A LOW-COST ENDLESS KNOB CONTROLLER WITH PROGRAMMABLE RESISTIVE FORCE FEEDBACK FOR MULTIMEDIA PRODUCTION

Yuri De Pra and Federico Fontana
University of Udine
yuri.depra@uniud.it
federico.fontana@uniud.it

Stefano Papetti
Zurich University of the Arts
stefano.papetti@zhdk.ch

Michele Simonato
Electrolux Professional
michele.simonato@electrolux.com

ABSTRACT

Multimedia production involves the editing of several tracks (e.g., audio, MIDI, video) and related parameter control envelopes. This activity unfolds through several iterations, each consisting of repetitive tasks. In such scenario, the use of an input controller providing multimodal feedback can reduce the cognitive load associated to task execution. In particular, tactile feedback can reinforce visual information to facilitate the detection of specific features in a waveform.

We present an endless knob controller prototype with programmable resistive force feedback to rotation. Its use in supporting basic audio editing operations is then informally tested in a pilot software environment developed in Processing.

1. INTRODUCTION

Modern mixing consoles, Digital Audio Workstations (DAWs) and video editing software are reducing the gap between ideas and the resulting musical or multimedia outcome through the implementation of novel editing procedures. Traditional interaction paradigms are in fact evolving to accommodate procedural improvements that, for their higher complexity, are now increasingly implemented on touchscreen interfaces [1, 2].

In spite of the growing diffusion of touchscreens in mixing consoles, most professional products continue to put tangible controls such as physical faders, buttons and rotary knobs available to the sound engineer. Moreover, the effectiveness of traditional controls in front of complex procedures can be further improved by augmenting them with additional feedback. Motorized faders can also be used to provide haptic feedback [3], improving user interaction [4]. Similarly to sliding, rotation can be motorized too.

Rather than active behavior, in this paper we deal with *resistive* force feedback as a mean to mark-up specific positions in controllers. A common example is that of the sound balance fader or pot in home stereo amplifiers: through physically marking the mid position with a point-wise change of the resistance operating in both sliding/rotating directions, it was far easier for the hi-fi listener to reset the stereophony to the center position. Similarly, standard knobs provide a constant resistance to turning, and sometimes add detents emphasizing regular scale points or specific positions depending on the encoder mechanical design. Our research goal is to freely program the resistance offered by such controls.

The benefits of tactile reinforcement of visual feedback made possible by haptic interfaces have been recognized also for audio mixing [5], suggesting that rotary controllers with programmable resistance improve the interactivity in mixing consoles and DAWs. Visually impaired users could instead rely on audio-haptic interfaces for controlling DAWs [6]. Although variable-resistance knobs have been made available for many years, high costs and encumbrance still limit their effective use in commercial products. In the music controller market, one product incorporating programmable haptic feedback technology is the Traktor Kontrol S4 DJ console [7].

In this paper we describe a knob with programmable resistive force based on an electromagnetic system, which provides different haptic effects. The proposed technology results in a significant reduction of costs, weight, space and power consumption as compared to existing products. As an application of such technology, we will enrich some visual-based examples of waveform editing: for instance, the association of detents to amplitude transients while moving the cursor along a timeline. The same interaction paradigm can be easily extended to contexts such as video editing, where it may e.g. help detect video cuts and support the temporal synchronization of different media tracks.

2. RELATED WORK

Rotary controllers have been studied from different perspectives: ergonomic studies defined guidelines concerning knobs' size and shape [8, 9], while other studies focused on user interaction [10]. Experiments comparing physical and virtual rotary controls highlighted that tangibility has positive effects on several interaction aspects [11, 12]. More specifically, it was proved that tangible control allows for better performance in terms of error rate and interaction speed: interaction with physical knobs was found to be 20% faster compared to virtual counterparts and additionally, subjective performance remained unaltered also when one's visual attention focused on a

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different task. These results are especially relevant when a knob is used as a multi-parameter controller integrating browsing and selection of items through turn-and-click actions. Also for this reason, many recent smart gadgets incorporate or offer additional physical knobs: examples include Google Nest [13], an intelligent touchscreen-based thermostat, Griffin PowerMate [14] and Microsoft Surface Dial [15], both being Bluetooth multimedia controllers.

In the last decade product designers have furthermore started to "brand" tactile cues [16]. Thus, tactile feedback is overcoming a traditional design approach linking mechanical features (e.g. torque, detents resistance number) to functional behavior [17, 18], and is progressively embracing the idea of characterizing the "feeling" of a machine interface.

Force-feedback rotary controllers can be found in many contexts, including car dashboards, piloting systems, audio/video editors, robot controls, medical devices, household and professional appliances. Most of them make use of DC motors to generate force feedback [18–20]. The use of such motors enables complex actuation, such as bouncing effects, at affordable costs. Hybrid solutions that combine motors and brakes have been proposed as well [21]: while they allow the design of previously unavailable subtle effects, additional components increase complexity, costs and size of the hardware. Even more advanced and expensive solutions make use of magneto-rheological fluids to generate variable torques [22, 23]: in this case, magnetic fields variations are used to change the density of a fluid in which the knob shaft is immersed, allowing a precise control of torque.

3. DESIGN

Our programmable knob generates variable resistive force feedback which induces tactile illusions of active force feedback. Resistance is generated by an electromagnetic braking system, whose cost hardly exceeds 40 Euros and with large-scale manufacturing can be easily contained within 10 Euros. The main hardware parts consist of a microcontroller offering Pulse Width Modulation (PWM) outputs (e.g. Arduino), a rotary encoder and the mentioned electromagnetic braking system. Compared to existing solutions, the use of an electromagnetic braking system has advantages and drawbacks. The main advantage is the possibility to couple a standard knob with an encoder using the braking hardware as a connection point, as shown in Fig. 1. Other benefits are the lower weight, thickness and price compared to any other similar design based on DC motors [19]. Power consumption is also reduced compared to DC motors, enabling portable battery-supplied solutions. The main shortcoming of our system consists in the lack of active movement which limits the available force feedback effects to variable torque, detents and barriers.

Although the knob resists turning in both directions, the system exploits the unidirectional movement performed by users during rotation gestures. Its control algorithm in fact determines strength and duration of the generated resistive force based on the encoder position and the estimated rotation speed.

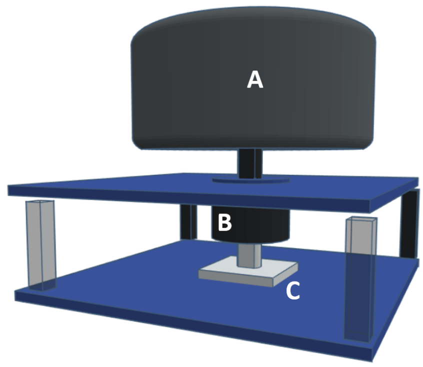

Figure 1. Schematic of the knob controller: the end effector (A) is connected to the encoder (C) by means of the electromagnetic braking system (B).

The algorithm processes the encoder position based on the desired force feedback. Every position variation generates an impulse on a corresponding pin of the microcontroller, that calls a specific interrupt routine. The encoder position is incremented or decremented one step by an asynchronous routine. The hand rotation speed is thus estimated by checking the encoder position (that is, counting the number of steps) every 100 ms.

The output voltage (between 0 and V_{CC}) of the microcontroller depends on the relative length of the PWM duty cycle. For example, if a constant torque is set, the output will always be active with a voltage proportional to the selected torque and the detected rotation speed.

The available force feedback effects include detents: once the encoder hits a position containing a detent, the algorithm will set the PWM duty cycle and a counter depending on the programmed resistance and the current rotation speed. The electromagnetic brake will remain active (with a constant PWM value) until the counter reaches zero. The counter in its turn will be decremented at every cycle. The deeper the detent, the longer the knob will be blocked. Figure 2 shows the temporal evolution of the mentioned variables concerning two different examples of the effect. In the leftmost event a soft detent blocks the hand movement for 50 ms, while in the second case the hand force is greater than the knob resistance which activates partially the braking system slowing the hand movement.

Since a high frequency PWM control is needed to avoid audible noise from the system, in the Arduino implementation it is mandatory to program the PWM using the low-level timer instructions of the microcontroller: for instance, using the 8-bit timer of Arduino UNO the largest PWM frequency is 16 MHz/255 = 62.7 kHz. Alternatively, it is possible to use the methods provided by the Arduino Motor library: this library in fact offers an abstraction of timer controls for many microcontrollers.

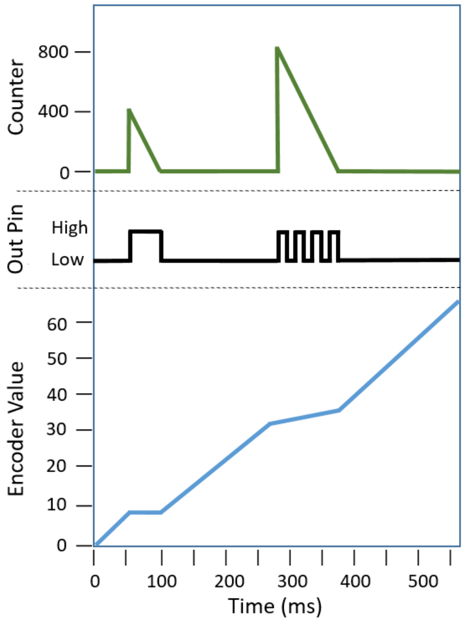

Figure 2. Example of the temporal evolution of the algorithm variables: when the encoder value reaches a detent, the output pin (black plot) is switched ON until the counter (green plot) is no longer great than zero. From left to right, the PWM values of the effects are 100% and 50% of the duty cycle, respectively.

4. PILOT TEST ENVIRONMENT

A pilot software application was developed in Processing to demonstrate the use of the device limited to some simple control of digital effects and music production. A screenshot of the GUI is reported in Fig. 4. The application communicates with the device through a serial bus. The operations made available by the software are described below:

Volume control: the controller is associated to the blue virtual knob of Fig. 4. Each discrete value is visually denoted with a small tick. Movements across ticks generate a resistance simulating soft detents. The ratio between encoder steps and ticks is 2:1. The topmost plot in Fig. 3 reports the space covered by the encoder in 500 ms (for a constant torque input). The absence of resistance enables fast motion, resulting in the accomplishment of many steps in little time (steep lines); otherwise, the knob resistance blocks hand movement for 100 ms (flat lines).

Multiple choice selector: the controller is associated to the green virtual knob of Fig. 4. Five possible choices are displayed with ticks. Movements across ticks generate a resistance feedback that simulates hard detents. The center plot in Fig. 3 visualizes the feedback effect: hard detents are rendered by blocking hand movement for 350 ms; otherwise, no resistance is generated resulting in large space covered.

Variable resistance: the controller is associated to the orange virtual knob of Fig. 4. The larger the encoder value, the stronger the resistance and vice-versa. When the largest value is reached, the resistance suddenly disappears generating the effect of an hard switch, as illustrated in the bottom plot of Fig. 3.

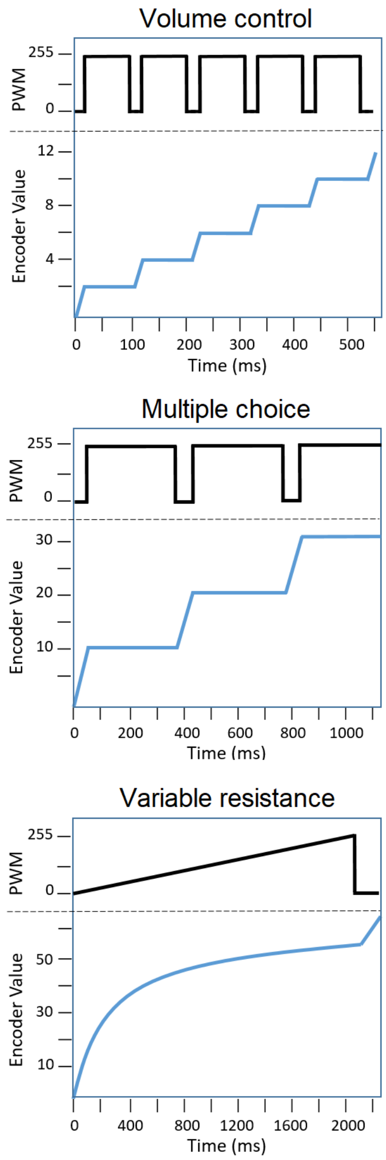

Figure 3. Example of different feedback designs for constant torque input.

Amplitude transient detection: the rotary controller allows to explore the track shown in Fig. 4 across time. A red cursor visually prompts the position on the waveform. Moving along the waveform produces a varying resistance, proportional to the energy of the signal crossed by the cursor.

Time window navigation: the rotary controller allows to explore the track across time. Time units are displayed above the waveform. A red dot marks the current position. A hard detent effect is generated each time the cursor moves through the marker.

A video footage of the haptic knob being used in the five

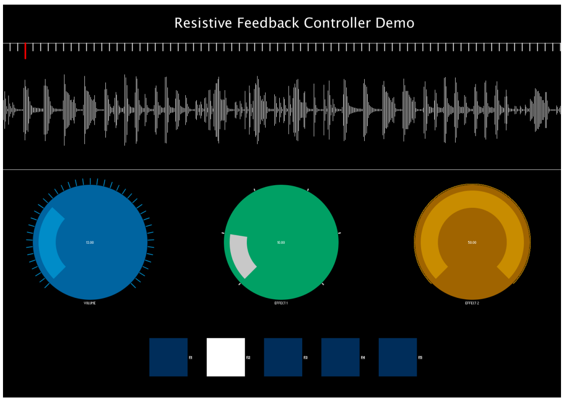

Figure 4. Software developed in Processing to test the designed haptic knob.

operations mentioned above is available in an open-access repository. [1]

5. CONCLUSIONS

A low-cost programmable resistive feedback knob controller was presented. Informal tests with a pilot application developed in Processing demonstrate the potential of the proposed tool for interacting with multimedia production software. As future work, we plan to implement bidirectional MIDI and OSC communication with the knob controller, allowing to read control data and activate various haptic feedback designs. Finally, we plan to have the device rigorously tested in combination with visual feedback in the context of multimedia editing operations and control of digital effects.

Acknowledgments

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