NEAR EAST UNIVERSITY

Faculty of Engineering

Department of Electrical and Electronic Engineering

ROBOT FOLLOWING IN SPACE (MATLAB PROGRAM)

Graduation Project
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After all I dedicate the successful of finishing my undergraduate studies to my great parents Yousof and Aziza who dream of seeing me achieving my ambitions successfully and I deeply wish them the happiness in their life.

CONTENTS

I. GENERAL DISCRIBTION ABOUT ROBOTICS

1.1 Introduction

Robotics is a very broad topic. No two sources will give the same definition of the term. In Japan, for example, any mechanical device that operates in a factory and performs a single simple task, time and time again, is considered to be a robot whereas in America, such devices are considered "automation systems".

The field of robotics is currently undergoing a change. While in the past, robots where predominately used in factories for purposes such as manufacturing and transportation, a new generation of "service robots "as recently begun to emerge.

Service robots cooperate with people and assist them in their everyday tasks. A landmark service robot is I Helpmate Robotics' Helpmate robot which has already been deployed at numerous hospitals worldwide (King & Weiman 199O). Helpmate however does not interact with people other than by avoiding them. In the near future, similar robots are expected to appear in various branches of entertainment, recreation, health care, nursing, and others, and we expect them to interact directly with people.

1.2 History of robotics and robots

A brief review of robot development is important because it puts the current machines and interests them into a historical perspective. The following list of dates highlights the growth of automated machines which led to the development of the industrial robots currently available.

1801

Joseph Jacquard invented a textile machine, which is operated by punch cards. The machine is called a programmable loom and goes into mass production.

1830

American Christopher Spencer designed a cam operated lathe.

1892

In the United States, Seward Babbitt designed a motorized crane with gripper to remove ingots from a furnace

1921

The first reference to the word robot appears in a play opening in London, the play written by Czechoslovakian Karel Capek, introduces the word robot from the Czech robota, which means a serf or one in subservient labor. From this beginning the concept of a robot took hold.

1938

Americans Willard Pollard and Harold Roseland design a programmable paint spraying mechanism for the DeVilbiss Company.

1946

George Devol patents a general-purpose playback device for controlling machines. The device uses a magnetic process recorder. In the same year the computer emerges for the first time. American scientists J. Presper Eckert and John Mauchly built the first large electronic computer called the Eniac at the University of Pennsylvania. A second computer, the first general-purpose digital computer, dubbed Whirlwind, solves its first problem at M.I.T.

1948

Norbert Wiener, a professor at M.I.T. published Cybernetics, a book that described the concept of communications and control in electronic, mechanical, and biological systems.

1951

A teleoperator-equipped articulated arm is designed by Raymond Goertz for the Atomic Energy Commission.

1954

The first programmable robot is designed by George Devol, who coined the term Universal Automation. He later shortens this to Unimation, which becomes the name of the first robot company.

1959

Planet Corporation marketed the first commercially available robot.

1960

Condec Corporation purchases Unimations and development of Unimate robot System begins. American machine and foundry, later known as AMF Corporation, markets a robot called the Versatran, designed by Harry Johnson and Veljko Milenkovic.

1962

General Motors installs the first industrial robot on a production line. The selected Robot was a Unimate.

1964

Artificial intelligence research laboratories are opened at M.I.T., Stanford Research Institute (SRI), Stanford University, and the University of Edinburgh.

1968

RS Mosher at general electric research built a quadruped walking machine (shown in Figure 1.2), this walking truck was over three meter long, weighted 1400Kg and was powered by 68Kw petrol motor.

1970

At Stanford University a robot arm is developed which becomes a standard for research projects. The arm is electrically powered and becomes known as the Stanford arm.

1973

The first robot commercially available minicomputer-controlled industrial robot is developed by Richard John for Cincinnati Milacron Corporation. The robot is called the T3, The Tomorrow Tool.

1974

Professor Scheinman, the developer of the Stanford Arm, forms Vicarm Inc, to market a version of the arm for industrial applications; the new arm is controlled by a minicomputer.

1976

Robot arms we used on Viking I and 2 Space probes. Vicarm Inc. incorporates a microcomputer into the Vicarm design.

1977

ASEA, a European robot company, offers two sizes of electric powered industrial robots. Both robots use a microcomputer controller for programming and operation. In the same year Unimation purchases Vicarm Inc.

1978

The Puma (Programmable Universal Machine for Assembly) robot is developed by Unimation from Vicarm techniques and with support from General Motors.

1980

The robot industry starts its rapid growth, with a new robot or company entering the market every month.

When, in 1954 George C. Devol filed a U.S. patent for a programmable method for transferring articles between different parts of a factory, he wrote “The present invention makes available for the first time a more or less general purpose machine that has universal application to a vast diversity of applications where cyclic control is desired”

1.3 Robots Today

Today’s mobile robots are beginning to achieve the dreams of early researchers While they’re not yet performing on the level of college students in human tasks like speaking and manipulating objects, robots are useful. We have learned that robot’s roles can be more important in assisting and extending, the reach and vision of humans, rather than trying to duplicate or replace them.

We have leaned that robots can outperform people on highly specialized, repetitive tasks that bore human beings. Robots can lift, pry or inspect objects and places that are difficult distant or hazardous for humans. Teams of robots can gather data from far a field and combine it for analysis. We and our computers can use the results to monitor the environment, investigate unknown places and gain more perspectives on phenomena that were far beyond our abilities to understand before. Together, robots and human, beings are venturing into places and knowledge spaces where no human can travel alone. Truly, we are beginning to turn science fiction into fact.

1.4 Parts of Robot

A robot is basically made up of

1. Base
2. Brain
3. Sensor
4. Actuators

The base of the robot can be stationary, (fixed) or mobile Robots used in manufacture are examples of fixed robots. They can not move their base away from the area they are working. Mobile bases are typically platforms with wheels or tracks attached. Instead of wheels or tracks, some robots employ legs in order to move about.

The brain of a robot is a computer. However, computer is by design very sensitive to movement, vibration and dust. Also computers have a finite minimum size, which limit their uses. Fixed robots are not generally limited in the size of the computer they can use as the "brain" can be placed in an unused corner and then linked to the robot by long cables. On the other band, mobile robots are limited in the size of the computer they can use, as the "brains' are transported on the platform (there are a Few exceptions). The constraints placed on mobile "brains" are size and weight, the larger in size the larger in weight. However small size also generally means little processing power, and large computers are as powerful as "dumb worms" as it is, so the processing power of most mobile robots is severely limited.

Sensors used by robots vary between robots depending on their needs and uses. Each robot needs certain information in order to work properly. The actual sensors take many shapes and forms.

Generally the sensors used by robots are:

- Visual sensors

- Inertial, Acceleration and Heading sensors

- Range finding devices
- Force/torque accelerometers, tactile sensors
- Sonar sensors
- Pan/tilt mechanisms
- Measuring linear notion
- Interfacing sensors

Actuators used in robotics are almost always combinations of different electromechanical devices. Sometimes robots use hydraulics, particularly in the car building industry. The electro-mechanical devices range from 'muscle-wires' to expensive RC-servo and motors. There are several types of motors available including:

- Synchronous
- Stepper
- AC servo
- Brushless DC servo
- Brushed DC servo

These are then connected to cable, gears, axles, pulleys and alike to give the robot movement, and he ability to interact with its environment.

1.5 Robots Applications

Robotics are used in many diverse applications from turtle robots in school classrooms to welding robots in car manufacturing factories, to the teleoperated arms on the space shuttle. Each application has its own set of problems, amid consequently, its own set of robotic requirements. Many new industries have arisen as a result, and we are likely to see more in the future, as new concepts are developed in research laboratories. While many of the consumer-oriented robots are of more novelty value than practical use, the introduction of robots into factories has already had a considerable impact on manufacturing processes.

American manufacturing sector has decreased, while the number of people employed by small, high-technology companies has increased by a greater amount.

Robotics technology can contribute to employment in small factories, because of he increased flexibility it gives to small-volume, batch-oriented manufacturing. This flexibility allows the company to manufacture a wider range of products with less equipment.

1.5.1 Industry

Robots are used in a wide range of industrial applications. The earliest applications were in materials handling, spot *welding,* and spray painting (see figure. 13). Robots were initially applied to jobs that were hot, heavy, and hazardous such as die-casting, forging, and spot welding. One problem in these industries is finding people who are willing to work with the poor equipment and under the poor conditions, which exist in some factories. For example, in die casting and forging a lot of existing plant is so old that it will have to be replaced before robots can be used.

Robots are used in many other applications, for example, grinding, tending machine tools, molding in the plastics industry, applying sealants to motor car windscreens and picking items up of conveyers and packing them on to fork lift pallets. These applications, and the problems involved, are reported innumerous conference proceedings. Innovative new applications include laser-beam welding and water-jet cutting. In the following sections, three industrial applications that are in various stages of research are examined.

1.5.1.1 Arc welding

Arc welding, which is potentially a large application for robots, places high demands on the technology. Unlike spot welding, where the weld has to be placed at a fixed spot, an arc weld has to be placed along a joint between two pieces of metal. Commercial arc welding systems (see Figure 14) rely on people to accurately fix the parts to be welded, and then the robot goes through a programmed welding sequence.

The only advantage this has over manual welding is the consistent quality of the weld. The human operator is now left with the tedious job of fixing. Having rotating fixture tables speeds up productivity, so that the operator can be fixing one set of parts while the robot is welding another

Fig 1.1 Robots in Welding

For all types of joints a minimum requirement for arc weld sensors is that they are capable of indicating the proper tracking position. Further requirements are that the weld is placed accurately ends of the required size and shape. To achieve these conditions, the robot must hold the electrode at the correct orientation to the seam at the correct distance from the seam, and move at a constant velocity so that a constant amount of material flows into the joint. These problems are more complex on three dimensional objects than on flat plates, and often require geometric modeling to plan the robot motion.

1.5.1.2 Assembly

One long-term goal of manufacturing technology is the totally automated factory where a design is conceived at a computer graphics terminal and no further human intervention is required to manufacture the article. Manufacturing in a totally automated environment would include the following steps:

- Product conception
- High level specification
- Product design

(All done interactively by human designers), materials ordering generation of machine tool commands, generation of parts flow strategies through the factory, control of parts transfer and machine tools, automatic assembly and inspection (all done automatically using robotics technology).

Today, there are two examples of highly automated factories where very few people are employed. One is he processing of films by photographic companies, and the other is the machine tool center operated by Fujitsu Fanuc, both are examples of successful hard automation with very few robots. The automation of photographic processing is possible because it is a high-volume single-task process. The machine center consists of numerical controlled machines, combined with robots and conveyor belts for tool changing and parts transfer.

A major potential application for robots is the automation of assembly this is currently a vary labor intensive process and much more difficult than it appears at first sight.

Fig 1.2 Robots in Assembly

Fig 1.3 Robots in Electronics Assembly

1.5.1. 3Machining Metals

Mass production *was* made possible by the ability to repeatedly machine parts to the designer's specification. There are eight basic ways of machining metals (see figure 1.5), as listed bellow:

- **Drilling**
- **Milling**

- **Grinding**

- **Tuning**

- **Boring**

- **Shaping**

- **Planning**

- **Slotting**

After this classification a short explanations of some of these basic ways is given bellow:

Drilling is the operation of producing holes in solid metal, usually with a rotating drill called a twist drill.

Turning is the operation of cutting or removing metal from a revolving work piece with a cutting tool, which is fed into or along the work piece.

Boring is the operation of enlarging a hole that has bee', drilled or cast into the work piece, by feeding the cutting tool into the work piece as it revolves.

Shaping, planning and **slotting** produce flat surfaces by moving the tool over the work piece. On a shaper the cutting tool moves back and forth over the stationary work piece. After each pass, the work piece is indexed (fed) across the path of the cutting tool in preparation for the next cut, which is parallel to the previous one. On a planer the work piece moves back and forth under the cutting tool. After each pass, the tool is indexed across the path of the work piece in preparation for the next parallel cut. A slotting machine is really a vertical shaper, with the cutting tool moving up and down. Machine tools come in various shapes and sizes, but each can be classified as performing tasks that can be fitted into one of these categories above.

1.5.2 Laboratories

Robots are finding an increasing number of applications in laboratories. They are good at carrying out repetitive tasks such as placing test tubes into measuring instruments relieving the laboratory technician of much tedious work. At this stage of their development, robots are used to perform manual procedures automatically. A typical sample-preparation system (Figure 1.2l) consists of a robot and laboratory stations such as balancers, dispensers, centrifuges, and test tube racks. Samples are moved from laboratory station to laboratory station by the robot under the control of user-programmed procedures.

Manufacturers of these systems claim they have three advantages over manual operation: increased productivity, improved quality control, and reduced exposure of humans to harmful chemicals.

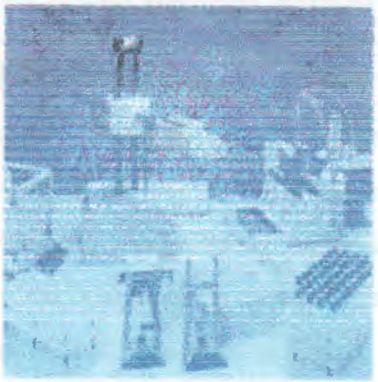

Fig 1.4 Robots in laboratories

1.5.3 Kinestatic Manipulators:

Robotics technology found its first application in the nuclear industry with the development of teleoperators to handle radioactive materials. More recently robots have been used for remote welding and pipe inspection in high-radiation areas. The accident at the Three Mile Island nuclear power plant in Pennsylvania in 1979 has spurred the development and application of robots to the nuclear industry.

Rover (or RRV), a Remote Reconnaissance Vehicle developed at Carnegie-Mellon University (Figure 1.6) was used to inspect the basement of the reactor containment buildings to obtain concrete cure samples from the walls, and to remove the top layer of concrete from floors in parts of the reactor building using a pneumatically powered scabbing machine.

1.5.3.1 Hazardous Environment

Nuclear reactors, deep sea beds, active volcanoes and minefields are all places where important jobs need to be done, but finding the people to do them can be hard. Robots can operate in these environments however, and agent controlled robots will be able to act on our behalf to do our dirty work.

A team of robot agents working on a minefield would reduce the currently considerable risk to soldiers and civilians alike. By communicating, the multi agent sytem could quickly and extensively search areas and declare them safe when all the ground had been surveyed.

In studying volcanoes, gathering data from active cones is hazardous at best. sulphurous fumes make breathing impossible, and robotic exploration is clearly called for. Robots such as Dante I and II have been used to collect samples and images from the very bottom of craters, but both suffered from falling. Under direct human control, this is not surprising, as on the near vertical sides of the volcano the going is tough, and with imperfect and incomplete information feeding back to the operator, mistakes are inevitable. An autonomus robot agent however would be able to react immediately to all information available to its sensors, reducing the chance of an accident due to loss of control or not seeing the ground underfoot

Fig 1.5 Mobile Robot For Cutting the Grass

1.5.4 Agriculture

One of the most successful projects so far has been the development of a sheep-shearing robot in Australia (see Figure 1.7). The trajectory of the cutting shears over the body of the sheep is planned using a geometric model of a sheep. To compensate for variations in the size of a sheep from the model, and for its changing shape as it breathes, data from sensors mounted on the cutter is used to modify the trajectory in real-time, as the wool is removed. Over *200* sheep have been shorn (though riot completely) with fewer injuries to the sheep than occur with human shearer.

Other experimental applications of robots in agriculture include transplanting of seedling, pruning grapevines in France, and picking apples. All these systems are in experimental stages, but they have each demonstrated their potential.

Fig 1.6 (a) Robots for strawberry harvesting

Fig 1.6 (b) Robots for grapes harvesting

1.5.4.1 Fundamental technologies of gripping, sensing and manipulator control sensring

A multispectral sensor which enables image acquisition at multiple wavelengths was evaluated for fruit detection. The system selected comprises of an acoustic-optic tunable filter (AOTF) with an appropriate optical adapter for mounting it on a camera. The filter's spectral range was defined from 500 to 1000nm, which covers most of the visible and part of the NIR spectrum. In addition, appropriate electronics were ordered which enabled switching between tuned wavelengths in 0.25ms. This system was connected to a sensitive B/M camera

An AOTF acts as an electronically tunable spectral bandpass filter. The fact that the filters can be switched electronically with no moving parts makes it suitable for field applications since it is immune to orientation changes and mechanical shock or vibrations. The AOTF consists of a crystal in which acoustic waves at radio frequencies are used to separate a single wavelength of light from a broad band or multicolor source. The wavelength of light selected is a function of the RF applied to the crystal. The AOTF diffracts at each time one specific wavelength of light independent of device geometry.

The image processing system used with the AOTF in the experiments consisted of a IVP-150 industrial video processing system which is a real-time PC compatible board. The board offers flexible image processing engines and includes on board a TMS320CC50 40 MIPS DSP (digital signal processing), a 30 MIPS DLUT (dual look up table) for real-time vector image processing, 9 video input channels, 3 independent frame grabbers for real-time RGB or 3 simultaneous B/W, 4MB image storage and 16 digital and 16 analog I/O lines. The IVP-150 is supported by a powerful software library which can be used either by the on-board DSP or the host PC. This provides a self contained, efficient and economical workstation for development of the image processing and pattern recognition algorithms and software and will enable real-time implementation and stand-alone operation

The AOTF system enables to adapt for changes in illumination conditions and provide an ability to adapt for features that may change between fruit varieties. Moreover, it enables a more general solution suitable for a multi-purpose agricultural robot. The optimal wavelength can be selected for each specific fruit and growing condition (e.g., type of soil, ground coverage). Experiments were performed in 2 different locations in Israel (Israel and Arava Valleys), in different seasons: summer 1997, fall 1997 and spring 1998 and in different growing conditions (greenhouse and field melons). Images were collected at the whole AOTF spectrum at 10 nm intervals in addition to regular B&W, color imaging and in part of the experiments imaging using specific filters.

1.5.4.2 Gripper

A gripper was designed for transplanting. The gripper seedlings grasping is composed of a pneumatic piston which actuates two parallel hinged jaws that perform a scissors type movement, which cause the jaws to grasp the plant in between. The size and shape of the gripper was adapted to fit trays with different plant cells sizes. Clearance between the gripper jaws can be adjusted to the plant and tray cell size in order to ensure suitable opening and closing of the jaws. The last part of the jaws is composed of two elastic metal strips internally covered with a spongy layer, to prevent pressure damages to the plants leafage. The jaws of the gripper form a L shape to enable approach to plants from the side. Gripping force can be changed by changing the outlet pressure of the compressor (the pneumatic components are situated on the base frame of the robot, including compressor). The exact grasping force was empirically found to be 1.5 - 2 Kg, this force was found to be efficient for appropriate gripping. Lower values of gripping force caused failure to pull seedlings out from the tray.

The gripper was constructed and placed onto the robotic melon harvester instead of the melon gripper. In addition its motions were programmed and extensive laboratory experiments were conducted.

1.5.4.3 Route Detection and Vehicle Path Determination

The research consisted of two parts: 1) image analysis to detect rows and paths in agricultural areas 2) recognition of path/row direction relative to the vehicle and calculation of vehicle steering commands

Image analysis to detect rows and paths was achieved using color imaging and analyzing the different categories in the picture (sky, path, trees) taking into account specific color, intensity, shape and size features and utilizing their connections between the red, green and blue images.

An algorithm was developed to generate the path midway curve and safety margins from the midway curve determined in the image processing section. The vehicle's desired course and steering command was then generated. This algorithm should be furthed developed to: 1) consider the motion speed and vehicle dynamics) provide a continuous steering angle for more accurate and gentle steering.

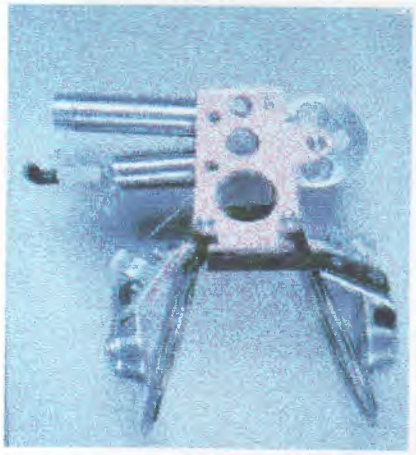

Fig 1.7 Gripper, Used for Transplanting

1.5.4.4 Development and Implementation of Additional Applications

The robotic melon harvester was adapted to the transplanting task. This included design and evaluation of combined components in the robotic workcell using graphic simulation to determine the best design parameters: actuator speeds and plants tray location and design and implementation of a gripper for transplanting.

A graphic simulation model was developed to obtain optimal tray location and actuator speeds. Simulation results indicated that the tray's height can be increased up to 400 mm above the ground without decreasing the cycle time. No improvement in cycle time is received for actuator speeds higher than 1500 mm/sec. Best performance can be achieved for a centered tray location with two actuators equipped with 1500 mm/sec motors (Y and Z) and the third one with 500 mm/sec.

Experiments with the prototype system equipped with an L shape pneumatic gripper were performed for lettuce, tomato plants for industry use and celery plants and yielded an average of 92% successful transplanting cycles.

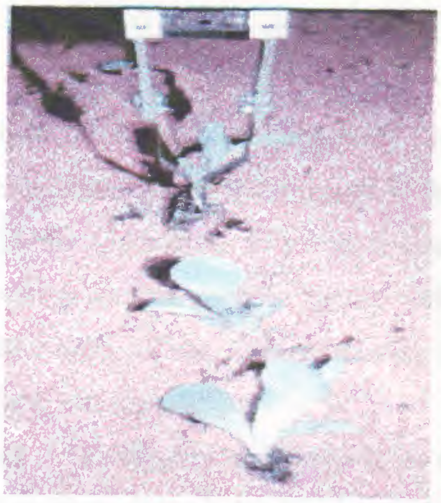

Fig 1.8 Transplanter Robot

1.5.4.5. Selective Sprayer Robotic System

The robotic melon harvester will be adapted to an additional task, selective spraying. A parallel research (BARD US-2415-94R) dealt with development of a site-specific expert system and sensor for selective spraying which includes detection of weeds in the field and development of a decision support system (DSS) to guide the system on decision such as spray (yes or no), when to spray, how much to spray.

As part of the "Multipurpose Agricultural Robot" research the decision support system has been integrated into the operation of the robot. This was conducted by integrating the decision support system developed in CLIPS/MATLAB into the graphic simulation model.

A full graphic simulation model was developed to simulate full forward movement of the tractor along a row in actual field conditions (different types of weeds detected with different certainty values), different forward speeds of the machine and actual spraying as a result of the final decision.

1.5.5 Space

Space exploration poses special problems for robots; they can not yet be used to replace people. Teleoperators, which combine human intelligence with mechanical manipulation, require a person in the loop. Future applications of robots in space include planetary rovers with manipulator arms, free-flying general-purpose robots within space stations, satellite maintenance robots, manipulator arms for space manufacturing and construction robots for the construction of space stations and space ships.

In November 970, Lunokhod 1, the Russian unmanned lunar rover landed on the Moon. In July 1976, Viking I landed on Mars. It carried a robot arm which was used to dig a small trench in the Martian soil and to scoop up soil samples for analysis. After a soil sample was screened, a miniature conveyor carried it to a highly sophisticated biological laboratory. In March 1982 the teleoperator arm (RMS: Remote Manipulatory System) on board the space shuttle Columbia was first used to move scientific payloads out of the hold into space.

1.5.5.1 Applications of Agent Controlled Robots

Controlling a robot with an agent system as opposed to a traditional procedural or reactive programming is a recent trend that stems from research in agent systems in distributed Realising robots as agents systems gives a degree of autonomy, as one of the defining properties of an agent is pursuing its own agenda. Applications where autonomy is required include those where the nearest human operator is unable to react fast enough or the lag in commanding a purely reactive robot would be intolerable, for example in space applications.

1.5.5.2 Space Exploration

In space, no-one can hear you giving orders to a robot - at least not for several minutes. The time delay between issuing a command and verifying that is has been carried out make direct control impossible. In this situation, the ability to give high level commands and know that they will be carried out without jeopardising the safety of expensive equipment is vital.

Martian rovers, unmanned spacecraft and many other applications suit the agent framework rather well. In an environment such as shown in the illustration, the rover would be able to navigate itself around obstacles by gathering data from its sensors, and move to whichever rock the scientists were interested in without further contact from Earth. In fact, the Sojourner rover had some autonomy, but not to the extent generally present in agent systems. With a ten-minute delay, automatic hazard avoidance was a neccesity, but there was no path-generation or autonomy of movement other than for the safety of the lander - for this mission, it was more cost effective to plan the rover's every move from Earth once the terrain could be observed, as it was a one-off, custom mission. If the scale of space exploration were to increase, and rovers like Sojourner were to be produced in tens or even hundreds, autonomy would become more attractive, as the cost of controlling each and every one down to the last detail would prove prohibitive in both time and money.

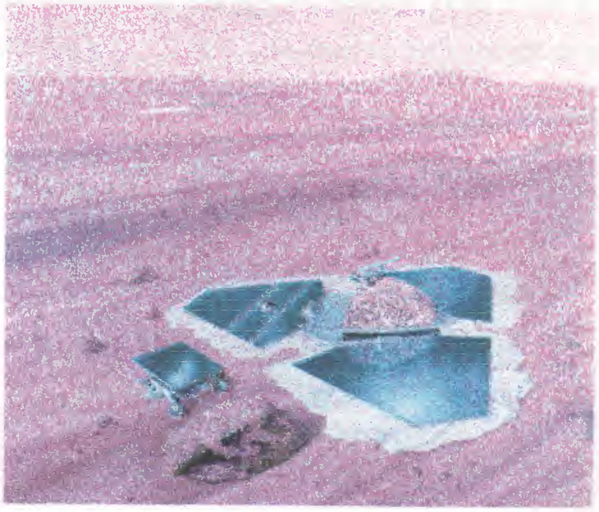

Fig 1.9 Robots in Space

1.5.6 Submersible Vehicles

Two events during the summer (in the northern hemisphere) of 1985 increased the public's awareness of undersea applications of robotics. In the first- the crash of an Air India jumbo jet into the Atlantic Ocean off the coast of Ireland – a remotely guided submersible robot, normally used for cable laying, was used to find and recover the black boxes from the jetliner. The second was the discovery of the Titanic at the bottom of a canyon, where it had settled after hitting an iceberg in 1912, four kilometers below the surface. A remotely controlled submersible vehicle was used to find, explore and film the wreck.

1.5.6.1 Cable-Controlled Under Water Recover Vehicle

The vehicle pictured at left was the *first* successful remotely operated undersea vehicle. The Cable-controlled Undersea Recovery Vehicle (CURV) was developed in the early 1960's by the former Pasadena Annex of the Naval Ordnance Test Station, one of SSC San Diego's parent laboratories. CURV was designed to recover test ordnance lost off San Clemente Island at depths as great as 2000 feet, but became famous in 1966 with the recovery of an H-bomb off Spain in 2800 feet of water. This success spawned later generations of vehicles designated CURV II, CURV II-B, CURV II-C and CURV III. CURV, now referred to as CURV I, pioneered the concept of undersea teleoperators.

Fig ١،٩ (a)Curve I

Fig 1.10 (b) CURV ll

Fig 1.11(c) CURVlll

In 1973 CURV III was used to rescue the two-man crew of the submersible Pisces CURV III which was bottomed off Ireland. After the Space Shuttle Challenger disaster, CURV III was transferred to the Navy's Supervisor of Salvage (SUPSAL), who directed that it be upgraded from 10,000 feet operations to 20,000 feet using technology developed for the Remote Unmanned Work System and the Advanced Tethered Vehicle (ATV). The redesign and upgrade, performed by Eastport International, produced what is essentially a new CURV III. CURV III continues to be operated by SUPSAL, as does the SSC San Diego-developed Advanced Unmanned Search System (AUS).

1.5.7 Education

Robots are appearing in the classroom, in three distinct forms. First, educational programs using simulation of robot control as a teaching medium. The programming language Karel the Robot, a subset of Pascal, is used as an introductory programming language. Karel has the control structures and syntax of Pascal, but a robot has replaced variables, objects for the robot to manipulate and a grid-based environment.

The second and currently most common use of robots in education is the use of turtle robots (Figure 1.9) in conjunction with the LOGO language to teach computer awareness. LOGO was intended to create an environment where learning mathematics would be natural and fun. The turtle is an object to think with and to be used to draw geometric patterns. While LOGO is used for this purpose the language has been, so well human engineered, from an educational point of view, that it provides a natural environment for a child's first excursions into programming.

Fig 1.11 Educational Robot

The third use is in lie robotics classroom. A range of low cost manipulators, mobile robots, and complete systems has been developed for use in robotics educational laboratories. Owing to their low cost, many of these systems suffer from poor mechanical reliability, low accuracy, non-existent sensors, and inadequate software.

1.5.8 Technological application For The Disabled

Potential robotic aids for the disabled range from automatic wheelchairs, which carry the occupant around a hospital in response to voice commands to robots, which feed severely handicapped people. The overriding goal of this research is to make machines, which restore some of the autonomy the user lost when he or she lost the use of his bodily functions.

This is one of the most liberating technologies that will ever come to the rescue of the disabled.

Figure 1.12 Mobile Robot for Disabled

These machines can do everything for the disabled, including administer periodic exercise vital for circulation, pick up equipment around them, carry the shopping, lift the wheel chair into the car, paint the room, change the tiles on the roof, fix the window - anything - so long as the tooling has been installed and the software written.

Previously, this is almost impossible because everything required a custom machines to be designed. But shape changing robots deform into other machines under software control which makes the whole exercise effortless when designing equipment for each kind of disability.

Machines like this do not cure disability but they allow people to lead a life of higher quality and with less dependency on others to help them along in life.

1.5.9 The Medical Application

In the field of medicine, we are always faced with operating on patients. Sometimes its done to remove things and other times its to put things there. We also do exploratory surgery to collect more data on a problem.

The use of shape changing robots in medical applications would probably become one of the biggest revolution in the coming decades.

Robotics has been used in the field of human surgery in different ways but the kind of robotics we are talking about is a far greater melding between flesh and metal. This melding in the future may even become so uncomfortable to the point that we may have to install laws that prevent certain kinds of uses of this technology!

Man has long sought after many cures for all kinds of illnesses. While it is not possible to prevent the outright cure of a great many conditions, it is possible in the very near future of dealing with surgery to levels unprecedented.

1.5.9.1 Shrinking Robots

The robotic cubes can be shrunk to 1 mm size and below with today's technology - e.g. glass extrusion technology. This is adequate for direct entry into the human body to perform very complicated surgery to remove cancers, cysts, blood clots, stones etc. Shape changing robots can squeeze through tiny holes no bigger than the largest cube and spread out once it has reached the other side which means that it can be used to perform pinhole surgery where the robot cuts its way into the patient and spreads out inside the body to perform the required operation around the affected area. The robot enters the body ideally through the nearest from the outside because it is so small, that the cut it leaves is not signficant. Figure 2 shows how the robot enters the body.

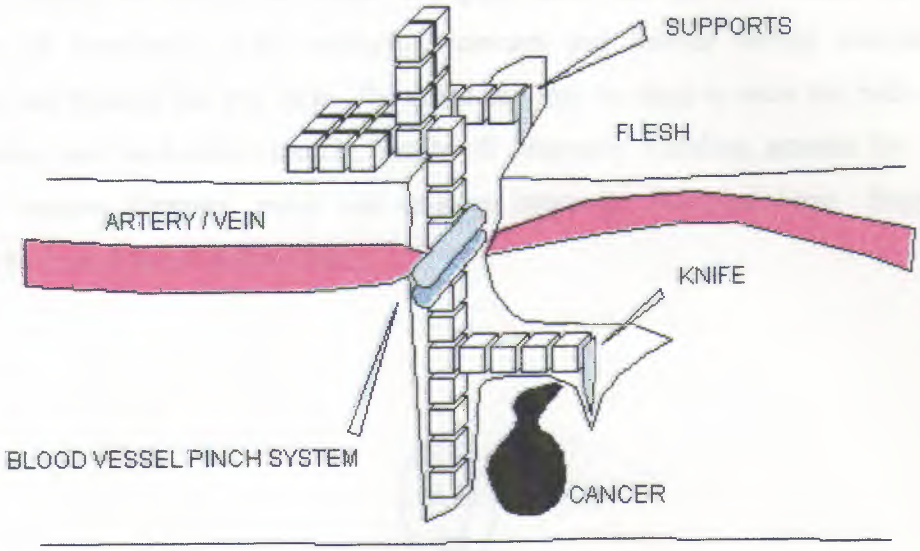

Figure 1.13 Operating the Robots in the Human Body

1.5.9.2 Operating on Humans

When cutting, the shape changing robot lins the hole using small tilable plates to prevent leakage of fluids through the hole. Blood vessels can be detected using infra-red sensors and with Doppler sensors. When it meets major blood vessels, it can cut around the vessel and pinch them off before severing them which means that the patient does not require blood transfusions in complex operations. This is probably a very significant medical advance in its own right because blood is a very scarce commodity especially during emergencies. It has to be donated as always by willing and suitable individuals. Even with modern precautions, blood transfusions carry the risk of infections from known agents and from as yet undiscovered agents.

1.5.9.3 Dealing With Complexity of The Human Body

Once inside the body, the shape changing robot can cut all around the complex contours of previously large inoperable cancers and lesions before mincing it and squirting out through the tiny hole. The robot can also be used to enter the body to inject pain killers and medication locally, pinch off internally bleeding arteries for accident victims, remove shrapnel, move and re-align internally shattered bone fragments all without having to open up the patient.

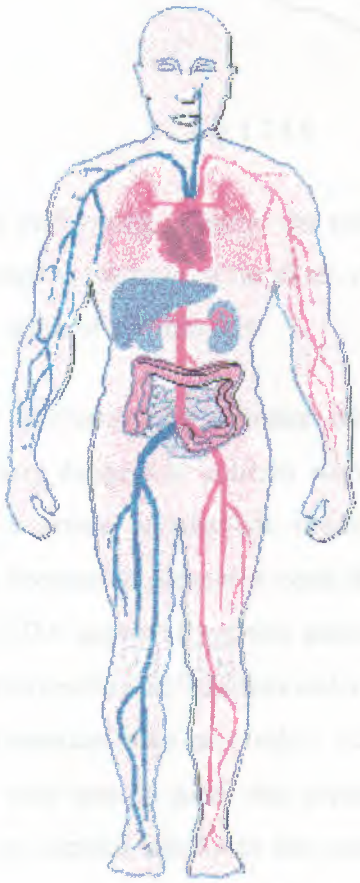

Fig 1.14 (a) Showing the Compexity of The Human Body

There are complex places in the body which is at best difficult to reach like the base of the brain shown below in the skull in figure 4.

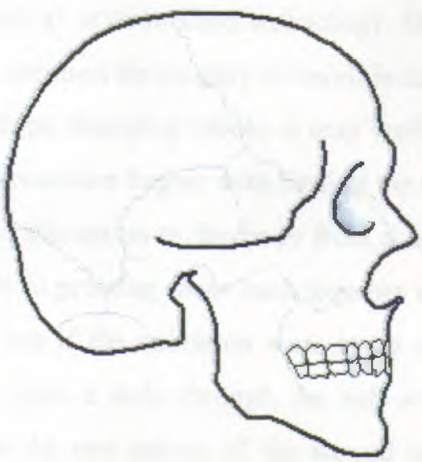

Fig 1.14 b

Instead of spending hours performing surgery, the robot could thread its way into the brain from any access point such as the base of the skull, or through the eye and ear sockets if the robots are less than one tenth of a millimetre.

Operations are normally performed in minutes which reduces the need for long anaesthesia which in itself carry dangers to patients who are not in perfect health. Shape changing robots are going to create an absolute medical revolution both in terms of advances and reducing costs because at present it costs $1000 million to develop a brand name drug and 10 years for FDA approval but this technology will be ready in less than five years with total costs not exceeding $25 million and save more lives in a shorter period of time and with far less resources than any other technology before it. Charity and sponsorship is probably the best way to push this aspect of the technology forward. It remain for those with funds to commit wholly to this technology now rather than later to get this technology rapidly developed for the benefits of it be widely available to society in a period less than five years.

1.5.9.4 Carrying Out Mission Impossible

The technology can be developed to perform a number of operations that are at present beyond the scope of current medical or even nano technology. One of the first application is surgery without scaring. It is common for surgery to result in scars. But since cells could be prized apart one by one by shape changing robots, it may well be possible at some time in the future, that the operating procedure begins with finding the best route to the objective using paths that contain the least disruption to the body from a healing point of view. The cells are prized open with a view to pressing them back together again for scarless healing. Some cell rupture is inevitable but if the operation were to be carried out with the most delicate of operations to prize open a hole through the cell walls then we can almost guarantee scarless healing when the two halves of the wound are brought back together again.

The mesoscopic shape changing robots are smaller than cells and could do this very easily if they are developed for medical surgery. All the technologies needed for making mesoscopic devices are available now, and its just a matter of sitting down and getting it developed as opposed to spending vast fortunes on blue sky research.

1.4.9.5 The Future

Another possibility is to make agents that hunt down and kill macro molecules. These sensors for detecting the macromolecules such as viruses are all chemical in nature using conductive polymers with antibodies specific to the molecule that is hunted down. These sub micron devices can travel into a cell, live there without interacting with any of the chemicals found within the cellular environment and when they detect their quarry - they can either destroy the chemical if it has a technique for capturing it, destroy the cell before more infection takes hold or release chemicals to mark the cell for destruction. However, we should be careful when making this technology - we are leaving open the question of natural selection pressure that tries to improve the chances of rogue molecules and agents getting past these artificial defences.

1.5.9.6 Medical Charity

Probably the best way to push this technology forward is to form a charity, Why a charity? These days, most medical advances can only be supported by people giving through charities because of the long term nature of the research and the huge costs involved. Although this technology is only a fraction of the costs compared to say a cancer drug, it is nevertheless quite high for a commercial venture. Governments could of course intervene but that depends on the long term of supportive nature of people in governments and their generousoty towards such research ventures

1.5.10 Other Ropotical Applications

1.5.10.1 Robots in Architecture

There are several different ways in which a robot's control system may be implemented using agents, and several different agent architectures which may be adopted.

A common form of a reactive architecture is the subsumption architecture. Here the robot has several goals at different layers, and tries to achieve all of them concurrently. Actions required to realise higher level goals can suppress lower level actions, but lower levels have no knowledge of higher levels. An example of a subsumption architecture for a foraging robot is shown below. The robot's goal is to wander around, avoiding obstacles, until it finds its target. It should then pick up the item and take it back to its

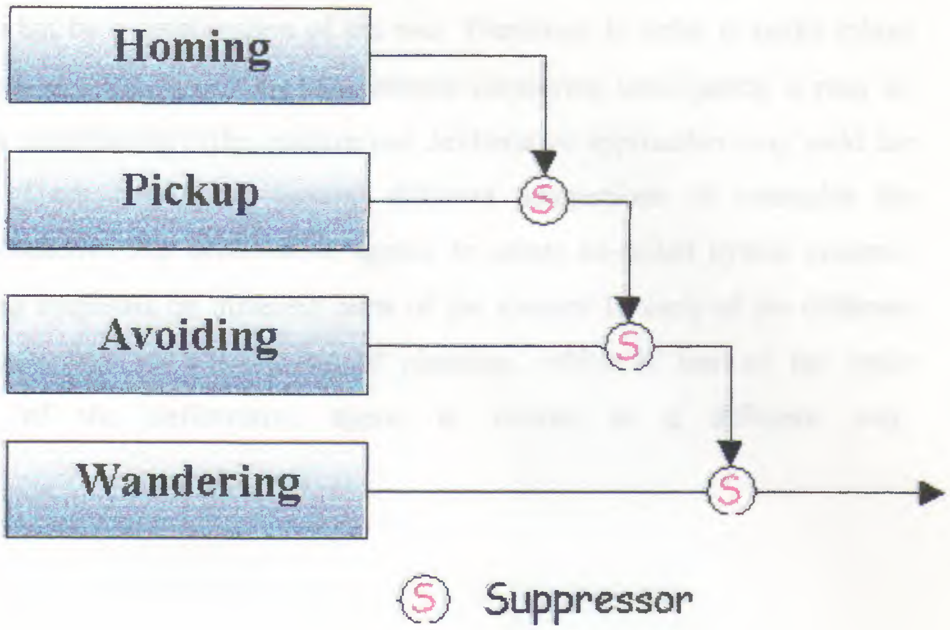

Fig1.15 Architecture in Robotics

The robot has four behaviours: wandering, avoiding obstacles, pick up an item and homing. It only executes one behaviour at a time, and a higher level behaviour can inhibit a lower level behaviour. The robot will wander around its environment if it can. If it encounters an obstacle then wandering behaviour is suppressed and the robot executes the avoiding obstacles behaviour. If the robot locates a target then it should not avoid it, so the pickup behaviour overrides the avoiding behaviour. Once the robot has collected the target, it must take it back to the base before it can pick up another item, so the homing behaviour subsumes the pickup behaviour.

An example of a deliberative architecture is the hierarchical planner. Here knowledge of the world and the goals specified by the user are considered to form a plan prior to execution. The robot then goes ahead and executes the series of actions which it had calculated. Unfortunately, it is not easy to change the plan during execution if things go wrong. Also, it is never possible to plan for every eventuality, and the more possibilities that are considered, the longer the planning process will take.

Looking to the natural world as a model for artificial intelligence, it is seen that animal behaviour is not determined solely by either reactive or deliberative considerations, but by a combination of the two. Therefore, in order to make robots behave autonomously in similar ways to animals displaying intelligence, it may be reasoned that a combination ofthe reactive and deliberative approaches may yield the best results. There have been several different suggestions of strategies for interfacing the reactive and deliberative agents, to create so-called hybrid systems, putting differing emphasis on different parts of the system. In each of the different architectures described below, the act of planning, which is one of the main characteristics of the deliberative agent, is viewed in a different way.

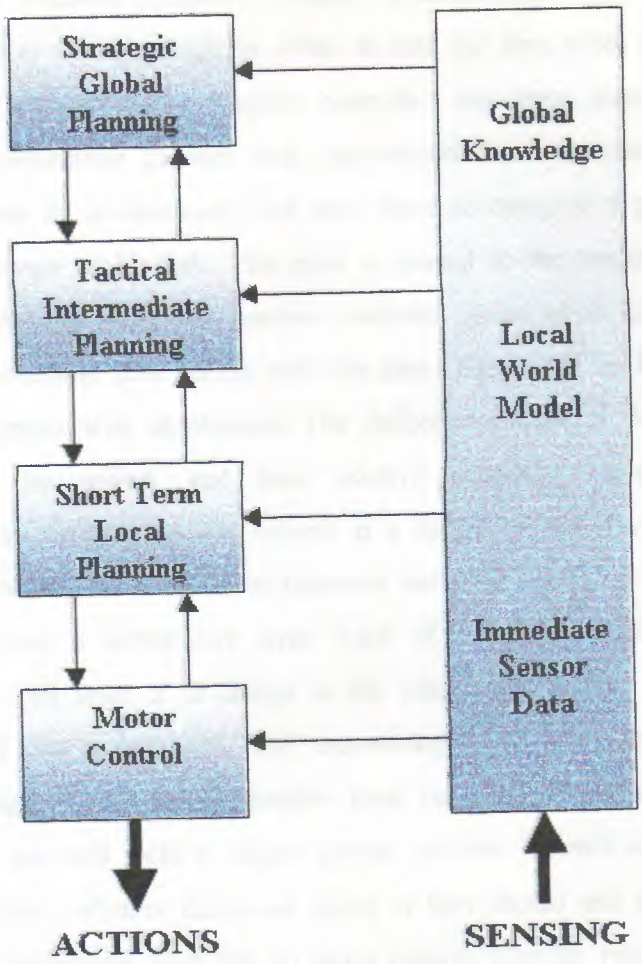

Fig 1.16 Robotics in Architecture

An example of a selective system – AuRA (Autonomous Robot Architecture) was developed by Arkin at Georgia Tech in 1986. It was the first robot architecture that had both a deliberative planner and a reactive controller, but these were present as distinct components. The deliberative planner took information from the user about the robot's goals, and data about its environment, and uses these to compute a plan for the robot to complete the next stage of its task. This plan is passed to the reactive controller for the robot to execute. At this point the reactive controller takes over, and there is no more deliberation until something goes wrong with the plan. This could be for instance when the robot comes into contact with an obstacle. The deliberative agent is then reinvoked, so that the problem may be solved, and then reactive controller takes over once again.

An example of an advising system Atlantis is a hybrid system developed by Gat at the Jet Propulsion Laboratory in 1991. Its architecture has three layers, a reactive control layer, a sequencing layer and a deliberative layer. Each of these layers runs independently and asynchronously. No one layer is in charge of the others, and activity is spread throughout the three layers of the architecture. The sequencing layer maintains a task queue and executes actions suggested by the deliberative layer on a priority basis. The execution of a plan is interuptible and will yield to higher priority actions. Monitor routines are present in the system which check whether things are going as they should and interrupt the system if they are not. The deliberative layer has no direct control over the reactive layer, and so its plans are considered as advice rather than orders. An example of an adaptation system - the Planner-Reactor Architecture. The Planner-reactor architecture was put forward by Lyons and Hendriks in 1992. Here the planner is a mechanism which continuously modifies the configuration of the reactive controller as it is executing. The two processes runconcurrently and asynchronously. The reactive controller runs under a set of assumptions about its behaviour, and when these assumptions are broken, either by the robot effecting an inappropriate action, or by a change in its environment, the planner alters the reactor's control system, refining the plan to better achieve the robot's goal. Here planning is an on-line process rather than an offline deliberation.

An example of a postponing system the Procedural Reasoning System The Procedural Reasoning System (PRS) was put forward by Georgeff and Lansky in 1987. Its approach to the integration of reactive and deliberative elements is rather different to the other examples given above. Under PRS, all of the robots actions are determined by the plan, rather than the reactive controller, but the plan is constantly being modified in response to changes in the robot's current situation. The execution of a plan may be interrupted or even abandoned at any time. The plan itself does not, as is normal, represent the goal state which the robot should achieve next, but represents the robot's desired behaviour instead. All of the information which the robot has about its situation, goals and intentions is used in reforming the plan. However, it is assumed that it is better to put off decision making until later, when more information will be available, and so all decision is postponed until it is absolutely necessary .

A development of the PRS system described above known as dMARS was the result of work by the Australian Artificial Intelligence Instittue dMARS is a development system which uses reactive software agents to model complex, distributed time-critical systems. dMARS is suited to the development of any application that requires both proactive goal directed behaviour and reliable time-critical response to change. It is particularly well suited to applications where a large number of complex but well-defined procedures or tactics exist for accomplishing particular tasks in a variety of situations. dMARS systems carry out tasks by dividing them into sub-goals and primitive actions. Each plan will have a trigger event. The system monitors its surroundings and puts any events that occur onto an event queue. It then puts ino action one of the plans whose trigger event is on the queue, either by executing a primitive action or by queueing a sub-goal. The cycle then repeats.

1.5.10.2 Robotic Neurons

This section is in response to a question originally posed was about immortality, cryonics, the soul and related matters. It was identified at this stage that robotic cubes about the dimensions of a micron with a microprocessor could replace a neuron. The discussion that followed was not how do you get there but more of what happens if you had got to that stage with miniaturisation!?

By introducing some extra functionality into a robotic cube, they could be used to mimick neurons. Neurons are connected to each other through hard wired connections which can be simulated in software. As the size of the robotic neuron gets smaller, its applications such as entering cells and monitoring their activity becomes ever greater. The functionality of the 'robotic neuron' increases rapidly to the point that they could actually be used to replace the functionality of neurons in an actual brain!

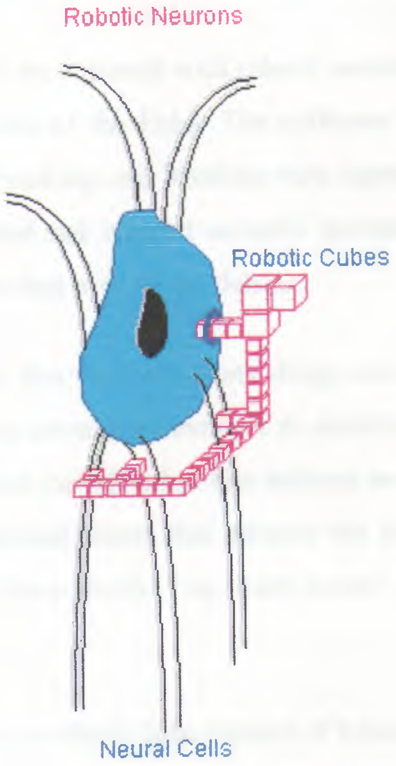

Figure 1.16 Robotic Neural

A robotic neuron less than a micron in size could be sent to live inside a brain cell and learn its trigger patterns. We are not trying to anything clever here like understand a person's personality etc.. All we are doing is recording how a typical neuron is connected to its neighbours and how it behaves to its everyday stimuli.

After learning, it could then sever the neuron and connect its own contacts to the neighbouring neurons by synthesising small wires and connections into the connected neural cells. It could also do this operation at the time of cell death by detecting changes in internal cell pressure and/or changes in cell chemistry or on command. To prevent neighbouring neurons from dying through programmed cell death (appoplexy) which is initiated once a nerve ending ceases to send appropriate chemical and electrical signals, the interface between a neighbouring cell and the robotic cube must be suitably compatible to prevent cellular appoplexy. If suitable interfaces could be developed, then the replacement robotic cube cannot be told apart by the brain from a real cell providing nothing else is missed out in our understanding of cells and how they function.

As more and more neural cells are replaced with robotic neurons, inter-cellular wires can be replaced with software versions of the links. The software versions can also be used to immitate the functionality of making and breaking new connections that the brain uses to adapt and reprogram the neural net without actually increasing the amount of hardware providing this does not lead to data processing delays.

(As an asside, one should note that there are many things one cannot do with the brain. The brain in general will resist any attempt to make it do anything it does not want to do. So you can't speed up some bits or cut off other bits without sending the brain into a seizure. Seizure is similar to an electrical storm that sweeps the brain in waves that cannot be controlled and will result in brain death. Too much neural activity will destroy a neuron irrepairably.)

Its interesting to note here that a robotic cube version of a neuron will not get destroyed and could be made to behave normally even under abnormal conditions which means that this technology could be directly implanted into the brain to substitute epileptic regions of the brain. Some forms of epilepsy is caused by malfunction of a very tiny region of the brain which may be no bigger than a grain of rice. Although it is a tiny region, it could trigger seizure of the entire brain with little or no provocation. The faulty region of the brain is normally the focus of where all the rapidly changing electrical storm is initiated before the rest of the brain follows suit and hence electrically discharging that region of the brain (which is done by inserting an electrode and passing an AC signal to polarise and depolarise the cells), the onset of an electrical storm and the initiation of an epileptic attack can be prevented.

How far can be go before the entire brain is replaced with robotic neurons? The likely answer is the all the brain cells could be replaced with robotic neurons provided that the cells we are replacing are pure neurons and do not have extra functionality such as synthesis of hormones which are vital for correct bodily functions. (It may be possible to provide a limited amount of this functionality using the sub-micron tube technology described in the mechatronics assembler section.)

What about replacing neurons of someone who is suffering from dementure as a result of disease and old age. Provided the disease is identified early and we seek permission from that person, it should be possible to introduce robotic neurons that live inside neural cells, learning the cell's responses and then to imitate those responses when the cell dies as discussed before. Many of the cells will die off as a result of the diseases that cause dementure but arguably the person who had the neurons roboticised should still be able to function as a normal human being.

If we can identify chemicals that are sythesised by the brain's specialised cells that are needed for the proper functioning of the brain and of the rest of the body, it should not be a difficult task to have those chemicals sythesised outside of the brain and delivered through tubes into the brain from where they are released as if released from an actual cell. However, there are precise timing considerations and environmental stimulus that the brain take into account when releasing chemicals and hence allowances must be made for appropriate detection equipment / software that initiates release of chemicals.

If all the brains cells were fully roboticised, it should be possible to control the rate of thinking by incrementally increasing the pace of activity of the robotic neurons. In software, if everything speeds up or slown down by the same amount, the programs cannot tell the difference between fast and slow mode of operation. Hence it will be possible for a fully roboticised brain to function thousands to perhaps even millions of times faster than a conventional brain. Inter-cellular communication delays, chip heating effects and speed of data processing within robotic cubes put a ceiling limit on the highest speeds at which the robotic brain could work.

It is estimated that the brain could live up to 800 years providing it is fed with the right nutrients. The prospect of a brain removed from its body, kept in a jar and linked to the outside world (e.g. Internet) via cables has been the subject of numerous science fiction movies. A lot of the previously impossible are becoming possible through the use of sensors and electrode arrays where sight and sound organs that have been irrepairably damaged have been replaced with direct insertion of electrode arrays into brain matter. Neurons in contact with the electrode arrays gradually train to recognise the new signals received which when processed by the rest of the brain results is remarkable vision / hearing considering just how little there is in terms of resemblance to the original devices.

In terms of actuators, its long been recognised that muscle signals are still present when a limb is severed which means that putting suitable electrodes into appropriate areas of the brain could lead to direct control of electromechanical equipment.

With both sensor and actuator technologies available to be interfaced to the brain, the question that should be asked is whether it will be possible to one day put a brain in a jar and connect up suitable sensors for hearing and seeing and then to link all that to a shape changing robot as the actuator. Such a robot would be able to walk and work in much the same way as a human being but much much better as the resolution of the robotic cubes improve.

Fantastic new worlds open up to a brain that has been roboticed. Sensors that could be used to see down to the smaller scales would be presented as images to the brain that then could see at those levels whenever it needs to. Since a robotic cube could be used to sythesise objects and conduct experiments, a mind that is directly interfaced to a robotic cube system could conduct thousands of experments very quickly. A very creative and intelligent mind would be able to read many on line digital books, peer into virtual worlds, write computer programs, write music and plays, listen to thousand and one stories all before a day has seen its full course.

Before we open this box of Pandora's delight, there will be many ethical considerations to be considered. For example, not everyone is perfect and since their personalities are reconstructed in their entirety when roboticised, if someone had a deviant trait, that trait and compulsion could be amplified a million fold over a few hours as the brain is switched into high speed mode. If they are attached to robotic cube machinery, databases and other hardware, they may use all those tools to do something that could put others in danger. But then again, you might have an absolute genious such as an Einstein who is prepared to be roboticised to donate their talent and create a better world. Should one refuse the offer? Could we be able to put up with competition of this category in our quest to humanly understand the world?

Once we set off on this path of roboticising neurons, there is no limit to what can be achieved. For example, we could take a back up copy of someone's personality. It is the personality that is immortalised into our memories when we think of other people and hence we could preserve those personalities in 'jars' (i.e. computer databanks). People preserved in this manner would not die as such from their physical death.

What will be more awsome is that we could transfer this personality around through networks just like computer data - and eventually download it into a silicon android with silicon muscles and silicon body. In other words we can take the brain and its personality and transfer it to a fully functional digital machine that looks and behaves very much like the original person. Is this the real person? Only time and ethical testing will tell.

Shocked yet? No? We could roboticise a babies brain - which is adept at learning - then we could download that data and then attach it to an adult's roboticised brain. This baby brain robotic neurons have no personality and is quickly assimilated into the adult brain with the result that he is able to think more deeply and remember more detail. You could keep on adding and increase your capacity to think and remember in ever increasing detail because you can keep on duplicating those roboticised baby neuron cells without limit.

Could you put two personalities together in the same brain to discover crime and secrets? Possibly yes, possibly no. Who knows..?!

1.6 Future Directions

The writings of some researchers look more like science fiction than the reality that is to be found in research laboratories. Most of the futuristic predictions of androids arc unlikely to be achieved in the near future. The complexity of the human brain is such that monitoring many of its activities is beyond current technology. Researchers investigate small sections of the brain in detail to try and pinpoint which areas perform which functions. At present, we don't understand the sensory process of hearing and interpreting speech, which involves the analysis of a single analogue signal Our knowledge of the brain is similar to that of a person who, when looking at a printed circuit board, can draw a map of the connections between the integrated circuits, hut has little understanding of what operations are performed inside the integrated circuits and even less idea of how the circuit interact to perform their overall function.

At a more practical level, one of the significant problems in robotics is communication between computers, sensors, and robots lack of common communications standards (both hardware networks and software protocols), creates real problems when integrating robots and sensors into a work cell. To overcome these problems, some manufacturers have adopted the Manufacturing Automation Protocol (MAP) standard.

1.7 Robot classification

The power of the software in the controller determines the utility and flexibility of the robot within the constraints of mechanical design and sensor availability. Robots have been classified according to:

- Their generation
- Their intelligence level
- Their level of control
- Their programming language level

These classifications overlap, but they all reflect the power of the software in the controller, in particular, the sophistication of sensor interaction.

1.7.1 Robot classification based on their generation

The generation of a robot is determined by the historical order of developments in robotics. Five generations are normally assigned to industrial robots. The third generation is used in industry, the fourth is being developed in research laboratories, and the fifth generation is largely a dream. The generations are:

1. Playback robots: which play back a sequence of recorded instructions, such as in spray painting and spot welding, these robots often have open loop control for example, pick-and-place robots which use mechanical stops to limit travel.

2. Sensor-controlled robots: which have closed-loop control of manipulator motions, and decision making based upon sensor inputs.

3. Vision-controlled robots: where the robot can manipulate an object using information from a vision system.

4. Adaptively controlled robots: where the robot can automatically reprogram its actions of the basis of sensor input.

5. Artificially intelligent robots: where the robot uses the techniques of artificial intelligence to make its own decision and solve problems.

1.7.2 Robot classification based on their intelligence level

The Japanese robot association (IIRA) has classified robots into six classes on the basis of their level of intelligence.

1. Manual handling devices controlled by a person.

2. Fixed sequence robot.

3. Variable sequence robots where an operator can modify the sequence easily.

4. Playback robots where the human operator 'cads the robot through the task.

5. Numerically controlled robots where the operator supplies a movement program, rather than teaching it the task manually

6. Intelligent robots, which can understand and interact with changes in the environment.

1.7.3 Robot classification based on their level of control

The programs in a robot controller can be grouped according to the level of control they perform.

1. Artificial intelligence level, where the program will accept a command such as, Pick up the bearing, and decompose it into a sequence of lower level commands based on a strategic model of the task.

2. Control mode level where the motions of the system are modeled, including the dynamic interactions between the different mechanisms. Trajectories planned, and grasp points selected. From this model a control strategy is formulated, and control commands issued to the next lower level.

3. Servo system level where actuators control the mechanism parameters using feedback of internal sensory data, and paths are modified on the basis of external sensory data. Also failure detection and correction mechanisms are implemented at this level.

1.7.4 Robot classification based on their programming level

The final classification we will consider is programming language level. The key to the effective application of robots to a wide variety of tasks the development of high-level robot language. Many robot-programming systems exist, although the most advanced are currently available only in research laboratories. Existing robot programming systems fall into three broad categories.

1. Guiding systems, in which the user leads the robot through the motions to be performed.

2. Robot-level programming systems, in which the user writes a computer program to specify motion and sensing.

3. Task-level programming systems, in which the user specifies operations by their motions on the objects the robot is to manipulate.

2. STEWART PLATFORM

2 1 Introduction

The Stewart Platform is a parallel link mechanism, which has the major mechanical differences from the typical serial link robot. The basic idea in this parallel link mechanism is to connect two platforms with a number of links, and to distribute the loads between the legs, which results in improved load carrying capabilities, and to improve both accuracy and repeatability, as error will tend to average out rather than accumulating as in the case of serial link mechanisms.

Stewart Platform was first designed and built to test tires at the Performance and Stressing Department over a decade before Stewart published his article in 1965. in his article Stewart has proposed the use of a platform for flight simulator, machine tools, universal milling machine and oil drilling rigs.

The Stewart Platform has attracted the attention of many researchers and gained an increased popularity within the industrial society nowadays. This attention brought such applications as machine tool technology, underwater research, air-to-sea rescue, flight simulation and satellite positioning …etc.

There are many different types of Stewart Platforms studied in the literature where shape of the base and the upper platform are either assumed to be a hexagonal or triangular. Also some of the platforms have either six legs or three legs. The connections of the legs are provided by a ball joints or a universal ones.

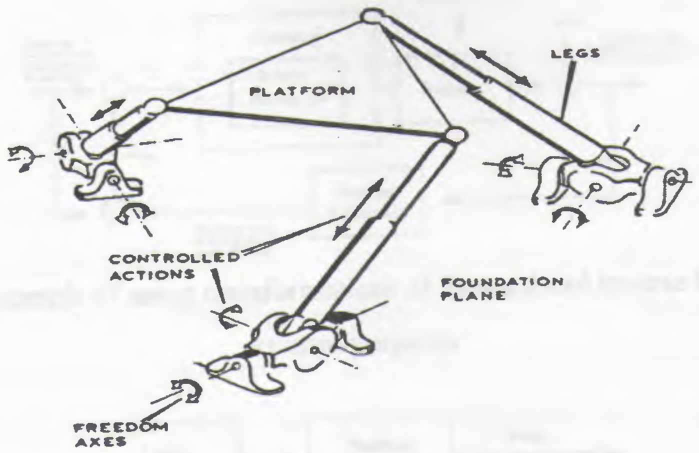

Fig 2.1 General Arrangement

Our algorithm has a number of advantages in comparison with the existing solutions. It uses a non linear equation with one unknown and two roots. It is not necessary to solve all 16 mathematically possible solutions for the platform but actually one should be sufficient, given that the structure of the platform is known and that we make sure that we are inside of some regions of existence that we will later define

The re sults can be used for real-time control application in a variety of settings. Control structures are being developed presently.

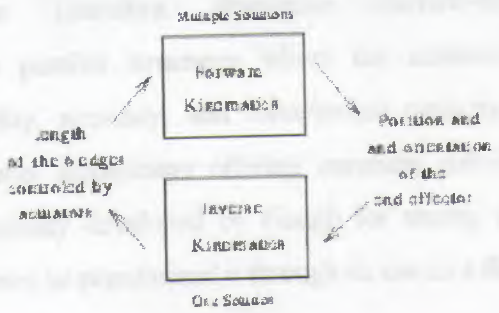

Fig 2.2 Forward and inverse kinematics

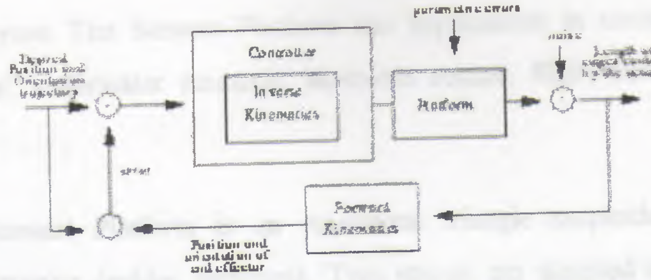

Fig 2.3 An example of using transformations of forward and inverse kinematics for control purposes

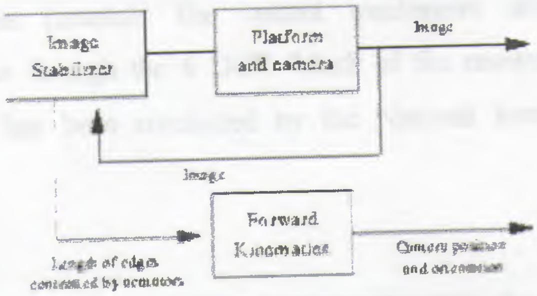

Fig 2.3 An example of using inverse kinematics for measuring purposes

To achieve higher *accuracy* during the machining process, high rigidity and stability of he machine's structure are necessary. The majority of today's industrial multi-axis machines consist of serially connected axes. A serial mechanism, one whose links and joints alternate with one another in a long chain, is inherently non-rigid due to is cantilevered structure. Therefore, alternative machine-tool designs have been investigated based on parallel structures where the actuators forma closed kinematic chains enhancing rigidity, accuracy, and force/torque capacity. The Stewart Platform is an example of a parallel architecture offering excellent stability and high stiffness. The structure although originally developed by Gough for testing tires, is widely regarded as the Stewart Platform since he popularized it through its use as a flight simulator.

2.2 DESCRIPTION

The Stewart Platform and the Inverted Stewart Platform parallel link manipulators are unique kinematically constrained work platforms. Both versions possess a control platform that can be manipulated through the six degrees of freedom (DOF) of x, y, z, pitch, roll, and yaw. The Stewart Platform has applications in machine tool technology, crane technology, underwater research, air-to-sea rescue, flight simulation, and satellite dish positioning.

The Inverted Stewart Platform is an equilateral triangle suspended in an octahedron frame by six actuators (cables orstrings). Two strings are attached at each corner of the suspended platform triangle. Each pair of strings is run through pulleys attached to the vertices of the top triangle, down to the base of the octahedron frame and then fastened to the control devices (cranks). The control mechanism allows the operators to manipulate the platform through the 6 DOF. Much of the research and development on the Stewart Platform has been conducted by the National Institute of Standards and Technology (NIST).

Fig 2.5 Stewart Platform as a miller

2.3 Construction

Stewart Platform has upper and tower platforms with equilateral triangular shape as shown in figure 2.2. There are many different types of Stewart Platforms studied in the literature where shape of the base and upper platform are either assumed to be hexagonal or triangular. Also some of the platforms have either six legs or three legs. The connections of the legs are provided by either through ball joints or universal (cardan) joints.

2.4 Applications

Stewart Platform has attracted the attentions of many researchers and gained an increased popularity within the industrial society nowadays. This attention brought such applications as machine tool technology, crane technology, underwater research, air-to-sea rescue, flight simulation and satellite dish positioning.....etc.

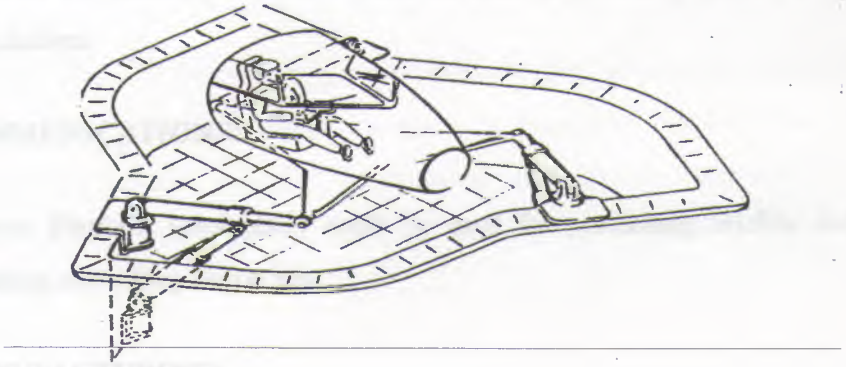

Fig 2.6 Pictorial view of Flight Simulator

To clarify this, some examples of Stewart Platform applications are listed bellow:

2.4.1 CONSTRUCTION

ON LAND: The Inverted Stewart Platform can be used to replace conventional crane technology. The Inverted Stewart Platform crane provides the crane operator with greater control of the crane hoist mechanism. The national Institute of Standards and Technology has developed a crane, known as ROBOCRANE, utilizing the Stewart Platform technology.

AT SEA: The Inverted Stewart Platform can be suspended from a single floating vessel or it can be suspended from three strategically located ships to place an underwater drilling platform, lay pipelines, or it can be used for underwater salvage.

IN THE AIR: An Inverted Stewart Platform can replace the conventional single cable hoisting technology currently being used on helicopters for use as an air crane or in air-to-sea rescue.

IN SPACE: An Inverted Stewart Platform could be modified for use as a Lunar Rover. Equipped with the necessary wheels it could be used to lift heavy objects or it could serve as drilling platform.

2.4.2 COMMUNICATIONS:

A Stewart Platform manipulator could be used for positioning satellite dishes on land or on a pitching and rolling ship at sea.

2.4.3 MANUFACTURING:

The Stewart Platform concept is currently being applied in machine tool technology in a machine manufactured by Ingersoll known as a Hexapod. The Hexapod is a unique milling machine which can be manipulated through six degrees of freedom. Conventional milling machines can only be operated in 3 to 4 axes (x, y, z, and rotational).

The inverted Stewart Platform can be suspended from a single floating vessel or it can be suspended from three strategically located ships to place an underwater drilling platform (as shown in figure 2.4), lay pipelines, or it can be used for underwater salvage.
The Inverted Stewart Platform can be used to replace conventional crane technology. The Inverted Stewart Platform crane provides the crane operator with greater control of the crane hoist mechanism. The national Institute of Standards and Technology has developed a crane, known as RODOCRANE (see figure 25\ utilizing the Stewart Platform technology.

An Inverted Stewart Platform can replace the conventional single cable hoisting technology currently being used on helicopters for use as an air crane or in air-to-sea rescue, and also the Stewart Platform manipulator could be used for positioning satellite dishes on land or on a pitching and rolling ship at Sea.

Stewart Platform is used in complicated heart surgery to assist the surgeon and ensure accuracy in dealing with critical position in human body.

An inverted Stewart Platform could be modified for use as a Lunar Rover. Equipped the necessary wheels it could he used to lift heavy objects or it could serve as drilling platform.

The Stewart Platform concept is currently being applied in machine tool technology in a machine manufactured by Ingersoll known as a Hexapod. The Hexapod is a unique milling machine, which can be manipulated through six degrees of freedom. Conventional milling machines can only be operated in 3 to 4 axes (x, y, z, and rotational)

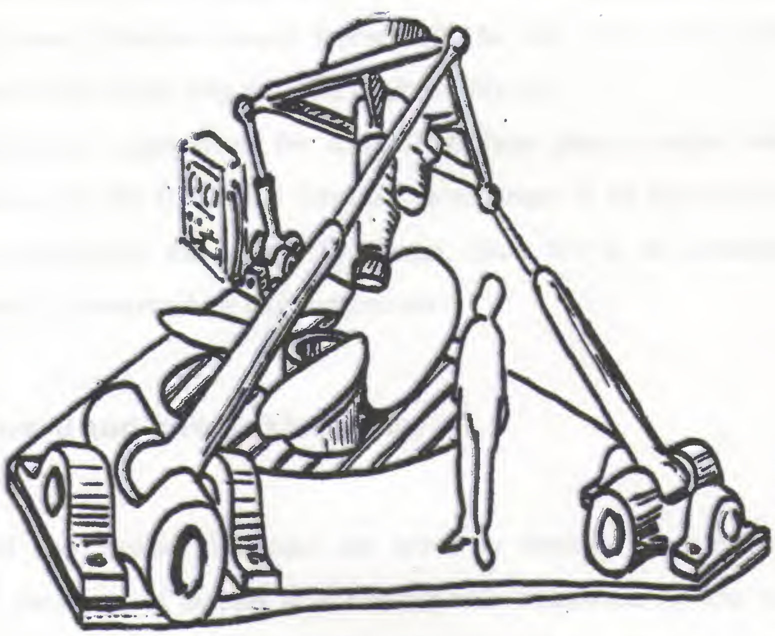

Fig 2.7 Impression of possible design of universal mill

2.5 Stewart Platform Classifications

The Stewart platforms can be classified into different configurations. The most general Stewart platform is the 6-6 platform, where the legs connect to six different points on the base and six different points on the top platform. The general configuration is given by "B-P", where B is the number of points legs connect to the base and P is the number of points legs connect to the top platform. Thus, the configuration for the two Stewart Platforms shown above would be 3-3.

The Configuration may also be given as "6-p", where p is the number of point's legs join the upper platform. Thus, the two platforms shown in the figure above would have configuration of 6-3

It has been analytically found out that the maximum number of solutions for most general Stewart Platform would theoretically be 40. This is an extremely non-linear equation and shows why the FDA might be difficult

For machine tool applications the issue of stiffness plays a major role in selecting the configuration. As the Octahedral Structure is supposed to be the most rigid structure, the structures resembling that should be chosen. Since 6-3 is an octahedral structure it is chosen for most machine tool applications.

2.6 Forward and inverse kinematics

Forward and inverse kinematics are terms to describe mapping from the space of inputs to the space of outputs of a non-dynamic mechanical system as shown in figure 2.8. Forward kinematics involves solving the forward transformation equation to find the oration of the hand in terms of the angles and displacements between the links while inverse kinematics involves solving the inverse transformation equation to find the relationships between the links of the manipulator from the location of the hand in space.

Figure2.9 shows a typical application of the forward and inverse kinematics algorithm. A trajectory for a device such a milling machine or welding system is to be followed. The controller, using the inverse kinematics algorithm (and calculating desired changes in position), computes he control signal given to the actuator. At the output of the platform we measure the lengths of the links controlled by the actuators, and then the forward kinematics algorithm transforms those lengths into (platform) position. The position signal is compared to the assigned position and added to the controller's input.

Because of the Stewart Platform closed kinematics chain, the rigidity of the end effectors, and the accuracy of the links length servos, a reasonably accurate feed-forward assignment is possible. Due to the complexity of older forward kinematics algorithms, most Stewart platforms are controlled without using feedback. The proposed algorithm will allow the calculation of the forward kinematics in real time. This opens the opportunity to increase the accuracy of the control algorithms and broaden the current uses of the platform

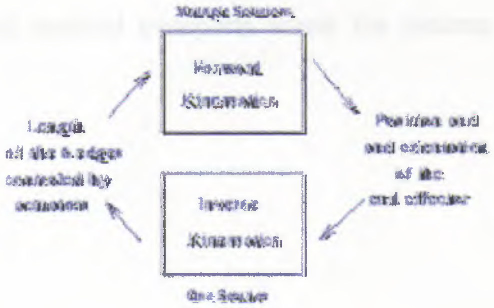

Fig 2.8 Forward and inverse kinematics

2.7 Advantage of Stewart Platform

Some of the advantages of Stewart Platform may be listed as follows:

Stewart Platform is a parallel link mechanism which has the major mechanical differences from the typical serial link robot. The basic idea in this parallel ink mechanism is to connect two platforms with a number of links and to distribute the loads between the legs, which results in improved load carrying capabilities, and to improve both accuracy and repeatability as errors will tend to average out rather than accumulating as Ti the case of serial lint mechanisms

In addition to the significant improvements over conventional technology in term of performance and cost, the Stewart Platform offers the possibility for further improvements towards ultra-fine-tolerance machining. An important means for achieving this goal is the development of error compensation capabilities based on the precise understanding of inaccuracy factors which cause position and orientation errors during the tool's motion.

If an object is transported on a mobile platform all accelerations of the mobile platform affect the object. This is of course undesirable, since accelerations can move or even damage the object. Stewart-Platforms are mostly used for simulation, where the platform generates accelerations that increase the simulations quality. Vice versa, it is possible to use a Stewart-platform mounted on a mobile platform to compensate the unwanted accelerations by generating a tilt. The necessary movement of the platform is calculated by a washout-filter. Applications of this combination include the transport of liquids in open boxes and medical transports where the patients must not be affected by any acceleration.

3. 4-DOF STEWART PLATFORM

3.1 Introduction

A 4-DOF Stewart Platform has upper and lower platforms with equilateral triangular shape. In this project our platform is augmented locating an extendible limb at the mass center of the upper platform along the direction of the unit normal vector.

The 4-DOT Stewart Platform manipulator shown in Fig (3.1) is used as the basic part of the manipulator considered in this topic. It consists of equilateral triangular upper and lower platforms. This platform here is augmented by locating an extendible limb at the mass center of the upper platform along the direction of the unit normal vector. All the previously obtained results for 3-DOF Stewart Platform are used and extended for this 4-DOF manipulator.

In particular the problem that is studied in this topic to determine die the motion of all the limbs when the tip of the extendible limb is constrained to move in space from one point to another along any function passing through these points with a suitable velocity and acceleration profiles.

If the positions of the two points in space, and also the z component of position vector of the mass center for the upper platform are given then the rest of the information about the inverse kinematic of the mechanism is supplied by a written Matlab program. Through this program one can easily calculate the lengths, velocity and acceleration for each limb.

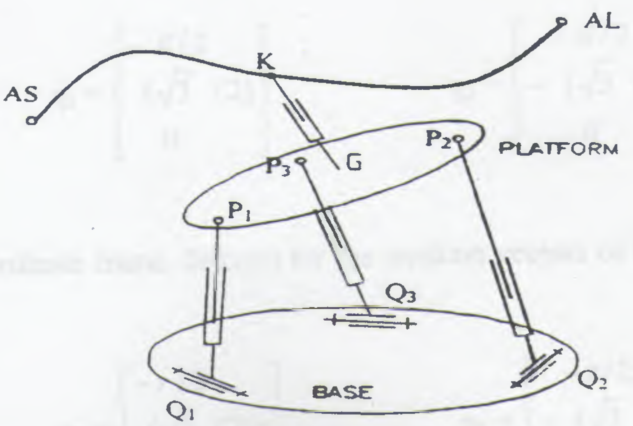

Fig 3.1 4-DOF Stewart Platform

3.2 Applications

This design can be applied in variety fields

For instance

1. The important use of the 4-DOF Stewart Platform is in the areas of painting, it represent a useful application. Through that application, things that have to be into consideration are:

   The distance between the plan and the tip of the extendible limb should be constant.

   The flow rate of the paint should be constant too.

2. In the industrial areas it represents useful applications in machining of metals, for example it can be used as a shaper machine to keyway in rods like crankshaft of the Cars. In this case there are necessary thing have to be considered:

   The orientation of the tip should be constant.

   The depth of the keyway should be equal to the length of the cutting tool.

   The width of the cutting tool should be equal to the separation between the adjacent lines.

3.3 Fundamental for Stewart Platform Calculations

A 3-DOF Stewart Platform has upper and lower platforms with equilateral triangular shape as shown in Figure 3.1.

With respect to the selected coordinate frame S(0XYZ) for the position vectors of the corners of the lower platform we have

$$q_1 = \begin{bmatrix} R \\ 0 \\ 0 \end{bmatrix} \qquad q_2 = \begin{bmatrix} -R/2 \\ (\sqrt{3}\ /2) \\ 0 \end{bmatrix} \qquad q_3 = \begin{bmatrix} -R/2 \\ -\ (\sqrt{3}\ /2) \\ 0 \end{bmatrix} \qquad (3.1)$$

Similarly for the coordinate frame $\Sigma(0xyz)$ for the position vectors of the corners of the upper platforms we have

$$p_1 = \begin{bmatrix} r \\ 0 \\ 0 \end{bmatrix} \qquad p_2 = \begin{bmatrix} -r/2 \\ (\sqrt{3}\ /2)r \\ 0 \end{bmatrix} \qquad p_3 = \begin{bmatrix} -r/2 \\ -\ (\sqrt{3}\ /2)r \\ 0 \end{bmatrix} \qquad (3.2)$$

Initially it is assumed that Σ and S are coincident and sharing the same origin 0. After the displacement of the upper platform with center G (center of the equilateral triangle), its corners P (i=1. 2, 3) lie on the respective vertical planes II, II, and II passing through the vertical 0Z axis. Let the position vector of G be

$$\xi = [x_G y_G z_G]^T \tag{3.3}$$

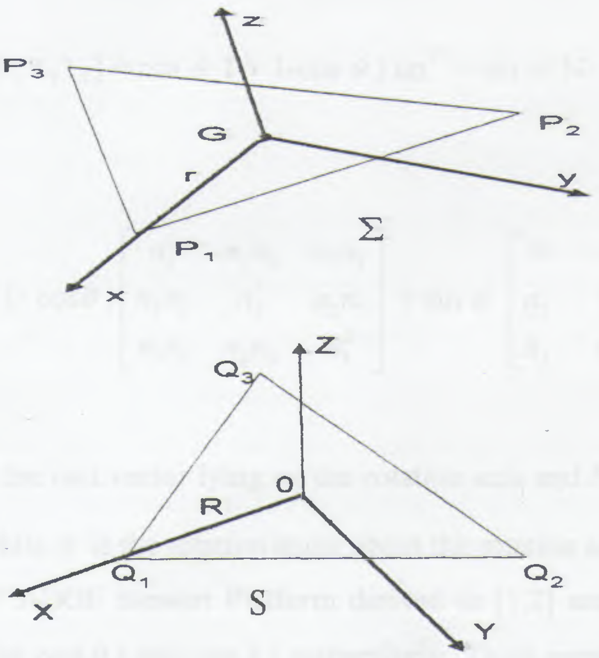

Fig 3.2 Upper and Lower platforms

$$\mathbf{T} = [\mathbf{t}_1 \ \mathbf{t}_2 \mathbf{t}_3] \tag{3.4}$$

Note that each limb has two degree of freedom:

A limb can rotate about the revolute joint at q_i (i=1,2,3) and also its length l_i may be changed; however the limb remains within the fixed vertical plane II_i. If represents the transformation matrix which transforms the initial position of the upper platform to its displaced position, then fro the position vectors of the joints P_i one can write

$$
\begin{aligned}
a &= T\,p_1 + \xi \\
b &= T\,p_2 + \xi \qquad (3.5) \\
c &= T\,p_3 + \xi
\end{aligned}
$$

According to Rodriguez's formulas we have:

$$T(n,\theta) = [t_1\ t_2\ t_3] = \cos\theta\ \mathbf{I} + 1\text{-}\cos\theta)\,nn^T + \sin\theta\ N \qquad (3.6)$$

$$T = \cos\theta \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} + (1-\cos\theta) \begin{bmatrix} n_2^1 & n_1n_2 & n_1n_3 \\ n_2n_2 & n_2^2 & n_2n_3 \\ n_3n_1 & n_3n_2 & n_3^2 \end{bmatrix} + \sin\theta \begin{bmatrix} 0 & -n_3 & n_2 \\ n_3 & 0 & -n_1 \\ n_2 & n_1 & 0 \end{bmatrix} \qquad (3.7)$$

$n = [n_1\ \ n_2\ \ n_3]^T$ is the unit vector lying on the rotation axis and N is its skew-symmetric matrix representation while θ is the rotation angle about the rotation axis.

Constraint equations of 3-DOF Stewart Platform derived in [1,2] are reproduced in (3.8). Where C and S stand for cos(θ) and sin(θ) respectively. Third equation in (3.8) states that either sin(θ)=0 (which means that $0=k\pi$ with $k=0, \pm 2$ ...) or $n_3 = 0$, where the occurrence of the second case is most probable.

Therefore assuming that $n_3 = 0$ and hence $\mathbf{n}_1^2 + \mathbf{n}_2^2 = 1$, the transformation matrix T in (3.6) takes the form given in (3.9).

$$
\begin{aligned}
x_G &= -\frac{r}{2}(1\text{-}C)(n_2^2 - n_2^1) \\
y_G &= -r\,(1\text{-}C)\,n_1\,n_2 \qquad (3.8) \\
0 &= Sn_3
\end{aligned}
$$

$$T(n,\theta) = \begin{bmatrix} C+(1-C)n_1^2 & (1-C)n_1 n_2 & Sn_2 \\ (1-C)n_1 n_2 & C+(1-C)n_2^2 & -Sn_1 \\ -Sn_2 & Sn_1 & C \end{bmatrix} = [t_1 \ t_2 \ t_3 \qquad (3.9)]$$

From these expressions one can deduce the following important property: The rotation axis and hence **n** lies in the 0XY plane. The unit vector $\mathbf{v} = \mathbf{t}_3$ is perpendicular to both the upper platform giving its orientation and also to the rotation axis as shown in Fig (3.3).

3.4 Inverse Kinematics of Augmented Platform

In this section 3-DOF platform is augmented by locating an extendible limb at the mass center of the upper platform along the direction of the unit normal vector as shown in Fig (3.1). We assume that the positions of the points AS, AL, ASn, and ALn are in space and z_G component in (3.3) are known. The problem here is to determine the motion of all the limbs when the tip K of the extendible limb is constrained to move in space following a curve plane. That is to move along set of parallel adjacent curves. We are going to determine the motion of all the limbs when the tip K constrains to move in space from the point AS1 to the point AL! along the sine curve with a suitable velocity and acceleration profiles, and by repeating this procedure for the parallel adjacent curves we can get the length, velocity and acceleration profiles.

For position changes of the end point of the extendible limb, a function $\lambda\ (t)$ indicated in Fig (3.3) must be selected so that its velocity and acceleration become zero at the beginning and at the end of the motion. To satisfy these conditions one way of selecting $\lambda\ (t)$ is:

$$\lambda\ (t) = \frac{1}{2\pi}\ (t - \sin t) \qquad 0 \le t \le 2\pi \qquad (0 \le \lambda \le 1) \qquad (3.10)$$

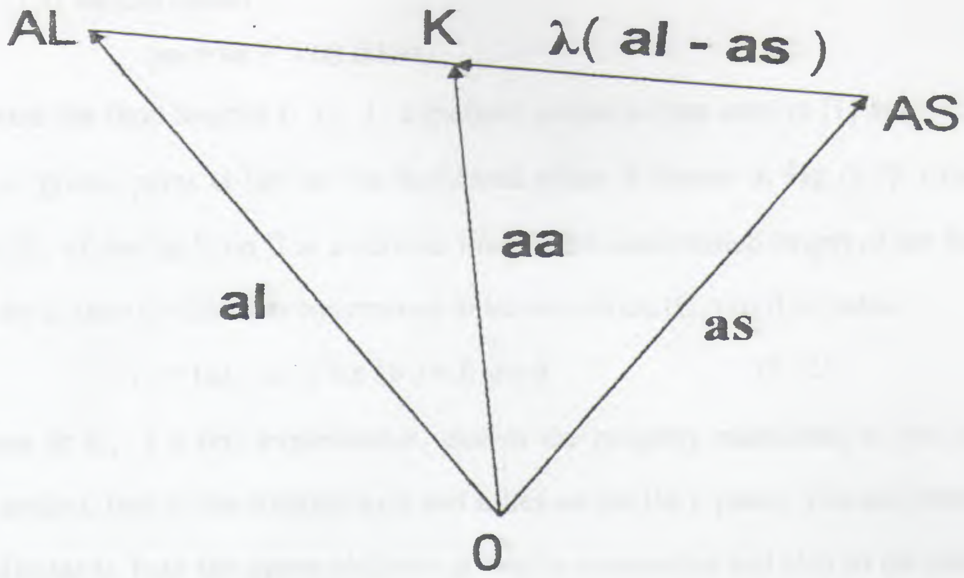

Fig 3.3 Vector representation for the path

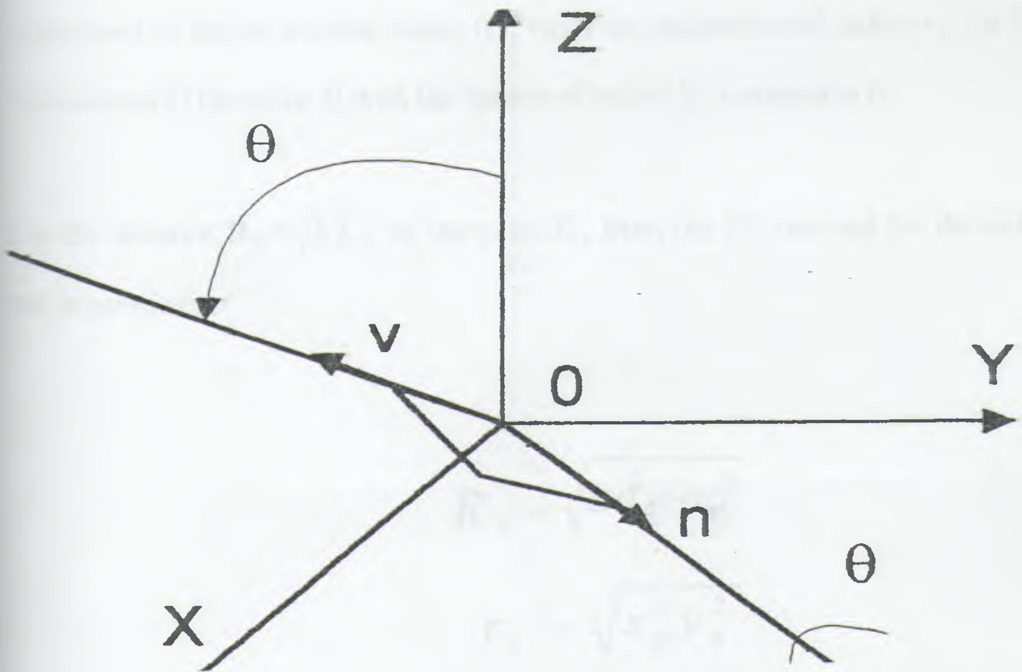

Fig 3.4 Interpretation of the transformation

From Fig (3.3) we can obtain

$$\mathbf{aa} = \mathbf{as} + \lambda (t)\, (\mathbf{al}\text{-}\mathbf{as}) \qquad (3.11)$$

To determine the limb lengths l_1 l_2 l_3 a method similar to that used in [1] may be repeated: since z_G is given, point G lies on the horizontal plane II shown in Fig (3.5). Consider the projection K_1 of the tip K on II at a definite time. If the undermined length of the limb KG is indicated by L, then G is further constrained to lie on a circle (C_1) in II of radius.

$$r_1 = (aa_z - z_G) \tan(\theta) = L \sin\theta \qquad (3.12)$$

with center at K_1. I n this expression θ, due to the property mentioned at the end of the previous section, that is, the rotation axis and **n** lies on the 0XY plane. The unit vector $\mathbf{v} = \mathbf{t}_3$ is perpendicular to both the upper platform giving its orientation and also to the rotation axis as shown in Fig (3.3), is the same as the rotation angle. Actually (C_1) is the intersection of the plane II with the sphere of radius L with the center at K. on the other hand G may also be considered to lie on another circle (C_2)with an undetermined radius r_0. In fact (C_2) is the intersection of the plane II with the sphere of radius $|\xi|$ centered at 0.

For the distance $\mathbf{R}_0 = \left|\overline{0_1 K_1}\right|$ of the point K_1 from the 0Z axis and for the radius r_0 we have the expressions

$$\boldsymbol{R}_0 = \sqrt{aq_x^2 + aq_y^2} \qquad (3.13)$$

$$\boldsymbol{r}_0 = \sqrt{x_g^2 y_g^2}$$

since both the circle (C_1) and (C_2) are lying in II, their intersecting points determine the location of G. in order to obtain a unique solution we shall consider the case where the circles are tangent to each other. However to keep G as close as possible to the 0Z axis we consider the case indicated in Fig (3.6).

Depending upon whether $R_0 - r_1$ is positive or negative we have

$$\overline{0_1 G} = k\, \overline{0_1 k_1} \qquad (3.14)$$

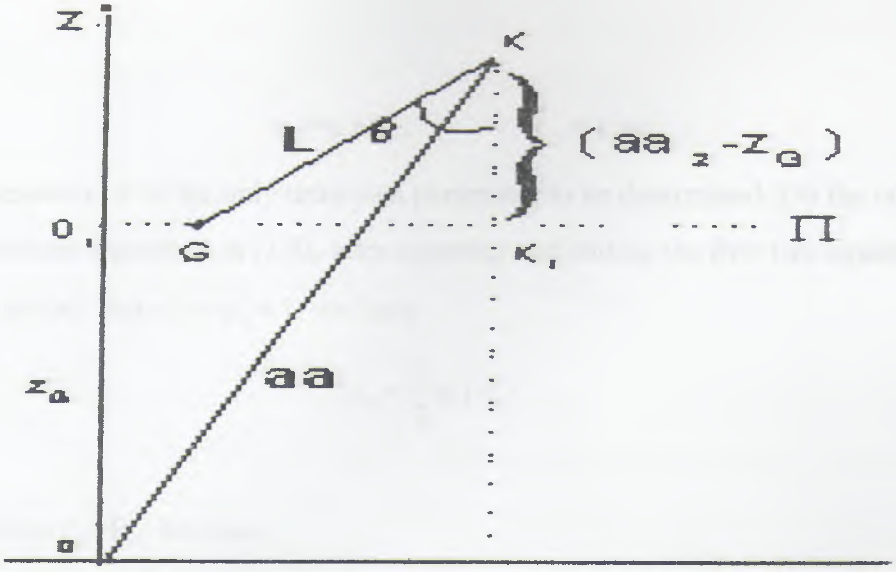

Fig 3.5 Vector representation on a vertical plane

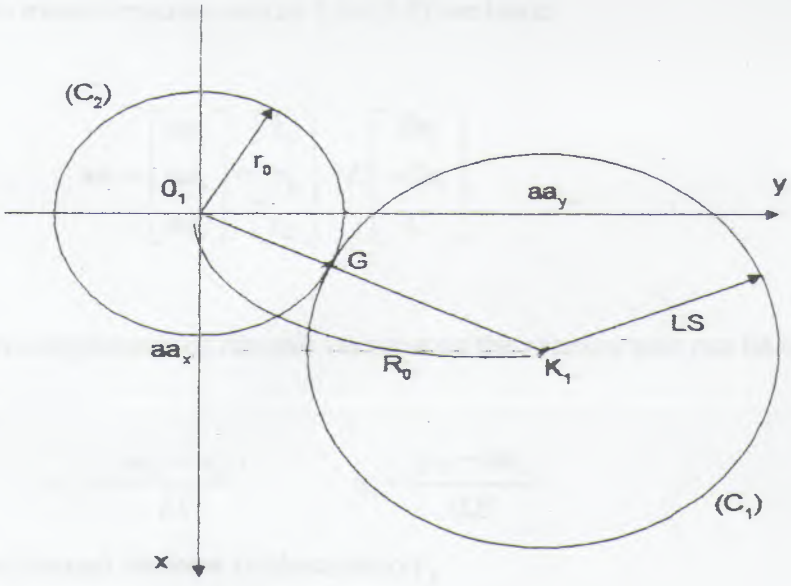

Fig 3.6 Geometry for the location of Gin II plane

And from (3.12) and (3.13) we write

$$\mathrm{K} = \frac{R_0 - r_1}{R_0} = \mathbf{1}\text{-}\frac{(aa_z - z_G)\tan(\theta)}{\sqrt{aa_x^2 + aa_y^2}} \qquad (3.15)$$

Therefore

$$x_G = k\, aa_x, \qquad x_G = k\, aa_y \tag{3.16}$$

in these expressions θ is the only unknown parameter to be determined. On the other hand from the constraint equations in (3.8), after squaring and adding the first two equations and considering the fact that $n_1^2 + n_2^2 = 1$, we have

$$r_0 = \frac{1}{2} r(1\text{-}C) \tag{3.17}$$

Then the relation $r_0 = R_0$ becomes

$$\sqrt{aa_x^2 + aa_y^2} = \frac{1}{2} r\,(1\text{-}C) + (aa_z - z_G)\tan(\theta) \tag{3.18}$$

And its solution for θ determines x_G and y_G in (3.16). From Fig (3.5) and from the expression of the transformation matrix **T** in (3.9) we have:

$$\mathbf{aa} = \begin{bmatrix} aa_x \\ aa_y \\ aa_z \end{bmatrix} = \begin{bmatrix} x_G \\ y_g \\ z_G \end{bmatrix} + L \begin{bmatrix} Sn_2 \\ -Sn_1 \\ C \end{bmatrix} \tag{3.19}$$

and the unknown components of the unit vector **n** on the rotation axis can be obtained as

$$n_2 = \frac{aa_x - x_G}{LS}, \qquad n_1 = \frac{y_G - aa_y}{LS} \tag{3.20}$$

Note that the unit normal vector **v** is identical to $\mathbf{t}_3$

In (3.9)

$$\mathbf{v} = \begin{bmatrix} Sn_2 & -Sn_1 & C \end{bmatrix}^T \tag{3.21}$$

With these information **T** is calculated from (3.9) or (3.6) and a, b, c from (3.5), all in turn give the limb lengths as

$$l_1 = |a - q_1|, \qquad l_2 = |b - q_2|, \qquad l_3\, |c - q_3| \tag{3.22}$$

Velocity of the limbs can be calculated by remembering that

$$l_1' = \frac{l_1(t+\Delta t) - l_1(t)}{\Delta t} \qquad (3.23)$$

Similarly acceleration of the limb length can also be obtained .

A written Matlab program given in appendix A calculates all these expressions. A close study yields that the in the result of the example considered below the speed and acceleration of the legs are not quite zero at the beginning and end of the motion. This situation may be improved if the expression of λ in (3.10) is used twice:

$$\lambda\,(lt) = \frac{1}{2\pi}\,(\left[\frac{2\pi}{Tt}lt - \sin(\frac{2\pi}{Tt}lt\right] - \sin\left[\frac{2\pi}{Tt}lt - \sin(\frac{2\pi}{Tt}lt\right]) \qquad (3.24)$$

Where Tt is the duration of time (lt).

3.5 The programs results

The figures bellows are representing the path taken by the tip point k of the 4-DOF Stewart Platform, the lengths, velocities and accelerations of the extendible limbs.
Fig (3.7) explains the motion of the tip which moves from the beginning of the first curve to its end and comes back in a straight line to the next curve.

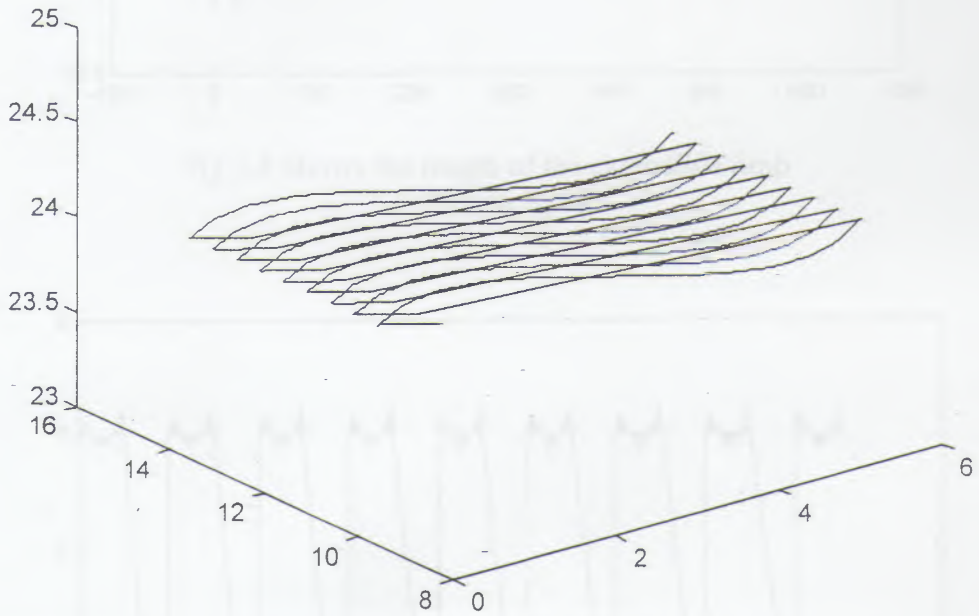

Fig 3.7 The motion of the tip k in sine curve plane
Plot3 (aax,aay,aaz)

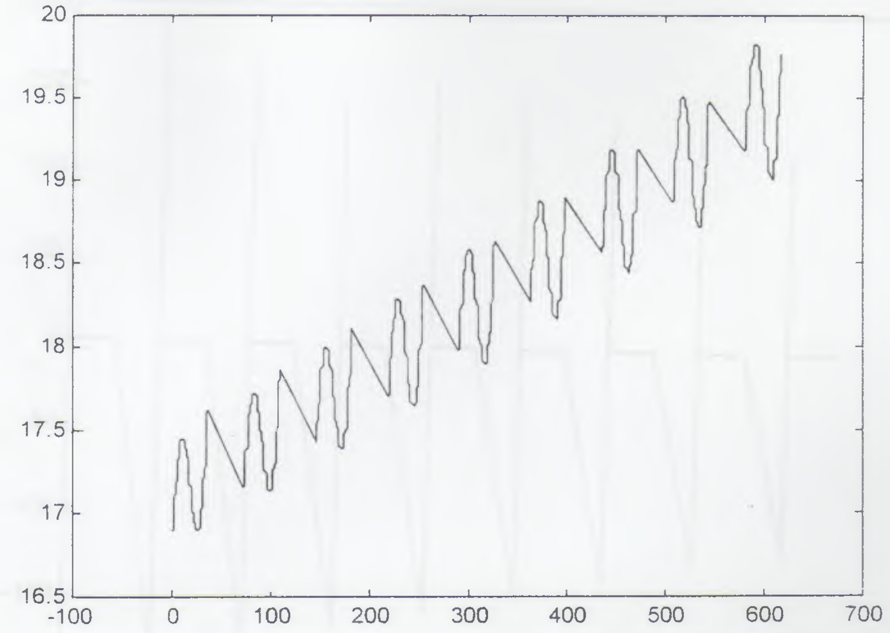

Fig 3.8 Shows the length of the extendible limb
Plot (ltt,ll)

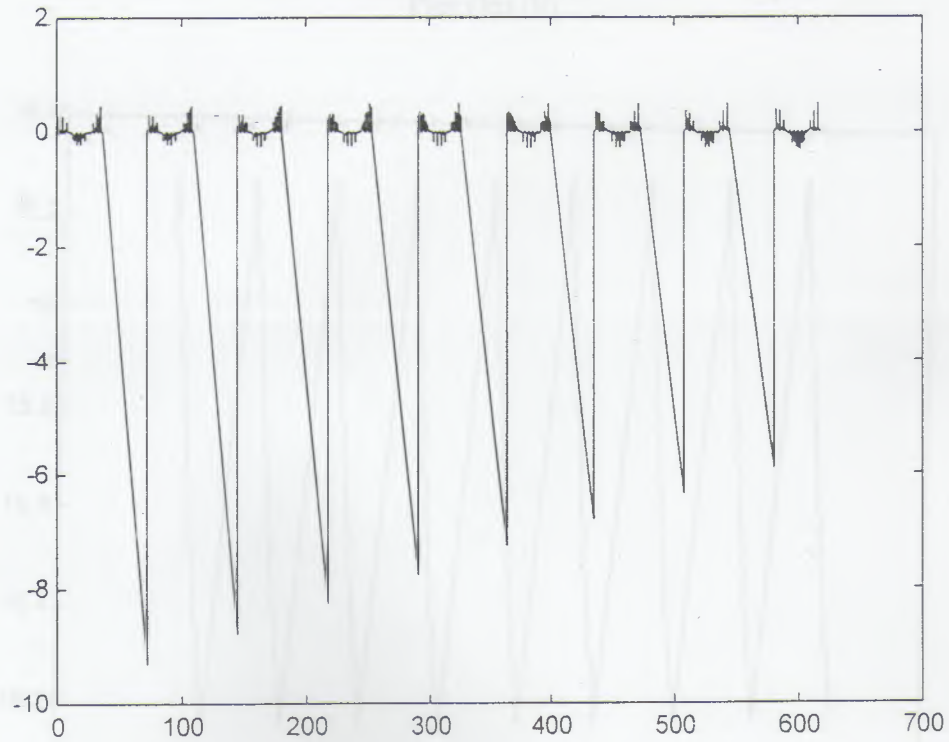

Fig 3.9 Shows the velocity of the extendible limb
Plot (ltth,llh)

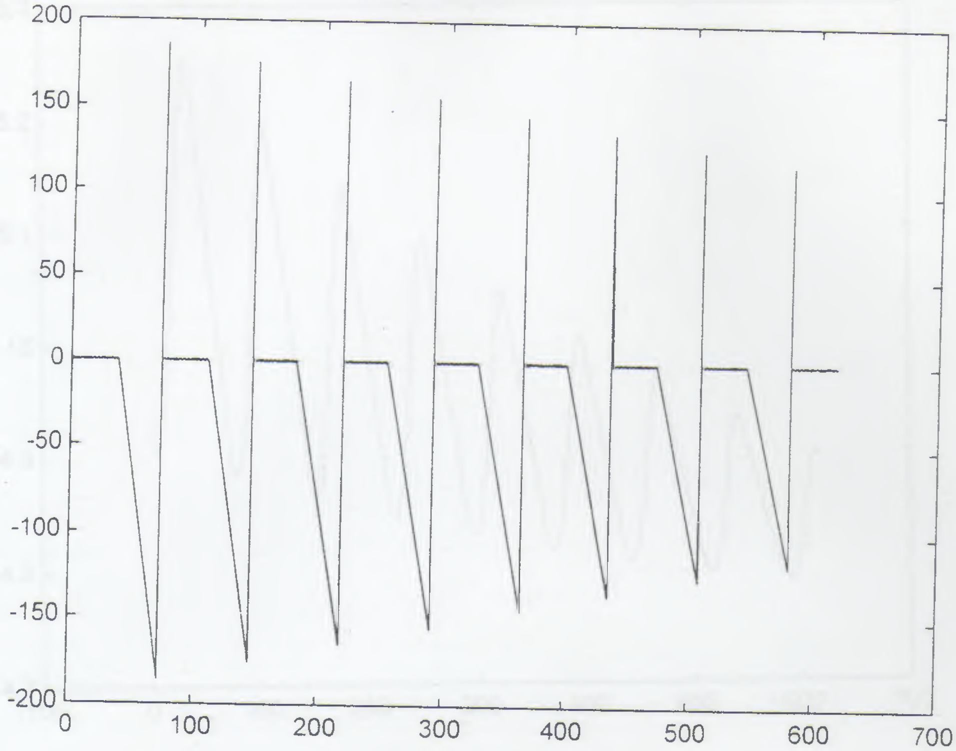

Fig 3.9 Shows the acceleration of the extendible limb
Plot (ltti,lli)

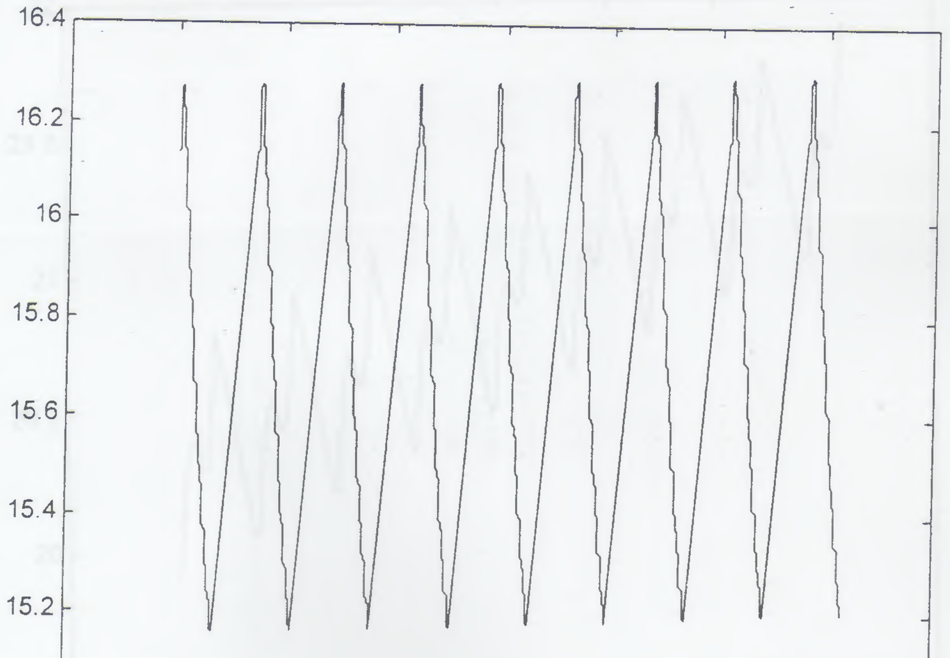

Fig 3.10 shows the length of the first limb
Plot (ltt,l1)

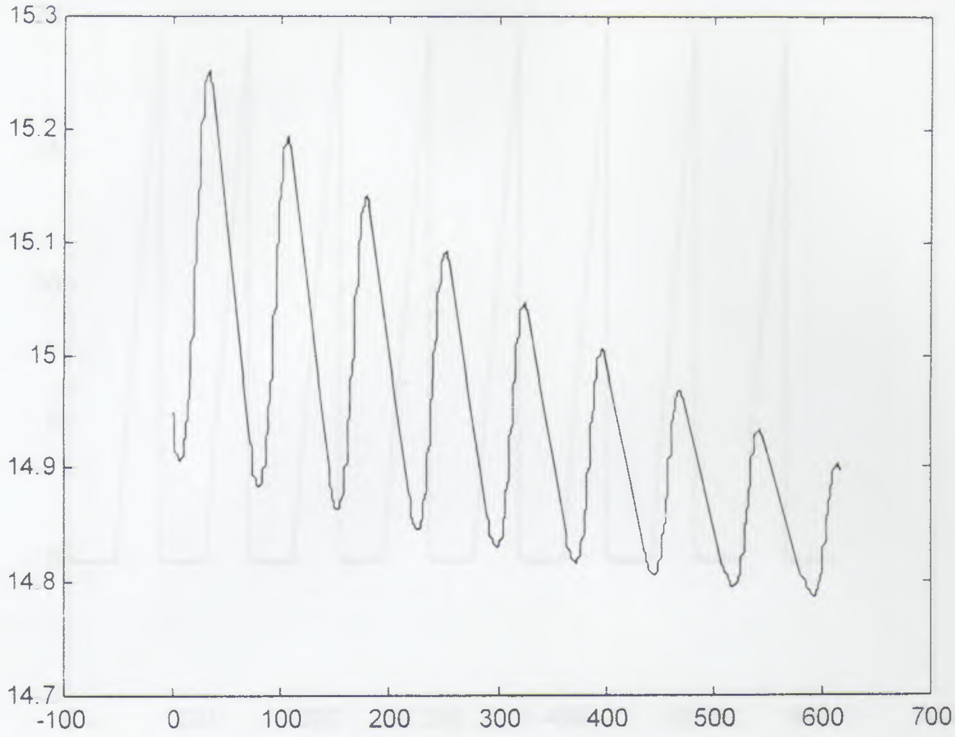

Fig 3.11 Shows the length of the second limb
Plot (ltt,l2)

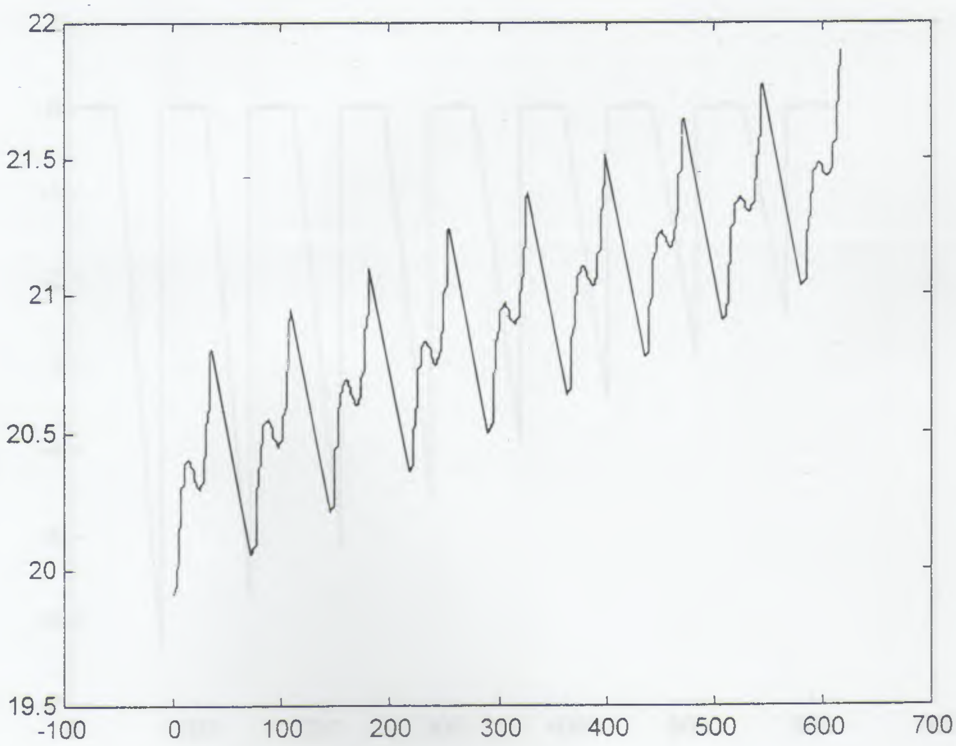

Fig 3.12 Shows the length of the third limb
Plot (ltt,l3)

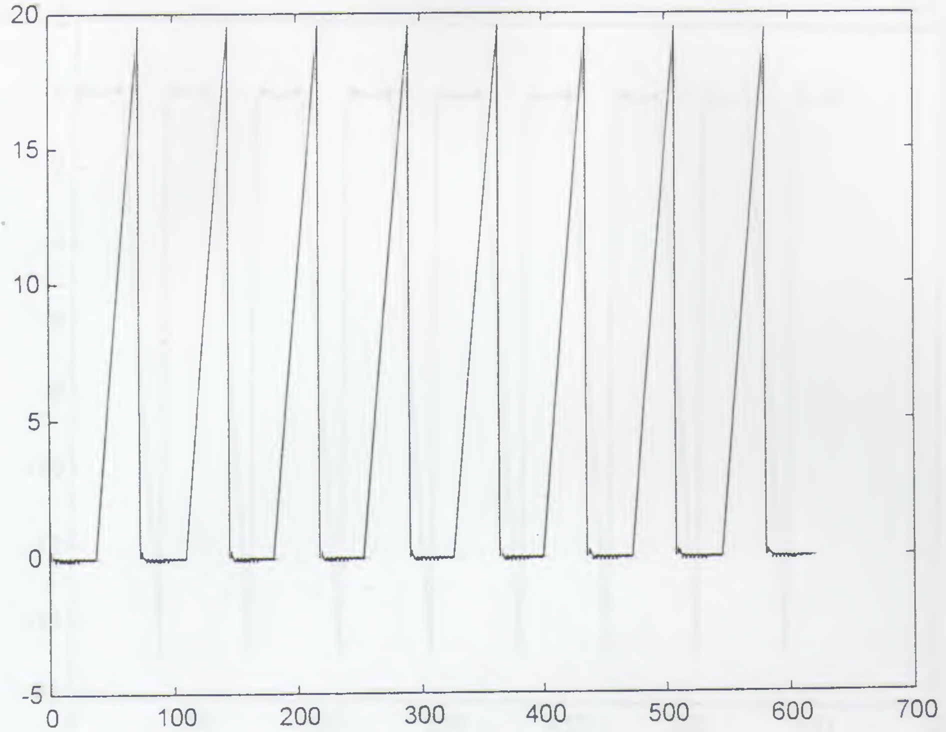

Fig 3.13 Shows the velocity of the first limb
Plot (lth,l1h)

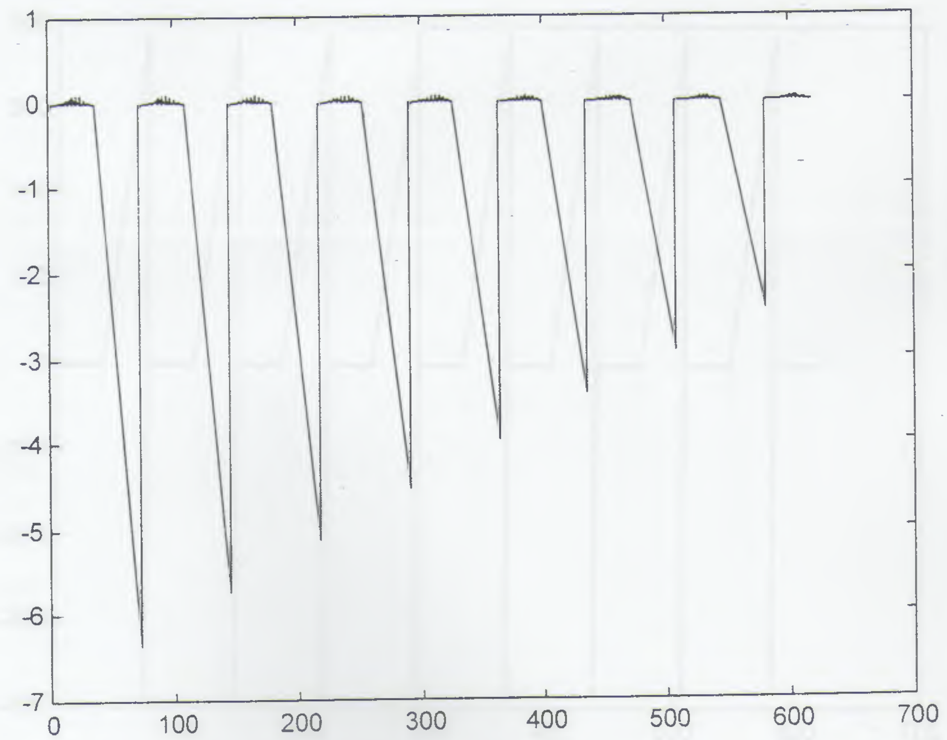

Fig 3.14 Shows the velocity of the second limb
Plot (lth,l2h)

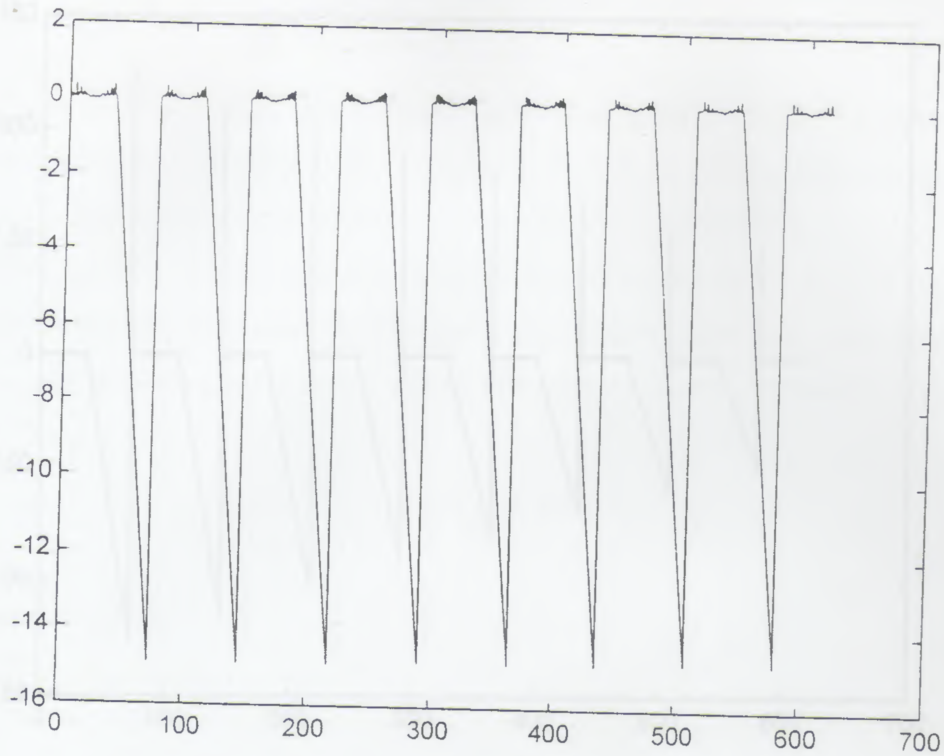

Fig 3.15 Shows the velocity of the third limb
Plot (lth,l3h)

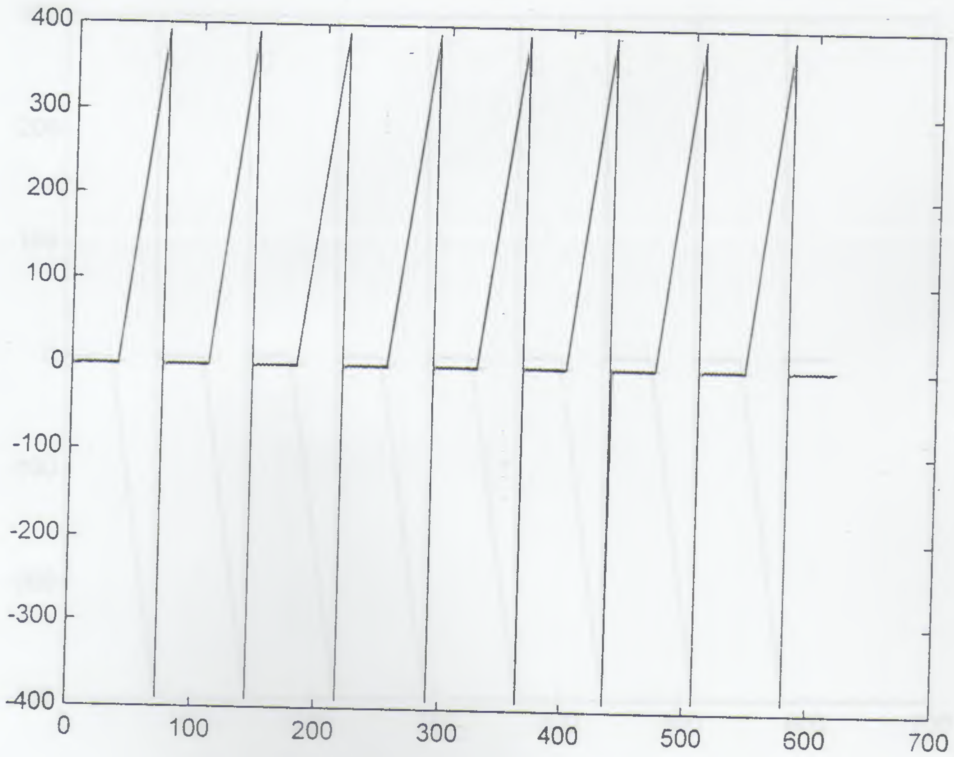

Fig 3.16 Shows the acceleration of the first limb
Plot(lti,l1i)

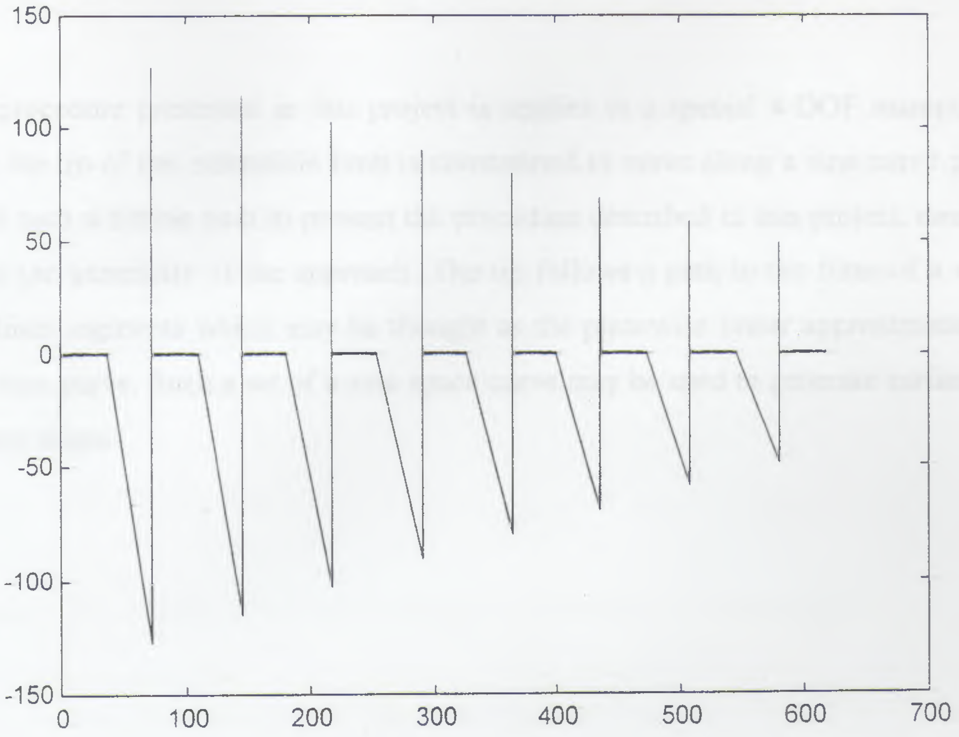

Fig 3.16 Shows the acceleration of the second limb
Plot (lti,l2i)

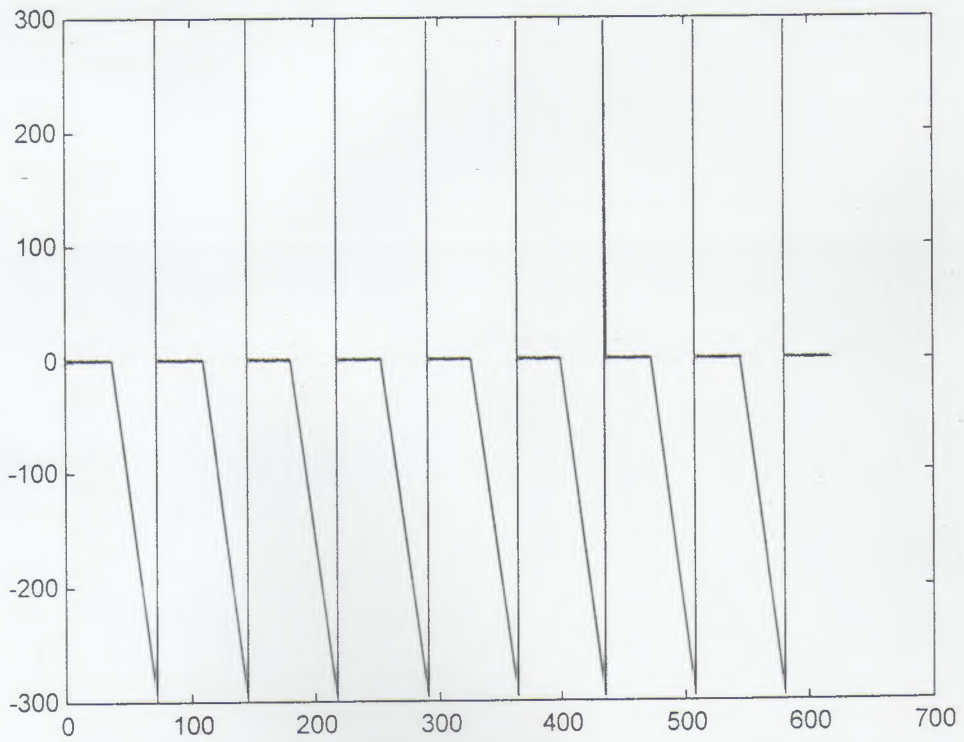

Fig 3.17 Shows the acceleration of the third limb
Plot (lti,l3i)

CONCLUSION

The procedure presented in this project is applies to a special 4-DOF manipulator where the tip of the extendible limb is constrained to move along a sine curve plane. Use of such a simple path to present the procedure described in this project, does not restrict the generality of the approach .The tip follows a path in the form of a set of short lines segments which may be thought as the piecewise linear approximation of space sine curve. Such a set of a sine space curve may be used to generate surfaces of arbitrary shape.

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[9] http;// google.com

[10] Altavista.com

APPENDEX A

The main MATLAB program

```
Clear pp=0;
j=0;
sa=0;
qa=0;
ss=0;
qq=0;


Ks(3)=10;
r=7;
R=20;
q1=[R;0;0];
q2=[-R/2;(3^0.5/2)*R;0];
q3=[-R/2;-(3^0.5/2)*R;0];
p1=[r;0;0];
p2=[-r/2;(3^0.5/2)*r;0];
p3=[-r/2;-(3^0.5/2)*r;0];
%fla = 1;

dt3=0.5;

as1=[4 10 30];
%al1=[10 12 40];
asn=[4 14 30];
%aln=[10 16 40];

kz=0;
xyz=-0.05;
%xyz=-dtteta/5;
```

```
for movy =as1(2):dt3:asn(2)
AA1=sin(1*pi/180);
BB1=sin(pi);
as=[as1(1) AA1+movy as1(3)];

dtteta=0.5;
dt=dtteta/10;
%xyz=-dt;
count=0;

for TTETA=dtteta:dtteta:2*pi
count=count+1;

aly=sin(TTETA);
al=[as(1)+TTETA as(2)+aly as(3)];
kz=kz+1;
zaman(kz)=TTETA;

%as=[2 10 30];
%al=[10 12 40];
%pp=0;
%j=0;
%sa=0;
%qa=0;
%ss=0;
%qq=0;

Tt=3;
C=2*pi/Tt;
dt=dtteta/10;
for lt=0:dt:3;
```

```
j=j+1;
z(j)=0;
%ltt(j)=lt;
ltt(j)=xyz;
xyz=xyz+dt;
l1tt(j)=xyz;
zg(j)=Ks(3);
A=sin(C*lt);
B=cos(C*lt);
D=C*lt-A;
landa=(1/(2*pi))*(D-sin(D));
aa=as+landa*(al-as);
hh=((al-as)*(al-as)')^0.5;
hiz(j)=(1/Tt)*(1-B)*(1-cos(D))*hh(1);
ivme(j)=(2*pi)/((Tt)^2)*(A-A*cos(D)+(1-B)^2*sin(D))*hh(1);
ww(j)=aa(1)/aa(2);
aax(j)=aa(1);
aay(j)=aa(2);
aaz(j)=aa(3);
f11
ll(j)=(aa(3)-zg(j))/ct;
if j>1;
  sa=sa+1;
  %ltth(sa)=lt;
  ltth(sa)=xyz;
  llh(sa)=(ll(j)-ll(j-1))/dt;
  if sa>1;
     qa=qa+1;
     %ltti(qa)=lt;
     ltti(qa)=xyz;
     lli(qa)=(llh(sa)-llh(sa-1))/dt;
  end;
end;
```

```
K=(1/(2*aa(2)))*((r/2)*(1-ct))^2+(aa(1)^2+aa(2)^2)/(2*aa(2))-(aa(3)-
Ks(3))^2/(2*aa(2))*(st/ct)^2;
KK(j)=K;
ca=(aa(1)^2+aa(2)^2)/(aa(2)^2);
cd=(aa(1)/aa(2))*K;
x(j)=cd/ca;
y(j)=-(aa(1)/aa(2))*x(j)+K;
yy(j)=-ww(j)*x(j)+KK(j);
zzz=(ll(j)*st);
n2(j)=-(x(j)-aa(1))/zzz;
n1(j)=(y(j)-aa(2))/zzz;
n=[n1(j) n2(j) 0];
v=[st*n2(j) -st*n1(j) ct];
vx(j)=v(1);
vy(j)=v(2);
vz(j)=v(3);
Ks=[x(j);y(j);Ks(3)];
T=[ct+(1-ct)*n1(j)^2 (1-ct)*n1(j)*n2(j) v(1);(1-ct)*n1(j)*n2(j) ct+(1-ct)*n2(j)^2
v(2);-v(1) -v(2) ct];
a=T*p1+Ks;
b=T*p2+Ks;
c=T*p3+Ks;
l11=-q1+a;
l22=-q2+b;
l33=-q3+c;
l1s=(l11'*l11);
l1(j)=l1s(1)^0.5;
l2s=(l22'*l22);
l2(j)=l2s(1)^0.5;
l3s=(l33'*l33);
l3(j)=l3s(1)^0.5;
if j>1;
  ss=ss+1;
  %lth(ss)=lt;
```

```
        lth(ss)=xyz;
        l1h(ss)=(l1(j)-l1(j-1))/dt;
        l2h(ss)=(l2(j)-l2(j-1))/dt;
        l3h(ss)=(l3(j)-l3(j-1))/dt;
        if ss>1;
          qq=qq+1;
          %lti(qq)=lt;
          lti(qq)=xyz;
          l1i(qq)=(l1h(ss)-l1h(ss-1))/dt;
          l2i(qq)=(l2h(ss)-l2h(ss-1))/dt;
          l3i(qq)=(l3h(ss)-l3h(ss-1))/dt;
        end;
      end;
    end;
    as=al;

  end;

  %if rem(fla,2)==0
  %tem=as;
  %as=al;
  %al=tem;
  %end
  %fla=fla+1;

xyz=xyz+(count-1)*Tt;

end;
```

Subprogram f11.m

```
%f11.m
format long
t1=1;
t2=89;
f12
while abs(ub)>0.0000001
  t1=teb;
  t2=tea;
  f12
end;
ct=cos(teb*pi/180);
st=(1-ct^2)^0.5;
```

Subprogram f 22.m

```
%f12.m
i=0;
ti=(t2-t1)/10;
for te=t1:ti:t2;
  i=i+1;
  t(i)=te;
  teta=te*pi/180;
  Ro=(aa(1)^2+aa(2)^2)^0.5;
  u(i)=Ro-(r/2*(1-cos(teta))+(aa(3)-zg(j))*tan(teta));
  if i>1;
    if sign(u(i))~=sign(u(i-1));
      tea=t(i);
      teb=t(i-1);
      ua=u(i);
      ub=u(i-1);
    end;
  end;
end;
```