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DEVELOPING A ONE DEGREE OF FREEDOM DUAL CLUTCH HAPTIC ACTUATOR

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Abstract: Haptics is the science of using the sense of feel to aid control and calibration of robotic control and feedback. One of the main applications of Haptics is in simulation and training of complex procedures. The present thesis is the description of the construction of a module capable of providing haptic feedback for the use in surgery simulation. The present device helps in solving the problems associated with high force DC motor coupling and cogging effects etc. to provide very fine motion simulation. The device developed is a part of a whole system being developed to integrate different aspects of the simulation mechanism including surgical setup, control software, visual simulation software etc.

The present device uses a unique dual electromagnetic clutch decoupling mechanism to offset the problems associated with normal systems. The system that has been developed can act as a linear actuator or as rotary actuator. The device is capable of being attached to similar units in a modular fashion to actuate in multiple degrees of freedom. The design needs more optimisation so that it can be used in different procedures.

INTRODUCTION

Haptic devices (or haptic interfaces) are mechanical devices that mediate communication between the user and the computer. Haptic devices allow users to touch, feel and manipulate three-dimensional objects in virtual environments and tele-operated systems. Most common computer interface devices, such as basic mice and joysticks, are input-only devices, meaning that they track a user's physical manipulations but provide no manual feedback. As a result, information flows in only one direction, from the peripheral to the computer. Haptic devices are input-output devices, meaning that they track a user's physical manipulations (input) and provide realistic touch sensations coordinated with on-screen events (output).

Take the simple example of riding a bicycle. We sense so many factors including the position of our body, the speed, the rumble of the road, the wind on our face, the exhilaration of gliding, the force we apply on the pedal and the effect it has on acceleration. Try doing that on a game console on your PC. You now know what you are missing.

According to medical science there are more than 28 different types of sensors in our human body. These sensations can be used as a feedback mechanism to add to our feel of our action as to its implementation by the machine being controlled by us.

Haptics is the science of feel for our perception senses so that our body can experience the result of our actions to control a robotic system. In a haptic system the end effector is attached to sensors to detect the process being undertaken. The force and orientation data is fed to the controlling device and the action is mimicked so that the operator can feel the effect of the actions being given through controlling device.

Traditionally the feedback was limited to the sense of force that is being applied by the end effector on our robotic system. So the force that is being applied is fed back to another robot actuator system that is integrated to our control device like a joystick. The feedback would be in a ratio as decided. It can be amplified if the force applied is very low so that the applied force perception is detectable. It can be as a lower ratio if the forces being applied by the robot are high.

The above definition of haptics will also allow a camera and display system attached to a robot to be called a haptic device as the operator guides the robot while viewing his actions. This form of haptics would be called a visual haptic system as the visual perception is used to control the robot system.

As technology is advancing more types of human perception are being used to function as a control feedback methodology to actively guide the robotic system. Sometime they are also being used as combination to achieve more complete involvement.

Below Fig 1 is a view of the different ways the haptic device can be implemented. The haptic device can have a feedback which is localized as in the vibration of a mobile handset. It just intimates that your attention is needed and you have to look for it. It does not have any direction to point you in any particular direction for your attention. Some devices can apply forces in a particular direction or vector. That is they can apply force in a 3D space of a particular size. These can be used to guide robotic arms in 3D space while knowing what are the forces being applied by the end effector. Sometimes more than one type of sensory input may be used to increase the feel factor which we call the multimodal interaction method. The haptic information can be used as the primary source of information to control your system or can be used as secondary information channel. Secondary signals may be like warning signals that a potential dangerous situation is being approached. The warning tone on your PC when you do some wrong command with your mouse is a prime example of secondary haptic audio information being provided by your ears

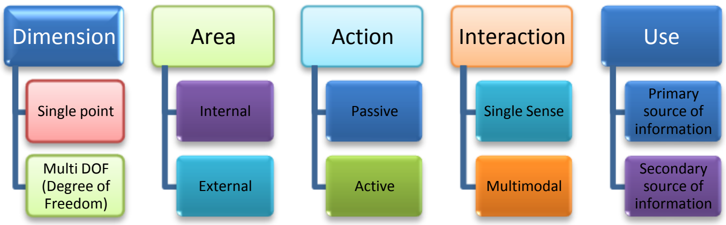

Fig 1.Different ways the haptic device can be implemented.

What are the components in a Haptic-based system?

The main parts of the haptic device are listed below:

1. Mechanical Design
    a. The appropriate actuator
    b. Its location
    c. Position sensors
    d. Force sensors
    e. Design of the end effector
2. The electrical and Electronic design
    a. Embedded controller and the drive circuits
    b. Event controllers
3. The Embedded control software
    a. To control
    b. To optimise
4. User Interface
    a. Visual Display
    b. Sensory Actuators
    c. Sensors

The main design parameters for haptic effect are:

1. Duration: How long the haptic effect will last
2. Envelope: It is the area that bounds the attack and fade portions of an effect (how the effect starts and ends) and allows you to change the level of the effect over its duration.
3. Magnitude: The strength of the output of the sensory perception actuator
4. Period: The timing between the sensation pulses.
5. Phase: It sets the point at which the effect begins with respect to an event.
6. Wave form: The shape of the repeated sensation pulses.

The main criteria for selecting an actuation technology are as shown in Fig 2:

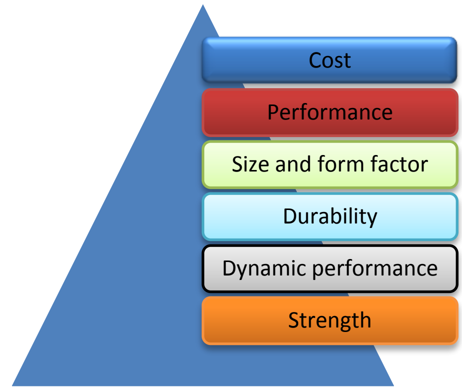

Fig 2Main criteria for selecting an actuation technology.

The main types of actuators can be divided into two main types as:

Active devices

1. Electric Motors-Rotary and Linear
2. Eccentric Rotating Mass (ERM) Actuators
3. Linear Resonant Actuators (LRAs)
4. Piezo Modules
5. Electro-Active Polymer Actuators (EAPs)
6. Bimetallic Thermal Expansion Actuators
7. Orifice Controlled Hydraulics and Pneumatics

And Passive devices

1. Mechanical Weight Shifters
2. Springs
3. Electromechanical Brakes
4. Electromagnetic Particle Devices
5. Eddy current Devices
6. Electromagnetic Fluid Devices
7. Electro Chemical Devices

Different types of actuation mechanism can be used to stimulate different types of sensory inputs to the human body. For example electrostatic technology can be used to stimulate friction and normal indentation. Piezoelectric technology can be used to stimulate normal indentation, lateral skin stretch and vibration. Similarly a particular feel can be stimulated by different technologies. For example normal indentation can be stimulated by electrostatic, piezoelectric, motor, shape memory alloys, electromagnetic micro coils, air jets, pneumatic valves and dimples, acoustic radiation pressure and electro stimulation.

This work has been done at M/s Designs and Projects Development,[5]. It is a Specialist Research based Product Developer. Working in close coordination with its customers it develops innovative devices mainly in robotics and mechatronics.

Designs and Projects Development has got its own mechanical workshop with dedicated precision tool set. It also has a fully equiped design section with the latest CAD software and tools. It also has got a full fledged electronics lab with the latest test and development equipment. It has a dedicated section for the development of software for all its activities including embedded systems.

M/s Designs and Projects Development is supported by DSIR Department of Science and Technology, Govt of India. It is also supported by FICCI, Autodesk Corporation USA, IUSSTF (Indo US Science and TEchnology Forum), IC2 Institute, University of Texas at Austin and Lockheed Martin Corporation USA.The members of M/s Designs and Projects Development has 8 International Patents and more than 15 International paper publication s in the name. It is working very closely with research institutes like IITDelhi,IIT Chennai and IIT Mumbai in various research projects.

RELATED WORK

Development of an Intelligent Robotic Haptic Interface to Perform Vocational Tasks:
Hollerbach [1] in his survey of research issues for haptic and locomotion interfaces statesthat one promising application area for haptic devices is prototyping human actions because these devices are in physical contact with a person, making them the most “personal of allrobots”.
Hybrid Design of Passive Mobile Robot Tele operation System:
In this paper we propose a teleoperation scheme based on the hybrid path planner algorithm for mobile robot. The hybrid path planner is composed of Potential Field method [2][3] and dynamically changing output feedback controller based on haptic information.
Design and Implementation of a Haptic Device for Training in Urological Operations:
This paper presents a new 5-DOF haptic device for training in male urological operations, of which all five DOFs are active. The mechanism allows 3-DOF tool orientation motions and 2-DOF translation motions. The orientation pitch-roll-yaw DOFs are decoupled from themselves and from the mechanism translational DOF. Unlike other haptic devices, in which the maximum forces or torques are of prime importance, here it is very important to have a device that can reproduce faithfully very small forces and torques, like those that appear in urological operations. Therefore, a major effort was placed in designing the mechanism such that it is characterized by small friction and inertia. The paper analyzes the kinematics and the dynamics of the mechanism, describes its mechanical design, and presents experimental results on its performance. Finally, it describes a control law and implementation solutions. [4]
.

PROPOSED METHOD

Earlier our team had developed a 4 DOF Haptic Device for Endoscopic Surgery Simulation
<u>The device included the following</u>:
There are four controlled motions in the device.

1) X axis Rotary joint 360 degree.
2) Y axis Rotary joint 90 degrees.
3) Z axis linear 10 inches travel.
4) 360 degree end effectors.
5) The X, Y and the Z axis are controlled by two clutches and a motor. The clutches are either mounted logically to the body or connected to the motor. This arrangement allows the motor to turn continuously without stalling. We get more controlled force to be applied to the different axis.
6) The end effectors at the tip of the Z axis has a force effecting motor which gives another rotary joint with its own rotary sensor.

<u>Main Features of the device includes the following:</u>

1) The four motions give almost all the motions needed for an endoscopy surgery.
2) The X, Z and end effectors has rotary sensors to give the digital output and the Y axis has a muli-turn POT to give the analog position.
3) As the different joints are not directly connected to the motors there is no force exerted in the normal position. The forces are exerted only when there is a voltage applied to the clutches or motors.
4) The motors can be disengaged almost instantaneously and the motor inertia or cogging does not affect the working of the haptic device.
5) The device is totally balanced for weight distribution by design. There is a slight variation in the weight only in the Z axis when the position changes.

The main objective of the present study is to try to make a new One Degree of Freedom Haptic Actuator with Dual Clutch Mechanism that has improved capabilities and can be used as a module that has the following capabilities:

1) Degree of freedom (DOF):One.
2) Expansion possibilities: Capability to connect to other actuators to increase DOF .
3) Main Active Actuation Device: High Torque DC Motor.
4) Secondary Passive: Actuation Device Electromagnetic Friction Clutch .
5) Tertiary Passive: Actuation Device Electromagnetic Friction Clutch.
6) Sensors: Rotary Position Sensor and Current Sensors.
7) Drive Mechanism: Linear Belt Drive and Rotary Direct Drive.
8) Drive Electronics: Linear Drive Motor Control.
9) Microprocessor Control: ARDUINO Mega ADK Based USB controller interface.
10) Software: Proprietary IDE Interface with UI.

Haptics has many uses in the industry and in our daily life. The main benefit of haptics is to feel the output of our action so that we can control the systems with better accuracies. The present work will be done under the on-going work at M/s Designs and Projects Development. I will be working as a part of the team developing the device.
If this device is made then we will have a new method to create better haptic controllers which can be used in any haptic device.

The present device will be capable of the following main benefits:

1) The present device will be modular and can be used as per the users design. Multiple units can be connected together to perform bigger applications.
2) The device will be more precise. Slightest motion effect can be created with ease.
3) The device will be of stronger construction.
4) Higher torque and force can be generated than similar devices.
5) Better software control will be incorporated into the design. User configurability will be a main consideration.

METHODOLOGY

The main considerations

1) The haptic device should have no or least effect of weight of the device on any of the axis. The entire axis should be balanced so that the least number of weight compensation is applied to the device. This will reduce the control processing necessary for the device.
2) The motors used for the actuation of the haptic device are 12V DC motors. These motors have a cogging effect. So if they are connected directly to the axis for actuation they will exert a force in the zero state condition. In other words the motors will hamper the free motion of the axis even when they are not active. This effect is compounded when the motor outputs are attached to a torque enhancer. The cogging effect will be amplified by the torque enhancer.
3) So it is imperative that the motor is disconnected from the torque enhancer when it is not active. To disconnect the motor we use a clutch system that disconnects the motor when it is not activated. The output of the motor is given to the clutch input and the final output is taken from the clutch output.
4) The position sensor has to be attached directly to the output axis. This reduces the errors due to backlash etc. Please note that if the rotary sensor is attached to the motor output then the backlash error is multiplied by the torque enhancer and other connecting mechanisms. There can be errors introduced by slipping etc. when we put the sensor directly on the output axis we are not concerned about the backlash or slip errors introduced earlier.
5) The device should be constructed as to replicate the natural movement of the surgeon during an endoscopic surgery.
6) Normally the surgeon uses both his hands to control two different endoscopic tools inserted into two different points in the patient's body. There is a third endoscope in an actual surgery to introduce a camera into the body. But here we are using only two. The controls for the third would be the same as for the second instrument and can be easily introduced later.
7) The haptic device has to be designed so that two or more can be placed near each other to simulate a real endoscope surgery. The main issue is the placement of the points of origin of the two devices as near as possible.

Construction Details of the device

Fig 3The photograph the completed device is shown below: photograph below.

Fig 4 The photographs of the dismantled device is given below:

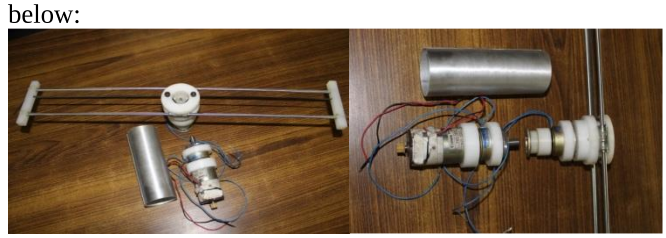

Fig 5 The output from the motor is given to the first clutch system. As shown below:

Unless the clutch is energized the output of the motor is not transmitted forward. Moreover the rotation of the clutch output does not turn the motor. Thus the cogging effect of the motor is discontinued.

Fig 6 The output of the first clutch is given to the input of the second clutch as shown below:

The output of the second clutch is grounded to the body of the device. Thus when the clutch is not energized the output of the motor is transmitted to the rotary or linear output. But if the second clutch is energized then the rotary or linear output of the system is grounded and it cannot move. This provided a large stopping force to the outputs that the motor alone cannot give.

The main facilities required are the following:

1) Mechanical Tool Room to create the various mechanical components. M/s Designs and Project Development has the facility in-house. I will be using their facility for this project.
2) Electronics Lab to create the electronic circuit boards and other electronic devices. M/s Designs and Project Development has the facility in-house. I will be using their facility for this project.
3) Software Development Lab to create the UI and the software interface. M/s Designs and Project Development has the facility in-house. I will be using their facility for this project.

Significance of proposed work

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PERFORMANCE METRICS USED

The haptic device made was to simulate force application nearing zero when the simulated volume of movement is in free space, to very high force simulation when the simulated volume of movement is in space consisting of very dense material space. The construction of the device had to be made very precise and using materials that were very light and strong. The positional sensors were integrated into the mechanism to provide a very precise feedback mechanism.

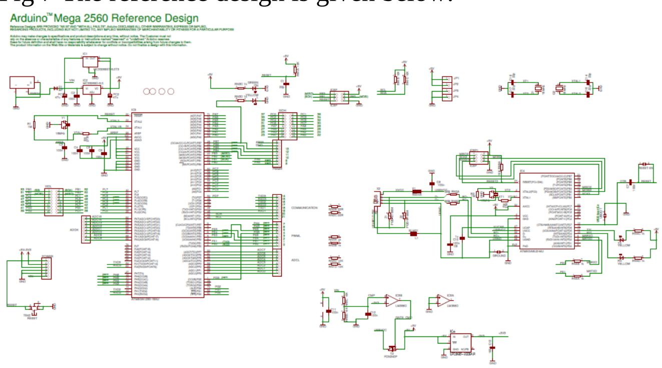
The main sensors used to measure the force applied by the device was done by cartridge type force sensors from Honewell USA which was factory calibrated to provide precise results. The force sensor is capable of measuring.

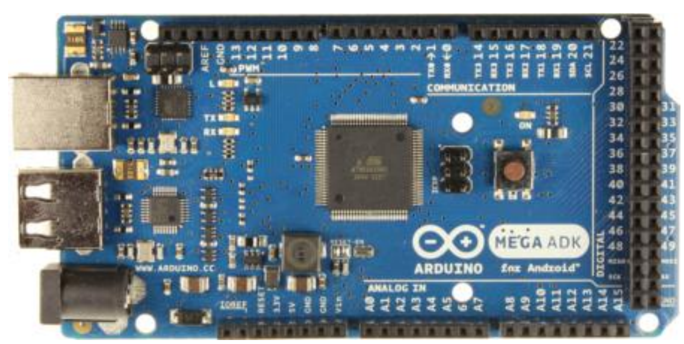
1) Pull force (-ve thrust)
2) Push force (thrust)
3) Angular force (sideways) along X, Y and Z axis
4) Rotational force (clock wise and anti-clock wise)
5) Speed
6) Delay in actuation

The control electronics provides actuation control of the motors depending on the positional feedback from rotary sensors on the device along each axis. The rotary sensors are capable of providing 512 Count per revolution to the actuating motor. This translates to 0.1mm linear translation resolution.

The motors are driven by PWM signals generated by the microcontroller board which is aArduino Mega 2560 ADK.

Fig 7 The reference design is given below.





The Arduino ADK is a microcontroller board based on the ATmega2560.

It has a USB host interface to connect with Android based phones, based on the MAX3421e IC. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button.

CONCLUSION

The device developed has many potential uses primarily in simulation and control of robotic manipulators. The precise feel of the actions of the robotic manipulators will help in using our sense of touch and forces feel to control the device and do the work efficiently. The sense of touch gives the operator more options

The device has a large potential in the simulation of operations without actually being present. The training of operators from such tasks as teaching assembly procedures is possible with this device. This device can also be used to simulate dangerous and hazardous procedures and train for worst case conditions. The sense of touch adds realism to the operators procedures and thus the operator is better able to use his faculties to precisely control machines.

The main application of the present device is to act as an endoscope simulator. The doctors can thus practice as many times as he pleases and get proficient in the task. The doctor will not be putting any of the patients at risk.

FUTURE SCOPE

The device is a first step in the direction of creating a system that can simulate the actual endoscopic surgery in the lab without putting any patient at risk. More precise and better devices can be developed to further refine the process and create better devices.

Better mechanism and software for control of the actuation mechanism can be made. Force and Positional sensors can be improved and integrated into a system that can simulate more precise information feedback to the operator.

More ways can be found to use the device in other fields to simulate and operate. Hazardous operations like bomb disposal can benefit from the use of this device.

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