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Design and Implementation of an Intelligent Robotic Manipulator using LabVIEW for Industrial Applications

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***Abstract*— The robotic manipulator plays a dominant role in the domain of process industries based applications such as pick and drop, quality based sorting, etc. With the advent of these intelligent systems, the overall performance has been grown at a quite fast rate. This system has been mostly developed with the help of various hardware and software modules with the help of graphical coding language i.e. LabVIEW by National Instruments or MatLAB by Mathworks. This virtual intelligent system basically consists of a robotic manipulator, vision based systems, AI based processors i.e. a microcontroller, conveyor belts, etc. In this system, the degree of freedom (DOF) i.e. the movement of the manipulator is quite important which depends upon the nature of the application. For this intelligent system, various algorithms based approaches are implemented so as to execute the task i.e. image processing, coordinate determination, movement of the end effectors using various servo as well as DC motors, etc. In this present work, author has put forward a high performance automated intelligent system that provides a precise output with desired level of accuracy. With such characteristics, this virtual intelligent system can be utilized in various industrial applications where the quality is expected at a high rate with other dominant parameters. The simulation work of the system has been carried out with LabVIEW 2015 edition along with other hardware modules with desired results.**

Keywords: Robot Manipulator, Microcontroller, Inverse Kinematic. NI-IMAQ-Machine Vision, Image Processing, DOF manipulator, DC servo motor. LabVIEW

I. INTRODUCTION

In today's era, the role of the virtual intelligent system with a robotic manipulator has tremendous role to play in the automation of various process based applications in the industries. With the use of such intelligent system in the industries the overall performance of the task to be executed gets enhanced in terms of accuracy, calibration, etc. The most common industrial applications which are contributed with the use of such intelligent system are processes where some odd objects are to be sorted out, color based sorting of an object, pick and drop of certain objects in various logistics based industries, etc. This system basically consists of certain hardware and software modules such as robotic manipulator i.e. an arm with some end effectors, some vision based mechanisms i.e. a simple camera, image processing tool and algorithms, microcontroller as a processor [1-5].

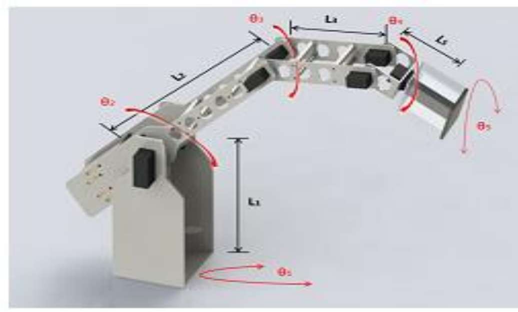

Fig. 1. Schematic arrangement of a Robotic Manipulator [6].

The above Fig. 1 shows the schematic arrangement of a robotic manipulator with the required degree of the freedom (DOF). In the most of the industrial applications, the requirement of this DOF ranges from 3 to 5 so as carry out the execution of the task with desired efficiency.

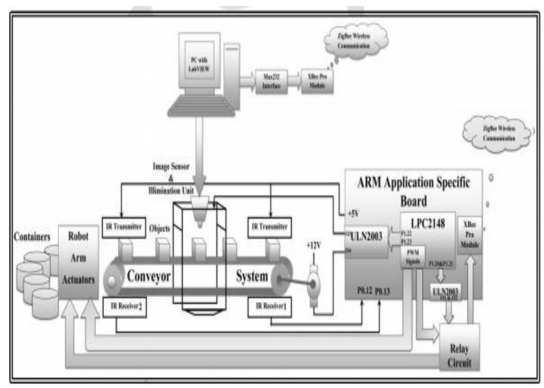

Fig 2. Detailed schematic arrangement of Virtual Intelligent System [7].

The Fig. 2 shows the typical arrangement of the virtual intelligent system for a typical application of sorting an object with the help of image processing algorithms and color based analysis. This industrial process gets executed with the use of two image sensors so as to increase the accuracy of perfection. The image acquired by these sensors is then analyzed with the standard one using the image processing tools along with the microcontroller. The most important module of this system is to determine the joint angle of the manipulator correctly so that the object sorting can be performed without any error.

This joint angle of the manipulator is calculated with the help of inverse kinematics (I K) approach [8-15].

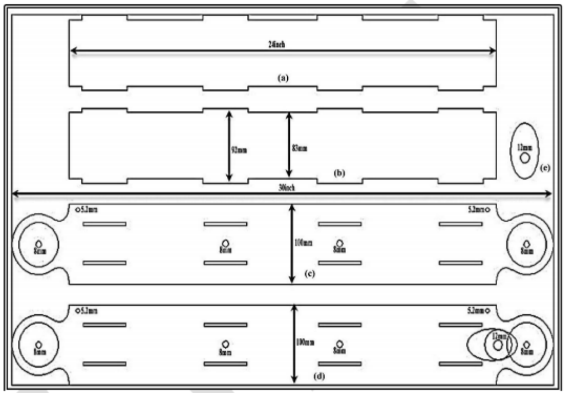

Fig 3. Model of the Virtual Intelligent System [16].

The robotic manipulator is usually an electro-mechanical machine which is guided by computer or electronic programming, and is thus able to do tasks on its own. Another common characteristic is that by its appearance or movements, a robot often conveys a sense that it has intent or agency of its own. Although the appearance and capabilities of robot vary vastly, all robots share the feature of a mechanical movable structure under some form of control. This control of robot involves three distinct phase- perception, processing and action. In common the preceptors are sensors mounted on the robot, processing is done by onboard microcontroller or processor and task (action) are performed using a motor or with some other actuators.

A conveyor system is a mechanical assembly unit or a mechanical handling system which moves the objects from one place to another place. It allows speed and efficient way of transporting a wide variety of materials in material handling and packaging industries. It consists of a belt, IR sensors and a DC motor. Idlers form the supports for the carrying and return of the belt. A structure supports and preserves the alignments of the idlers, pulleys and supports the driving machinery 12VDC motor. A pulley support and moves the belt to control its tension [17-25].

II. MATHEMATICAL MODELING OF THE VIRTUAL INTELLIEGNT SYSTEM

In today's scenario of the industrial applications, it has been seen that the robotic manipulators have been categorized depending upon the nature and sensitivity of the applications and the safety of the human intervene. This motive can be easily implemented through the programming tools so that the process can be automatized with enhanced overall performance. Thus, with the use of this robotics manipulator in addition to a virtually intelligent system, the overall shape of the system has been changed dramatically. This virtual intelligent system is basically comprised of a manipulator with end effector, vision system, conveyor belt, processor, etc. This intelligent system can be designed and implemented with the use of the hardware and software modules of the National Instruments i.e. LabVIEW (Graphical Coding Language), Machine Vision System Module with all the tools of image processing, Robotic arm, Embedded Processor with Real Time Execution Modules. This intelligent system has proved to be a boon for the various domains of the industrial applications, especially; the logistics based applications which involve the pick and drop of an object. Another, important application domain which uses this system involves the sorting of an object on the basis of the color or shape that requires quite high accuracy based execution of the task. The sorting systems based applications remain essential in numerous areas with diverse applications such as in the manufacturing industry, libraries, factories, warehouses, pharmacies, supermarkets [26-30].

Another important aspect that affects the execution of this system is the degree of freedom, i.e. movement of the end effector of the robotic arm. This movement of the arm is mainly dependent on the combination of the various actuators i.e. servo motors with proper coordinate systems. The DOF of any robotic arm defines the ultimate efficiency equivalent to a human interface. The robotic manipulator of the system is mainly constructed with a microcontroller which thereby has provisions to interface with a PC so that it works dynamically in all the possible directions which in turn provide a control signals as output to the servomotors which controls the robotic arm. In this process, the USB camera i.e a module of machine vision system captures the image of the object to be picked and move to new specified location. The captured image is further processed with Image processing algorithms which are running on PC with the NI-LabVIEW IMAQ Machine Vision tools and function modules. LabVIEW IMAQ toolsets provide sophisticated functions to implement the Digital Image Processing algorithms in a PC [31-35].

$$\alpha = \frac{\Delta\omega}{180^\circ - 0^\circ} = \frac{2500-500}{180^\circ - 0^\circ} = 11, (1) Roboticvalues \qquad (1)$$

Where 2500 is the maximum and 500 is the minim robotic value. With this assumption, the manipulator can make a maximum movement of 180º. Now for color based sorting applications, one has to determine first the color threshold with the help of either RGB approach or HSV values of the image.

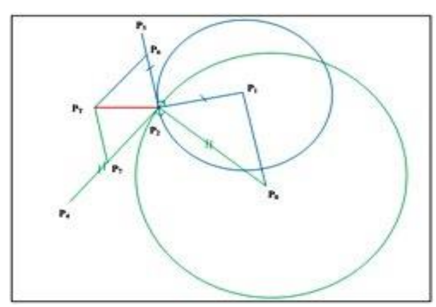

Fig 4. Geometrical Layout of the Robotic Manipulator [36].

The above Fig. 10 shows the geometrical layout of the robotic manipulator with the best possible movement i.e. DOF. In this intelligent system, an image can be acquired using the machine vision module. The difference between vectors of the image acquired can be expressed with the help of below equations i.e. [37]

$$vx = x_2 - x_0 \tag{2}$$

$$vy = y_2 - y_0 \tag{3}$$

Now the orthogonal vector of an image can be calculated with the help of the following mathematical equations i.e.

$$temporary = x \tag{4}$$

$$x_0 = y \tag{5}$$

$$y_0 = -temporary \tag{6}$$

$$x_4 = vx_{0x} - 2vx_{0x} + x_2 \tag{7}$$

$$y_4 = vx_{0y} - 2vx_{oy} + y_2 \tag{8}$$

$$x_5 = vy_{0x} - 2vy_{0x} + x_2 \tag{9}$$

$$y_5 = vy_{0y} - 2vy_{0y} + y_2 \tag{10}$$

The parallelogram i.e. the distance traversed by the manipulator can be calculated in the following manner i.e.

$$m_1 = \frac{y_5 - y_2}{x_5 - x_2} \tag{11}$$

$$m_2 = \frac{y_4 - y_2}{x_4 - x_2} \tag{12}$$

$$y = mx + b \tag{13}$$

$$y_2 = m_1 x_2 + b \tag{14}$$

$$y = m_1 x + y_2 - m_1 x_2 \tag{15}$$

$$y_6 = m_1 x_6 + y_2 - m_1 x_2 \qquad 16)$$

$$y_7 = m_1 x_7 + y_2 - m_2 x_2 \tag{17}$$

$$y_6 = m_2 x_6 + y_T - m_2 x_T \tag{18}$$

$$y_7 = m_1 x_7 + y_T - m_T \tag{19}$$

$$m_1 x_6 - m_2 x_6 = y_T - m_2 x_T - y_2 + m_1 x_2 \tag{20}$$

$$x_6 \frac{\left(m_1 x_2 - m_2 x_T + y_T - y_2\right)}{m_1 - m_2} \tag{21}$$

$$y_6 = m_1 \left(x_6 - x_2\right) + y_2 \tag{22}$$

$$m_2 x_7 - m_1 x_7 = y_T - m_1 x_T - y_2 + m_2 x_2 \tag{23}$$

$$x_7 = \frac{\left(m_2 x_2 - m_1 x_T + y_T - y_2\right)}{m_2 - m_1} \tag{24}$$

$$y_7 = m_2 \left(x_7 - x_2\right) + y_2 \tag{25}$$

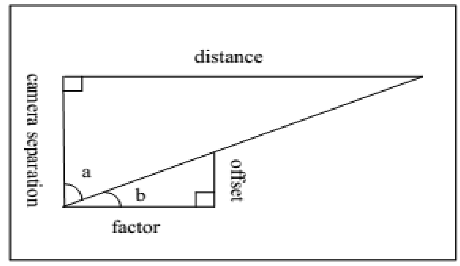

Fig. 5. Stereo distance calculating algorithm [38].

The above figure shows the algorithm used by this intelligent system so as to determine the path utilized by the robotic manipulator to successfully execute the task with desired level of accuracy. Another important mathematical tool of this system which plays a dominant role in the execution of the task is the angle of the movement and inter-comparative analysis of the pixels and coordinate of the image [39].

$$t_g\left(a\right) = \frac{dis\tan ce}{cameraseparation} \tag{26}$$

$$t_g\left(b\right) = \frac{offset}{factor} \tag{27}$$

$$\alpha = \frac{\Pi}{2} - b \tag{28}$$

$$offset = \left|x_{OR} - x_{OL}\right| \tag{29}$$

$$offset = \frac{offset}{t_g\left(\frac{\Pi}{2} - arct_g\left(\frac{initialdis\tan ce}{cameraseparation}\right)\right)} \tag{30}$$

$$offset = \left|x_{2R} - x_{2L}\right| \tag{31}$$

$$finaldis\tan ce = t_g\left(\frac{\Pi}{2} arct_g\left(\frac{offset}{factor}\right)\right).cameraseparation \tag{32}$$

The desired angle of the movement is calculated with the help of below given mathematical expression, i.e.

$$\alpha = \frac{180°}{\Pi}.arct_g\left(\frac{\tan gentlength}{radiuslength}\right) \tag{33}$$

Thus, the resultant parameters of the robotic manipulator can be calculated as follows:

$$roboticvalue = \alpha . \frac{2000robotic}{180°} \quad (34)$$

The real world coordinates were converted to pixels with the following formulas i.e.

Horizontal resolution = 320 Vertical resolution = 240

Diagonal = 19”

Display size of image = 15.2” x 11.4” = 21.05 PPI

Thus, the distance on display [Pixels] = real world distance [cm] x 21.05 [PPI]/2.54 [cm]

III. OPERATIONAL ASPECTS OF THE VIRTUAL INTELLIGENT SYETM

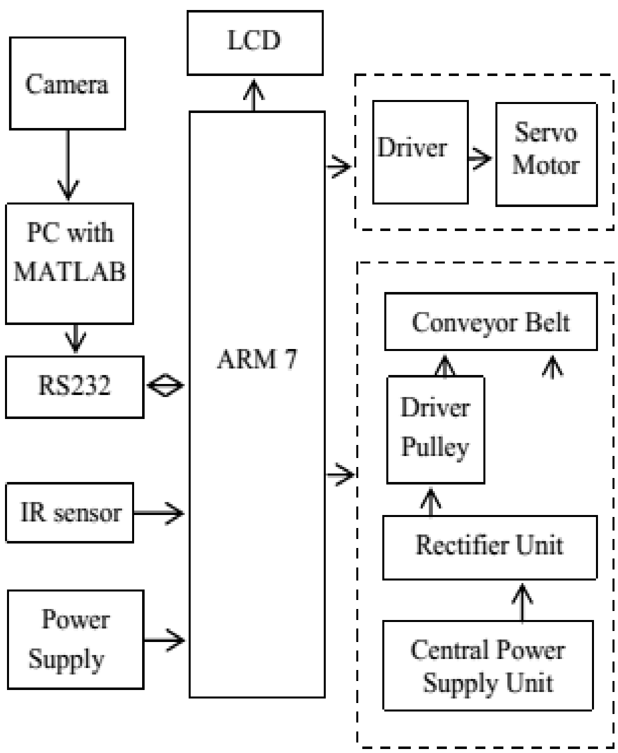

Fig 6. Block diagram of the system [40].

The above Fig. 6 shows the block diagram with detailed modules of a virtual intelligent system. It reflects all the dominant software as well as hardware modules of the system. And the Fig. 7 shows the detailed flow diagram for a specific application of an object sorting using the tool of image and color. The Fig. 8 depicts the mimic of the system using the National Instruments LabVIEW i.e. a graphical coding approach. It is also called as the front panel of the system that contains all the visual aspects of the system, say, variables, alarms, graphs, etc.

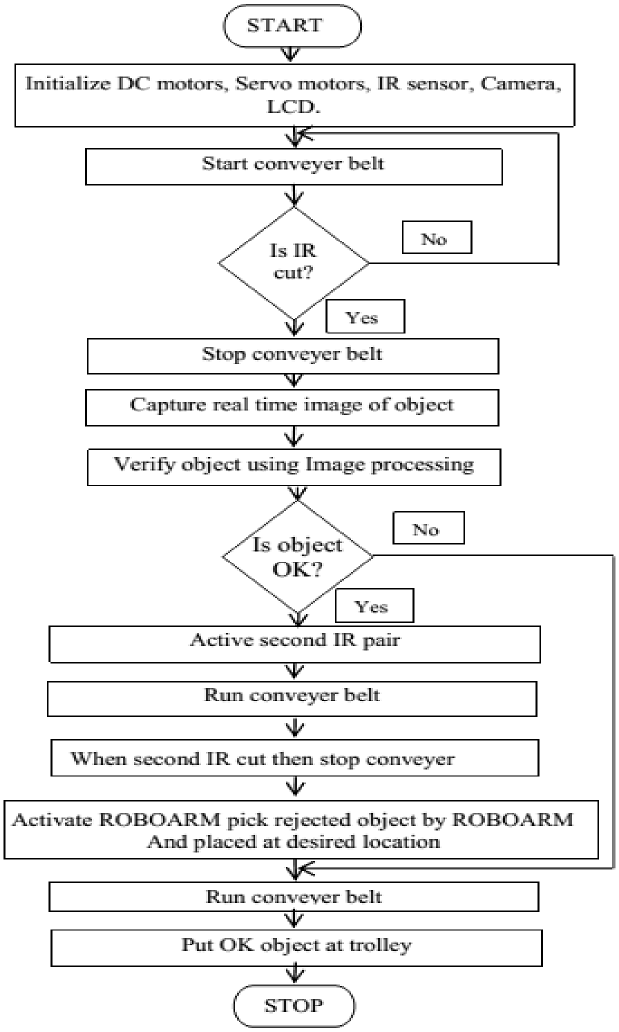

Fig. 7. The systematic flow of the process for a specific application for sorting of an object [41].

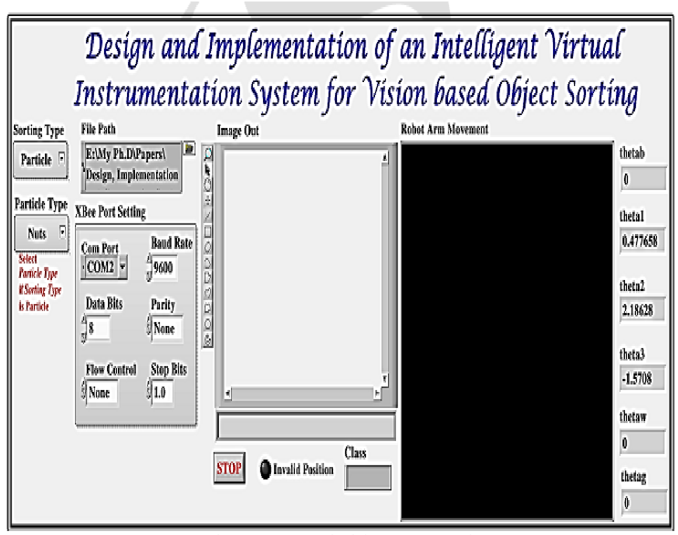

Fig. 8. Mimic Screen of the Virtual Intelligent System using LabVIEW [42].

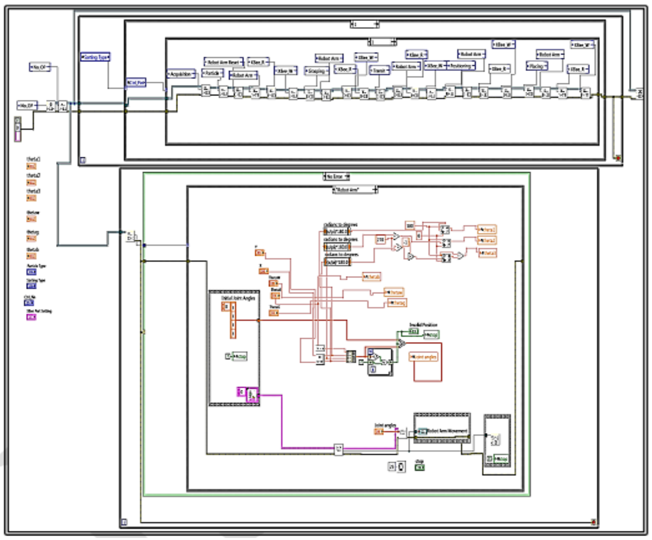

Fig. 9. Block Diagram of the Virtual Intelligent System [43]

A LabVIEW program contains front panel and block diagram i.e. a kind of Graphical User Interface (GUI) which acts as an interface between user and the block diagram of the system. It contains inputs control elements and output indicator/display elements i.e. the actual program which guides the front panel inputs through outputs. The above Fig. 8 represents the front panel of the system that contains various sub modules required to execute the process i.e.

- Sorting Type i.e. particle or color based sorting
- Particle Type i.e. a particular particle based sorting
- File Path i.e. type of classifier
- X_{Bee} Port Setting
- Image Out
- STOP
- Invalid Position
- Class
- Robotic Arm Movement with θ_1, θ_2, θ_3, θ_w & θ_g

The Fig. 9 shows the LabVIEW block diagram of the intelligent system. This module has the following sub modules i.e.

- Acquisition, Particle
- Color
- XBee_R
- XBee_W
- Robot Arm
- Robot Arm reset
- Grasping, Picking
- Transit and Placing.

The acquisition module of the system acquires the image from the image sensor through USB. Particle is the classification program for all particle types. Particle classification was performed by keeping lower thresholding value as 10 and higher thresholding value as 254. Color is the classification program for color bottles classification. Color classification was performed by keeping luminous value on and resolution in medium. XBee_R and XBee_Ware ZigBee read and write programs. XBee_R reads the Ctrl_Pin status from microcontroller and XBee_W writes robot arm joint angles followed by Ctrl_Pin status to the microcontroller. Robot Arm reset, Grasping, Picking, Transit and Placing are the movements of the robot arm. Each movement has its own coordinate system and depending on the Class coordinate variables varies. Robot Arm evaluates the IK model of the robot arm and displays the robot arm movement on the front panel. IK model. To initialize the process of sorting two objects are placed manually, one in the illumination unit and other at IR_2. It starts by selecting/setting the inputs and file path. Here inputs refer to the Sort Type, Particle Type, XBee Settings and File Path refers to the classifier file path. LabVIEW control executes the XBee_R to read the Ctrl_Pin from LPC2148 and waits until it is equal to 1. Then most recently captured image was acquired by the Acquisition program. Classification process starts depending up on the inputs and classifies the object in the image. Depending upon the class name of the object robot arm movements such as reset, grasping, positioning, transit and placing is going to feed on by one as inputs to IK model. IK model calculates the correct joint angles, transmits the Ctrl_Pin as 0 and joint angles [44-45].

TABLE I. TABLE TYPE STYLES ACTUAL POSITIONS OF THE ROBOT ARM END-EFFECTOR [46-47]

Position	Inputs				Outputs				
	X	Y	Θ_B	Θ_G	Θ_b	Θ_1	Θ_2	Θ_3	Θ_g
Reset	12	-2.13	0	90	0	101.5	0	14.7	90
Grasping	12	-2.13	0	16	0	101.5	0	14.7	16
Picking	12	1.89	0	16	0	120.6	0	14.4	16
Transit	12	1.89	15	16	15	120.6	0	14.4	16
Placing	12	-4.36	15	90	15	90.7	0	18.6	90

The above Tab. shows the output of the various parameters which plays dominant role in the movement of the robotic manipulator while executing the task of a specific application. These are the values of the parameters which are set during the simulation process using the LabVIEW software along with other hardware modules.

IV. SIMULATION RESULTS & DISCUSSION

The experimental simulation work has been carried out on the platform of National Instruments' software and hardware modules, i.e. LabVIEW and other hardware of the intelligent system. Under this process of execution of the task, the input module acquires the information i.e. image of the object to be sorted out based on the color and design with enhanced accuracy. For this purpose, LabVIEW has in built function i.e. Express VI as shown in Fig. 10

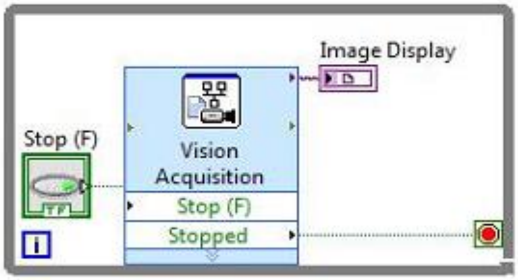

Fig 10. Block diagram of Input System i.e. Express VI.

This inbuilt function is nothing but simply a program which acquires and displays the image of the intelligent system.

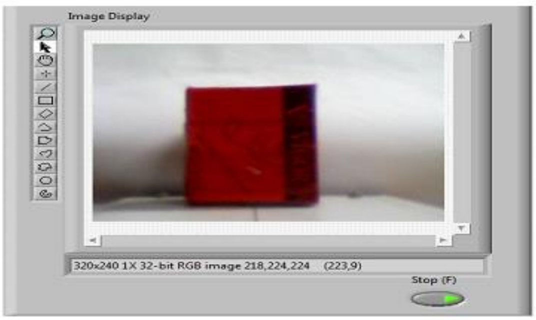

Fig. 11. Front Panel of Input to the Virtual Intelligent System.

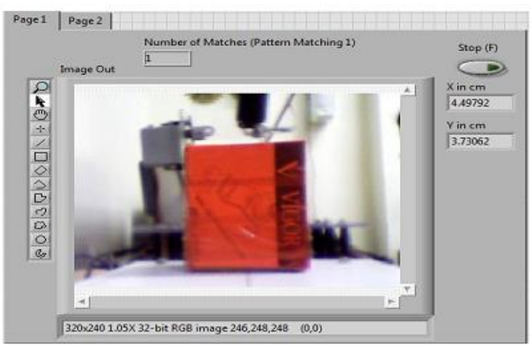

Fig. 12. Front Panel of the Processing of Input data.

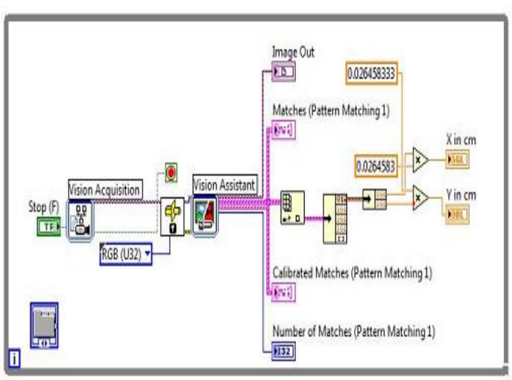

Fig. 13. Block diagram of processing of input data.

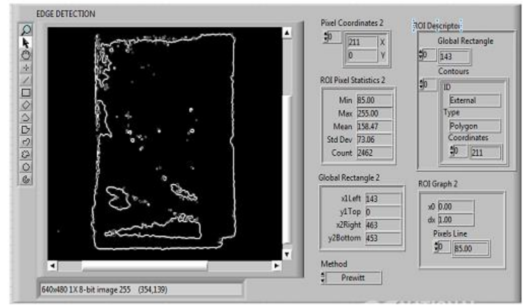

Fig 14. Front Panel of the Algorithm of the Input processing system.

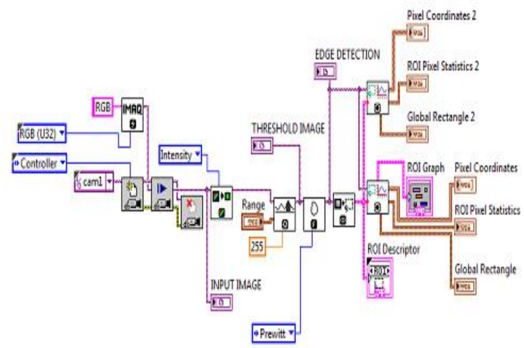

Fig. 15. Block diagram of Algorithm of Input Processing System.

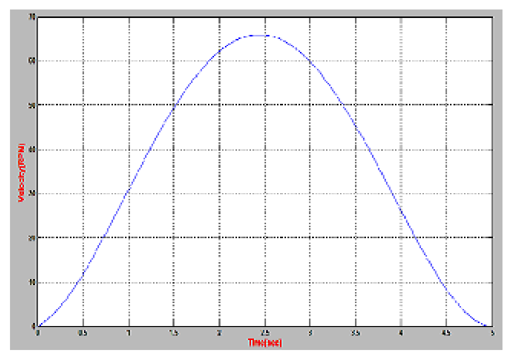

Fig.16. Velocity Plot of the Gripper.

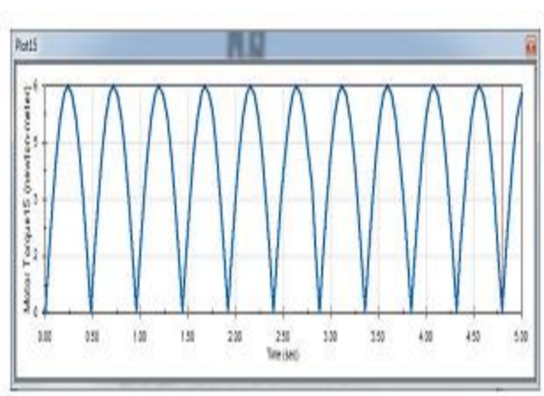

Fig. 17. Output of the Motor Torque.

The above Fig. 10 -17 shows the screen shots of the various program modules with the mimic of the various sub modules of the robotic manipulator. The torque of the servomotor plays a vital role in the movement of the end effector thereby determining the DOF desired for industrial applications. In order to reduce the torque of the link balancing weight and springs maximum torque equals 0.15 Nm link 3, and the maximum output torque is 2.7 Nm motors will be attached to link 3 link 4 and the base as well.

V. CONCLUSION

In the present scenario, the robotic manipulator with a virtual intelligent system has got enormous applications i.e. in the domain of quality based sorting of the desired objects, pick and drop application, fault detection objects in various industries, etc. For this nature of applications, a virtually intelligent system has been developed using LabVIEW application software. This intelligent system involves an input acquisition module that has to be processed using LabVIEW i.e. a graphically coded language. The machine vision tool of the LabVIEW plays the most dominant role in processing the data for the specific applications. In addition to this, the edge detection algorithm in coordination with IMAQ Vision tool serve as the heart of the system and carries out the task using a robotic manipulator with 5 or 7 DOF. This intelligent system can be easily extended for the various embedded based applications with a real time environment based hardwares and FPGA modules. The author has also proposed the future extension of this virtual intelligent system based on WIFI utilities. With this modification in the system, the overall performance of the system can be enhanced i.e. accuracy, reliability, calibration of the system, etc.

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