Design and Implementation of Automated Packing System APMC Yard Using Delta Robot

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***Abstract**: Delta robots are widely used in automated process as pickers, delta robots can be used to pick and place of products from production line. Usually delta robots are implemented in vertically positioned portals. At its simple, delta robots consists of frame portal, three actuator arms and three motors. This investigation concerns the design and implementation three degrees-of-freedom (DOF) DELTA robot, covering the entire mechatronic process, involving kinematics, control design and optimizing methods. To accelerate the construction of the robot, 3D printing is used to fabricate end-effector parts. The parts are modular, low-cost, reconfigurable and can be assembled in less time than is required for conventionally fabricated parts. The controller, including the control algorithm. Delta robot design has attracted a great interest in industry and in academia. proposed the evaluation methodology of three degrees-of-freedom (DOF) which consists of local manipulability, transmission quality, stiffness and dexterity.*

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1. Introduction

The delta robot is a parallel robot, i.e. it consists of multiple kinematic chains connecting the base with the end-effector. The robot can also be seen as a spatial generalisation of a four-bar linkage. The key concept of the delta robot is the use of parallelograms which restrict the movement of the end platform to pure translation, i.e. only movement in the X, Y or Z direction with no rotation.The robot's base is mounted above the workspace and all the actuators are located on it. From the base, three middle jointed arms extend. The ends of these arms are connected to a small triangular platform. Actuation of the input links will move the triangular platform along the X, Y or Z direction. Actuation can be done with linear or rotational actuators, with or without reductions (direct drive).Since the actuators are all located in the base, the arms can be made of a light composite material. As a result of this, them moving parts of the delta robot have a small inertia. This allows for very high speed and high accelerations. Having all the arms connected together to the end-effector increases the robot stiffness, but reduces its working volume.The version developed by Reymond Clavel has four degrees of freedom: three translations and one rotation. In this case a fourth leg extends from the base to the middle of the triangular platform giving to the end effector a fourth, rotational degree of freedom around the vertical axis.

1.2 Overview of delta robot

The parallel or delta robot configuration (Figure 1.a) is one of the most recent configuration developments. This includes machines whose arms have concurrent prismatic or rotary joints. These were developed as overhead mounted machines with the motors contained in the base structure driving linked arms below. The benefit of this approach is that it reduces the weight within the arms and therefore provides very high acceleration and speed capability. However they do have a low payload capacity, typically under 8 kg.

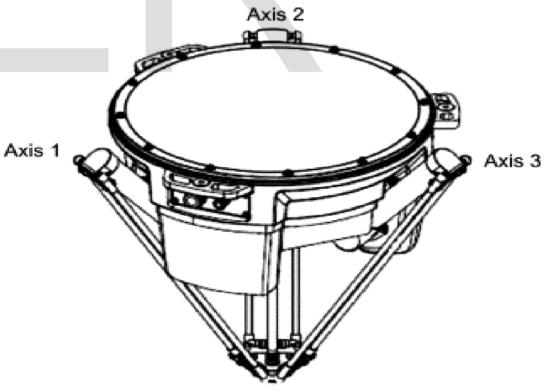

Fig 1.1

2. Kinematic modelling of the Delta robot

Robot kinematics applies geometry to the study of the movement of multi-degree of freedom kinematic chains that form the structure of robotic systems. The emphasis on geometry means that the links of the robot are modeled as rigid bodies and its joints are assumed to provide pure rotation or translation.

Robot kinematics studies the relationship between the dimensions and connectivity of kinematic chains and the position, velocity and acceleration of each of the links in the robotic system, in order to plan and control movement and to compute actuator forces and torques. The relationship between mass and inertia properties, motion, and the associated forces and torques is studied as part of robot dynamics.

2.1 Kinematic equations

A fundamental tool in robot kinematics is the kinematics equations of the kinematic chains that form the .

Forward kinematics uses the kinematic equations of a robot to compute the position of the end-effector from specified values for the joint parameters.[3] The reverse process that computes the joint parameters that achieve a specified position of the end-effector is known as inverse kinematics. The dimensions of the robot and its kinematics equations define the volume of space reachable by the robot, known as its workspace.

There are two broad classes of robots and associated kinematics equations: serial manipulators and parallel manipulators. Other types of systems with specialized kinematics equations are air, land, and submersible mobile robots, hyper-redundant, or snake, robots and humanoid robots.

2.2 Forward kinematics

Forward kinematics specifies the joint parameters and computes the configuration of the chain. For serial manipulators this is achieved by direct substitution of the joint parameters into the forward kinematics equations for the serial chain. For parallel manipulators substitution of the joint parameters into the kinematics equations requires solution of the a set of polynomial constraints to determine the set of possible end-effector locations.

2.3 Inverse kinematics

Inverse kinematics specifies the end-effector location and computes the associated joint angles. For serial manipulators this requires solution of a set of polynomials obtained from the kinematics equations and yields multiple configurations for the chain. The case of a general 6R serial manipulator (a serial chain with six revolute joints) yields sixteen different inverse kinematics solutions, which are solutions of a sixteenth degree polynomial. For parallel manipulators, the specification of the end-effector location simplifies the kinematics equations, which yields formulas for the joint parameters.

2.4 Velocity kinematics

The robot Jacobian results in a set of linear equations that relate the joint rates to the six-vector formed from the angular and linear velocity of the end-effector, known as a twist. Specifying the joint rates yields the end-effector twist directly.The inverse velocity problem seeks the joint rates that provide a specified end-effector twist. This is solved by inverting the Jacobian matrix. It can happen that the robot is in a configuration where the Jacobian does not have an inverse. These are termed singular configurations of the robot.

2.4 Work volume of robots

robot. These non-linear equations are used to map the joint parameters to the configuration of the robot system. Kinematics equations are also used in biomechanics of the skeleton and computer animation of articulated characters

A cylindrical configuration robot has an arm that has got the ability to reach horizontal and vertical directions. Moreover, it can make a rotary motion by placing the arm at the centre of the robot. As a result, this robot requires a *cylindrical* type of work volume for performing an operation. It is mostly used in the *material handling* process. One setback of this robot is that it cant pick the tools from the floor.

3. Dynamic modelling of the robots

Robot dynamics is concerned with the relationship between the forces acting on a robot mechanism and the accelerations they produce. Typically, the robot mechanism is modelled as a rigid-body system, in which case robot dynamics is the application of rigid-body dynamics to robots. The two main problems in robot dynamics are:

- Forward dynamics: given the forces, work out the accelerations.
- Inverse dynamics: given the accelerations, work out the forces.

Forward dynamics is also known as "direct dynamics," or sometimes simply as "dynamics." It is mainly used for simulation. Inverse dynamics has various uses, including: on-line control of robot motions and forces, trajectory design and optimization, design of robot mechanisms, and as a component in some forward-dynamics algorithms.

Other problems in robot dynamics include:

- Calculating the coefficients of the equation of motion.
- Inertia parameter identification --- estimating the inertia parameters of a robot mechanism from measurements of its dynamic behaviour.
- Hybrid dynamics: given the forces at some joints and the accelerations at others, work out the unknown forces and accelerations

3.2 Equation of motion

The equation of motion for a robot mechanism can be written

$\tau=H(q)\ddot{q}+c(q,\dot{q},fext)$.(1)

In this equation, q , $\dot{q}$, $\ddot{q}$ and τ are vectors of joint position, velocity, acceleration and force variables, respectively, and they are called the joint-space position, velocity, acceleration and force vectors. Each is an *n*-dimensional coordinate vector, where *n* is the number of (independent) joint variables in the mechanism. The force variables are defined such that $\dot{q}\mathrm{T}\tau$ is the power delivered by τ to the system. Thus, $\dot{q}$ and τ qualify as a set of generalized velocity and force variables for the system.

fext denotes an external force acting on the robot, due to contact with the environment (so the robot is exerting a force of −*fext* on the environment). Typically, *fext* is a spatial (6D) vector describing the contact force acting on the robot's end effector. This is appropriate if the robot makes contact with its environment only through its end effector. If the robot makes multiple contacts, then it can be regarded as having multiple end effectors (e.g. the hands and feet of a humanoid robot); and f_{ext} is then the concatenation of the individual contact force vectors. If there are N_E end effectors, then f_{ext} is a $6N_E$-dimensional vector.

H is called the joint-space inertia matrix, and it is an $n\times n$ symmetric, positive-definite matrix. c is called the joint-space bias force, which is the value of the joint-space force that must be applied to the system in order to produce zero acceleration. (The choice of symbols varies from one author to the next.) The expressions $H(q)$ and $c(q,\dot{q},f_{ext})$ indicate that H is a function of q , but c is a function of q , $\dot{q}$ and f_{ext} . Once these dependencies are understood, they are usually omitted. Together, H and c are the coefficients of the equation of motion. The kinetic energy of the robot mechanism is

$T=12\dot{q}^{\mathrm{T}}H\dot{q}$.

Although H is never singular, it can be highly ill-conditioned.

Equation () is the most useful for calculation purposes. However, there are two other ways to write the equation of motion that are useful for robot control systems. The first is

$\tau=H(q)\ddot{q}+C(q,\dot{q})\dot{q}+\tau_g(q)+J(q)^{\mathrm{T}}f_{ext}$,(2)

in which the bias force has been broken into its component parts. The term $C\dot{q}$ includes the Coriolis and centrifugal forces, and it is the product of a square matrix C with the vector $\dot{q}$. Gravity terms are included in the vector τ_g ; and the effect of the external force is given by $J^{\mathrm{T}}f_{ext}$. The matrix J is the Jacobian of the end effector (or set of end effectors). It satisfies the equation

$v_{ee}=J\dot{q}$,

where v_{ee} is the spatial (6D) velocity of the end effector, or the concatenation of the spatial velocities of the end effectors, if the robot has more than one. Thus, J is a $6N_E\times n$ matrix.

The second alternative form for the equation of motion is called the operational-space formulation. It expresses the dynamics in the robot's task space, which is the space in which the robot is commanded to operate. Typically, the task space is the space of positions and orientations of the end effector. The operational-space formulation is written

$\Lambda(x)\dot{v}+\mu(x,v)+\rho(x)=f$,

where x is a vector of position coordinates, v is a spatial vector giving the end-effector's velocity, f is the spatial force acting on the end effector, and Λ , μ and ρ are the coefficients of the equation of motion. Λ is called the operational-space inertia matrix; μ contains Coriolis and centrifugal force terms; and ρ contains gravity terms. f is the sum of an external force acting on the end effector and the projection onto the end effector of the actuator forces acting at the joints.

4. Methodology

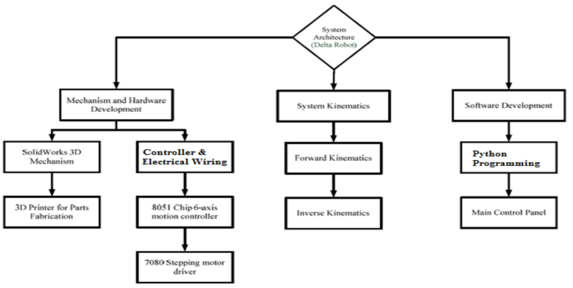

Fig 1.2

4.1 **Mechanical design of the robot**

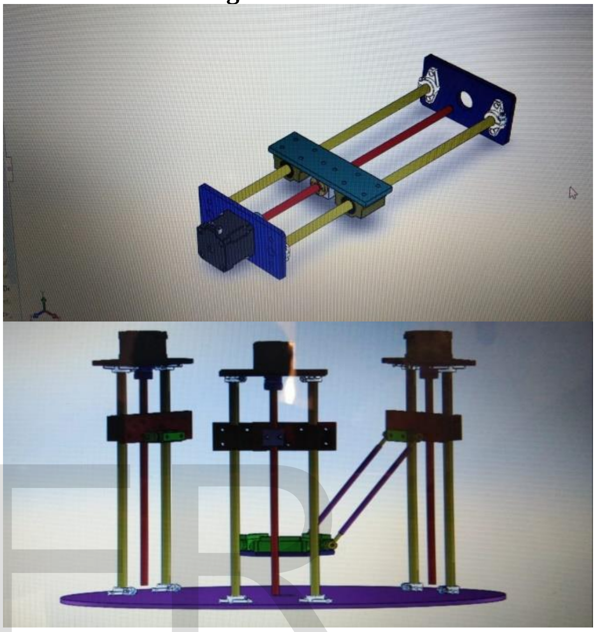

Fig 1.3

4.2 **3D printers for part fabrications**

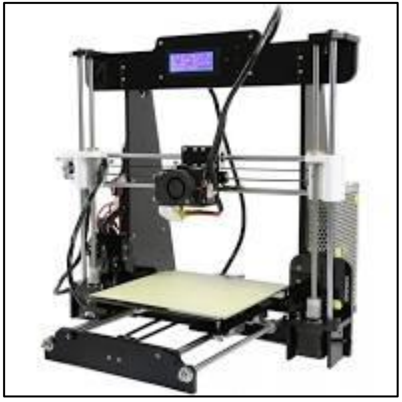

Fig 1.4

The 3D printing process builds a three-dimensional object from a computer-aided design (CAD) model, usually by successively adding material layer by layer, which is why it is also called additive manufacturing. The term "3D printing" covers a variety of processes in which material is joined or solidified under computer control to create a three-dimensional object, with material being added together (such as liquid molecules or powder grains being fused together), typically layer by layer. In the 1990s, 3D-printing techniques were considered suitable only for the production of functional or aesthetic prototypes and a more appropriate term for it was rapid prototyping. As of 2019, the precision, repeatability, and material range have increased to the point that some 3D-printing processes are considered viable as an industrial-production technology, whereby the term additive manufacturing can be used synonymously with "3D printing". One of the key advantages of 3D printing is the ability to produce very complex shapes or geometries, and a prerequisite for producing any 3D printed part is a digital 3D model or a CAD file.

5. Speed calculations

Displacement and the speed of the Velocity We all know what velocity is, but how do you design a robot to go at a defined velocity? Of course you can put a really fast motor on your robot and hope that it will go fast enough. But if you can calculate it you can design it to go your required speed without doubt, and leave the rest of the motor force for torque. So how to do this? For an example, suppose you have a wheeled robot that you want to run over old people with. You know from experiments that old people can run at 3 feet per second. So what motor rpm do you need, and what diameter should your wheels be, so they cant get away or hide their medicine. Conceptually, every time your wheel rotates an entire revolution, your robot travels the distance equal to the circumference of the wheel. So multiply the circumference by the number of rotations per minute, and you then get the distance your robot travels in a minuteFor example, if your motor has a rotation speed (under load) of 100rpm (determined by looking up the motor part number online) and you want to travel at 3 feet per second, calculate.3 ft/s = diameter * pi * 100rpm. Robot Wheel Diameter vs Torque You probably noticed that the larger the diameter of the wheel, or higher the rpm, the faster your robot will go. But this isn't entirely true in that there is another factor involved. If your robot requires more torque than it can give, it will go slower than you calculated. Heavier robots will go slower. Now what you need to do is compare the motor torque, your robot acceleration, and wheel diameter. These three attributes will have to be balanced to achieve proper torque. Motor Torque and Force High force is required to push other robots around, or to go up hills and rough terrain, or have high acceleration. As calculatable with statics, just by knowing your wheel diameter and motor torque, you can determine the force your robot is capable of. You must add this acceleration to what you already require for movement on flat terrain. Note that motor acceleration and torque are not constants, and that motor acceleration will decrease as motor rotational velocity increases. As it's very dependent on the motor, this tutorial will gloss right over it for simplicity.

6. Results and discussions

The project has been completed 70%, so we couldn’t get the output. And the work we did is, designing of the robot by SOLIDWORKS 2016, part manufacturing by 3D printers, laser cutting of plates, surface finishing of ROD 10, and mechanical assembly process of the robot. As per the schedule on the March first and second week, we would have completed the remaining work. Due to COVID-19 shutdown we couldn’t complete the left out works. The left out part was, the electrical assembly of the robot and programming of the robots.

7. Conclusion and Future work

This work introduces a novel design of a DELTA robot with an end-effector for performing multifunctional operations, and provides insight into the way this academic innovation has been transformed into a mechatronic kit for university education. The design of the proposed DELTA robot includes the two-axis rotation of the wrist, a gripper and a six-axis robotic arm. The robot system’s implementation involves the development of the mechanism, both its hardware and software. The cost of implementing the whole of the proposed robot system is about US$1,000, which is only 10% of the cost of an equivalent commercial robot. Hence, the main advantages of the proposed system are that it is modular, reconfigurable and less costly than its alternatives. A repeatability test was performed to ensure the accuracy of the robot system. To evaluate the performance of the DELTA robot, various experimental scenarios were introduced. The results reveal that the proposed DELTA robot completes the tasks effectively. It is hoped that the proposed solutions to the problems that are discussed in this research are useful in the construction, automation and large-scale manufacture of parallel-link robot systems. The future work is to realize the robot in its physical form. In order to realize the robot in its physical form, a lot of material procurement is to be done and then the work will be to integrate the electrical and mechanical systems together and provide the end user with an easy-to-use user interface. The mechanical parts are likely to be fabricated within the industry and the electrical parts are to be optimally chosen and procured. Most of the mechanical parts will be fabricated within the industry itself except for a few parts like carbon fiber tubes for the arms which will be procured from other manufacturers. The electrical part of the robot will include servo motors and drives and the control system used to run them in an accurate and synchronized manner.

Once the system integration is complete, the robot system has to be to be put to test runs in real time operating conditions and the system has to be tuned accordingly. Apart from successfully integrating a working system, one has to provide the end user with a proper and easy-to-use interface. The interface is usually a compact HMI providing real time information about the robot or a teach pendant that is hand held by the user or both.

8. Acknowledgment

The satisfaction and excitement that accompany the successful completion of any task would be incomplete without the mention of the people who made it possible, whose consistent guidance and encouragement crowned our efforts with success. We consider ourselves proud to be a part of **REVA University** family, the institution which stood by our way in all our endeavors. We express our sincere thanks to **Dr. K S Narayanaswamy** Director and Professor, School of Mechanical Engineering, for his support and encouragement. We express profound thanks to **Prof. Kumaraswamy K L**, Assistant Professor, School of Mechanical Engineering, for his valuable support & for his inspiration, guidance, constant supervision, direction and discussions in successful completion of this project. We are thankful to the project coordinator's, teaching and non-teaching staff members of School of Mechanical Engineering for their co-operation extended towards this work. Finally we express ourselves heartfelt gratitude to our parents, members of our family and our friends, for their constant support, motivation and encouragement throughout this project. Above all we would like to thank God, Almighty, for having showered his blessings on us.

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