# "HAP-KIT"

# A HAPTIC INTERFACE FOR A VIRTUAL DRUM-KIT

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## ABSTRACT

The aim of this project is to prove that the addition of a controllable damper to a haptic interface will allow improved control through the modulation of stiffness, thus improving the haptic experience. This concept is proven through the design, construction and testing of a haptic interface tailored to 'display' a virtual drum kit.

## 1. INTRODUCTION

Haptic means: 'relating to or based on the sense of touch.' [1] Thus haptic interfaces are those that transmit and receive information through the sense of touch. Several commercial haptic interfaces are available [2] [3], however these have certain limitations in terms of size of workspace and maximum applicable force. This paper defines a new type of haptic interface that attempts to overcome both of these problems.

Both increasing the size of the workspace and the maximum force actually have a common problem. This is the problem of instability when the user is in contact with a virtual object. Any instability present in a haptic display is greatly amplified either mechanically (increasing the length of the arm to increase the workspace) or through the motors (increasing the force of the oscillations). Methods have been proposed that use passive damping to remove (or greatly reduce) these instabilities ([4], [5], [6]).

The problem with passive damping is that it increases the damping throughout the entire workspace. This reduces the perceived permeability of free space, as the damper is constantly removing energy from the system. One solution is to use an active damping device so that the damping can be switched on when needed and the damping force can be accurately controlled.

A virtual drum is used as the model that the haptic system interfaces the human user with. The reason is that high forces and a large reach are essential for the user to obtain meaningful interaction. Low impedance through free space is also preferred, so that the user can move and accelerate the drumstick at realistic speeds. These three criteria: high force, large work-space and low free-space impedance, are all critical in determining the quality of any haptic system, hence the virtual drum proves to be a good test for new haptic systems.

### 1.1. Current Haptic Interfaces

The most common haptic interfaces are vibro-tactile units (rumble pads) found on games controllers, such as the Sony Playstation or Nintendo Game-Cube. Slightly more advanced haptic interfaces can be found in the form of force-feed-back joysticks for computers. These are all very limited in terms of maximum force and workspace area. Higher quality haptic devices such as the phantom [2], are available but these are not designed with a heavy-duty application such as drumming in mind. Hence it was necessary to design and build a new interface.

### 1.2. Haptic Musical Instrument Interfaces

Several haptic musical instrument interfaces have already been investigated. These include interfaces for a Theremin and a violin and even entirely new instruments.

The Theremin is an instrument that requires no physical contact to play. The user moves their hands near to two aerials, one to control the pitch and one to control the volume. However, it has been found that the addition of haptic feedback allows greater accuracy to be achieved [7].

The vBow [8] is a four degree of freedom haptic controller for a physical modelling violin synthesiser. The four degrees of freedom allow the user to feel the longitudinal, vertical, lateral and rotational forces on the bow. This haptic instrument is particularly advanced as it uses the physical synthesis model of a violin as the reference for both the sound and the forces transmitted back through the haptic interface.

Other haptic musical instrument interfaces have departed from modelling real instruments and create entirely new ones that may not even be physically conceivable in the real world [9].

### 1.3. Study of a Real Drum

To design a haptic interface for a drum-kit it is first necessary to study the features of a real drum. Especially relevant to the design of a haptic system is the average displacement and speed of a drum stick. As no previous research (to the knowledge of the author) has been undertaken to determine these, they had to be measured. First a video was taken of a drumming sequence, hitting a snare drum repeatedly. The next step was to record the coordinates of the tip of the stick, one frame at a time. As the frame rate of the camera was known it was then possible to find the values of each point in seconds. This can then be plotted as distance from the surface of the drum against time (Fig.1, top line). These values can then be differentiated to find the velocity. (Fig.1, bottom line)

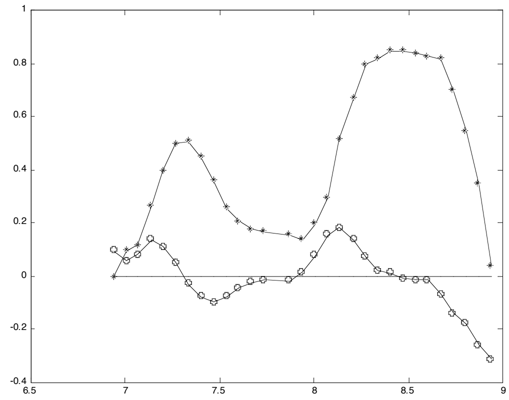


**Fig. 1** Displacement (top) and Velocity (bottom) of Drumstick Tip versus time (measured in m & $ms^{-1}$). Dashed line indicates position of drum skin (zero displacement)

## 2. DESIGN OF THE HAPTIC INTERFACE

The haptic interface needs to be both robust, to transmit the large forces required and light, to reduce inertia in the system. A damper needs to be included in the system, along with a motor (or two) that can generate sufficient torque. The system also needs to be capable of a similar reach and velocity as shown above (Fig.1)

### 2.1. MR-fluid Brake

To obtain the necessary damping, a Magneto-Rheological fluid brake is used. MR-fluid brakes work by magnetising a chamber of fluid saturated with iron particles. The particles form chains that exert a shear force between the housing and the rotor. When the magnetic force is removed, the chains break and only residual damping forces are applied between the rotor and the housing.

MR-fluid brakes have many advantages over other more commonly found brakes. They exert a high torque at low speed, use substantially less power to operate than eddy current or magnetic hysteresis brakes, operate silently, have a quick (under 10 ms) response time and prove to be highly controllable.

### 2.2. Mechanics

The main mechanical part of the haptic system consists of a 15:1 wire gearing system between the motor shaft (Fig.2 label A) and the damper shaft (Fig.2 label B) . This allows the motors to apply a large torque, whilst ensuring that the residual damping from the brake is not amplified through the gearing. Attached on the damper side is the arm. This terminates in an endplate that houses the strain gauges (Fig.2 label C), which in turn is connected to the universal joint (Fig.2 label D) that holds the drumstick. (Fig.2 label E)

Wire gearing has some useful features that are beneficial over cogged gearing. Wire gearing allows smooth continuous movement, avoiding the 'cogging' that occurs with cogged gears. There is no back-lash when the gears are reversed. Wire gears generally have a lower friction than cogged gears. They can be built to have a low inertia and they also have a high power to weight ratio (a heavy motor can be used to power a light-weight tip, through the use of pulleys.) The only disadvantage is that they have to be built specifically for the application to gain all of these benefits.

The two major mechanical parts were specially designed and manufactured. A screw thread (Fig. 3) to couple the two motors, and a pulley (Fig. 4) that serves three functions; it increases the radius of the brake shaft to 15 times the screw thread, it tensions the wire that runs around its radius and provides a secure point to screw the arm into. This pulley mechanism is made from aluminium and is mostly hollow to maintain low mass and hence low inertia. Struts from the radius to the edge ensure that the rim remains stiff.

A wire is wrapped several times around the screw-thread shaft (Fig.3) that couples the two motors (Fig.2 label A). Either end is then attached and tensioned around the larger part of the gear (Fig.2 F & G). When sufficiently tightened, the motor and brake shafts are very stiffly linked.

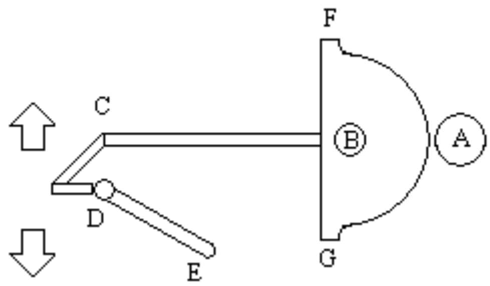


**Fig. 2** Diagram of the Mechanical System

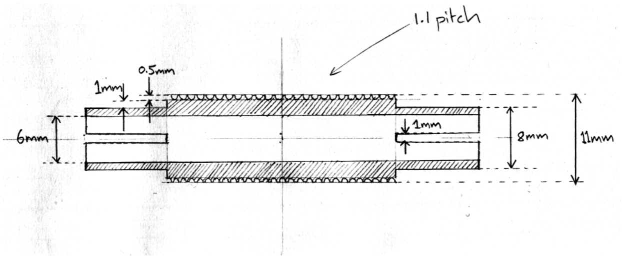


**Fig. 3** Screw Thread Coupler

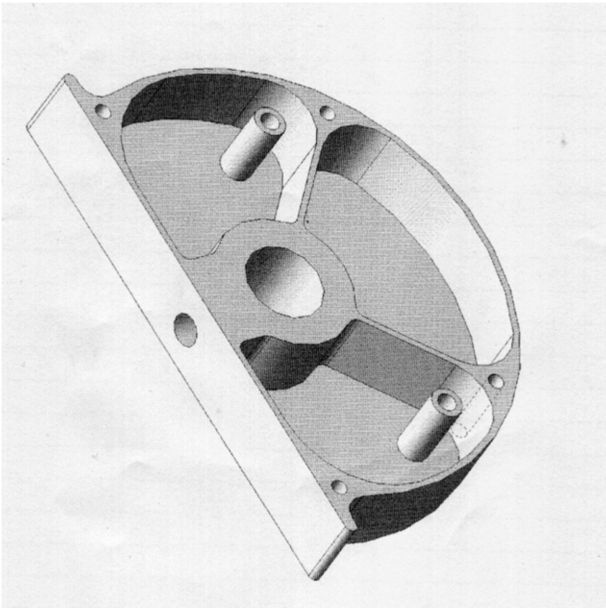

**Fig. 4** Pulley Mechanism

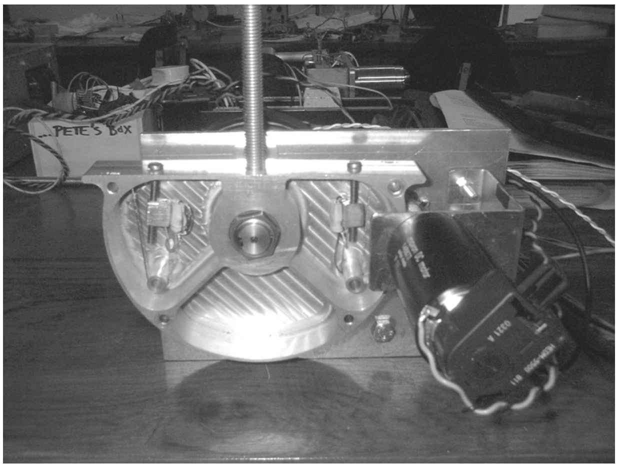

**Fig. 5** Whole Mechanism with Arm in Upright Position

### 2.3. Electronics

The motors are driven using two separate motor drivers. The drivers are set to a current controlling mode. This effectively allows torque control of the motors. The drivers are powered by a custom made power supply that delivers 50V dc. As the motors will be dumping a lot of energy back into the power supply, it is necessary to use two large capacitors to receive this excess energy.

The brake uses a current-controller to limit the maximum current passing through the brake to 1 Amp. The power supplied to this circuit is from a standard variable power supply.

The drivers' set value inputs are connected to the Multi-Q I/O board, so that the torque can be controlled from within the Matlab Simulink control package. The brake's limiting circuit also acts as a variable input, so that a control voltage (between 0-5V) can be applied to generate a linear output (from 0A to 1A) across the brake.

## 3. CONTROL OF THE HAPTIC INTERFACE

The interface is controlled by using the drag-and-drop block diagram program Simulink. Real-Time Workshop allows these models to be compiled into a real-time executable program. The use of a software controller allows the quick prototyping necessary for this project.

The basis of haptic control is a non-linearity in the feed-back loop. This ensures that control is only applied in a specified portion of the workspace, creating the apparent 'free space' when there is no control, and a virtual object when control is applied.

The instability most common to haptic displays are limit cycles. These occur when the 'point of perception' (the tip of the drumstick) is in contact with the virtual surface, and especially when force is being applied against the virtual surface. Oscillations build up as the controller tries to compensate for the opposing force, and although normally small, these oscillations can occasionally become large enough to cause serious harm to both the operator and the machinery.

These oscillations can be removed by taking out excess energy from the system, hence the use of the MR fluid brake.

### 3.1. Motor control

The motors utilise Proportional control, with a non-linearity in the feedback loop so that the control only switches on past the point of contact with the virtual drum surface. The proportional control increases the force exerted on the stick tip in proportion to the distance that the tip is below the virtual drum surface. This is a rough approximation of the physical properties of a drum, the model used being that of a stiff spring.

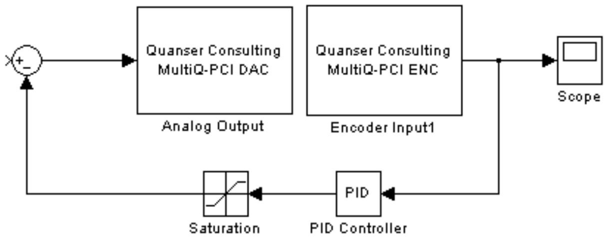


**Fig. 6** Motor Control

### 3.2. Brake control

The brake was initially designed to simply turn on when the virtual surface was reached. However this caused 'stickiness' problems where the drum stick would stick to the surface. This was solved by using a velocity based control where the brake only switches on if the drum surface is reached and the velocity of the stick tip is in the downwards direction. The velocity ($V_{est}$) is estimated by subtracting the previous encoder output from the current encoder output, then weighting this value by adding an arbitrary 20% of the previous velocity estimate ($V_{estold}$). (Fig.7)

$$V_{est} = 0.2 \times V_{estold} + 0.8(x_n - x_{n-1}) \qquad (1)$$

Gravity compensation was also introduced into the motor control, to counteract the weight of the arm and end plate. This is achieved by simply converting the encoder output as the arm is moved between a horizontal and vertical position into a value that corresponds to O and Pi/2 respectively. The cosine of this value is then used to modulate the gravity compensation force between maximum force (mass of arm multiplied by 9.8) when arm is horizontal to zero force when arm is vertical.

It is also possible to modulate the damping force of the brake, although currently only an on-off control sceme is used. Through modulation it would be possible, for instance, to control the damping force with a Proportional – Derivative controller.

## 4. RESULTS

To test the response of the virtual drum it is necessary to hit the virtual drum skin and record the encoder output (Fig.8). This shows that the tip of the drumstick only passes the virtual drum skin by a small amount. Given that the peaks in Fig.8 represent a height of approx. 30cm above the surface and the base line is where the tip is resting on the surface. It also shows the absence of instability at the point of contact. Comparisons can be drawn between the ideal response of a real drum (Fig.1) and these results (Fig.8).

Tests to determine maximum applicable force can then be determined. Results where found by pushing down the end of the arm with a compressive force sensor and recording the maximum force. (Table 1)

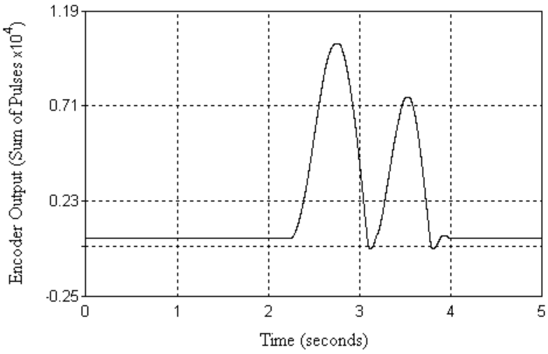


**Fig. 8** Encoder output during two successive drum hits

**Table 1** Results of Maximum Force Test

| | Measured Force (grams) | Force (N) |
|---|---|---|
| Motors Only (Half Power) | 578g | (578 / 1000) * 9.8 = 5.7N |
| Brake Only (Full Power) | 570g | (570 / 1000) * 9.8 = 5.6N |
| Both Motors and Brake | 1179g | (1179/1000) * 9.8 = 11.6N |
| Estimate of Maximum Power | n/a | (5.7 * 2) + 5.6 = 17N |

The motors are calibrated to run at exactly half power (1.5A) during testing so that they will not overheat. Operating the motors at maximum power would generate double the force, thus an estimate of the maximum overall force can be estimated. As shown in table 3 this estimate is 17N. With the addition of a second brake (in-line with the first) this would increase to 22.6N. To make a comparison: the Phantom Premium 1.5 is one of the most common, and commercially available, haptic interfaces and only has a maximum exertable force of 8.5N.

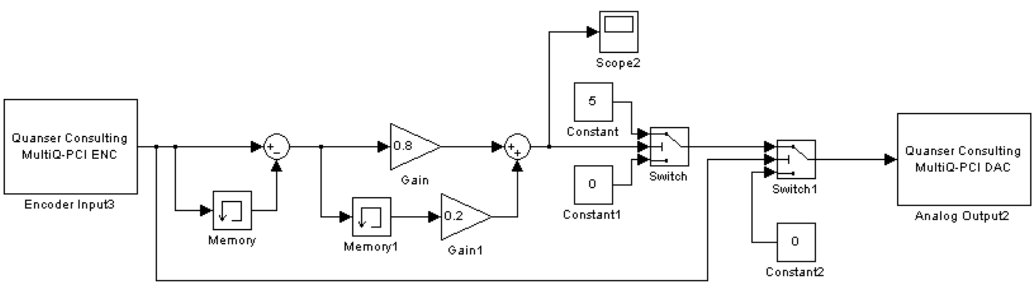


**Fig. 7** Brake Control

### 4.1. Use as a drum

The haptic interface proves to be very capable at producing a drum-like experience. It also copes with the large forces that a user can exert when hitting the virtual surface.

## 5. FURTHER WORK

Now that the interface has reached a working stage, work can begin on assessing its use for teaching people to drum. There are two ways the interface could be used; it could forcibly ‘play back’ the patterns generated by an experienced player, or it could be used ‘guide’ the user though a pattern. The guide would work not by forcing the user through the patterns, but by making the correct path easier to pass through than the surrounding space.

A major improvement would be to add another two degrees of freedom. This would allow a full drum kit to be modelled, with varying surfaces. This could be achieved with the current mechanical set-up by adding extra motors and brakes to the base and then conveying the power through cable gearing to the required second and third joints.

Coupling the haptic control with a physical modelling sound synthesiser would be a great advantage, as even if the model was not accurate, the surface would convincingly feel like it was producing the sound. A proposed method of achieving this coupling is to use the C++ Synthesis Toolkit to provide the real-time model. [10]

It has been proven [11] that Passive Impedance Modulation allows human drummers (and robots) to precisely control the frequency of drum rolls that are too fast to perform directly through muscle control. It would be an interesting to see if Passive Impedance Modulation could be used in a similar way when used in a haptic interface. This may allow the haptic interface to transmit frequencies that are beyond the controllers speed. Frequencies this high would be particularly suitable for virtual instruments as the user would benefit from feeling the note being played.

## 6. CONCLUSION

This paper proves that including an active damper in a haptic system helps to greatly reduce the problem of limit cycles. This results in a harder virtual surface, whilst maintaining the safety of the user. It is then shown how this improved haptic system can be used to successfully implement the control of a virtual drum.

## 7. REFERENCES


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