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Simulation, design, fabrication and computer control of a four – axes CRUST 2020 stationary articulated robot selective compliance assembly (SCARA) robotic manipulator arm

[1]Dr. Nirmalkumar S. Benni, [2]Dr. Manjunath G. Asuti, [3]Dr. Arun Kumar G., [4]Dr. T.C.Manjunath

[1]Associate Professor, Information Science & Engineering Department, RNS Institute of Technology,
R R Nagar Post, Channasandra, Bengaluru - 560 098, Karnataka
[2]Associate Professor, Electorniсs & Communication Engineering Department, BNM Institute of Technology, 12th Main Road, 27th Cross, Banashankari Stage II, Banashankari, Bengaluru, Karnataka 560070
[3]Professor & Head of the Department, Electronics & Communication Engineering Department, JSS Academy of Technical Education, C-20/1, C Block, Phase 2, Industrial Area, Sector 62, Noida, Uttar Pradesh 201301, India
[4]Professor & Head, Electronics & Communication Engineering Department, Dayananda Sagar College of Engineering, Kumaraswamy Layout, Bangalore-560111, Karnataka

E-mails : [1]nirmalkumar.benni@gmail.com [2]manjunathasuti@bnmit.in
[3]arunkumar.stjit@gmail.com [4]tcmanju@iitbombay.org

Abstract: In this research paper, the Simulation, design, fabrication and computer control of a four – axes CRUST 2020 stationary articulated robot manipulator arm is presented in a nutshell. The paper presents the design, fabrication of each part and construction of a four axes SCARA robot with indigenous components and control it with a personal computer using the visual basic language. The main objective of this work is to design a educational model to do pick and place operations by avoiding the obstacles in its path of motion from the source to the destination. The robot is modeled using AutoCAD package.
Keywords: CRUST, Robot, Articulation, Arm, Manipulator, Application, PNP.

Organization of the Paper

The paper is organized as follows. First, a brief introduction to robotics and robots is given. Second, the design of the mechanical assembly is presented. Third a brief introduction to the electronic design is given. Fourth, the computer control of the robotic system using the visual basic language is presented. Finally, the conclusions are drawn. The hardware & the fabricated system along with the results shows the efficacy of the methodology that is being developed by the robot research team.

1. Introduction Remarks

In this section, a review of the robotics and the robots is presented. “I’ll be back”, he said, in his deep, synthetic voice. And back he did come – to enchant millions around the world, to fascinate young and old alike, to etch his name in the annals of immortality. He was the Terminator, a robot. Robots have often been considered as competitors to the human race. They have taken up some of our difficult jobs. They save costs because there is no need for them to change shifts, they do not take tea or coffee breaks, they do not fall ill and they do not go on strike. But, though robots are very effective replacements in some areas, they are still a long way from having the perception, dexterity or flexibility of human beings [1] [2].

This project's inception is rooted in our deep-seated fascination with the realm of robotics. Combined with our genuine desire to create something substantial, it motivated us to embark on this ambitious journey, considering the interdisciplinary nature of robotics. However, the task ahead was monumental. Robotics spans a wide spectrum, from mechanics to electronics to computer software, providing us with an unparalleled learning experience. We scoured the entire city in search of indigenous components that met our rigorous requirements. Despite the challenges, we take immense pride in our collective efforts and, most importantly, in the end product. Allow us to introduce CRUST 2020, the Computerized Robotic Unit with Selective Tractability, as depicted in Figure 3 [3][4]..

2. Mechanical design of the system

The Robot has R-R-P (Rotary-Rotary-Prismatic) type of axes. Hence, the assembly consists of three main parts namely the base with the shaft providing one rotary motion, the elbow joint joining the two arms provides the next rotary motion, the prismatic up/down motion is provided by the Rack-Pinion arrangement. The end-effector is a parallel-jaw gripper that also has a roll motion for tool orientation [5][6].

The main consideration in the design of the system has been to reduce the weight of the components situated away from the center shaft. But because of the requirements of the design most of the mechanism is aggregated towards the end of the arm. Hence to minimize the leverage developed at the ends, more compact mechanisms are used for actuation of motion and components made up of very light weight materials, such as Deldrin, Aluminum and PVC, are used towards the end. For greater stability the base is made heavy [7][8]. The Fig. 1 gives the 4-axis Adept One Selective Compliance Assembly Robot Arm (SCARA).

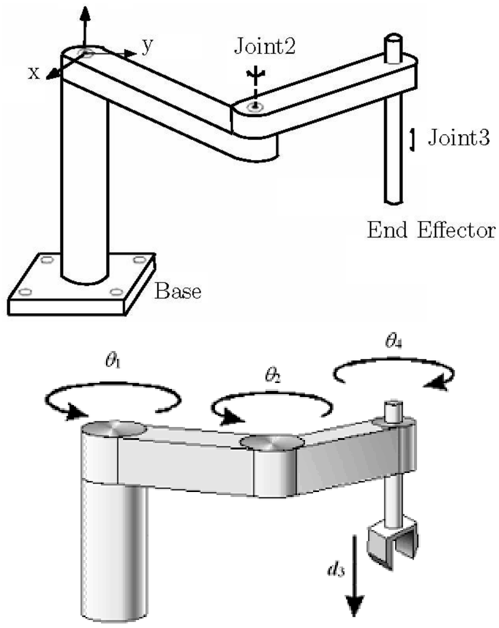

Fig. 1: The 4-axis Adept One Selective Compliance Assembly Robot Arm (SCARA)

3. Base Assembly

The base assembly consists of a mild steel box, which has the center shaft protruding from its center. The shaft can rotate about its axis thus providing the revolute motion for the shoulder joint. The motion is actuated using a pair of spur gears. The smaller gear (12 teeth) is coupled to a larger gear (80 teeth). This type of coupling increases the rotating torque by six times, but at the same time, the speed is reduced by the same amount. The obtained speed, however, meets the requirements of the robot. The shaft rotates in a pair of bearings mounted on the lower and the upper plates of the box. The bearings provide very smooth motion, thus reducing load on the motor and the wear and tear of the metal [9][10].

The shaft is thinner at the lower end so that the gear fits onto it. The motor used for the motion is a DC-servomotor. The advantages of using these motors are that they consume less power and can be easily controlled using an on-board driver circuit which is interfaced to the computer. These motors are used in car wipers. The specifications of the motor are Torque 10kg-cm, Current rating 1A, CW-CCW Motion, Base Motor Speed : 60 r.p.m. The motor characteristics available at the center of the arm are 10 r.p.m., 60 kg-cm torque, since the gearing ratio is 1:6 [11][12].

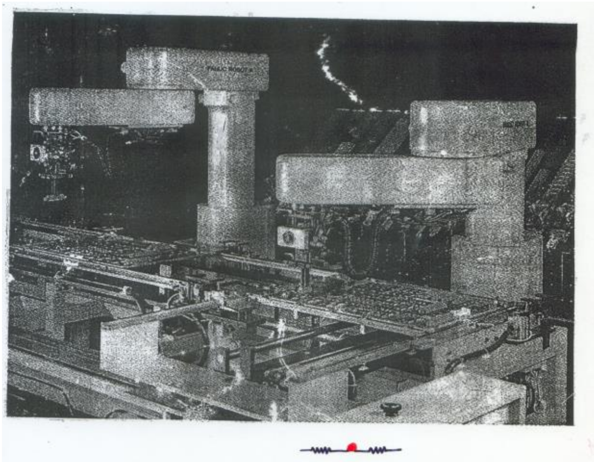

Fig. 2: SCARA robot doing an PCB assembly manufacturing operation

4. Elbow Joint Motion

The Fig. 2 gives the SCARA robot doing an PCB assembly manufacturing operation. The shaft is equipped with a set of parallel aluminum plates that move in tandem with the shaft's motion. These plates serve as the housing for the mechanisms responsible for driving the joint's movement. At the opposite end of these plates, there's another shaft pin, which imparts rotational motion to the outer arm along its axis, thus facilitating the elbow joint's revolute motion. Both the inner and outer arm plates are constructed from lightweight yet durable aluminum. This choice of material minimizes the leverage exerted by the arms on the base while remaining robust enough to support the motors and enclosed mechanisms. The motion is actuated by a compact worm and worm wheel mechanism. A double helical worm is mounted on the motor shaft, while the worm wheel is affixed to the shaft that controls elbow rotation [13][14]. The speed ratio in this configuration is 1:10, meaning the worm wheel completes one full revolution for every ten revolutions of the worm. The DC motor responsible for driving this motion is small in size, offering substantial torque and speed. It is lightweight, weighing only 200 grams, and easily controllable, making it the ideal choice for actuation. You can find the motor's specifications in [15][16].

- Type : DC Motor,
- Torque : 7 kg-cm,
- Current rating : 0.5A,
- Direction : CW-CCW Motion,
- Elbow Motor Speed: 30 r.p.m.

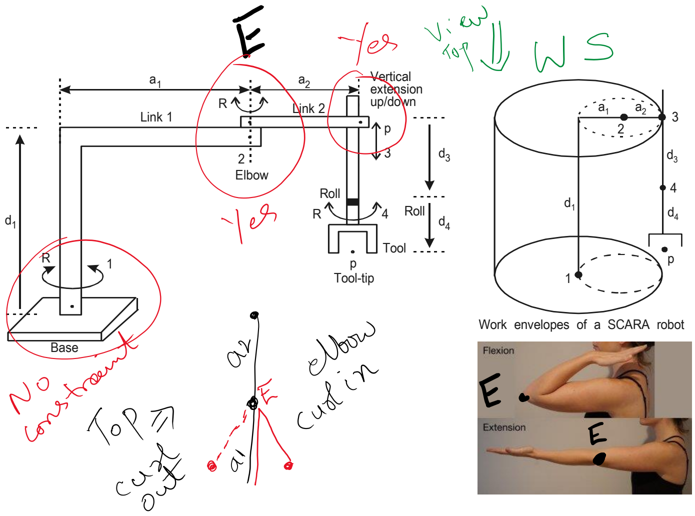

Fig. 3: SCARA robot top view, side view & its resemblance with the human hand w.r.t. the elbow joint limitations and constraints

5. Prismatic Up / Down Motion

The third joint is a prismatic joint. Since the motors provide revolute motion we need a mechanism, which converts revolute motion to rectilinear up/down motion. The rack and pinion mechanism is one such arrangement. In this arrangement the rack is a teethed rod of dieldrin while the pinion wheel, made of the same material, is a gear, which matches the rack. The pinion when rotated, moves the rack up or down accordingly [17][18]. SCARA robot top view, side view & its resemblance with the human hand w.r.t. the elbow joint limitations and constraints is shown in the Fig. 3 followed by SCARA robot top view, side view & its resemblance with the human hand w.r.t. the elbow joint limitations and constraints in Fig. 4 respectively [1].

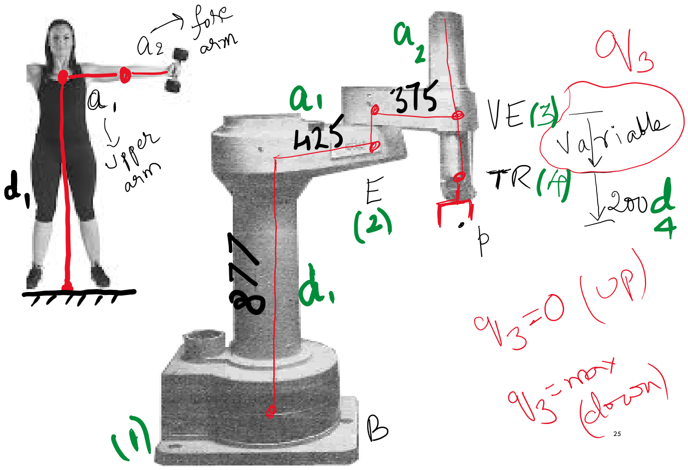

Fig. 4: SCARA robot top view, side view & its resemblance with the human hand w.r.t. the elbow joint limitations and constraints

The pinion can be directly coupled to the actuating motor. But this is not advisable because, when the motor is switched off, the weight of the rack, the gripper and motors at the end can cause the rack to slide down. The obvious answer to this problem is keeping the motor at one end and driving the pinion at other end through a chain and sprocket gear arrangement. But, this is not an ideal choice because chains slacken in the long run [19][20].

The second and most important reason is that the weight of the rack and the gripper at its end can produce enough torque to move the pinion and the motor shaft. This will cause the rack to slide down, thus damaging the gripper or the object held by the gripper. This calls for a mechanism that provides locking and is compact. The worm and worm wheel arrangement is one such mechanism. Hence the two mechanisms should be used together to produce the motion. The worm is fitted to the motor that is mounted vertically on the lower plate of the outer arm. The worm wheel and the pinion wheel are fitted on the same horizontal shaft. This provides a very compact and efficient mechanism [21][22].

The shaft moves in the brass bushes fitted in the side plates of the outer arm. The rack moves in collar bushes made of Aluminum and fitted coaxially on the upper and lower plates. The worm and worm wheel are identical to the ones used for elbow motion. The shaft of the motor is extended so that the worm fits on the entire length of the shaft. The side plates of the outer end are cut on the side of inner arm for free rotation of the elbow joint. The specifications of the prismatic motion are up Speed : 8.5 mm/s, Down Speed : 10.52 mm/s [23][24].

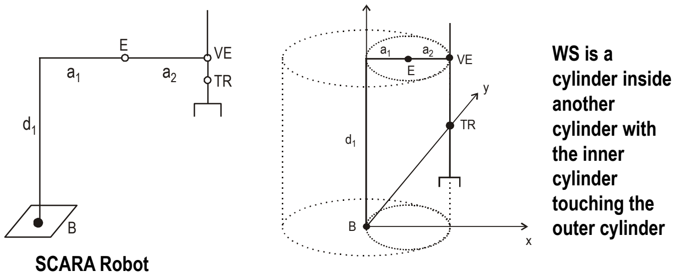

Fig. 5: SCARA robot work space shape (cylinder inside another cylinder)

5.1 Roll Motion

The mechanism for this motion is the simplest. The actuating motor fits to the lower end of the rack by means of a PVC coupling. The motor is coupled to the gripper through a flange made of PVC. The motor used is identical to the ones used for elbow and prismatic motion [25]. Fig. 5 gives the SCARA robot work space shape (cylinder inside another cylinder).

5.2 gripper

The robot, designed as a PNP-type system, incorporates a gripper as its end effector. This gripper follows a parallel jaw design, functioning on the principle of a left-hand/right-hand screw mechanism. Enclosed within a U-shaped metal frame crafted from mild steel, the gripper features specially shaped Deldrin jaws designed for object manipulation. These jaws are threaded on a screw that combines both left-hand (LH) and right-hand (RH) threads. This dual-thread configuration ensures that the gripper jaws move in opposite directions. Specifically, the jaws can either approach each other for gripping an object or move apart from each other to release it, as illustrated in Fig. 4 [2].

The LH / RH moves in a pair of collar-bushes made of brass that fit in the U-shaped bracket. A thin Aluminum cross pin prevents the jaws from rotating on the screw. The LH / RH screw is coupled to a dc motor shaft via a spur gear arrangement in the ratio 4:1 to increase the rotational speed by the same ratio. The entire gripper assembly is mounted on the roll motor shaft with the help of a flange made of PVC. The motor used has the following specifications : Type : DC Motor, Torque : 3kg-cm, Current rating : 0.5A, Direction : CW-CCW Motion, Opening speed: 4.6 mm/s, Closing speed: 7.9 mm/s [3].

6. Electronic system design

The mechanical set up forms the skeleton of the robot and what adds intelligence to it is the electronics and the software module. Electronics and software go hand in hand. Without the electronics system in place, the software has no scope and without software the electronics system is a waste. Here, in this section a brief review of the design of the cards is presented. The block diagram of the designed robotic control system is shown in Fig.5. For convenience, we divide our electronic circuitry into various cards and finally, the integration of all these cards is obtained.

Motor Driver Circuit

The motor driver circuit is the interface medium between the PC and the Robot as shown in Fig. 5. It is designed using an IC L293D. It consists of an : INPUT SECTION and an OUTPUT SECTION which is described as follows [5].

Input Section

The Input section in the motor driver circuit consists of the following parameters, which are mentioned one below the other as follows [4].

25 in 1 D male connector

This establishes the link between the driver circuit and the PC, utilizing the RS232C connection via the parallel port. The program transmits the specific byte combination to activate the chosen motors. This transmission is carried out through a 3-meter Data Cable, extending from the PC to the input of the driver circuit.

Power supply connections

The driver circuit needs a +5V supply for the ICs used and 12V supply for driving the motors. It gets its power form the power supply through the +12 V and +5V connectors. The ground return in the driver circuit is common [6].

The T T L short circuit prevention logic

As part of the input section, this circuit serves as a protective mechanism. It is designed to prevent the motor driver IC from simultaneously receiving a logic 1 signal on both the CW and CCW inputs, which could potentially result in motor stall situations. The L293D motor driver IC features two direction inputs for each motor, and these inputs should be activated exclusively, not concurrently. The TTL Short Circuit Prevention Logic ensures that if both CW and CCW signals for a motor are high simultaneously, the input to the driver on both direction lines will be set to Logic 0. The output of the Exclusive-OR (Ex-OR) gate will only be Logic 1 if one of the inputs is

Logic 1. Subsequently, this output is logically ANDed with the two inputs to generate the final outputs for CW (clockwise) and CCW (counterclockwise).

Input Connector

The Input connector is used to connect any input signal to be fed back to the PC from the driver circuit. It sends them to the PC via the unused lines of the parallel port. We use 3 lines from the status port of the parallel port connector as feedback signals to indicate Base Reset position, Elbow Reset position and Gripper status (limit switch).

Output Section

The output section is composed of the dual motor driver IC L293D, which is a quad push-pull driver capable of delivering output currents of up to 1A or 600mA per channel. Each channel is controlled by a TTL-compatible logic input, and each pair of drivers, forming a full bridge, is equipped with an inhibit input that can turn off all four transistors simultaneously. To reduce dissipation, a separate supply input is provided for the logic, allowing it to operate at a lower voltage. Furthermore, the L293D IC incorporates output clamping diodes within the package, ensuring seamless interfacing with inductive loads. Both devices are available in 16-pin Batwing DIP packages, as well as in Power S0IC and Hermetic DIL packages. The enable lines for the ICs are maintained at logic 1 to enable all the ICs. The outputs from the ICs are connected to diode bridges, which are employed for interfacing with inductive loads. The motors are connected across the bridge as depicted in the figure 6 [7].

Features of the L293D IC : Peak Output Current 2A Per Channel(1.2A for L293D), Inhibit Facility, High Noise Immunity, Separate Logic Supply, Over-Temperature Protection, The inputs to the ICs come from the short circuit prevention circuit. Each IC receives 4 signal lines namely – CW and CCW signals for two motors [8].

7. Working Of The Circuitry Designed & Fabricated

The circuit employs two 74LS86 Quad Ex-OR ICs and three 74LS08 Quad AND ICs for the short circuit prevention circuit. 10 signals which are used to control the robot are [9]

BM CW: Base Motor Clockwise ;
EM CCW : Elbow Motor Counter Clockwise ;
BM CCW : Base Motor Counter Clockwise ;
RM UP : Rack Motor UP ;
EM CW: Elbow Motor Clockwise ;
RM DN : Rack Motor Down ;
ROLLCW : Roll Motor Clockwise ;
ROLL CCW : Roll Motor Counter Clockwise ;
GM OPEN : Gripper Motor Open ;
GMCLOSE : Gripper Motor Close.

These signals act as output bytes to the PC's parallel port. These signals reach the short circuit prevention logic circuit. This logic ensures that CW and CCW, UP and DN, OPEN and CLOSE are not high simultaneously. The output of the short circuit prevention logic is given as inputs to the output section. The output section employs three L293Ds to drive the 5 motors. One of the three ICs is dedicated to driving the Base Motor [10].

The internal driver circuitry of both channels in this IC is externally shorted to make use of both the drivers to drive this motor as can be seen in the circuit. This is because the Base motor has a 1AMP current rating as against the Output current of 600mA per channel capability of the IC. Thus by using both the channels of this IC we can achieve the driving requirements of the base motor. This also prevents excessive heating of the IC [11].

The dual channels of the remaining two ICs drive the remaining four motors. Depending on the signal to the inputs of each channel, the output polarity switches to positive or negative to drive the motors in the clockwise or counter-clockwise direction. The four diodes in the output diode bridge act as free wheeling diodes to prevent energy feedback from the motors by freewheeling the energy stored. They are especially used to interface the IC L293D to inductive loads such as motors [12].

Maintenance : If the ICs drive the motors for prolonged periods, they may burn out due to excessive heat generated internally (on account of the high output current and high output voltage). To prevent heating and burnout of the ICs, we provide heat sinks for each IC. A heat sink coolant paste compound also has been applied to cool the

ICs. The DC Motors employed in the project are 12V DC motors, which need 12 V to get energized and start rotation. The motor driver circuit also needs supply voltages of 12V and 5V [13].

Thus, we design a power supply to give a 12V output at 5A and 5V at 1A. A 5V / 12V supply is chosen because the cumulative current drawn when all the motors are energized is around 3A. Thus as a safety measure, a 5A supply is selected. The power supply consists of the step down transformer, the filter circuit, the bridge rectifier and the regulator circuit. The various parts of the power supply are shown in the figure. A fuse of 5 A is used to protect the circuit from an overload of current drawn from the mains [14].

8. About The Power Supply

The power supply features a step down multi secondary winding transformer, which delivers a stepped down ac voltage to the two power supply circuits. The supply unit consists of two circuits namely [15]

A 5V/1A power supply employing a 78L05 IC regulator

A 12V/5A power supply employing a 338K IC regulator

The regulator comes in a T0-3 case and must be used with a "LARGE HEATSINK". A small fan is also recommended for blowing air across the regulator [16].

9. Dynamic Reset Facility

CRUST 2.1 needs a reset facility as all angles are calculated relative to reference position. When the system is switched on all 'current' values of angles are zero by default. If the unit is not in reference position, further calculations will be done relative to the position the robot was in the last time it was switched off. This potentially problematic situation can be avoided by using an infrared reset detector circuit. The infrared LED's and Receivers used in our circuit are double- heterojunction, surface mounted devices made of Gallium Arsenide. Some features of infrared devices : Highly directional control beam, Low power, low cost, immunity to ambient light. The circuit consists of a comparator with a bridge at the input. The inverting terminal is kept at a voltage of 2.7V by a potential divider circuit. The non-inverting terminal is connected to a potential divider formed by a fixed resistor and an infrared sensor diode [17].

The diode, in the absence of infrared light, is reverse biased and hence acts as an open circuit keeping the voltage at the non-inverting terminal lower than that at the inverting terminal. Hence the output of the comparator is low. The output of the comparator is connected to the parallel port, as an input signal, and to an NPN transistor, which switches on an LED to indicate the home-position. When light falls on the infrared sensor diode, its resistance drops drastically. Hence the input to the comparator's non-inverting terminal exceeds the reference of 2.7V and it is turned ON. The output of the comparator turns the transistor ON and a signal is sent to the parallel port to turn the motor OFF. At the same time the LED goes ON to indicate home-position is reached [18].

Ultrasonic sensors, limit switches, and potentiometers play crucial roles in the robot's functionality. Ultrasonic sensors are strategically positioned at four locations along the robot's links to detect potential obstacles. These sensors transmit signals to the computer via the parallel port. The computer, in response, processes these signals and takes action to prevent collisions by altering the arm's direction. Limit switches are strategically placed on the inner surfaces of the grippers. Their primary function is to determine whether the gripper has successfully held or picked up an object. Potentiometers are mounted at the joints to provide precise measurements of movement, enhancing the robot's accuracy and control. These components collectively contribute to the robot's efficient and safe operation [19]..

10. Design of the software module

CRUST 2020 utilizes an advanced application control interface designed in Visual Basic 6.0, chosen for its excellence in application software development. Visual Basic is a user-friendly and robust programming language tailored for Windows platforms, offering a comprehensive array of tools that expedite the development of applications. Figure 1 and Figure 2 illustrate the software module designed to control the robot's functions. The Application facilitates user interaction with CRUST 2020 and features [20]

- Real time manual mode control
- Real time run mode control
- Programming interface

- Facility to loop operations
- Dynamic reset tractability
- Accurate positioning
- Advanced settings to change dynamic parameters of crust 2.1
- Parallel port interface and control
- Reset and grip feedback
- Intelligent path decision making
- Dynamic software controlled angular limits

11. The Logic Algorithm

The application utilizes Visual Basic's timers as its primary component [21]. The core function of the program is to compute the angles and distances of movement for the robot based on user-supplied data. These calculated movement angles and distances are then translated into time units. A predefined value, representing the time required for one full revolution (360 degrees), is available. It's important to note that this time value differs among the base, elbow, and roll motor shafts. This variance is influenced by motor speed, gear ratios, and loads. These pre-calibrated values are loaded into the software as reference variables. Additionally, the program includes a feature that allows users to modify these values in the event that motors are replaced [23].

The program performs angle calculations and subsequently determines time intervals associated with these angles. These intervals are loaded into the timers integrated into the program. Subsequently, the program sends the necessary command byte to the parallel port to activate the desired motors. The timers are then initiated (enabled). Upon the expiration of a timer's interval, the respective timer triggers a timer event. This event serves as a signal for the program to halt the intended motor by sending a command byte to the parallel port. Importantly, this action does not impact the status of the other motors [24].

12. The Application General User Interface

This section explains the GUI of the application. It basically explains the different user screens in the application and their function. An algorithm has been developed for the robot to do a pick and place operation as shown in Fig. 4 [25].

Algorithm

Step 1 : Get R, θ, Z, ϕ from the user [26].

Step 2 : Now get the angle of shoulder from segment CD using

$$\text{Cos } \theta_1 = \{ (CA)^2 + (CD)^2 - (AD)^2 \} \div 2 \times (CA) \times (CD)$$

Step 3 : Get the angle of the elbow with respect to segment CA, that is, θ_2[27]

$$\text{Cos } \theta_{2'} = \{ (AD)^2 + (CA)^2 - (CD)^2 \} \div 2 \times (CA) \times (CD).$$

The elbow angle θ_2 is then calculated as [28]

$$\theta_2 = 180 - \theta_{2'}$$

Step 4 : Now we decide the optimum path of movement, that is, clockwise or counter-clockwise. We know that there are only two ways to reach the desired point D (that is, the user defined point). They are the ones shown in the diagram [29].

- To decide on which of the two paths is to be chosen we calculate the angles ϕ_{11} and ϕ_{12} given by :

ϕ_{11} -- The angle between the shoulder CA and the reference CO when moved in the clockwise direction

ϕ_{12} -- The angle between the shoulder CE and the reference CO when moved in the clockwise direction

$$\phi_{11} = \phi - \theta_1$$

$$\phi_{12} = \phi + \theta_1$$

- After calculating the angles ϕ_{11} and ϕ_{12} we check to see which position would require a lesser angular displacement of the shoulder while moving from the current position to the new one. To do this, we find the absolute difference between the current position angle (more aptly called the old angle) and the new angles ϕ_{11} and ϕ_{12}.

- If ϕ_{1old} is the old (current) shoulder angle, we need to find the individual differences between ϕ_{1old} and ϕ_{11} and ϕ_{1old} and ϕ_{12}. The magnitudes of these differences are then compared [30].

$$|\phi_{11} - \phi_{1old}| \text{ and } |\phi_{12} - \phi_{1old}|.$$

- The smaller difference is the obvious choice for the shoulder angle. The final shoulder movement angle 'θ_1 required' is the smaller of the two. The direction of displacement is decided by the sign of the selected difference. If the sign is positive, the movement should be clockwise else it should be counter-clockwise [31].
- We now calculate the elbow angle :

Now for the elbow angle, the calculation is simple and depends on which of the two segments CA or CE chosen; that is, of the two absolute differences : $|\phi_{11} - \phi_{1old}|$ and $|\phi_{12} - \phi_{1old}|$, the one chosen determines the sign of the elbow angle [32].

If $|\phi_{11} - \phi_{1old}|$ is chosen then the elbow angle is positive.

If $|\phi_{12} - \phi_{1old}|$ is chosen then the elbow angle is negative.

- The elbow movement angle (the angle by which the elbow has to move from the current position) is given by :
- Old Elbow Angle – New Elbow Angle ($\phi_{2new} = \phi_{2old} - \phi_2$).
- Depending on ϕ_{2new} we get : New elbow movement angle = $\phi_{2new} - \phi_{2old}$.

Step 5 : For Up – Down motion we simply decide on the home position of the rack and also the pick up height. This is done in-order to have a fixed pick up height to which the object is picked up prior to placing it at a different position on the ground [33].

- Pick Up Operation [34] :

Now when rack is to be activated for pick up operation we simply calculate the amount of vertical distance to be traveled by subtracting the height of the object from the home position of the rack. This gives us the Rack movement distance. After the gripper operation is completed we pick the object to the fixed pick up height.

- For Pick [35] :

  Rack Down movement Dist = Home position – Height Of Object

- Place Operation [37]:

For place operation, we activate the rack in the downward direction till the rack assembly is above the ground by an amount equal to the height of the object. This rack down movement distance for PLACE is obtained by [36] :

- For Place :

  Rack Down movement Dist = Pick up height – Height of Object

Step 6 : To calculate the roll movement angle we take the user specified roll angle ϕ roll and subtract the value of the current roll angle stored in a variable ϕ $roll_{old}$ from it. This will give us the value of the new roll movement angle [38].

Thus,

$$\phi_{roll\ new} = \phi_{roll\ old} - \phi_{roll},$$

where $\phi_{roll\ old}$ = old value of the roll angle and ϕ_{roll} = new value of roll angle specified by user in program [39]

Step 7 : The gripper is always kept in the open position. When the gripper motion is desired we call the gripper procedure where we send the close command to the driver circuit and then poll the Input port (status port) of the parallel port till we obtain a trigger signal from the limit switch attached to the gripper. This indicates that the object is gripped successfully. We then stop the gripper motion [40].

13. Use Of Parallel Port For Data Control / Acquisition

This section outlines the use of the parallel port to establish a connection between the PC and CRUST 2020. In a Visual Basic application, code is structured hierarchically, typically consisting of one or more modules. These modules include form modules for each form in the application, optional standard modules for shared code, and optional class modules. Each module contains one or more procedures with various types of code, such as event procedures, sub or function procedures, and property procedures. For interfacing between the computer and the robot, RS 232C has been utilized [41].

The PC printer port is a cost-effective yet robust platform for implementing projects that involve controlling real-world peripherals. This port offers eight TTL outputs, five inputs, and four bi-directional leads. However, Visual Basic cannot directly access hardware on a system. All hardware requests must pass through the

Windows operating system. Consequently, the closest we can get to manipulate the parallel port is by utilizing the printer object, which works well for printing tasks but is not suitable for direct hardware control [42].

To gain direct control of the port, an external component is required. In this case, we utilize WIN95IO.DLL for VB6. The DLL file itself should be placed in the Windows\system directory of any machine where the interface control software is intended to be used or developed [43].

The parallel port consists of three distinct sections: data lines, control lines, and status lines. There are 8 data lines, primarily used for transmitting information from the port. The control lines encompass another 4 outputs designed to send control signals to the printer, such as form feed or initialize [44].

The status lines serve as the only inputs on a standard parallel port, totaling 5 in number. They were originally intended for the printer to communicate information such as errors, paper out, and busy status to the PC. Each of these sections has its own unique address and operates independently of the others, functioning as if they were separate ports [45].

The addresses are given by [47]:

- Port Address for data lines (Decimal) – 388 &(Hex) – 378h
- for control line (Decimal) – 890 and (Hex) – 37Ah
- for status line (Decimal) – 889 and (Hex) – 379h

THE APPLICATION GUI

The different forms /screens used in the application are the [46] :

- Programming mode screen
- manual mode screen
- run mode screen
- advanced settings screen.

Programming Mode Screen

This is the default screen that appears when the software is launched. Users can create their own programs using the provided commands. These user-written programs make use of the application's intelligent path decision feature, which calculates various angles related to the robot's movements and makes decisions about activating one or more motors simultaneously. This optimization helps save time and power when the robot is moving toward a user-specified destination [48].

Key Features are

- Startup screen for the software application.
- Comprehensive HELP file accessible from the provided menu.
- Menu offering a variety of options for user selection.
- Intuitive and user-friendly interface.
- Support for looping operations.
- Cut, copy, and paste instruction functions.
- Capability to save the current program.
- Option to save the current program under a different name.
- Insert function for efficient programming.
- Program editing via up/down buttons..

PROGRAM Commands

The screen provides the user with following commands in the form of buttons [49]:

- MOVE,
- LOOP,
- START,
- LOOP,
- STOP,
- OPEN,
- CLOSE,
- INSERT,

- RUN,
- TERMINATE,
- RESET, UP / DOWN.

The user generates a CRUST 2.1 command by simply clicking on the buttons thereby avoiding time consumed in typing a program [50].

The Manual Mode Screen

This screen provides direct motor control for each component of the CRUST 2020 system. Users can access this screen via the programming mode screen by selecting it from the menu bar. Its key features include [51]:

- Manual control over individual motors
- Precise positioning control for the base, rack, elbow, and roll
- Motor rotation in both clockwise and counterclockwise directions
- Automatic RESET function for returning the robot to its home position on startup
- Dynamic reset function, allowing users to reset the robot at any time
- Auto-Teach feature for simplified operation.

The Run Screen

This screen is invoked from the programming mode screen and features facilities such as single stepping, run through and looping for the program loaded from the programming screen [52]. The Fig. 6 gives the designed Software Module in the form a GUI, whereas the Fig. 7 gives the designed Software Module in the form a GUI [53]. Then, the Fig. 8 gives the designed & fabricated 4-axes SCARA robot arm, whereas the Fig. 9 gives the Scara robot's gripper using rack & pinion motion [54]. The Fig. 10 gives the simulation & mathematical formulation of finding out the distance w.r.t. the Euclidean space, whereas the Fig. 11 gives the proposed block diagram for controlling the robot with the help of peripherals [55].

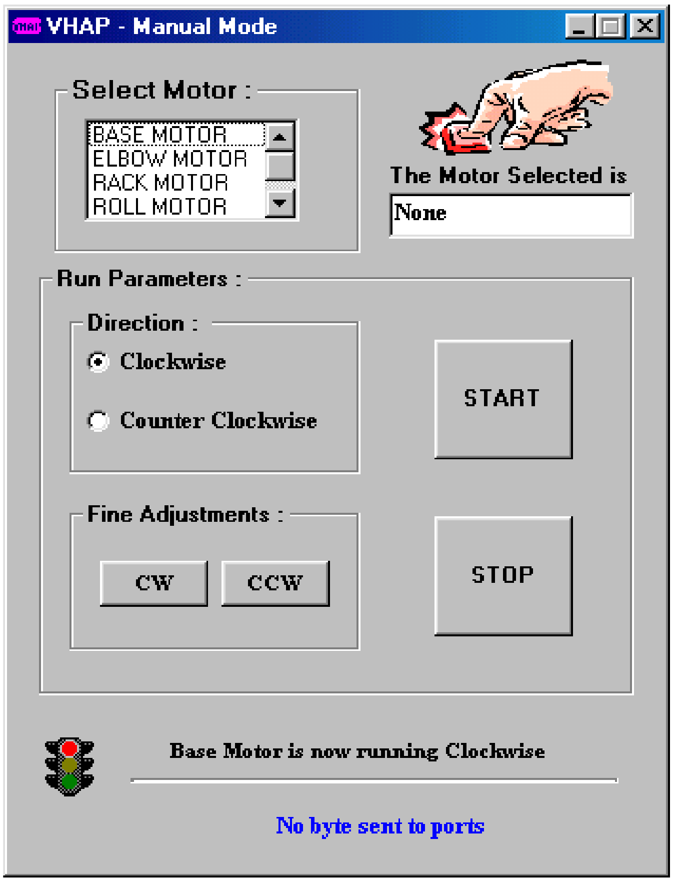

Fig. 6: Designed Software Module in the form a GUI

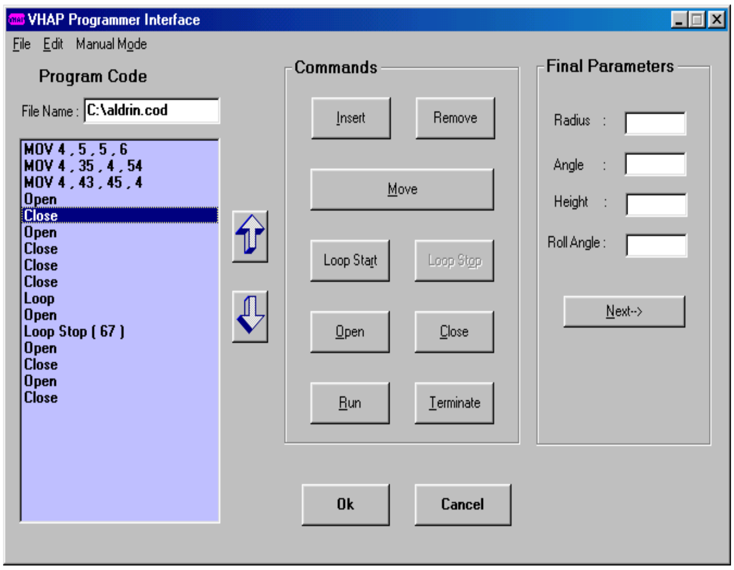

Fig. 7: Designed Software Module in the form a GUI

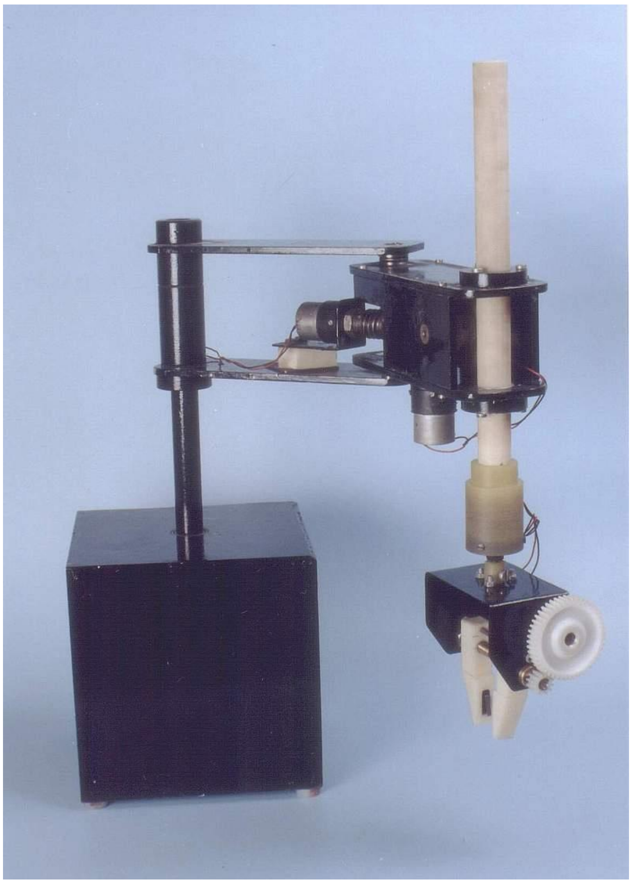

Fig. 8: The designed & fabricated 4-axes SCARA robot arm

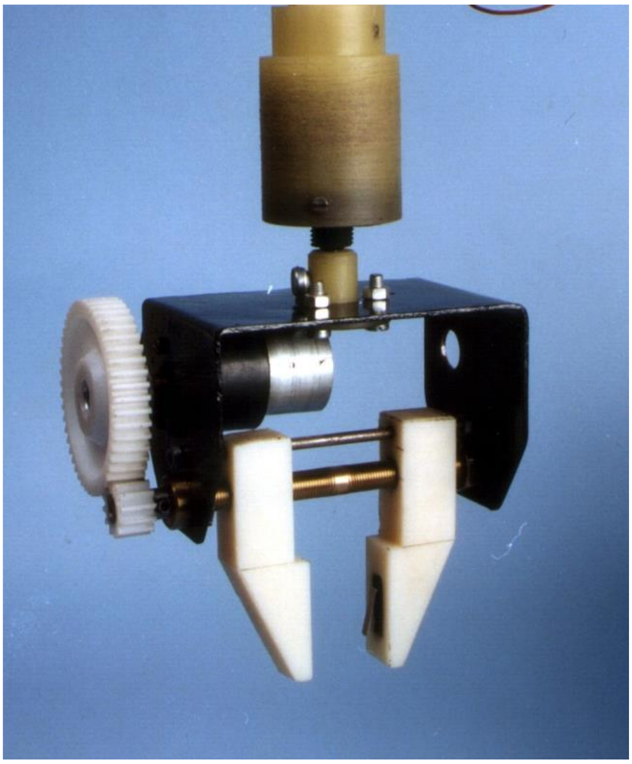

Fig. 9: Scara robot's gripper using rack & pinion motion

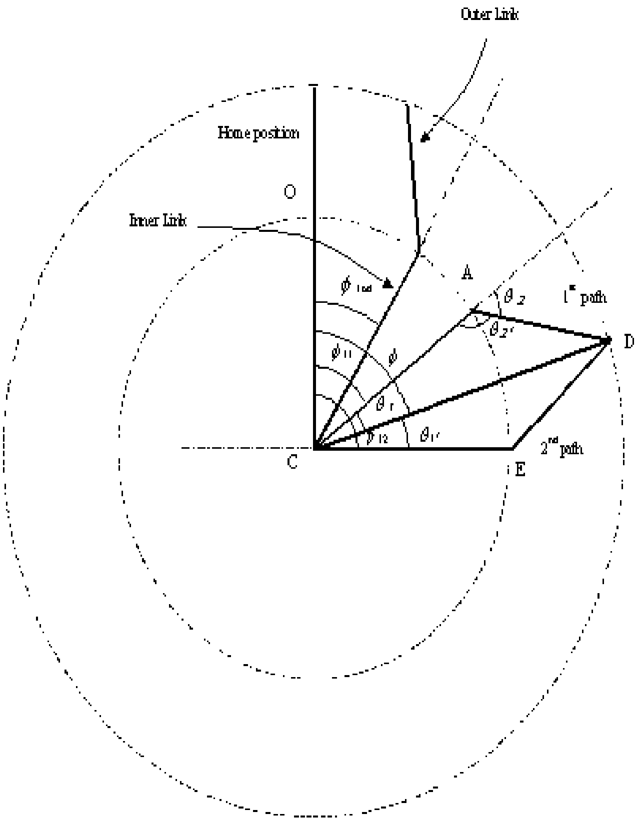

Fig. 10: Simulation & mathematical formulation of finding out the distance w.r.t. the euclidean concepts

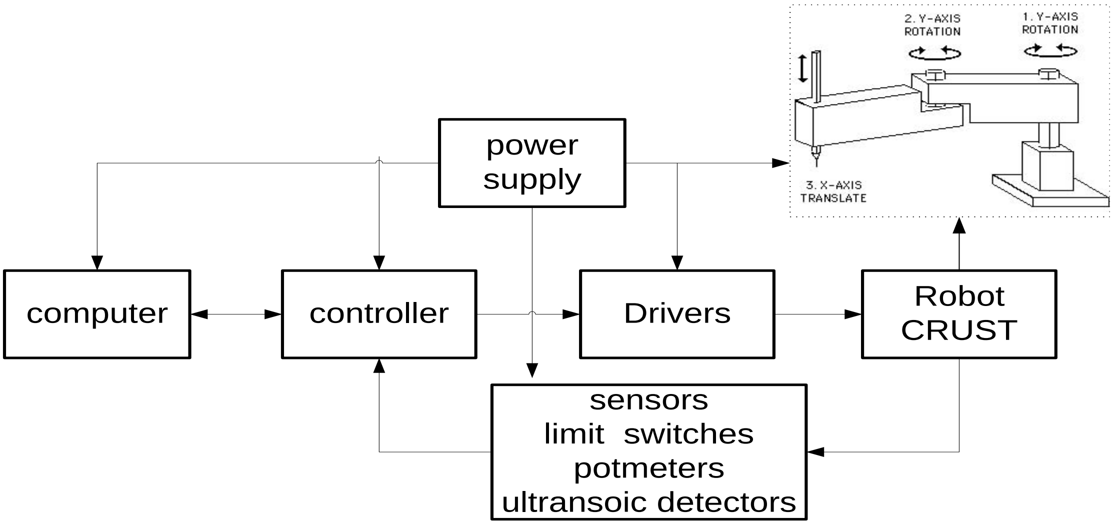

Fig. 11: Proposed block diagram for controlling the robot with the help of peripherals

14. Conclusions

This study introduces a four-axis robot system, which underwent simulation, design, fabrication, and successful testing. The mechanical assembly consisted of three core units: the base assembly, arm assembly, and the end-effector assembly. The electronic section encompassed the power supply unit, controller unit, and the driver unit, enabling diverse modes of control via a visual basic GUI. A concise kinematic analysis of the robot was conducted, leading to the successful execution of multiple pick and place operations in teaching, manual, and programming modes. The paper summarizes the research on the simulation, design, fabrication, and computer control of a four-axis CRUST 2020 stationary articulated robot manipulator arm. The methodology's effectiveness was validated through simulation results, highlighting its potential for real-world applications.

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