Thing:
A Robotic Hand with Realistic Thumb Pronation

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ABSTRACT

Thing is a robotic hand with three digits, a pronating opposable thumb, and a 2 D.O.F. wrist. Designed to more accurately model human hand positioning and grasping capabilities than previous models, Thing is controlled by a flex-sensor-equipped glove which relays the user's finger positions by means of flex sensors. It will also, by time of publication, incorporate an image-processing system for determination of wrist posture.

INTRODUCTION

The opposable thumb can arguably be counted as one of the single most important developments in primate physiology, allowing development of society and civilization in general and the robotics industry in particular. It is no surprise, therefore, that the construction of artificial hands for prosthetic and research purposes

BACKGROUND AND OVERVIEW

The mechanical hand is not a new development by any stretch of the imagination. The Utah/MIT Dexterous Hand project [1] is just one example of the hundreds of humanoid hands and gripper mechanisms created for use as prosthetics or pure research tools. The Machine Intelligence Lab has experimented with grippers – for example, the Omnibot project [3] was equipped with a three-tined grasper which was capable of operating a PC mouse – as well as with a humanoid hand.

Jack Peach (IMDL, Spring 2000) created the robotic hand High-5 [2], which sported three fingers and a flexible thumb mounted perpendicular to the palm of the hand. High-5, controlled like Thing by a power glove, had excellent finger dexterity; however, the thumb was not fully opposable and therefore limited the hand's grasping ability.

The creation of High-5's successor Thing involved careful inspection of possibilities for development of that basic idea, and three areas in which significant development seemed possible were ascertained.

The primary forum for development lay in the extension of the project from a disembodied hand to a limb capable of performing a task. To this end, Thing incorporates a wrist with two degrees of freedom, the positioning of which is determined by analysis via image processing of the object which Thing is intended to grasp. The angle of the major axis of the object is then translated to the angle of Thing's wrist, aligning the grasp axis to the axis of the object.

There were also two significant mechanical areas in which new work could be conducted. The first was experimentation with alternate mechanisms for finger flexion; and the second was the development of a more realistic thumb motion that included pronation/supination as well as simple flexion.

MECHANICAL DESIGN

The first version of Thing incorporated Shaped Memory Alloy (SMA) electric pistons (figure 1) from Mondo-tronics, Inc., for finger flexion instead of servos.

SMA wire, also known as "memory wire" or "muscle wire", is a nickel/titanium alloy which contracts when heated and returns to its original dimensions upon cooling. The pistons used in this project are 100 mm in length and, upon application of six volts at 2 to 5 amps, exhibit a total unloaded draw length of 23 mm. They have a functional advantage over servos in this particular application in that they provide direct linear motion, better approximating tendon and muscle movement in the human hand; and they are both lightweight and small.

Fig. 1: SMA piston from Mondo-tronics, Inc.

However, it was determined that SMA pistons are not appropriate for use in this project for three significant reasons. For one, a maximum cycle rate is 2 cycles per minute: 90% actuation and relaxation require at least seven seconds each. More importantly, however, the pistons failed to provide sufficient contraction to fully flex the artificial hand; and, most significantly, pistons cannot provide partial flexion. Given that the objective of this project is to approximate human hand motion and finger positioning, the SMA pistons do not provide the necessary flexibility and control.

The second version of Thing, therefore, returned to the model established by High-5 and used servos, mounted with the axis of rotation orthonormal to the axis of flexion (figure 2), to control the movement of the fingers.

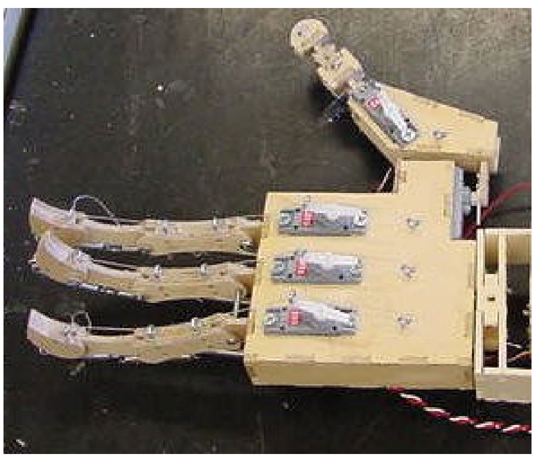

Fig. 2: Thing, palm view

Version two, like version one, also included a fully opposable thumb. However, a significant design flaw was realized upon discovery that the thumb and forefinger could not actually touch. Not only was the thumb's axis of rotation located too far toward the anterior plane of the hand, the servo actuating the thumb rotation was not actually on the axis of rotation, requiring development of a cam system.

The third and current version of Thing, therefore, incorporates both the servo-operated finger flexion as well as a redesigned thumb (figure 3) that places the axis of rotation of the pronator servo on the axis of rotation of the thumb itself.

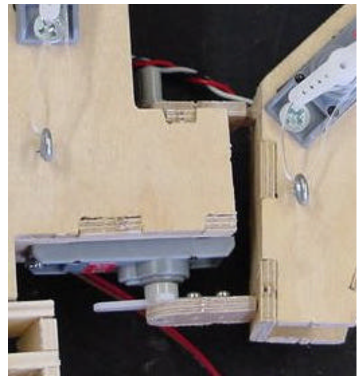

Fig.3: close-up of thumb pronator joint

The fingers display three degrees of freedom. The flexion is actuated by a micro servo which, when activated, winds the 30-lb. monofilament test line around the hub, thereby shortening its effective length and causing the finger to curl toward the palm. Relaxation of the finger is achieved via small extension springs extending from eyelets attached approximately midway between the joints of the distal and medial phalanges, medial and proximal phalanges, and proximal phalanges and the back of the hand (figure 4). Thumb flexion is achieved via the same mechanism, albeit with one fewer joint.

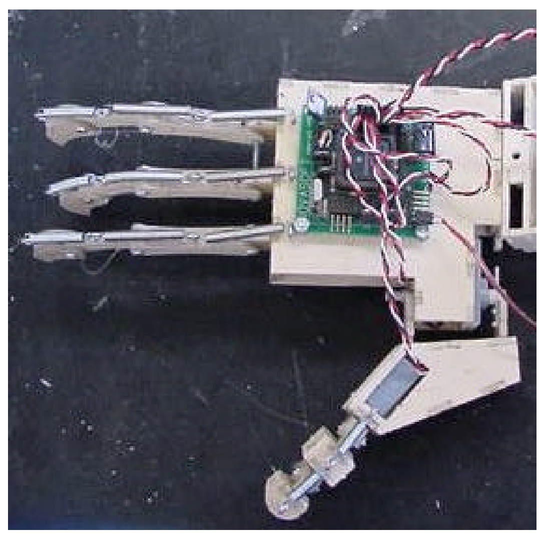

Fig. 4: Thing, dorsal view

SENSOR SUITE

Thing's articulation is directed by two primary methods of control: a "power glove" outfitted with bend sensors across the dorsal surfaces of the fingers and thumb to detect flexion, and across the palm to detect thumb pronation; and a camera system which, through simple image processing, determines the angle of orientation of an object and thereby the wrist posture necessary to grasp the object.

The bend sensors (figure 5) are variable-resistance films, 4 inches long by 0.25 inches wide by one sixty-fourth of an inch thick, made by Abrams Gentile Entertainment for use in video game controllers and other similar applications. The resistance value ranges from 12 ohms when unbent to 30 ohms when fully flexed (approximately 90 degrees). Over their functional range, they display roughly linear behavior, which allows the output to be directly correlated to servo position.

Fig. 5: flex sensor from Abrams Gentile Ent.

The flex sensors are attached by Velcro patches on the dorsal joint surfaces of the glove and across the palm from the base of the thumb to the distal heel of the hand (figure 6).

Fig. 6: control glove, dorsal view

For the image-processing portion of the experiment, an object – e.g a brightly-colored soda can – is placed in a specific background context for ease of processing. The camera location and settings (distance to object, focus, etc.) are fixed, and the object is placed on a table against a black background.

The camera used to obtain the images for processing is a Sharp VL-H860 Viewcam, connected to a 6x86 running Linux Mandrake. The image-capture routine, written by Dr. Michael Nechyba, saves a user-specified number of screenshots in *.ppm format, wherein the pixel information is stored in RGB format as three arrays, each containing the pixel coordinates and the red, green, or blue value.

At the current stage of development, this image is then imported into Matlab, where the 640x480 image is cropped to a standard frame size of 480x480.

Several methods for vision processing have thus far been explored, including linear regression and wavelet transforms. Because the project is at this time in the proof-of-concept stage, it was determined to simply use the available Matlab tools for these functions in order to ascertain which method would yield more promising results.

For the linear regression method, the background is assumed to be black, providing for a standard threshold to be set below which all pixel values are set to zero and above which the values are set to 254. This yields a representative set of pixels to which the linear regression calculations are then applied, yielding the slope and intercept of the line of best fit for the data set (figure 7).

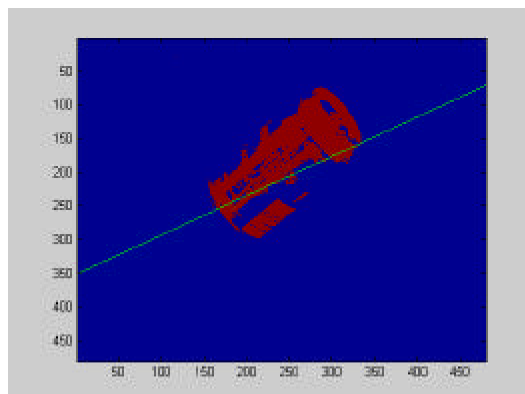

Fig. 7: example of linear regression

This was repeated for several such images in which the can was placed at different orientations.

Similarly, the Daubechies wavelet transform was applied to the image set. In this case, the intent was to ascertain the edges of the object and determine the vertical and horizontal separation.

Preliminary results for linear regression were excellent, yielding a qualitatively accurate response that can easily be converted to a servo rotation angle and transmitted to the microcontroller. The wavelet transform, however, while providing workable results for vertical and horizontal orientations, did not provide particularly good results for diagonally-oriented images.

However, for non-stationary applications in which the object in question cannot be assumed to be against a featureless background, theory would indicate that the wavelet transform may be more robust.

PROCESSING

Thing's low-level processing is conducted on a Motorola 68HC11E2 microprocessor installed in a TJ-Pro board from Mekatronix. This board accepts sensor inputs from the analog port, and relays servo control commands to a second 68HC11 via the serial port.

This second 68HC11 has been programmed with a servo-control multiplexer that allows it to run up to 16 servos at once, off ports B and C.

FUTURE WORK

Once the camera system has been completely integrated, Thing can be further modified to actually grasp lightweight objects with the inclusion of contact sensors on at least two surfaces (e.g. thumb and forefinger).

Further, with a simple sonar module, distance to an object can be easily determined. Given this information, the parallax or angular diameter of the object in question can be calculated, and the angles of the finger joints and thumb separation determined via inverse kinematics.

The wrist-posture program can be ported to other platforms and applications, including the ever-popular valet robots, giving them the capability to actually deliver objects using a gripper claw. As mentioned previously, this application will require the more robust wavelet processing rather than simple background subtraction, since the background values cannot be assumed to be stationary as they are for a non-mobile robot.

CONCLUSIONS

Thing, with three degrees of freedom per finger and a fully opposable thumb, is comparable in dexterity to the Utah/MIT Dexterous Hand project. Beyond simple remote-operation possibilities with the power glove, Thing will also incorporate a visual processing system which, when completed, will have application to larger, more complicated platforms.

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