

A 3D Manipulation Robot for Internet Use with Sensory Substitution

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Abstract

The Ihands project [1] at Roger Williams University is an online robot that allows Internet users to manipulate objects through a graphical user interface. The robot resembles a hand with two pairs of opposed fingers and a perpendicular thumb. The fingers are integrated with sensors to provide haptic feedback to the users. Users also have visual feedback and are able to move the hand and grab objects placed on a table. In its early stage, the Ihands project let users squeeze and pop balloons. This helped in identifying the weaknesses of the fingers and improvements have been made accordingly. Currently, users have the opportunity to model clay. The robot has proven to be robust and has operated for five months without any errors. Users can access the robot at ihands.rwu.edu. This paper will describe how the system was designed and how it works.

1. Introduction

The objective of this research is to develop a pair of mechanical hands that will allow internet users to perform three-dimensional manipulation. Internet users should be able to model clay while receiving some form of haptic feedback from the fingers. Currently, the hands allow users from anywhere in the world to grab and squeeze balloons or other objects they may request. The robot consists of two pairs of opposable fingers and a thumb. The fingers are mounted on a platform that has a horizontal displacement of about one foot. All the hardware and circuitry are controlled by a Galil Inc. DMC motion controller. The DMC motion controller resides on a PCI slot in a host computer. Since the skeleton for the fingers and the platform were already designed and built by another student [2], this paper will focus on the construction of the robot. It will cover the design and implementation of a thumb and a table that allows the hands to move back and forth without any interference. This paper will also discuss how the open and close motion for the fingers was reproduced along with how haptic and visual feedback was obtained. This paper includes improvements made on the original fingers. Finally, it will give an insight on the current performance of the robot and its limitations.

2. Reproduction of finger motion

The four fingers are mounted horizontally onto the platform, parallel to the surface of the table where the robot rests. The whole platform resembles two hands, touching at their base, each with two fingers that are parallel to each other. Figure 1 represents two hands in such position. Figure 2 shows the actual robot.

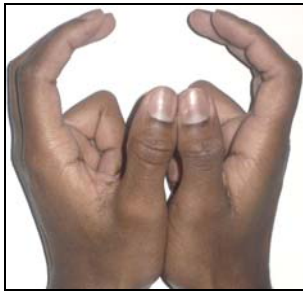


Figure 1: Hand representation of robot position



Figure 2: View of actual robot

Throughout this paper, the top two opposable fingers will be referred to as the upper fingers and the bottom two resembling pinky fingers as the lower fingers. A lead-screw mechanism converts the rotational motion of the DC motor to a linear motion that moves the bottom of each finger from left and to right, or vice versa, reproducing the open-close motion of an actual finger.

DC motors, connected to the DMC panel and controlled by the Galil Inc. software, are mounted at the end of the sliders. Each motor is associated with one of the four possible axes available on the DMC panel. Two switches are placed on the limits of travel of each lead-screw mechanism. This feature safeguards against drift in the control scheme, which has been observed over long periods of use. It is also a failsafe to prevent the motors from overheating if a slider reaches the end of travel. The DMC controller allows direct connection of limit switches and automatically stops motion when the end of travel is reached. At the activation of any switch, the motor decelerates to a stop and will not move in that direction until the switch is cleared. In order to obtain a quicker stop, the deceleration rate on the control software was set at a maximum while the motors were moved at a slow speed. This was also done to help web users keep up with the visual feedback. The time delay associated with the use of the internet as a channel of communication becomes less of an issue the slower the movement of the fingers.

An encoder is mounted on the shaft of each motor and is connected directly to the DMC card. While the switches can be used to determine whether the finger is in its open or closed position, the switches can be used to send the finger to its open or close position, an encoder is needed to move the finger to any specified position within the travel range set by the two switches. The Galil software automatically handles digital encoder feedback, so little was required other than hooking these up. Since the motors are also controlled by the Galil software, a voltage and current is supplied to a motor when a position is specified on its axis. However, the motor command output (MOCMD? on the DMC panel) only supplies a control signal at ± 10 volts with a current of 3mA. This current is not nearly enough to run the motors. To solve this problem, we built the following linear transistor circuit. This is a simplified version of the circuit used to control the joints of a PUMA robot.

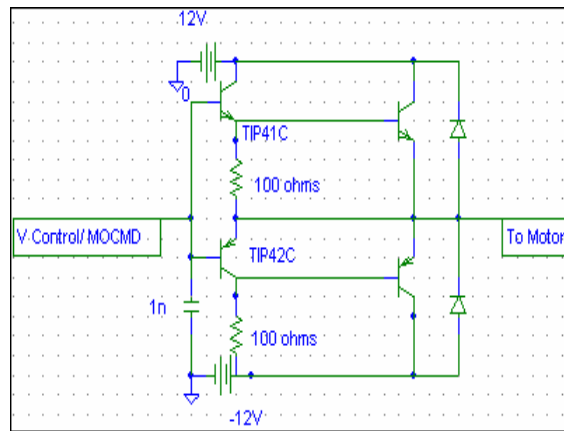


Figure 3: Multitransistor circuit for motor control

The current from the “MOCMD?” output is supplied to the base of the first set of transistors. The current goes into the base of the first NPN transistor. Most of the current from the emitter then goes to the base of the high power transistor. The current is amplified again, supplying enough current to run the motor. A fan is blown over the whole circuit to increase convective heat transfer from the transistors and remove waste heat.

3. Touch feedback

An objective of this project was to provide haptic feedback to the user. In other words, users must be able to make use of a sense of touch during operation of the robot instead of relying purely on visual feedback. However, most internet users only have access to visual and audio cues (monitor and speakers). Therefore, we decided to use sensory substitution. Contacts made by the finger will be displayed to users through a graphical user interface (Figure 16). The first step toward implementing this feature was to add a skin to the steel bar skeleton of the finger. The skin should be able to protect the joints and not interfere with the motion of the finger. PVC pipe was chosen as the material for the skin because of its availability and flexibility. Each finger is made up of a sensing and retractable part that recreates a sense of touch and of fixed parts that allow gripping and pressing. In each finger, the sensing part is the tip segment of the finger and the rigid skin is on the middle and base segments as shown in 4.



Figure 4: Upper finger of robot

To help better understanding the skin structure, parts of the robot finger will be compared to a human finger.

The upper fingers are made of four skin parts. The first two parts, covering the first segment, are a rotating tip and a retractable piece that forms the third phalanx. The other two parts are rigid

interlocking pieces of PVC pipe, two inches in diameter, that make the second and first phalanges used to press against objects. Figure 5 shows a close-up view of the second phalanx.



Figure 5: View of second phalanx showing rigid pieces

The rotating tip is made of a rubber cap (Figure 4) inserted over an inch long piece of PVC measuring one inch in diameter (Figure 6-7). A one eighth inch diameter stainless steel shaft, 1.5 inches long, threaded at each extremity, goes through the cap and through a bearing situated on the steel bar and holds the tip in place. The tip is able to rotate under pressure and come back to its original position once that pressure is taken away due to a spring between the PVC and the top face of the steel bar. The rotating point is situated 0.375 inches from the end of the steel bar that makes the skeleton of the finger. The cap is pinned between two nuts to limit side displacements. Currently, no sensors are installed on the tip but the ability to sense when it is under pressure is a future goal. The following pictures are AutoCAD drawings of the tip and sensing skin. Bearings, sensors, springs, shafts and PVC are showed. One is a rendered view and the other is an x-rayed side view.

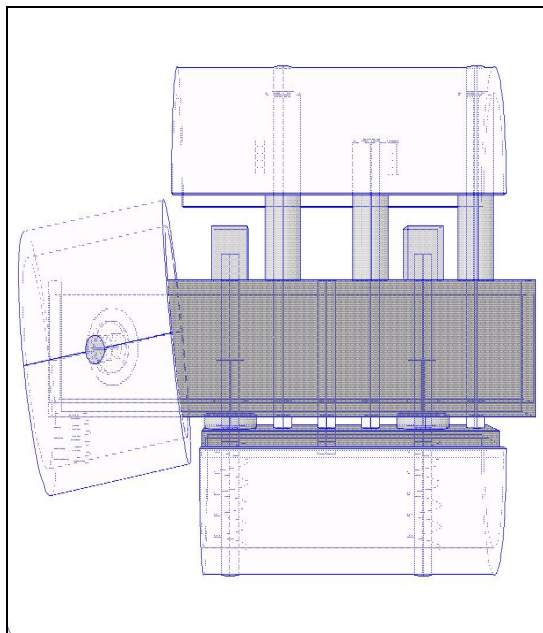


Figure 6: X-rayed side view of tip and sensing part

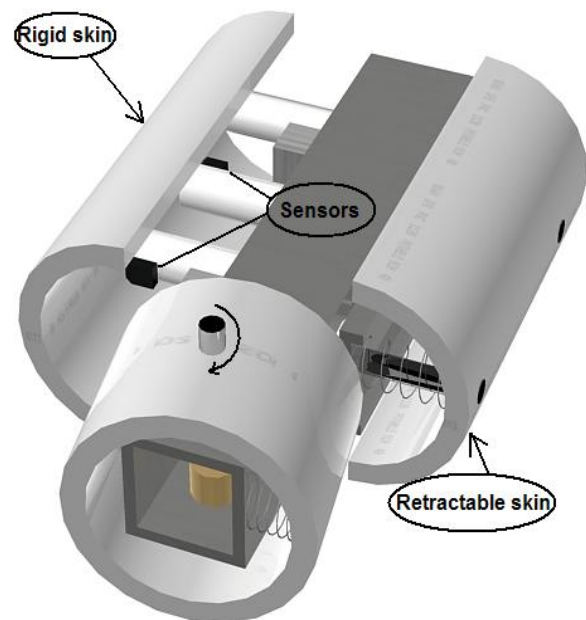


Figure 7: Rendered view of tip and sensing part

The second part, which is the sensing piece is after the tip and is shown in the figures above. It is made of two halves of 1 inch diameter PVC pipe that are each 2.5 inches long. They are mounted on the front and on the back of the steel bar. Two optical sensors are placed under the back half. The back half is screwed to the aluminum bar and is rigid. It is added to protect the sensors from shock and the influence of light. The front half can retract up to 0.5 inch. Two stainless steel rods of 1/8 inch of diameter, threaded

at each end and measuring 1.25 inches in length, are screwed under the front half 1.5 inches apart. Two corresponding holes, $\frac{1}{4}$ inch in diameter, are drilled on the steel bar so that the rods can move freely. To eliminate any side to side displacement and allow smoother retraction, nylon bearings of $\frac{1}{4}$ inch outer and $\frac{1}{8}$ inch inner diameter are inserted into the holes. Each rod also goes through a $\frac{1}{2}$ inch linear spring situated under the front skin. The springs permit the skin to return to its original position after the skin is released. On the back side, small rectangular blocks, threaded to screw onto the rods, are used to keep the front skin from falling out. The block also serves in activating the optical sensor an inexpensive photo-reflective sensor purchased from DigiKey Inc..

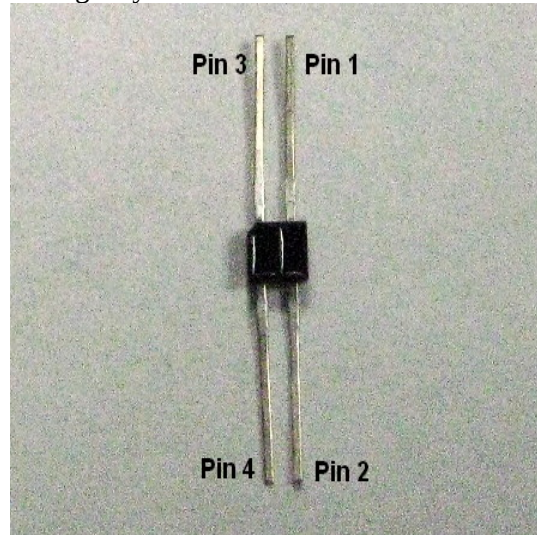


Figure 8: Optical sensor

The sensors, which are the small black rectangles in Figure 7, are mounted sideways on a nylon cylinder placed $\frac{1}{4}$ inch away from the center of the blocks. When the skin is pushed, the block moves up to obstruct the optical sensor. With the current configuration, users are able to know which side of the finger is being pressed, given only one extremity is, or if the front skin is fully pressed. In the latter case both sensors are obstructed and the front skin is pressing against the steel skeleton of the finger. A future goal is to add two more sensors under the back skin. Each sensor will be placed below an existing one. This will allow users to know the difference when the skin is barely touching or fully pressed.

The lower fingers skin structure is somewhat similar to the skin structure of the upper fingers with one less part. Even though the lower fingers only have two phalanges like a thumb, they are better representations of pinky fingers. The skin is made of three parts and, as before, the first two parts cover the tip segment and are similar to the skin of the upper fingers. The third skin part, which covers the base segment, is a 9 inches long rigid piece of PVC pipe 2 inches in diameter. The following pictures represent the third skin piece of the lower finger.



Figure 9: Front of lower finger skin piece

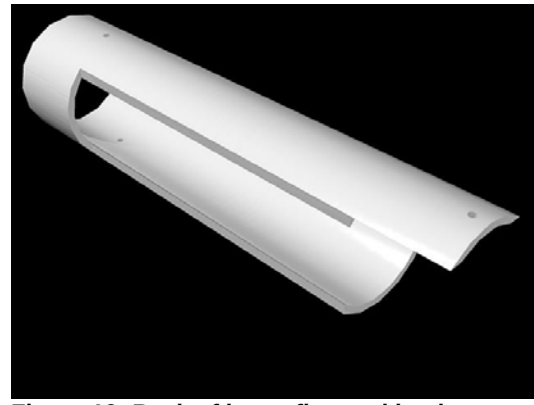


Figure 10: Back of lower finger skin piece

Sensors are also installed on the lower fingers under the second part. In order to read the sensors, the following circuit is built.

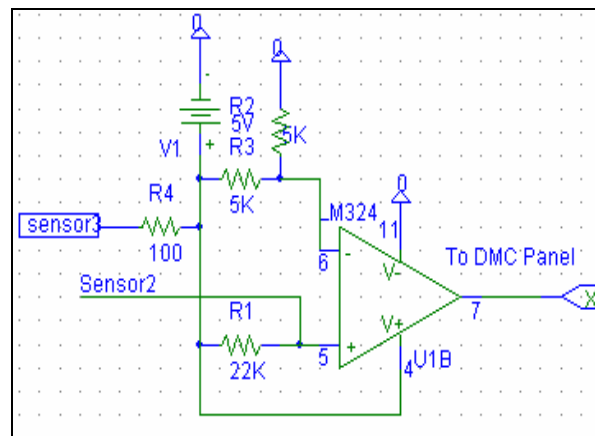


Figure 11: Op Amp circuit used for each sensor

Pin 1 and pin 4 from the sensor are sent to ground. Pin 3 goes to a 100ohms resistor to 5 volts. Pin 2 from the sensor is connected to the positive input of the amplifier. The resistor (22 K) on that node is used to control the sensitivity of the sensor. The amplifier compares the voltage coming from pin 2 to 2.5volts. If the voltage is higher than 2.5 volts, the sensor is cleared, and the sensor is obstructed if the voltage is less than 2.5 volts.

While the fingers are able to grab small objects or pinch a blob of clay, a palm is required to squeeze larger objects. A wood structure, with a flat piece perpendicular to the tip of the fingers at their closed position, is used as the palm. One of the two cameras used to provide users with visual feedback was initially mounted on top of the wood structure (Figure 2) giving users an into the palm view. This camera therefore moves with the robot. Another camera mounted on a stand gives an isometric view of the robot and of the table.

4. Table and balloon containment

A special table had to be built to bring objects to the level of the fingers. This new table must fit between the three inches space between the bottom of the platform and the lower fingers. Remember that the platform itself is mounted on a moving stage. The table must not interfere with the motion of the hand and must support the given material at any position on the travel range of the platform. To achieve those specifications a thin 0.75 inch table is placed at the reach position of the finger. Wood legs and rubber caps are added to attain the desired height. To cover the rest of the travel, aluminum sheets 1/8 inch thick

are cut and added to the table. The pieces are screwed to the side of the table so that their top is flush with its surface. The whole extension is made of 3 pieces that slides right through the platform as it moves up and down. Each piece is spaced by two inches and measures 2 feet in length. The following picture represents the table built.

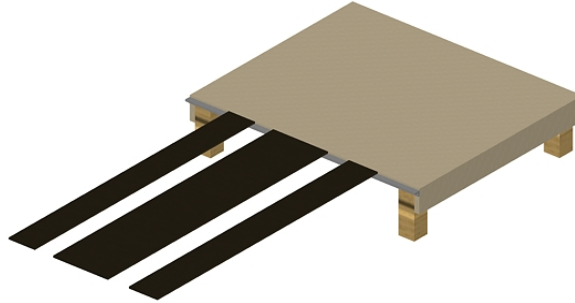


Figure 12: Table

A wood cage is built around the table to hold the balloons dispensed from a hoop placed on top of it. White paper is used to cover the cage so that users can easily see objects placed on the table. One problem encountered with the cage is that balloon will sometimes get stuck between it and the hands. When that happens, the hand pushes on itself causing the platform to slide back. To solve this problem, a ramp, made out of thin and flexible aluminum sheet, is built on the table. This allows balloons to just slide over or between the fingers, depending on their size, when they are caught between the cage and the fingers. Since the cage only covers a foot of the table, if users want to dispose of a balloon that will not pop, they can always bring it back and throw it off the table. The cage and hoop were later dismantled because we moved on to manipulating clay.

5. Design and implementation of thumb

In order to add another degree of freedom to the robot and allow more dexterous interactions, a thumb was designed and added to the platform. The original two fingers could only move in the horizontal plane. The thumb allows users to move in the vertical plane and is positioned above and between the two pairs of fingers at the previous location of the moving camera. The following picture is an AutoCAD drawing of the thumb.



Figure 13: AutoCAD drawing of the thumb

Unlike the other fingers, the thumb has no sensing parts and is mainly designed to pinch and to squeeze objects. It is made of an inch square channeled aluminum bar measuring a foot in length. Each side of the bar has a 4 inch long slot. The bottom slot is $\frac{1}{4}$ inch wide and the side slots are $\frac{1}{8}$ inch wide. The bar rotates at its end where the rotating shaft is held in an aluminum box mounted above the palm. The skin for the thumb is a PVC pipe 8 inches long and 2 inches in diameter. A cap is mounted at the end of the bar to give it the appearance of a fingertip; however, unlike the other fingers, it does not rotate and is not designed to provide haptic feedback. Instead of a DC motor, a 12 inch pneumatic cylinder activates the thumb. Using the Galil software, we were able to move it up or down by releasing or compressing air into the cylinder. To do this, a piece, which slides through the slots on the bar and attaches to the $\frac{1}{4}$ inch shaft coming out the cylinder, was made. Figure 14 represents the built piece and Figure 15 shows how it is used.

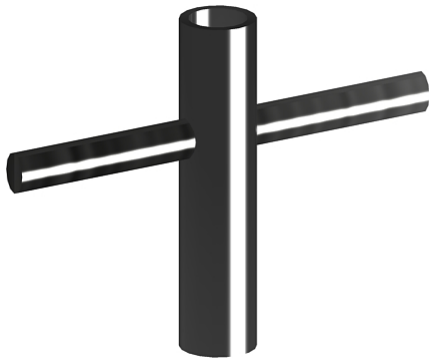


Figure 14: AutoCAD drawing of sliding piece.

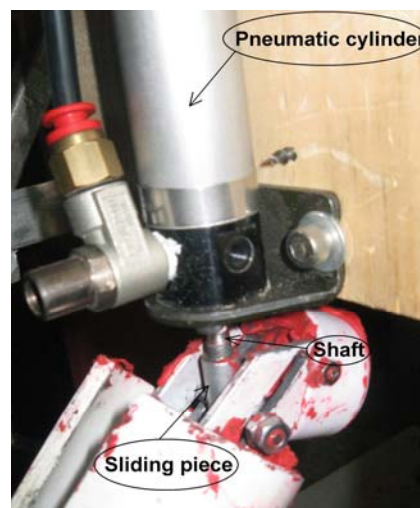


Figure 15: Picture of thumb with sliding piece

It is a threaded $\frac{1}{4}$ inch inner diameter cylinder with a nail inserted through it. The built piece is then screwed to the end of the cylinder shaft which is also threaded. As the shaft goes down, the nail slides in the side slots pushing the thumb downwards. The thumb was designed to let users squeeze objects by compressing air into the cylinder, or to simply pin objects by sending short bursts of air inside the cylinder in short intervals. Users should also be able to bring the thumb up if they want to. In order to achieve those actions through the interface, the rubber seal valve that lets the air through must be controlled by the Galil software. Another transistor circuit is built to do so. The digital output ports on the DMC panel are used to turn on or turn off the two sides of the valve. Every time one of the output ports is set to high, 30 volts is supplied to the valve, and the corresponding port opens up, letting air through. The negative effect of designing the thumb is that it is placed at the initial position of the moving camera.

6. User interface

After creating the thumb, the moving camera was placed at different positions in order to find the most helpful and attractive view. Currently, it is mounted above the fingers, giving users a top view of the table. The stationary camera was also moved so that a closer view of the clay can be obtained. The views are displayed in two squares at the center of the graphical user interface, as shown in Figure 166. The top and the bottom square represent the stationary and the moving camera respectively. While the visual feedback might take some time to get accustomed to, the interface is fairly easy to use. It allows users to directly control the fingers and the platform by moving sliders up and down. Each slider is graduated from 0 to 900, where 900 represents the max reach or totally closed position. Text boxes are used to display the actual position of the robot and to let users move the robot to a specific position by simply typing a number. Three buttons let users move the thumb. Users can bring it up, bring it down, or apply pressure in short intervals. Near each finger slider, a box with a sketch of the finger is seen. When that finger is touching, red arrows are displayed in the box pointing at which sensors are pressed.

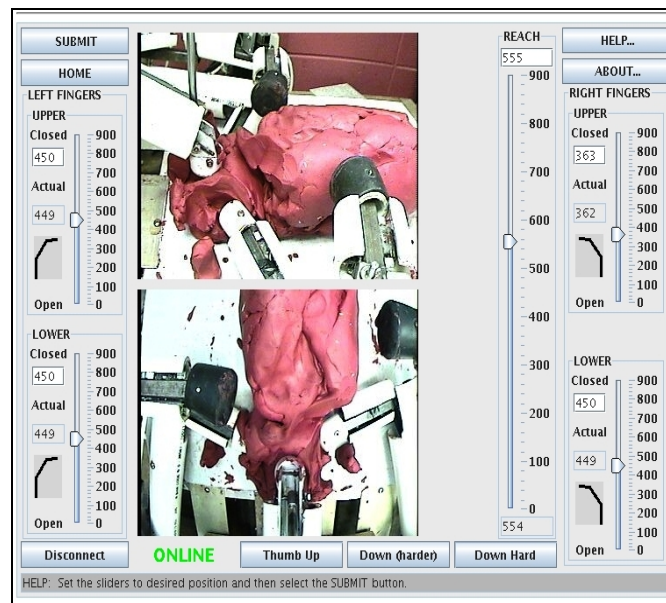


Figure 16: Screen shot of GUI

7. Improvements and results

Internet users have been able to use the interface since the early days of the project. Users were able to squeeze and pop balloons while the robot was being monitored. From observation, changes were made on the fingers to improve performance and reliability. After repeated usage, the shaft at some joints on the fingers was bent. To keep that from happening, the original 1/8 inch diameter shaft was changed to a 3/16 inch diameter at the bent joints. It was also noticed that once a balloon was popped, the upper finger would quickly close and the third phalanx would get stuck in the close position. A sort of stopper was added to the upper fingers to make sure that the third phalanx would not rotate past the closed position. Figure 17 shows an upper finger with the stopper and some of the shafts labeled. The joints with the most stress have a larger shaft.



Figure 17: Improvements made on upper fingers

After multiple testing to make sure that the robot was functioning as intended, the robot was allowed to operate continuously without constant monitoring. This phase started in the summer of 2007. The balloon containment was still used to see if it would attract more users. However, the machine only received about two connections per day throughout the summer. Finally the balloons were replaced with clay. The response did not differ much from when the balloons were used. Users would log in and squish the clay without making anything really interesting. While the few that have used the robot seemed to find it interesting and came back, the access log from the http daemon shows that only 526 unique machines have actually used the interface since May 23 2007. This is certainly not a large number; however, it proves that the robot is quite robust since it had operated for that long without any need to reset or reboot the computer.

8. Conclusion

The Ihands project can be considered a success since it has allowed internet users to manipulate objects and has done so without any major failure. The robot has been functioning beautifully; however, there are a lot of improvements that can be made to attract more users or to give users a better control over the environment. Such improvements would include: adding more cameras for visual feedback or allow users to move the camera for a better view, adding more fingers and sensors and finally allowing the fingers or only the thumb to rotate would give more degree of freedom to the users. The Ihands project shows that it is in fact possible to control a robot, which manipulates objects in a remote environment, through a communication channel such as the Internet. While, this can be applied in the exploration of an unknown environment, it can also be another thing internet users can do to besides goofing off. Perhaps in the future, a doctor will perform an operation over the Internet or a scientist will acquire and analyze samples in a remote environment using the Internet.

References

- [1] <http://ihands.rwu.edu>
- [2] Christopher P. Madden, Matthew R. Stein, "A Robotic Device for Three-Dimensional manipulation Over the Internet", ASME 28th Biennial Mechanisms and Robotics Conference, 2004