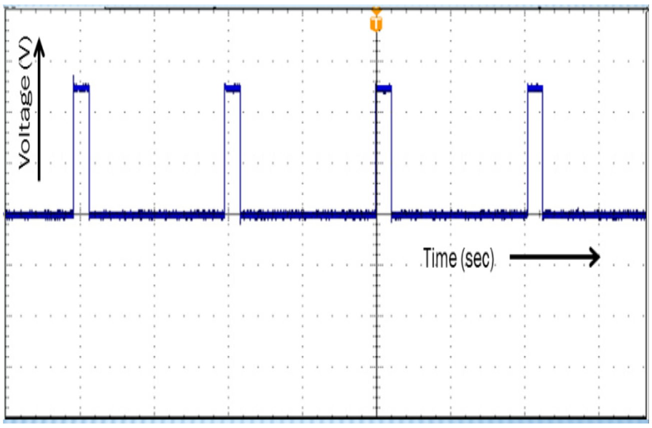

Fig 9: Fuzzy-arduino output when sensor output is 2.9V
(when human is 1meter far from robot workspace)

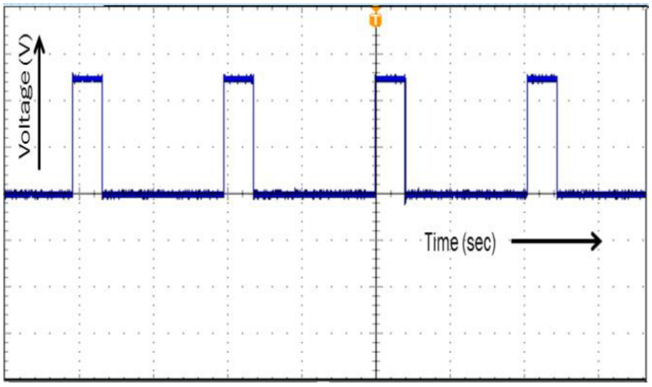

Fig 10: Fuzzy-arduino output when sensor output is 4.86V
(when human is less than 1meter far from robot workspace)

B. Arduino Based Control Strategy

Similar to Fuzzy control strategy, in this strategy sensors are directly connected to the Arduino board and then to IRC5 controller through voltage shifter circuit. But here algorithm is designed in Arduino based software called Arduino IDE. So digital signals are taken across output pins instead of PWM signals. The area around robotic manipulator is divided into two regions close zone and far zone; safe zone automatically omitted because of two level digital signals. When human approaches in the far region, sensors will give logically LOW signals and when in case of close region sensors will give logically HIGH signals.

The logic for Arduino based strategy is such that for particular sensor/s output combination, it should activate the corresponding digital output. For example when sensor S_1 energizes due to human presence it will give HIGH signal across any output pin let us assume D_1 but the same output pin D_1should not activate for other sensor/s.

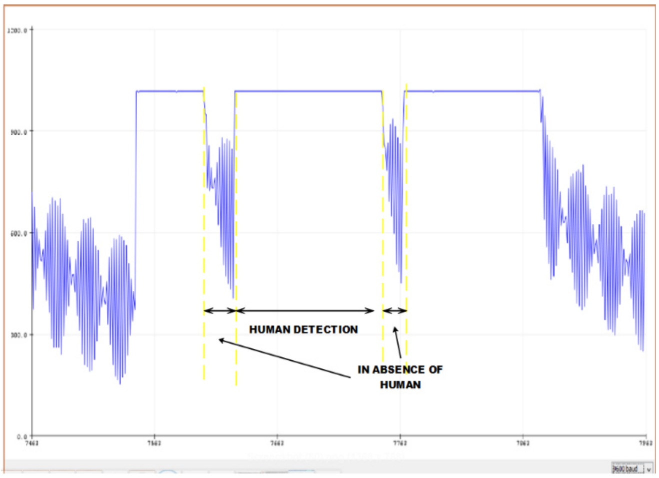

Figure10. Arduino output for human detection

IV. DISCUSSION

To detect human presence, various types of sensors are available in market. The above results are calculated by using PIR motion sensor, which detects change in movement of human but if human is steady, it will not even sense human in the nearby places. The motion sensor detects human by sensing infrared signals coming from human body. But it cannot differentiate infrared coming out from human and hot objects with same temperature range.

In this paper close proximity action is achieved by two different strategies, Fuzzy Control Strategy is suitable for analog signals while Arduino based strategy is favourable for digital signals. For ABB robot, the I/O board (DSQC 651) is digital. So in such case IRC5 controller cannot sense analog signals, that's why Arduino based strategy is more suitable than fuzzy. In Arduino based strategy, to move robot manipulator away, total motion is divided into number of saved positions and at every position, it checks the sensor condition. But this method is not efficient, every time it delays to take proper action and trajectories loses its smoothness.

V. CONCLUSION

This paper presents real time, cost-effective proximity system which can be implemented in the ABB industrial robots to avoid collisions between human and robots. This paper presents two novel methods which are added externally without changing internal programming or structure of the robot. The fuzzy controller with sensor output demonstrated virtually in MATLAB Simulink. The Arduino based circuit also demonstrated using Arduino programming and interface with I/O units of ABB industrial robot. In this way, controller is designed which takes proper control action to avoid collisions. The advantage of this method is we can easily interface sensors with robotic controllers to get expected results.

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