HIGHLY PROGRAMMABLE SURFACE

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ABSTRACT

A highly programmable electro-mechanical surface is developed using an effective array of individual pins arranged in a grid form. Each pin can be independently raised or lowered to create a wide range of contoured surfaces. It was found that as the number of elements increased, high levels of accuracy could still be achieved, however the required processing power increased logarithmically. This finding was attributed to the large amounts of data being passed, and subsequently led to a second focus; various methods of data management and flow control techniques within large-scale multi elemental systems. Results indicated a large potential for highly programmable surfaces within industry to provide a computer controlled surface for rapid prototyping. The research also revealed the potential for such a device to be used as a HID within Haptic applications.

KEYWORDS: Programmable Surface, Dynamic Contour, Rapid Prototyping, Multi-element, Data Control, haptics.

1. INTRODUCTION

The production of highly dynamic surfaces has always been a logistically arduous task. Physical space constraints, limitations on processing power, accuracy of component fabrication, data flow control and management strategies, actuator speeds, collective power consumption, maximum and minimum translations, and cost of available components all contribute to the complexity of the task. The focus of this research is to investigate these constraints and find a cost effective method of constructing a highly programmable surface.

Highly programmable surfaces have applications for streamlining industrial processes, allowing environmental immersion into haptic worlds, and providing extra sensory feedback to physically challenged individuals. Tactile surfaces as used for HID’s (Human Interface Devices) have proven to be successful [1] in providing extra sensory feedback to the user. Such devices have been successful in redirecting a user’s visual spatial attention by fusing information from a tactor array with corresponding changes in the visual environment [2]. The development of a low-cost, medium-to-high resolution device capable of representing computer or real-life generated models will allow users the opportunity of physically interacting with a virtual environment, resultanty furthering the user’s emersion into virtual worlds from the real.

2. EXPERIMENTAL RIG

The apparatus built for analysis is the third of a number of devices being constructed with the focus of investigating highly programmable surfaces. Such devices have significant value and can be used for tasks such as: rapid prototyping, accurate construction of single plane moulds for automotive and aeronautical applications, dynamic vehicle panels incorporated into prototype vehicles which can be used for air-flow testing, and glass forming, to name a few. In the haptics world, such a device can provide users with a physical representation of objects existing only in the virtual world. Products such as the PHANToM™ range of haptics devices [3] or the CyberGrasp™ from 3D Interaction™ [4] provide the user the ability to feel a ‘virtual object’. Highly programmable surfaces differ in that they allow the user the ability to really feel the virtual object, as it exists in the physical realm right in front of them.
Artistic constructions such as "The Shiny Mirror Balls" [5] or the "Wooden Mirror" [6] have shown the popularity of interactive art. The World Wide Web now offers a number of online art galleries where people can view artwork from all around the world [7]. Using highly programmable surfaces would allow users the opportunity to physically touch Michael Angelo's David or feel the contour of a Ming Dynasty vase, while not causing damage to the original piece.

Despite this range of possibilities, in all cases, the challenge in constructing such a device is one of cost, component size and device resolution. To simplify the model, a system of this nature can typically be broken into 4 independent components; tactor array, drive mechanism, control system and user interface. In this device, the tactor array is a matrix of pins constructed of square extruded aluminium. Each pin has a radius on one end to provide a smooth surface for the user to interact with. Ultimately, the finer the pin the greater the resolution and the more convincing the interaction becomes. This device would classify as a medium resolution surface, with each pin being 10mm square aluminium and each has a total linear translation of 200mm. All together, 64 identical pins have been placed in an 8x8 array, however only the middle 4x4 grid are driven. The 8x8 array is held together using a specifically built box around the outer perimeter which allows any of the 64 pins to move freely, while holding the structure in formation.

3. MECHANICAL DESIGN

Lead screws are used to achieve linear motion from a torsional force, however there are number of other devices capable of producing this movement. Pneumatic and hydraulic cylinders provide smooth motion with relatively fast response times and can also be manufactured with a very small radius with respect to the travel they poses. These characteristics amply suit the tight physical limitations. Linear actuators and lead screws will both provide the mechanical linear deflection required, but can be both bulky and/or expensive. Electric motors have been chosen for their ease of use, low cost, availability, and consistent operation. To achieve the desired motion, the electric motors are coupled to lead screws with a short length of flex-drive. Using the flex drive allowed the tactor array to traverse up and down, while keeping the motors stationary. It was found that the lead screw mechanism provided a reliable, neat, flexible and accurate solution with high repeatability and relatively low cost. The chosen motors deliver a torque of 0.99kg/cm at a speed of 66rpm.

![Figure 1. a) Flexdrive Model b) Physical Flexdrive Mechanism](image)

Figures 1a and 1b show the FlexDrive connection between the motors and tactor array. The FlexDrive was rated to deliver up to 5kg/cm, much more than required to raise or lower any of the elements. While the pins are stationary, a load of >40kg has been successfully held by the 16 pin array. Under load, the motors can retract pins, but not extend.
The lead screw mechanism has been designed to incorporate a thread-pitch of 1mm, which was chosen for both its ease of ‘angular to linear conversion ratio’ and ability to withstand relatively high lateral loads. The 1mm pitch gave a simple relationship between linear and angular displacement (1).

\[ \text{Linear Vertical Displacement} = 1\text{mm} \times \text{no. Revolutions} \]  

The linear resolution could be increased or decreased by decreasing or increasing the thread pitch respectively. This would give greater maximum traverse speed, however also alters resolution, error related to overshoot, maximum lifting strength, and other variables fundamental to basic operation.

4. ELECTRONIC CONTROL

The electronic control system is based around a BASIC\textsuperscript{TM} Stamp\textsuperscript{®} 2P\textsuperscript{TM} \textsuperscript{[8]} microcontroller, and is designed to operate in conjunction with a personal computer (Figure 2). Coupled with 4 Parallax\textsuperscript{TM} PWMPALs\textsuperscript{TM} \textsuperscript{[9]}, the 2P\textsuperscript{TM} is capable of controlling 16 bi-directional motors, each incorporating individual digital feedback. To create a surface, custom software compiles a matrix of \(x\), \(y\) and \(z\) coordinates from the selected 3D computer generated model. These co-ordinates are then passed to the surface controller via either a RS-232 (serial) or USB connection, and where appropriate, compared to the set stored in the controller from the previous configuration. Each pin’s desired position is compared to its previous position, and the required displacement is calculated. This displacement value is finally passed to one of the four PWMPALs\textsuperscript{TM}, and the respective pin translates to its new position. Using the ‘New over Old’ methodology results in a faster set-up time, as only the pins which have to moved need be repositioned. All other pins can remain static. This control flow Figure 3 clearly depicts the flow of actions to setup the table.
Depending on the control topology being simulated, the process in Figure 3 can be performed simultaneously on any or all of the 16 pins. To assist in predicting how long any configuration should take to set up, the following formulae (2, 3, 4) were derived:

\[ P_{MS} \left( \frac{T_r T_i \times APT}{P_wP_i} \right) \]  
\[ T_p = \frac{T_w}{T_r} \]  
\[ T_m = \frac{60 \left( \frac{T_r T_i}{P_wP_i} \right)}{T_i} \]  
\[ T_c = T_r + T_m \]

where:

- \( P_w \): Pin width (mm)
- \( P_i \): Pin length (mm)
- \( T_r \): Table width (mm)
- \( T_i \): Table length (mm)
- \( APT \): Av. Pin Travel (mm)
- \( TP \): Thread Pitch (mm)
- \( MS \): Motor Spacing (mm)
- \( T_r \): Pin translation time (min)
- \( T_m \): Motor translation time (min)
- \( TT \): Travel Time between pins (min)
- \( T_c \): Time Complete (min)

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The gearbox output shafts provides 1 full pulse for

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![Figure 5](a) Programmabl

**Figure 6** shows operational differences be
Equation (2) predicts the time required for all tactors to be in their required position, and formula (3) is used to allow for any delay between motors switching, be it mechanical or software. The total setup period is the summation of the two individual times (4).

Relative feedback is incorporated into the design, which allows the number of revolutions of the gearbox output shaft to be counted. The digital feedback channels on the PWMPALs are setup to act as pulse accumulators, and the software within the ZP microcontroller can monitor the position at any of the pins at any point in time. Simple Hall effect devices coupled with tiny neodymium iron boron rare earth magnets mounted on each of the gearbox output shafts were used to capture the number of shaft rotations. The feedback provides 1 full pulse for every half-rotation of the gearbox, or every 0.5mm of linear translation. Feedback of higher resolution could have been incorporated although medium tolerances in the manufacturing of the pins would have deemed the higher resolution redundant. Absolute feedback was considered, but most types did not lend themselves to significant changes in physical pin length, in the case of hardware modification.

Figure 5. a) Programmable actuator matrix (Physical Rig)  
(b) Programmable actuator matrix (Computer Generated Contour)

3. RESULTS

Figure 6 shows the results of three standard tests constructed to compare the operational differences between the various control topologies.

Figure 6 – Comparison of setup time for various operational conditions

Two of the tests consisted of a single direction movement, and the third had a bi-directional movement. In each case, the PC configuration was quickest, always followed closely by the FPGA. Configuring the tactor surface ‘one-by-one’ proved in all counts to be
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the slowest of all by a considerable margin. For small movements, the 'row-by-row' configuration was only slightly slower than either the PC or the FPGA times, generally around 180-200%, as opposed to almost the 1000% increase in time recorded by 'one-by-one' configuration. It was also found that although such a device could operate accurately without feedback. The main concern for error using an open loop control system was cumulative error. The same tests performed with feedback, provided a positive result with all pins as returning to their correct positions each time under all test conditions.

4. CONCLUSION

Highly programmable surfaces have applications in many fields. It has been shown that modularising designs opens up a number of data control possibilities, all of which can reduce the complexity of the multi-element control network. It is possible to control large-scale multi element systems and achieve high data flow rates from both an electronic and logistical perspective. Throughout this research a number of control algorithms were developed that can be used with a range of different size tactor array. If needed, the controller has the ability to limit any of the control variables, such as the number of pins traversing at any one time, speed at which data is passed, or the constraints that defines the tactors growth pattern. Various manufacturing techniques have been explored and specialised methods have been developed to rapidly produce the large quantity of parts. The flexibility and modularity of the prototype rig makes it suitable for large scale production for applications in manufacturing, rapid prototyping, advertising, highly expressive artistic mediums, haptic interfaces and high fidelity HID’s.

5. REFERENCES


