KUPLEN: A HANDS-ON PHYSICAL MODEL

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ABSTRACT

Kuplen is a fully embedded digital musical instrument, whose tactile, tiltable surface is mapped to parameters of a physical modelling synthesis sound engine. The underlying stiff string physical model, excited by a bow with movable damping element, can produce a variety of pitches and timbral qualities.

Players reported their interest in exploring the expressive capabilities of the instrument. Indeed, by combining free-form modes of interaction with established higher-level descriptor mapping strategies, Kuplen invites the user into novel sonic explorations and gestural controls over an exploratory framework of the physical model.

1. INTRODUCTION

Kuplen is a novel instrument that seeks to explore and redefine the paradigm of interface design for physical modelling synthesis. It does that by building an experimental inter-dependent framework that proposes: 1) a novel interaction with physical modelling synthesis; 2) a physical model that matches the explorative paths of the interface.

The approachable mappings and the transparent mode of interaction make it an instrument that complies with the Cook's principles of *instant music, subtlety later* [1]. However, its manifold timbral and tonal qualities and the numerous instrumental gestures associated with it highlight an underling layer of complexity. Early stage evaluation proved its potential as an instrument with *low entry fee, but no ceiling on virtuosity* [2].

2. DESIGN AND IMPLEMENTATION

2.1 Construction

With its appearance resembling that of a mushroom, the instrument consists of two distinct bodies. The top part is a 220 mm diameter curved *dome* constructed from laser-cut acrylic slats, into which a capacitive grid of 0.7 mm copper-wired rows and columns is threaded. The dome is attached to an open disk surface, the *wheel*.

The spokes of the wheel are 3 mm elastic strings attached to the rim and terminating at a central hub, which is partially enclosed within the hollow top of the lower body. The elastic properties of the spokes allow the dome to bounce, tilt, and be rotated about its axes.

The *lower body* of the instrument, formed from stacked laser-cut 3 mm HDF slices of progressively increasing diameter provides space to accommodate the embedded Bela [1] hardware platform. Finally the two distinct bodies are connected by means of four additional elastic strings, which are threaded between the wheel and four corresponding eye hooks attached to the lower body. In this way, not only is the body guaranteed a degree of stability, but a level of tension is also added to the four corners of the wheel.

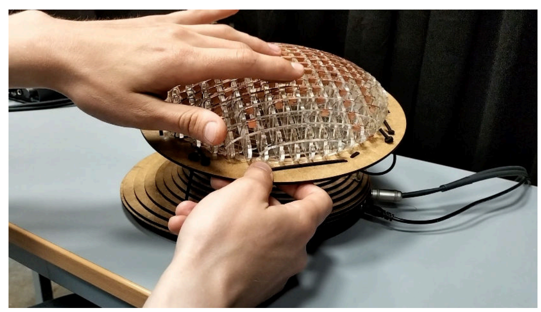

Figure 1: Kuplen in performance.

2.1.1 Sensors

The sensor system is constituted of a *Trill Craft* capacitive touch sensor and a GY-521 inertial measurement unit (IMU).

The *Trill Craft* is used to retrieve the position and pressure data from the capacitive grid. Position is derived by detecting touch at the intersection of each row and column, while pressure corresponds to the amount of force applied onto the surface. The IMU measures the tilt orientation of the upper body, expressed as pitch and roll.

The real-time stream of data is fed into Bela via the I2C protocol and used to control various parameters of a simulated bow and damping element.

2.2 Sound Engine

Bela's comparatively powerful CPU and compile-time vectorisation permitted implementation in C++ of a physical

[1] https://bela.io

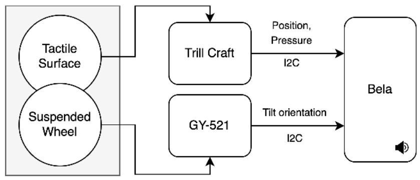

Figure 2: Sensor data flow

model based on finite difference time domain methods, as described in [3] and [4]. The following finite difference scheme forms the basis for the synthesis engine:

$$\begin{aligned}\delta_{tt}u_l^n &= c^2\delta_{xx}u_l^n - \kappa^2\delta_{xxxx}u_l^n - 2\sigma_0\delta_{t\cdot} + 2\sigma_1\delta_{t-}\delta_{xx}u_l^n \\ &- J_b(x_B^n)F_B^n\phi(v_{rel}^n) + J_p(x_P^n)F_P^n,\end{aligned} \quad (1)$$

This equation describes the displacement u of a stiff string at position l and timestep n, with frequency-independent (σ_0) and frequency-dependent (σ_1) losses, a bowed excitation, and a massless spring-damping element. c is the wavespeed in the string, κ a combined stiffness parameter; F_B^n and F_P^n are time-varying forces applied by the bow, and the damping element respectively. $J_i(x_I)$ is an ith-order spreading operator that distributes the effects of the bow and damper at continuous string positions x_B and x_P. $v_{rel}^n = \delta_{t\cdot}u_l^n - v_B^n$, is the relative velocity between the bow and string, and ϕ is a static friction model for the bow:

$$\phi(v_{rel}^n) = \sqrt{2}a v_{rel} e^{-a(v_{rel}^n)^2 + (1/2)} \quad (2)$$

Though having no explicit solution, equation (2) is continuous and differentiable, thus v_{rel}^n can be computed iteratively.

The damper is a combination of a simple linear oscillator, a cubic nonlinear oscillator, plus a localised loss term:

$$F_P^n = -\omega_0^2\mu_{t\cdot}\eta^n - \omega_1^4(\eta^n)^2\mu_{t\cdot}\eta^n - 2\sigma_P\delta_{t\cdot}\eta^n, \quad (3)$$

where $\eta = I_p(x_P^n)u_l$ is a pth order interpolator applied at the continuous damper location x_P. ω_0, ω_1, and σ_P can be adjusted independently or in combination to create different *preparation* effects at the damping position.

Output is taken as the interpolated velocity of the string at continuous position x_I:

$$y[n] = (1/2k)\left(I_j(x_I)u_l^n - I_j(x_I)u_l^{n-2}\right), \quad (4)$$

where $k = 1/f_s$ is the sampling interval. Two output positions were used, and output delivered independently to Bela's stereo output channels.

2.3 Mappings

The approach to mapping was based on Hunt's method of abstracting control and musical variables into higher level descriptors, e.g. control input = energy, synthesis parameter = brightness [5]. Such a model, inspired by the core functions of acoustic instruments, describes a straightforward and organic strategy for the cross-mapping of parameters.

Along those lines, the musical variables of the model were categorised as relating to pitch, timbre and amplitude. Mappings were devised as shown in Figure 3, following an iterative process involving parallel adjustment of the relationship between the control variables and musical criteria.

	IMU Pitch	IMU Roll	Row Position	Column Position	Row Magnitude	Column Magnitude
Pitch	Damper Position (-1, 1)	Damper Position (-1, 1)	N/A	N/A	N/A	N/A
Timbre	Damper Position (-1, 1)	Damper Position (-1, 1)	Bow Position (0, 0.5)	Damper Position (-1, 1)	Bow Velocity (-0.4, 0.4) Bow Force (0, 0.4)	Damper Non Linearity (0; 900)
Amplitude	Bow Velocity (-0.4, 0.4)	Bow Velocity (-0.4, 0.4)	N/A	N/A	Bow Velocity (-0.4, 0.4) Bow Force (0, 0.4)	N/A

Figure 3: The mappings

3. CONCLUSION & PERFORMANCE METHODS

Initial test performers reported that Kuplen provides a rewarding, exploratory musical interaction. The sensitivity of its tactile surface facilitates instant sound generation, and the mapping scheme offers subtlety of control.

Performers may touch the surface to excite the modelled string at its fundamental frequency, then slide their finger towards a different location, moving the bow and changing the timbre. Tilting the upper body can then adjust the bow velocity. Additional touches may introduce the damping element, dividing the string in two and altering the pitch. Rapid introduction and removal of the damping element may give rise to transient, 'hammer-on' effects, and percussive sounds.

In light of its affordances, *Kuplen* supports multiple playing techniques, that allow the combination of a wide array of gestures into a fluent stream of control data. The distorted, rattling high-pitched textures achieved by tilting the upper body while simultaneously tapping the surface manifest the potential of its expressive capabilities.

4. REFERENCES

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