Automation and Modelling of Delta Robot for Solar Cells Assembling

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***Abstract*— *The manufacturing community is on the cusp of a development and innovation. It is vital to find the most cost-effective tools and processes to increase productivity and decrease costs within a set capital plan. Robotic automation is a significant part of manufacturing process. Image processing has become a highly adopted tool to improve the productivity of robotic automation in all industries and all facets of placement which offer tremendous flexibility. The proposed paper gives comparison of the robotic structure such as serial and parallel manipulator and different technologies that have been implemented. The proposed paper introduces a low cost system that will automate the production of the solar panels. This objective can be achieved by using a delta robot along with control unit, image processing and a camera. The delta parallel manipulator is a mechanical structure that allows a rigid body (called end effectors) to move with respect to a fixed base. The position and the orientation of the end effectors can be described by its generalized coordinates which will be controlled by a control unit and image processing.*

keywords: Image processing, parallel manipulator, serial manipulator .

I. Introduction

This is era of automation where each and every field is trying to automate the tasks. The robots are one of the key structures used in automation. A robot may be defined as a machine that perform various complex and often repetitive tasks; guided by automatic controls. Industries are the area where the automation is geared up to increment the productivity within given time period. One of such a industries is photovoltaic industry. The global photovoltaic (PV) manufacturing community is on the cusp of a resurgence in investment, development and innovation, a revolution that largely will be driven by technology. Robotic automation is a significant part of solar cell manufacturing. One of the tasks in PV industry is to mount solar cells on the supportive base made up of glass or any other substrate with gentle handling. This process can be done by using parallel manipulators.

A. Necessity

In recent years, photovoltaic industry has been experiencing an enormous growth at the global level. The increasing costs of conventional fuels as well as the growing demand for Renewable Energy Sources (RES) are known to be the main drivers behind this rapidly expanding industry. Hence, robots in the photovoltaic manufacturing process are important due to their ability to significantly reduce costs while continuing to increase their attractiveness compared to manual labour [13]. History has shown that automation has played a significant role in reducing manufacturing costs in many manufacturing industries. Since the solar cells are fragile, in PV industries they must be handled precisely and gently. Parallel manipulators are suitable for such job which has good repeatability and accuracy. Hence we need an automotive system that will automate the process in PV industry [13].

B. Objectives

The objectives of the proposed system are given below

- To select and design a parallel manipulator robot for a required workspace.
- To control the movements of the end effector by using a control unit.
- To develop a MATLAB code for the processing of the images captured by camera to calculate the positional information of the object .
- To obtain good repeatability and accuracy with high speed movements of the robot.

II. LITERATURE SURVEY

ABB Flexible Automation launched its Delta robot in 1999 under the name IRB 340 Flex Picker. Three industry sectors were aimed: the food, pharmaceutical, and electronics industries. The Flex Picker is equipped with an integrated vacuum system capable of rapid pick and release of objects weighing up to 1 kg. The robot is guided with a machine vision system by Cognex and an ABB S4C controller. After nearly ten years research and experience in the field of packaging technology came Flex Picker IBR 360 with the second generation of Delta ABB robots. This second generation is even more efficient [10].

In 2004, the German company Bosch Group purchased the SIG and SIG Pack Division Demaurex and included it in their packaging technologies. Many Delta robot models have been developed by BOSCH, for example: XR31: higher performance and higher reliability, XR22: a combination of compact design and high accuracy, Paloma D2 built in stainless steel in order to meet hygiene standards and regulations for food industry. These robots have been placed in the following production lines:1) Mono Packer 2) LDM: A very flexible system used to place large volumes of products in containers directly from the manufacturing process. 3) Feed Placer [10].

André Olsson implemented the Pac Drive automation system by ELAU is used to control different applications with the same software. The applications is programmed with help by the program EPAS-4 and then transferred into a Pac Drive controller which controls the motions of the different drives in the system. The Pac Drive controller is the brain of the system where the program code is stored, which in turn synchronize and sends information over a SERCOS bus to the different servo drives (MC-4 motor controllers) connected to the system. Each servo drive then controls the motion of the motor shaft using the information from the Pac Drive controller[18].

Another system was implemented using robot to play a game of checkers using DSPIC30F4013 using its PWM modules. It involved creating a GUI for two human players to interact with and have the robot carry out the players' actions on a physical checkers board. A more complex system using image processing software, the robot could then operate independently of any controlling computer implementation could have included giving the robot an artificial intelligence for checkers and play against the player. Our final implementation involved having the robot draw pictures on a piece of paper using a magic marker.

Filippo Sanfilippo and Domenico Prattichizzo proposed an Arduino microcontroller to manage the robot via USB. They programmed the Arduino to read OSC serial messages, and an interface for the iPhone that reads the accelerometer's data and sends them to a server application via OSC messages. When the server receives them, it calculates inverse kinematics and sends the joint angles' values to the Arduino. The angles are used to drive the motors [3].

III. SYSTEM DESIGN

Following fig.1. shows typical PV process steps. The steps are broken into four basic groups where high concentrations of robots are deployed. The ingot processing step predominantly uses Cartesian gantries and large articulated arms due to the requirement for heavier payloads and large workspace optimization. Wafer manufacturing uses a variety of arm types depending on volume and process requirements. Cell processing tends to use gantries, SCARAs and parallel linked robots and the decision usually lies with the reach and repeatability considerations. Module build process uses parallel robots.

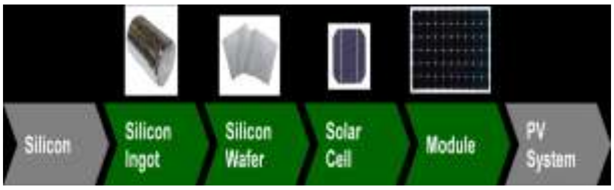

Fig.1: Typical PV process steps.

The comparison of the four robot categories of industrial robots is shown in table I.

A robot is a reprogrammable multifunctional manipulator designed to move material, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks. Robots can be classified according various criteria, such as degrees of freedom, kinematic structure, drive technology, workspace geometry, motion characteristics, control. Serial robot consists of several links connected in series by various types of joints, typically revolute and prismatic. One end of the robot is attached to the ground and the other end is free to move in space. For a serial robot direct kinematics is fairly straightforward, whereas inverse kinematics becomes very difficult. Whereas parallel robot manipulator is composed of two or more closed-loop kinematic chains in which the end-effector (mobile platform) is connected to the fixed base platform by at least two independent kinematic chains. Between the base and end effector platforms are serial chains called limbs [1].The following table II shows the comparison between serial and parallel robots.

Table I: Comparison of the four robot categories

Type	Specification	Model
Cartesian Robots	• Too slow for loading/unloading using • Cells require pre-alignment • Less flexible when reconfiguring for different size wafers is required	
SCARA Robots	• Faster and more flexible than Cartesian robots when used with vision guidance • Table mounted versions could limit work space and multiple robots may required to cover pallet/matrix	
Articulated Robots	• Too slow for loading/unloading • Spherical work envelope isn't ideal for covering pallet/matrix	
Delta / Parallel Robots	• Overhead mount design ideal for loading/unloading equipment • Larger delta robots can cover the width of most PECVD pallets • When used with vision guidance, enables extremely good positioning • Excellent flexibility and quickly reconfigurable • Robot design optimal for handling cells (lightweight) at high speeds	

Table II: Characteristics of serial and parallel robot

Features	**Serial**	**Parallel**
Workspace	Large	Small and complex
Position error	Accumulates	Averages
Workspace/ robot size ratio	High	Low
Accuracy	Low	High
Stiffness	Low	High
Solving forward kinematics	Easy	Very difficult
Solving inverse kinematics	Difficult	Easy
Modelling and solving dynamics	Relatively simple	Very complex

A. Mechanical Structure Design

The basic idea behind the Delta parallel robot design is the use of parallelograms. There are three kinematic chain containing an arm and forearm. The forearm is a parallelogram made up of stainless steel. The use of three such parallelograms restrains completely the orientation of the mobile platform which remains only with three purely translational degrees of freedom. The input links or arms of the three parallelograms are mounted on actuators. These actuators are servo motors. Finally, a mechanism is used to transmit rotary motion from the base to an end-effector mounted on the mobile platform. The end effector is an electromagnet which is used to pick the object. Mechanical structure of Parallel manipulator is shown in fig.2.

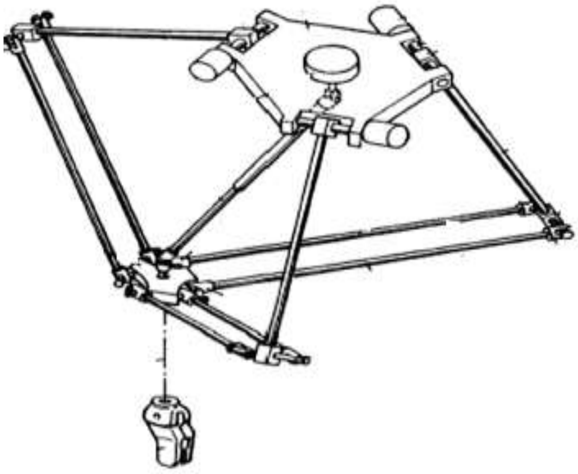

Fig. 2: Mechanical structure of Delta manipulator [10].

The components of parallel manipulator are explained in fig.3.

Fig. 3: Components of parallel manipulator

1) Structure: The structure of a robot is usually mostly mechanical and can be called a kinematic chain. The chain is formed of links, actuators, and joints which can allow one or more degrees of freedom. Most contemporary robots use open serial chains in which each link connects the one before to the one after it. These robots are called serial robots and often resemble the human arm. Robots used as manipulators have an end effector mounted on the last link. This end effectors can be anything from a welding device to a mechanical hand used to manipulate the environment.

2) Actuation: Actuators are like the "muscles" of a robot, the parts which convert stored energy into movement. The most popular actuators are electric motors that spin a wheel or gear, and linear actuators that control industrial robots in factors. But there are some recent advances in alternative types of actuators, powered by electricity, chemicals, or compressed air.

3) Vision: Computer vision is the science and technology of machines that see. As a scientific discipline, computer vision is concerned with the theory behind artificial systems that extract information from images. The image data can take many forms, such as video sequences and views from cameras.

4) Manipulation: Robots which must work in the real world require some way to manipulate objects; pick up, modify, destroy, or otherwise have an effect. Thus the 'hands' of a robot are often referred to as end effectors, while the arm is referred to as a manipulator. Most robot arms have replaceable effectors, each allowing them to perform some small range of tasks. Mechanical gripper is one of the most common effectors is the gripper. In its simplest manifestation it consists of just two fingers which can open and close to pick up and let go of a range of small objects. Fingers can for example be made of a chain with a metal wire run through it. Pick and place robots for electronic components and for large objects like car windscreens, will often use very simple vacuum grippers. They can hold very large loads provided the pretension surface is smooth enough to ensure suction.

B. Basic Methods of Programming Robots

There are three basic methods for programming Industrial robots as follows

1) Teach Method : The logic for the program can be generated either using a menu based system or simply using a text editor but the main characteristic of this method is the means by which the Robot is taught the positional data. A teach pendant with Controls to drive the robot in a number of different co-ordinate systems is used to manually drive the robot to the desired locations. These locations are then stored with names that can be used within the robot program.

2) Lead Through : This system of programming was initially popular but has now almost disappeared. It is still however used by many paint spraying robots. The robot is programmed by being physically moved through the task by an operator. This is exceedingly difficult where large robots are being used and sometimes a smaller version of the robot is used for this purpose. Any hesitations or inaccuracies that are introduced into the program cannot be edited out easily without reprogramming the whole task. The robot controller simply records the joint positions at a fixed time interval and then plays this back.

C. Programming languages

1) Visual Language: The approach is to start with the program rather than the data. The program is constructed by dragging icons into the program area and adding or inserting into the sequence. For each icon programmer has to specify the parameters (data). For example for the motor drive icon you specify which motors and by how much they move.

2) Parallel Language: All robotic applications need parallelism and event-based programming. Parallelism is where the robot does two or more things at the same time. This requires appropriate hardware and software. Most programming languages rely on threads or complex abstraction classes to handle parallelism and the complexity that comes with it, like concurrent access to shared resources.

3) MATLAB: The name MATLAB stands for Matrix Laboratory. MATLAB was written originally to provide easy access to matrix software developed by the LINPACK (linear system package) and EISPACK (Eigen system package) projects. MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming environment. Furthermore, MATLAB is a modern programming language environment: it has sophisticated data structures, contains built-in editing and debugging tools, and supports object-oriented programming.

4) C Language : As a programming language, C is rather like Pascal or Fortran. Values are stored in variables. Programs are structured by defining and calling functions. Program flow is controlled using loops, if statements and function calls. Input and output can be directed to the terminal or to files. Related data can be stored together in arrays or structures. This can result in short efficient programs, where the programmer has made wise use of C's range of powerful operators.

D. **Software Requirement**

MATLAB has many advantages compared to conventional computer languages (e.g. C, FORTRAN) for solving technical problems. It also have easy to use graphics commands that make the visualization of results immediately available. A personal computer incorporating MATLAB is used in this system for image processing of the image captured by the camera. A MATLAB code is to be developed using this software. The positional information as well as physical parameters of the object to be picked can be obtained from the image processing output.

E. Hardware requirements

The system incorporates Arduino UNO controller board with ATmega 328 microcontroller. The 16×2 LCD is interfaced with the controller to display the status of the system. A camera is connected with the computer to capture the images.

F. Concept of Proposed System

The proposed system uses a parallel manipulator along with controller, camera, MATLAB tool, motors, drivers ICs, etc as shown in above fig 4. In this system, the pick and the place of the object at appropriate position is to be carried out. For this purpose the camera is used which will be placed on the assembly. This camera is used to capture the images of incoming solar cells. Upon capturing image the image processing will be carried out on that image to calculate the positional information of that object by using suitable algorithm in MATLAB tool. The output of the image processing will be conveyed to microcontroller through serial receiver. The proposed visually servoed robot does not need to know a priori the position of objects in its workspace. It has integrated visual control systems to monitor precise product pickup and placement. This avoids positioning errors and incorrectly aligned products, thus reducing downtimes. Visual servoing is a rapidly maturing approach to the control of robot manipulators that is based on visual perception of robot and work piece location. More concretely, visual servoing involves the use of camera to control the position of the robot's end-effectors relative to the work piece as required by the task.

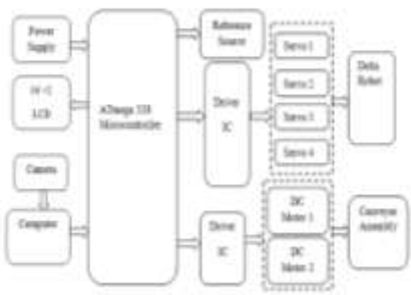

Fig.4: Architecture of the proposed system

G. System implementation

The following fig.5 and fig.6 shows the architecture of the proposed system and designed delta structure respectively. The basic idea of the delta robot is explained earlier. The delta robot is a mechanical structure having three arms mounted on the steady platform in such a way that the three links are at 120^0 each. The movement of the links is carried out by the three servo motors. The system uses ATmega328 to control these servos as well as the conveyor belts. There are two conveyor belts one for the incoming solar chips and other for the outgoing solar panel. These conveyor belts are driven by the DC motors. A camera is mounted on the set up as shown below. The captured images will be processed by the image processing tool MATLAB. The solar chip may have some inclination or may not be properly oriented. Hence it calculates its actual orientation and then conveys it to the controller. The appropriate movement of robots and hence the end effector is positioned. The end effector is an electromagnet to pick up the object.

Fig.5: Implemented System hardware.

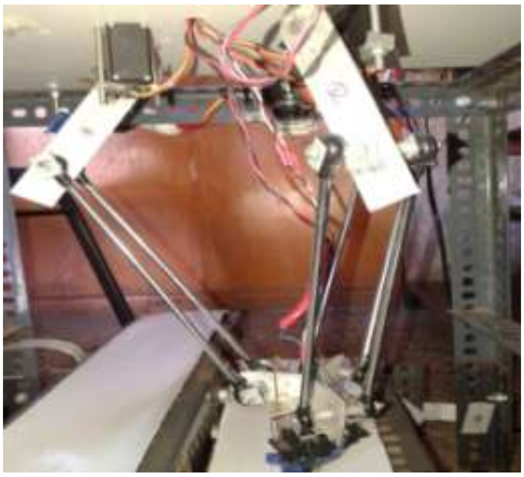

Fig.6: Implemented Mechanical Structure of Delta Robot.

III. RESULT

The Graphical User Interface indicate the result of the complete system discussed in the previous sections. Following fig.7 shows the number of iterations and the calculated parameters such as angle, element width, area and percentage error.

(a)

(b)

(c)

(d)

(e)

(f)

Fig.7: GUI showing number of iterations through (a) – (f)

The above GUI shows that for the elements that have physical parameters more than required are eliminated. Fig.7 shows the total 6 iterations performed by the system. In third iteration the robot eliminates the solar object due to the excess size of solar element to be picked. The assembled solar cells are shown below in fig 8.

Fig.8: Assembled solar cells

IV. CONCLUSION

The manipulators available in the market are very costly. So the proposed system is a step towards the low cost solution to industrial robot. This system automates the process of producing solar cell module by placing solar cells on the substrate. By analysing above comparison it is clear that parallel robots offer potential advantages compared with serial, with higher overall stiffness, higher precision and higher operating speeds and accelerations. Many applications incorporating delta parallel robot has been used in industries. Giving robots perceptual systems they can advance in working undetermined environments. This system can be customized easily to meet the needs of a wide range of wafer and solar cell handling tasks. Even subsequent changes typically only involve reprogramming. The optional integration of image processing systems provides efficient identification of objects and their position. Also instead of using hierarchical model based system, use of vision systems makes it faster and more accurate.

A. Advantages

1. The system robot is built with wide reaches and slim arms, steady repeatability. All these features makes it accurate.

2. This system is easily programmable. They are able to accommodate multiple changes in product shape and type.

3. Robotic movements are regulated, so the results are always the same. Quality is improved because of this regularity.

4. Robot is Space-Efficient i.e., it can be programmed to move within strict limits leading to even better use of space.

5. Save with Pick and Place Robots: Incorporating this system can effectively cut down the costs. Robotic precision and reliability allow for less wasted

material and more efficient use of time. Also, the initial investment in robots is low.

B. Future Scope

The system composing the solar panel are available in the market but at very high cost. The proposed system can be perfected by increasing the accuracy and the acceleration. This can be achieved if the highly precise motors and high tech drives are considered in implementation. Lot of work can be done on the design of the system and progressed forward to reach the highest accuracy.

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