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Performance of a millimeter manipulation on a telepresence Delta robot

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Abstract

The telepresence Delta robot is designed and built for millimeter tasks where an operator controls its motion via human machine interface (HMI). Three HMI devices, including manual pulse generator, Kinect camera, and PHANToM OMNI Haptic Device, are benchmarked on task performance when used to control the Delta robot. The Delta robot is installed with Logitech C310 camera in its hand and controlled by an open architecture controller that is configured to control the robot to follow the motion of the selectable HMI devices at the fastest speed. The Fitt's Law is used as a framework to evaluate the task performance. In this paper, the evaluation task is three dimensional "connect the dot" game which the robot is tele-operated with visual feedback to go point to point from position 1 to 21 within specified accuracy. The result demonstrates that PHANToM OMNI Haptic Device is a better HMI compared to manual pulse generator and Kinect since it gives a better response to human operator and mobility to the task and thus the shortest time to completion.

Keywords: Robotics, Telepresence.

1. Introduction

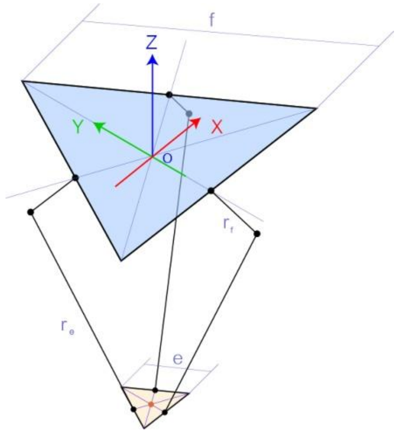
A telemanipulator is a device for transmitting hand and/or finger movements to a remote robotic device, allowing the manipulation of objects that are too heavy, dangerous, small, or otherwise difficult to handle directly [1]. In a more usual context, it is a remote control of a (slave) robotics system where human partially or fully control the operation. In the beginning, the mechanical linkage is used as a link between a control device and a slave manipulator as used in nuclear industry 40 years ago. A telemanipulator is now designed with more advanced technology.

A modern telemanipulator uses Haptic as a human machine interface, which can sense a human movement and then generate the control signal to control a slave manipulator, while generating the feedback force, which the manipulator senses the environment, back to the operator. A mechanical linkage is now replaced with electronics wires which are used as a link between Haptic and a slave manipulator. The modern telemanipulator is a very complex system involving human factor, a complex robotic system, and an advanced communication.

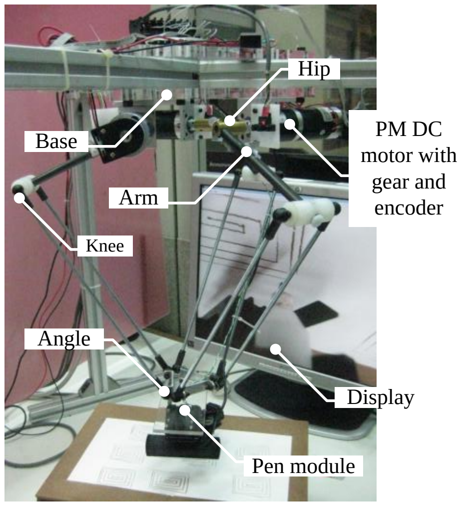
In this project, a telepresence Delta robot is designed for millimeter tasks to improve overall working performance. The Delta robot is designed and built for three dimensional precision millimeter tasks along with electronics and software which are designed such that it can be reconfigured. To improve our telepresence Delta robot, a performance evaluation framework is designed based on Fitt's Law [2] where similar works can be found in [3] and [4]. Roughly, the task is to control the robot to go three dimensional point to point (PTP) in image space while the time to completion is the performance index (PI). Three input devices are investigated including (1) Manual Pulse Generator (MPG) (2) Kinect and (3) PHANToM OMNI Haptic Device and used to control the slave Delta robot to complete the task. The paper is divided into eight sections where section 1 is introduction. Section 2, 3, and 4 describes the Delta robot, the Human Machine Interfaces, and the control diagram, respectively. Section 5 and 6 describes the evaluation task and the results respectively. Section 7 is the conclusion while section 8 is the future work.

2. The Delta Robot

A Delta robot consists of three parallel mechanisms to constrain the end effector such that it parallel to the base at all time. Three motors sit on the base where their joints, called Hip joints, connect to the rigid link called upper link. The upper link connects to the parallelogram mechanism called lower link using two spherical joints where the other side of lower link connects to the end plate via the other two spherical joints. In this way, the rotation of the three motors is transferd to three translations of the end plate. The torques from the motors can be transmitted to the end effector via low inertia rigid link. Thus, the robot is very rigid with very low inertia. In total, there are eleven links, twelve spherical joints, and three active rotational joints that are driven by three motors.



a) The kinematic model



b) The built Delta robot

Fig. 1 The Delta Robot

2.1 Kinematics of the delta robot

Compared to serial link manipulator, the kinematics solution of the parallel Delta robot is more complicated since it involves twelve passive spherical joints which their positions must be eliminated prior to map the encoder's positions to the end effector's position in the closed form kinematics. Several techniques to solve kinematics are proposed including [5-9]. In this project, the solution propdosed by [6], is implemented to solve inverse kinematics in real time. Let set the reference axes at point O, then the parameters and direction of x, y and z will be as in Fig. 1.

2.1.1 Forward Kinematics

This kinematics can be calculated by using the concept of intersection of 3 spheres. By using the vector from base to point J and then move to point J'. Therefore, we will get the three spheres which center is J' and radius is length of lower link r_e. Finally the position of end effector can be calculated from three sphere equations as in Fig. 2.

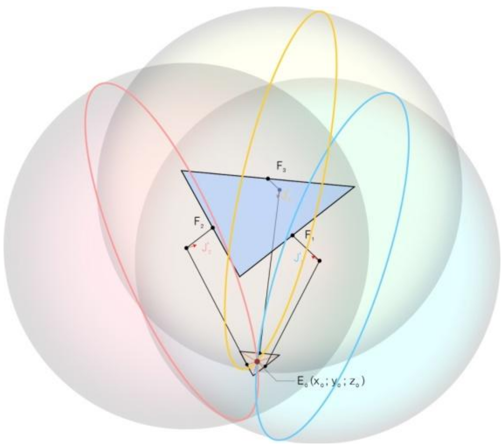


Fig. 2 Forward Kinematics Relation

2.2.2 Inverse Kinematics

In the same way as forward kinematics, inverse kinematics can be also calculated from the sphere and circle. Starting from the point at the center of end effector E and then move to the edge of end effector E'. As the same concept, we will get the sphere that center is E' and length of lower link is radius. Also, at point J we will get the circle which center is point F and the radius is length of upper link. As in Fig. 2, the point J is the intersection of the sphere and circle. As a result, the angles of upper link and base can be calculated by solving this relation.

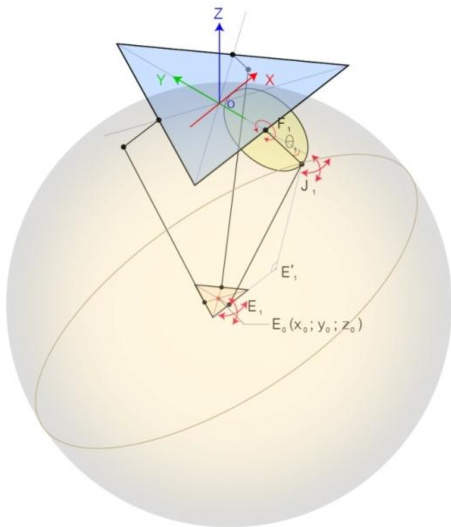


Fig. 3 Inverse Kinematics Relation

2.2 The design and built delta robot

The built Delta robot is three translational degrees of freedom robot (Fig. 1). The lengths of the upper and lower link are 152 and 296 mm respectively while the side lengths of the base triangle and the end effector are 207.8 and 92.6 mm respectively. Three 24V PMDC motors, with 500 PPR encoders and 1:600 planetary gears are used to drive the robot. Thus, the resolution of the joint position is 300000 PPR. Logitech C310 HD camera is installed at the end plate.

Table. 1 Specification of the Delta robot

Motor and Gear	PMDC with 1:600 planetary gear.
Encoder	500 PPR with 1:600 multiplier.
Camera	Logitech C310
Motor driver	Copley Controls 4122P

3. Human Interface Devices

Three Human Interface Devices (HMI) are investigated and used to command the Delta robot to complete a task, including (1) Manual Pulse Generator (MPG) that is widely used to jog the CNC machine, (2) Kinect sensor that is used as HMI for Microsoft XBOX game console, and (3) PHANToM OMNI Haptic Device that is directly designed to tele-operate a robot.

3.1 Manual Pulse Generator

A manual pulse generator (Fig. 4) is an interface device designed for CNC machine to jog its position. It consists of one rotating knob with an encoder attached. The signal from the encoder can be directly wired to the Delta robot's controller which is processed at the same speed as the motor's encoder. There are switches to select the axis to jog and the amplification.

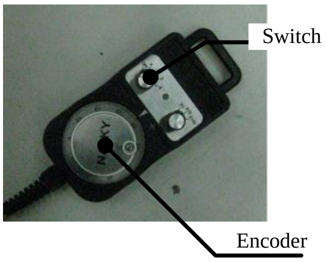


Fig. 4 Manual Pulse Generator.

3.2 Kinect sensor

Kinect sensor is an interface device for the Microsoft's Xbox 360 video game console. It consists of the RGB camera, depth sensor, multi-array microphone, and motorized tilt (Fig. 5). The camera and the depth sensor is able to output the 8-bit RGB and 11-bit depth images with 640x480 resolutions at the speed up to 30 fps respectively. Both images can be combined and treated as a single image with four dimensions called RGBD (Red, Blue, Green, and Depth) image. The depth image significantly simplifies the segmentation tasks, especially when an object's color is close to an environment. Using Kinect, the object and background with the same color can be easily distinguished by their depths and the RGB image can be processed further to extract the useful information of an object such as the centroid of a hand that is used in this project. The hand tracking program from Prime Sensor™ [10] is modified to print the position of the hand through TCP/UDP to the Delta robot's controller.

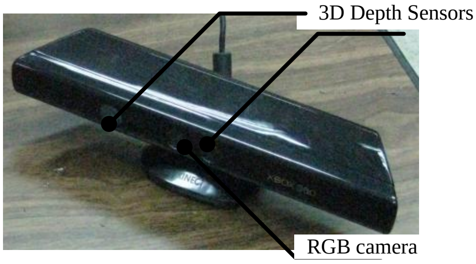


Fig. 5 Kinect.

3.3 The PHANToM OMNI Haptic Device

The PHANToM OMNI [11] (Fig. 6) is a commercial six degrees of freedom haptic that is used to generate the Cartesian (x, y, z) position and orientation and, in the same time, give the force feedback to an operator. This device is widely used as an interface device to control a slave manipulator in tele-operation task. The device comes with the driver on Windows and low level C library (HDAPI) to receive the Cartesian position and command force to the device. Its interface is IEEE-1394 Firewire. In this project, The Prok.Phantom [12] is used as an interface to Matlab and the Matlab's Instrument Control Toolbox is used to send the Cartesian position to the Delta robot's controller.

Fig. 6 The PHANToM OMNI Haptic Device.

4. The Control Diagram

The signals from the three input devices: MPG, PHANToM OMNI and Kinect are sampled at 1 kHz, 300 Hz, and 30 Hz respectively. The signal from MPG is printing to the robot controller directly while the signals from The PHANToM OMNI and Kinect are printing to the Windows based computer which are then sent to the robot controller via 100 MB/s TCP/UDP. There are software switched to manipulate these signals. These signals are the position reference that the robot will follow. The inverse kinematics block is then used to convert the position reference into the three joint references which are then compared to the actual joint positions sensed by encoders. The PID controller block is then process the difference signals in parallel and generate the control effort signals to the amplifiers which drive the current into the motor. The PID gains are tuned for the best performance. The Logitech C310 camera transmits the image signal back to the Windows computer. The live video is shown on screen along with useful information from image processing.

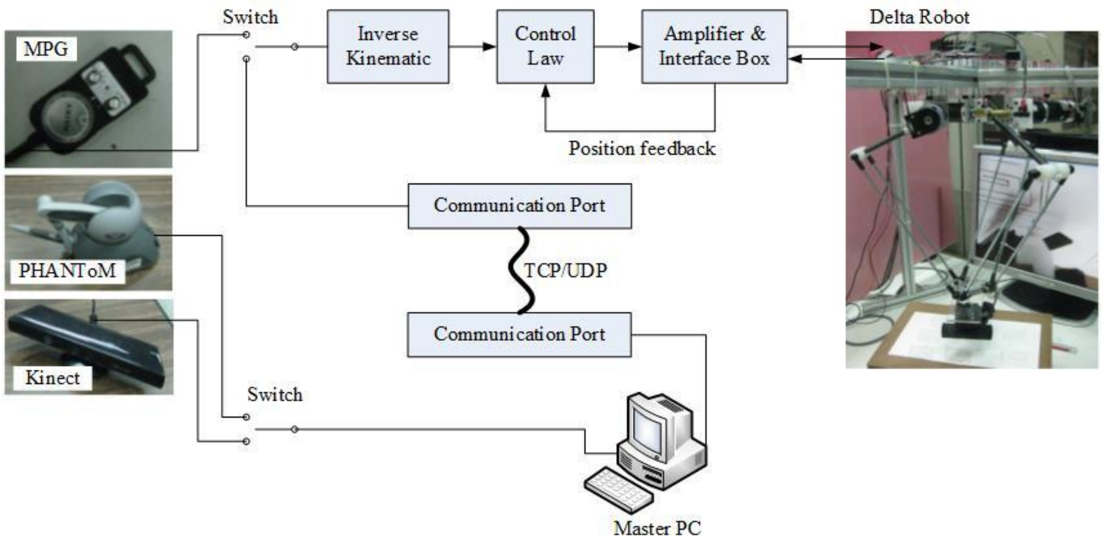


Fig. 7 The Control diagram of the Delta Robot

5. The Evaluation Task

The evaluation task is the three dimensional point to point in image space, i.e. to complete "connect the dot" as in Fig. 8. An operator sees the target objects only in a screen and then makes decision and commands the Delta robot through HMI device. The target objects are the circle marks in three colors: red, green, and blue and in three slightly different sizes. There are 21 targets consists of seven- red, green, and blue targets. For each color targets, there are letter mark, A, B, C, D, E, F, and G. The operator is to go from red A, then green A, …, until blue G, and come back to red A to complete the task. The marks are in a zigzag pattern as seen in Fig. 8.

The position of the Delta robot with eye in hand camera is to be controlled such that the target is at the center of the image while its size is also as specified. The positioning error must be within 10%. There is an assisting mark and box at the center of the image to aid the operator such that he/she can easily move the target in image plane such that the centroid and bounding box of the target match the assisting marks. Once the position of the Delta robot is on the target, there is a beep to inform the operator and the next target symbol is shown on screen. The next target will be in different color. In case that the target, as seen by the camera, is too close or too far, the text "ZOOM OUT" or "ZOOM IN" is displayed on screen respectively.

The elapsed time from one target to the next is recorded and analyzed. This time is then used as the performance index. The images captured at each of the target positions are also recorded to check that the robot is really at the target positions within the giving accuracy.

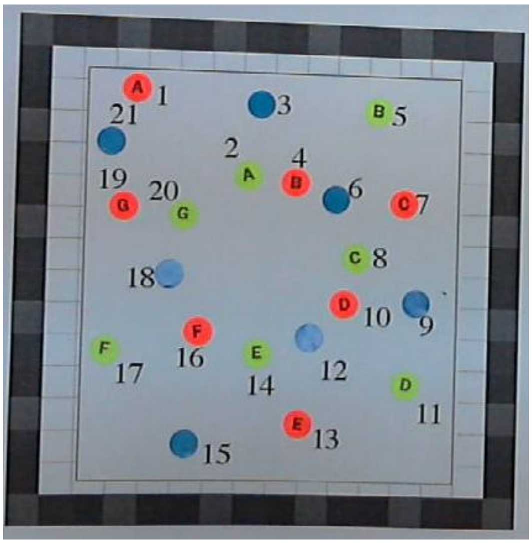


Fig. 8 Connect the Dot task.

6. Experimental Results

The result indicates that PHANToM OMNI gives the best performance, followed by Kinect and MPG respectively (Fig. 9). The PHANToM OMNI reduces the time to completion by 4 times compared to MPG and about 50% compared to Kinect.

This is because MPG can only move the robot only one axis at a time and thus take a much longer time for a three dimensional PTP task. The signal from PHANToM OMNI is about 10 times higher sampling than from Kinect and the resolution of the signal is much better. Furthermore, the attractive force is activated to assist the operator to know the absolute position of the device which is unknown when using Kinect. This feature is really help since there is a noticeable delay in the system. The operator has to face both slow sampling and delay when using Kinect to control the robot.

Table 2 Overall comparative performances (time) of the three input devices: MPG, PHANToM OMNI, and Kinect.

Round	Time (s)		
	MPG	Haptic	Kinect
1	Start	Start	Start
2	12.5	3.5	3.1
3	13.1	1.3	5.6
4	21.3	3.4	7.0
5	10.4	7.0	6.6
6	20.2	1.7	2.7
7	23.2	5.7	5.0
8	13.1	1.7	2.0
9	30.0	0.1	2.5
10	20.3	10.4	18.2
11	25.9	3.9	3.8
12	31.9	2.3	3.6
13	13.1	2.7	3.2
14	12.3	3.9	1.7
15	21.6	7.2	18.4
16	16.9	5.2	6.2
17	8.2	2.4	13.3
18	16.5	1.9	13.6
19	12.8	6.6	2.4
20	9.7	1.1	2.8
21	22.5	5.2	NA
22	14.5	6.7	2.5
Average	17.6	4.0	6.2

It is noted that Kinect cannot command the robot to the position (round) 21 where the robot is near its workspace boundary. This is because the signal from Kinect is quite slow and fluctuating. This signal results in a shaking motion of the robot and also the camera, especially near the boundary of the robot's workspace. In our test, an operator cannot go to position 21 and skip this position after trying in 250 second period. The MPG, which is directly connected to the robot's controller and is sampling in the same rate as the servo algorithm gave the smoothest motion of the robot even at the position 21. In comparison, PHANToM OMNI gives a shorter time but little shaking motion is noticed. However, PHANToM OMNI still gives the best overall performance in term of time and working experience.

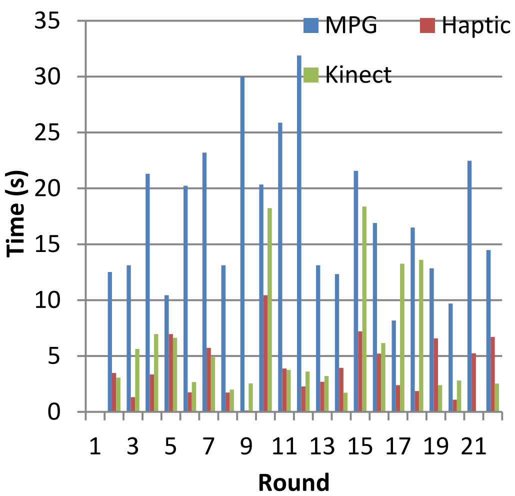


Fig. 9 Comparative performance of the three input devices: MPG, PHANToM OMNI, and Kinect.

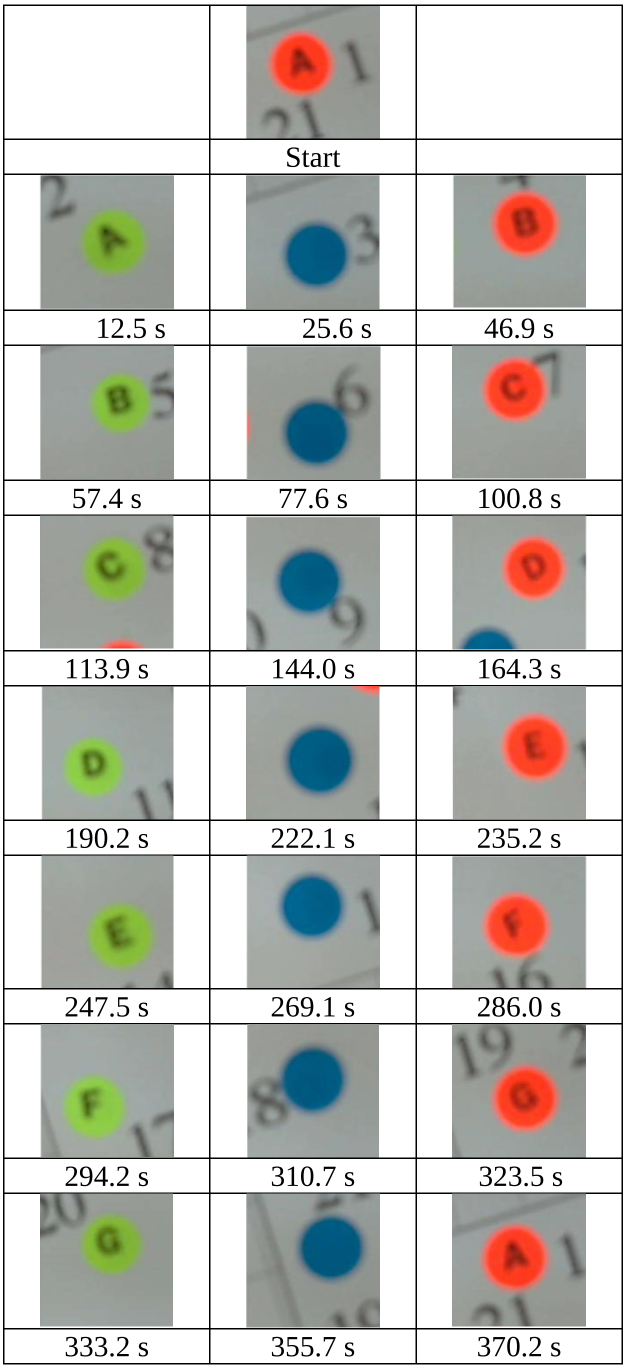


Fig. 10 Images captured at the target points with time stamped during the task (MPG case).

7. Summary

The PHANToM OMNI Delta robot is designed and built for millimeter tasks where performance evaluation framework is designed to improve the working performance. Based on the proposed evaluation framework, PHANToM OMNI gives the best performance to the telepresence system compared to MPG and Kinect, i.e., shortest time to completion.

8. Future Work

The working performance of the telepresence system will be further investigated on various time delay and servoing rate. The on screen display (OSD) that shows the target information extracted using image processing technique in realtime will be developed further to effectively aid the operator to complete a task.

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