Design and Fabrication of SCARA Robot with 5 Degree of Freedom

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Abstract: ***These Robots are autonomous systems which can perform desired tasks in unstructured environments without continuous human guidance. Many kinds of robots are autonomous to some degree. Different robots can be autonomous in different ways the daunting task is delays and interruptions in robotic communication system. Control of the robotic arm has been achieved successfully by using servo motors. The micro-controllers implement inverse kinematics algorithms and position control is achieved through Stepper motors. The stepper motors are actuated using the internal stepper motor drivers and servomotors are controlled directly by micro controller. The robotic arm also has the provision of being controlled. The end effecter is a two finger gripper. The robotic arm has a load bearing capacity of around 100gms. The micro controller is programmed such that all the movements of the robot are synchronized to achieve Switches and force sensors are deployed for safety and continuous running of robot. For a robot it is obviously important that it can operate from batteries. Since the micro-controller runs with 5V and motors are with 6V. The main objective is to study the motion constrains and redundancies in positioning the gripper. An extensive study carried out for understanding inertia affect on links due to velocities and acceleration. Axon micro controller which is exclusively designed for robot is used and the software is implemented in embedded system and written in C and C++.***

Keywords: micro controllers, stepper motor, servo motors, inverse kinematics

1. Introduction

"A robot is a reprogrammable, multifunctional manipulator designed to move materials, parts, tools or specialized devices through variable programmed motions for the performance of a variety of tasks" Robot is an intelligent and human operated self controlled. Robotics has made a revolution in the field of industry and in many domestic applications. Robotic plays a vital role such as surgery, exploration and majority robots used in field of industry and industrial applications. Some of the industrial applications are in automobile industries, home appliance manufacturing industries, aero-space industries, computer assembly etc. Robotics is a prominent component of manufacturing automation which affects human labour at all levels, from unskilled workers to professional engineers and manager of production. Future robots may find applications outside of the factory in banks, restaurants, and even homes. It is possible, likely, that robotics will become a field, like today's computer technology, which is pervasive throughout our Society. It is a system that contains sensors, control systems, manipulators, power supplies and software all working together to perform a task. Designing, building, programming and testing a robot is a combination of physics, mechanical engineering, electrical engineering, structural engineering, mathematics and computing. In some cases biology, medicine, chemistry might also be involved. The study of robotics means that we are actively engaged with all of these disciplines in a deeply problem-posing problem. Robot can be defined as programmable multi-functional manipulator. It is used to move or hold work pieces or specialized devices and it can able to perform verity of tasks. The use of robots is necessary to meet production demands. There are many advantages to incorporating robots such as, decreasing cost and waste material while speeding production. Robots are also removing the risks to employees by performing dangerous tasks. Since the first industrial machine-tending robot was introduced in North America in the 1960s, the industry has grown to more than 135,000 robots in operation, according to figures from the Robotic Industries Association (RIA). These are very advanced state of robot and posses sufficient artificial and machine intelligence. Somewhat analogous to the sensory perception of the neuromuscular co-ordination that human being of capable of intelligent robots cannot only explore the environment on their own perceptions and evaluate them in real time. But also execute the necessary motor functions to match the action of the sensor inputs. Advance robots have been built with mobility to not only move over flour but also to climb. Compactly assemble with no board sensors, instruments and power supplies.

2. Literature Survey

SCARA type robotic arm with rotary hydraulic actuators and showed that it's difficult to obtain high speeds and torques with electrical actuators. A comprehensive literature review related to dynamic analyses of flexible robotic manipulators is presented by Dwivedy & Eberhard (2006). The review of the published papers is classified as modeling, control and experimental studies. In case of modeling, they are subdivided depending on the method of analysis and number of links involved in the analysis. In this work both link and joint flexibilities are considered. Total of 433 papers presented between the years 1974–2005 have been reviewed in this work. Akdağ (2008) presented integrated cae procedures to design and analysis of robot manipulators. He designed three different robots which are following this process and also investigated new concept named as "Rigidity Workspace" according to the end point static deflections and modal behavior of the robot. Das (2003) worked on SCARA robot motion control with a PLC unit. He developed PLC codes of Siemens S7-200 and controlled the SCARA for three different sized objects to pick and place from one point to the target. Sayğılı (2006) designed a SCARA type manipulator and manufactured its parts with CNC machine. He also obtained kinematic equations of SCARA type manipulator. Due to rapid point- to-point movements, SCARA robot arms exhibit large vibrations after reaching the destinations position. So, their residual vibration analysis must be done before manufacturing (Tao, Zhang, Ma & Yun, 2006). In the early 1800's mechanical toys were first built in Europe, just for entertainment value. And these were called robots since there parts were driven by linkage and cams. In 1801 Joseph Maria Jacquard made the next great change and invented the automatic draw loom. The draw loom would punch cards and was used to control the lifting of thread in fabric factories. This was the first to be able to store a program and control a machine. After that there were many small changes in robotics but we were slowly moving forward. The first industrial robots were Animates developed by George Devol and Joe Engelberger in the late 50's and early 60's. Engelberger has been called the "father of robotics" for his contributions. For a while the economic viability of these robots proved disastrous and thing slowed down for robotics. But the industry recovered and by the mid-80's robotics was back on track. George Devol Jr, in 1954 developed the multi-jointed artificial arm which leads to the modern robots. But mechanical engineer Victor Scheinman, developed the truly flexible arm know as the Programmable Universal Manipulation Arm (PUMA).

3. Design and Fabrication of SCARA Robot with 5 Degree of Freedom

3.1 Kinematics of Robot

Kinematics is the science of motion. It is restricted to a pure geometrical description of motion by means of position, orientation, velocity, and acceleration. Forces and torques causing the motion is not considered here. The most important application of technical kinematics is in robotics and gearing design. In robotics, the kinematic descriptions of manipulators and their assigned tasks are used to set up the fundamental equations for joint control.

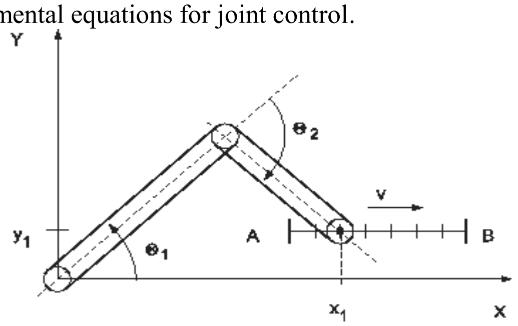


Figure 1: Planar two-link mechanism

3.2 Inverse Kinematics

Given a transformation of the form,

$$\mathbf{T} = \begin{bmatrix} nx & ox & ax & px \\ ny & oy & ay & py \\ nz & oz & az & pz \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

The inverse transformation of T, denoted by $\mathbf{T}^{-1}$ is defined as follows

$$\mathbf{T}^{-1} = \begin{bmatrix} nx & ny & nz & -p.n \\ ox & oy & oz & -p.o \\ ax & ay & az & -p.a \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Where

p.n, p.o and p.a represents the dot products of the column vectors n, o, a and p.

The dot product p.n is the scalar pxnx + pyny + pznz.

Similar interpretations apply to p.o and p.a. The effect of an inverse transformation T-1is to undo operation accomplished by the transformation itself.

3.2 Denavit-Hartenberg Notation

In order to find a transformation from tool tip to the base of a manipulator, it is required to define link frames and to derive a systematical technique, which allows describing the kinematics of a robot with n degrees of freedom in a unique way. A set of 4 x n parameter will turn out to be sufficient for that purpose.

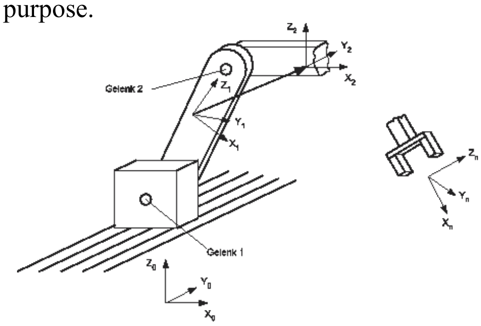


Figure 2: Links of a kinematic chain

The base and each link Ki of the chain is assigned to a specific frame, which is fixed to the link. Therefore coordinate frame Ki can be described from its precedent link frame Ki-1 by means of a homogeneous transformation. This homogeneous transformation includes the joint angle for rotary joints or the joint offset for prismatic joints.

3.3 Fabrication

The robot consists of a cart with four wheels on which the base link is mounted on two C channels. This cart is front wheel drive and driven by two stepper motors. All the drivers for stepper motors, microcontroller and connecting cables were placed within the cart. The cables used for connecting the drivers of the links are passed through central opening of base link. The origin of the robot is located at the base link to the shoulder link connecting member i.e. shoulder shaft. To facilitate the griper to reach bottom most point below the bottom of the cart base, the shoulder shaft elevation is raised by 65mm from the top plane of the base link.

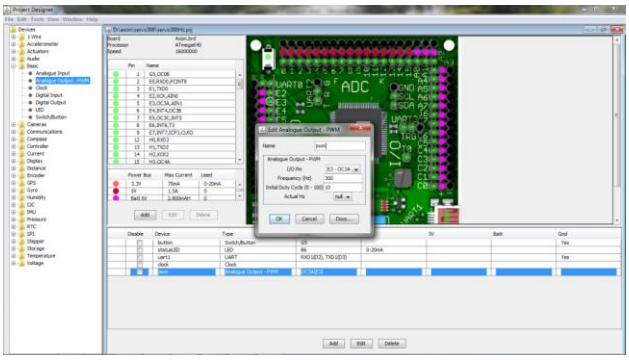
To provide stability and reduce the friction a groove is provided for stainless steel balls of diameter 4mm in between base top and bottom disks. It is also prevent the top of the base plate from tilting when the gripper reaches extreme positions. A stub end for both top base plate & bottom base plate is provided to maintain verticality and to provide protection to the cables coming from all the links to batteries and microcontroller. High carbon steels is selected for the making base links and supporting lugs. Since high carbon steel is more corrosive resistance and high strength material. The cart body is made of rolled mild steel of gauge 16 and to improve rigidity front and back faces are made with corrugated sections. The total cart is made from a single sheet and web sections are provided to improve stiffness. For safety reason, the ends of the plates are riveted and gas weld. To prevent corrosion the cart is painted red oxide and resin paint. The bottom plate is made from 2mm aluminum sheet. The wheels of the cart is made of plastic reinforced with stainless steel web section and wrapped with rubber thread. In order to increase that radius and improve the gripping additional layer of rubber is provided. The base link is allowed to rotate 360 degrees with a gear train connected to a stepper motor. The stepper motor gear is made aligned with gear connected to base link by using four studs and bolts and it is secured to bottom plate. The cable passing through centre of the base link is restrained by c-clamps and cable guard is used to identify the route and protect the cables from crushing. A switch is fastened to body of the cart to switch on and off the power. Shoulder link is made from 3mm aluminum sheet after modeling of the link using solid modeling software the relative positions of shaft holes and servo motor fixture holes were located. The cross section of the link selected is C. After establishing development of surface drawing, the profile of links was cut from the aluminum sheet, is bended using press. To fix the aluminum link with shaft made of mild steel a spacer is used. The spacer and link were drilled with three holes and fastened by using screws and nut. A servomotor is secured in position in the link by using screws and nuts. A gear is attached to servomotor by a long screw. The shaft of shoulder link connected to a stepper motor through a gear train to rotate elbow link and the distance between axes is 75mm. The reduction ratio selected is 2:1 to reduce torque requirement.

Pug screws are used for securing gears with stepper motor and shoulder link shaft. Similar way the elbow link is made. The elbow link is connected to shoulder link is using gear train with 2;1 reduction ratio. The shaft of elbow link connected to a stepper motor through a gear train to rotate wrist link and the distance between axes is 30mm. A gripper is fabricated as for the drawing and is mounted on to the elbow link using a gear train of 2:1 reduction ratio. The gripper consists of two gears coupled with two fingers. One of the gears is directly connected to a gear mounted on servo motor. This construction makes the finger move either inward or outward.

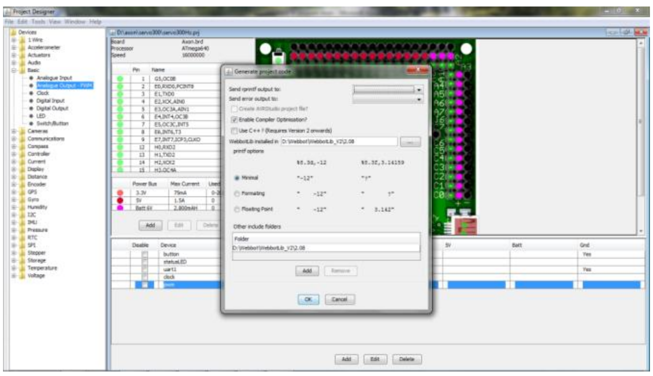
3.4 Programing

The microcontroller used to control the robot is Axon exclusively designed for robots. To carry the programming, it is required to install the Java first in the computer. WinAvr studio, Atmel AVR Studio, Webbotlib project designer, Ro0110_ex_Fboot and Webbotlib version controllers to be installed in the computer. Open the project manager. Select the new project and choose the Axon micro controller, set actual voltage to 6 volts & rating to 2100mAH and name the project and save it to the hard disk.

Add the desired inputs to the program by just dragging them from Devices menu.



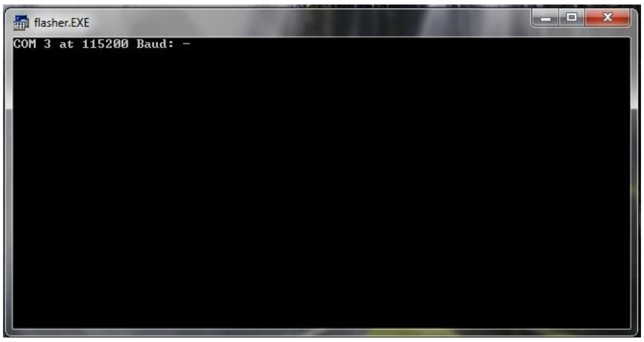
Name the device and give the initial values. After adding the all devices save the file and select tools menu to generate the project file. Enable create the avrstudio project file, locate where the Webbotlib is installed and set the path where the generated files to be stored. A project file will be created.



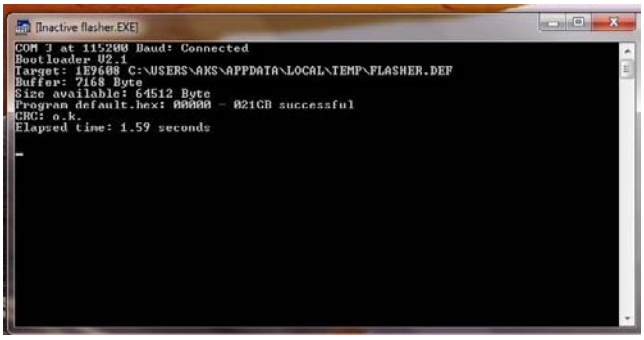
Open the project file using AVRStudio and make necessary changes to the C program and build all the files. You see the following message in command window.

avr-size --format=avr --mcu=atmega640 servo300Hz.elf
AVR Memory Usage
Device: atmega640
Program: 8652 bytes (13.2% Full)

(.text + .data + .bootloader)
Data: 223 bytes (2.7% Full)
(.data + .bss + .noinit)
Build succeeded with 0 warning
A Hex file with program name is created. Initiate the Ro0110_ex_Fboot program.



Select the baud rate to 115200 and the COM port. Locate the HEX file and press the flash button. It will initiate the port. Connect the Axon microcontroller using USB cable and switch on the microcontroller power. The file will be transferred to the microcontroller memory.



SUCCESS!
YOU HAVE SUCCESSFULLY PROGRAMMED YOUR MICROCONTROLLER!

Now, connect the relevant stepper & servo motors, sensor and switch etc. to relevant port and connect the power and run the program by switching the power on to the microcontroller. The robot is designed carry out PICK and PLACE operation. Using inverse kinematics find the angels of the corresponding links to rotate to gripper to reach the designated point in work envelope The stepper motor is controlled by a digital output pulse to make it rotate and another digital output pulse to change direction. First the digital output to be set to a frequency. The number of pulses required to rotate the stepper motor shaft on rotation i.e. 3600 is equal to the frequency. To make the stepper motor to rotate by certain degree, set the digital output to high and low alternatively in a loop that runs N number of times equal to angle*frequency/360. Whenever the direction of the stepper motor to be changed, toggle the direction changer digital output. A servo motor can be continuous positioning or Fixed positioning. It can be regulated by PMW output. For fixed positioning, either 90 or 180 position control is widely used. Based on the frequency the initial and final positions are calculated Servos are composed of an electric motor mechanically linked to a potentiometer. A standard RC receiver sends pulse-width modulation (PWM) signals to the servo. The electronics inside the servo translate the width of the pulse into a position. When the servo is commanded to rotate, the motor is powered until the potentiometer reaches the value corresponding to the commanded position. RC servos use a three-pin 0.1" spacing jack which mates to standard 0.025" square pins. The most common order is signal, +voltage, ground. The standard voltage is 6 V and 12 V has also been use for a few servos. The control signal is a digital PWM signal with a 50 Hz frame rate. Within each 20 ms timeframe, an active-high digital pulse controls the position. The pulse nominally ranges from 1.0 ms to 2.0 ms with 1.5 ms always being center of range. Pulse widths outside this range can be used for "over travel" moving the servo beyond its normal range. The servo is controlled by three wires: ground, power, and control. The servo will move based on the pulses sent over the control wire, which set the angle of the actuator arm. The servo expects a pulse every 20 ms in order to gain correct information about the angle. The width of the servo pulse dictates the range of the servo's angular motion. A servo pulse of 1.5 ms width will typically set the servo to its "neutral" position or 45°, a pulse of 1.25 ms could set it to 0° and a pulse of 1.75 ms to 90°. The physical limits and timings of the servo hardware varies between brands and models, but a general servo's angular motion will travel somewhere in the range of 90° - 120° and the neutral position is almost always at 1.5 ms. This is the "standard pulse servo mode" used by all hobby analog servos.

3.4.1 The Gripper Servo

It is continuous position servo. The gripper servo frequency is set to 50 Hz. It is set to 00 or initial position and allowed to move 250 micro second to move by setting the band width to 10. The gripper fingers closes and set the band width to 0 to make it stay in the same position. To open fingers, band with is set to 5 and allow it to move for 250 micro seconds and again set the band width to 0 to maintain the fingers remains in the same position.

3.4.2 The Wrist Servo

The initial position of the servo is at 00 and band width is at 5 and when the band with is set at 10, it goes to 900. In order to maintain the angels between 0 and 90, the band with is to be changes from 05 to 10 in proportion to the angles.

3.4.3 The Gripper Servo

The initial position of the servo is at 00 and band width is at 5 and when the band with is set at 10, it goes to 900. In order to maintain the angels between 0 and 90, the band with is to be changes from 05 to 10 in proportion to the angles.

3.4.4 The Left and Right Wheel Stepper Motors

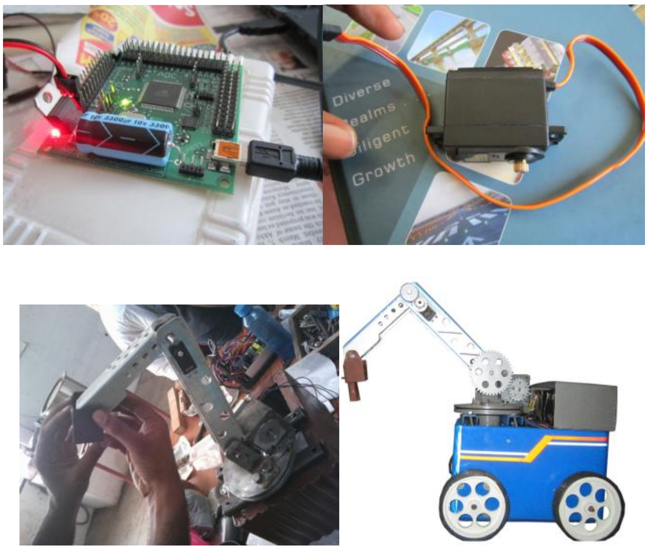
The frequency is set at 1000. It requires 1000 signals to make one rotation. To make 5 rotations, it is expected to give 5000 signals. To Change the direction, direction pulse to be set to high to make it rotate clock wise and low to make it rotate anti-clock wise.

3.4.5 The Shoulder Stepper Motor

The frequency is set at 10000. It requires 10000 signals to make one rotation. To make 900 rotations, it is expected to give 2500 signals. To Change the direction, direction pulse to be set to high to make it rotate clock wise and low to make it rotate anti-clock wise.

3.4.6 The Shoulder Stepper Motor

The frequency is set at 20000. It requires 20000 signals to make one rotation. To make 600 rotation, it is expected to give 3333 signals. To Change the direction, direction pulse to be set to high to make it rotate clock wise and low to make it rotate anti-clock wise.



Fabrication Process

4. Results

The robot is successfully fabricated as per the design and drawings and programmed and demonstrated all the links movement. The fowling observations are recorded during fabrication. The cart vertical walls are not parallel to each other and perpendicular to the ground plane. This caused variable loads on the wheels and due to different drag force the wheels are moving with variable velocities. The Shoulder, elbow and gripper links fabricated from AL and it is very difficult to attach them to the shafts which are made from Mild Steel. The straight teeth spur gear train is used for difficulties in sourcing them in small quantities. It is always advisable to use inclined teeth or radial teeth as it reduces the backlash error. The links must be closed to minimize the deflection on the side of open C. The gripper to be made smaller and stiffer to engage the job in question precisely. The length of finger in gripper must be reduced to minimize the bending moment. Servo motors are reacting quickly to the change in signal. There is supposed to be time delay while executing the movement with servo motors. Charging facility to be incorporated with cart. Marginal vibration that are caused by the cart initial movements to be suppressed by using spring and damper system.

5. Future Work

Conduct analysis of increase in velocities and accelerations and observe the overshooting and undershooting phenomenon. Continuous path algorithm to be developed and implemented. Using GPS system, feedback control to be incorporated to reduce positional error. Continuous path control to be implemented using LEDs. Force sensor to be used to prevent damage to the links in case of excess load carrying conditions. The links to be fabricated using Stainless Steel sheet to reduce the weight and improve the stiffness. The spiral gear trains to be used for all the gear transmission requirements to reduce the back lash error and improve rigidity.

References

[1] Shizhe Tan,Ruqing Yang. Based on analysis of SCARA ontology open robot kinematics a nd dynamics modeling. Modular Machine To ol & Automatic Manufacturing Technique. pp. 22-24,2011.

[2] Xihuang Lai,Jiying Yin,Yong Gao. Kinematic s analysis and dynamic equation for an exper imental robot. Machinery Design & Manufact ure. pp. 116-117, 2006.

[3] Lina Li,Hongyi Liu,Xiaolv Ning. The Applica tion of Matlab in the Graphics Simulation Sy stem of Robot. Machinery & Electronics. pp. 54-55, 2006.

[4] Xueqing Zhai,Yurong Zhu,Kuangrong Hao. T he Realization of Dynamic Simulation for 6R Robot under the Environment of MATLAB. Light Industry Machinery. pp.48-51, 2005.

[5] Jiajia Luo,Guoqing Hu. Study on the Simulat ion of Robot Motion Based on MATLAB. Jo urnal of Xiamen University(Natural Science). pp. 640-644,2005.

[6] Jian Fang. Design and Application research o f SCARA robot motion controller. Jilin unive rsity. 2007.

[7] Jian Fang,Junyi Liu, Dongyou Wang. The De sign of SCARA Robots' Motion Controller. Journal of Jilin Teachers Institute of Engineeri ng and Technology. pp. 66-68,2008.

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