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The scope of this project is the creation of a controller for composition, performance and interaction with sound. Interactions can be classified to one of three types: (i) end-user triggering, controlling, editing, and manipulation of sounds with varying temporal dimensions; (ii) inclusion of multi-sensor feedback mechanisms including end-user biological monitoring and; (iii) integration of sensed, semi-random, environmental factors as control parameters to the output of the system. The development of the device has been completed in two stages: (i) conceptual scoping has defined the interatction space for the development of this machine; (ii) prototype development has resulted in the creation of a functioingl prototype and culminated in a series of live performances. The final stage presupposes a custom interaction design for each artistic partner, reinforcing the conceptual role of the device as a novel mechanism for personalized, visualizable, tangible interaction with sound.

1 Introduction

Currently, we are in the second stage of the development process, having designed and built a prototype of the physical device, and implemented the necessary low-level I/O code for sensing user interactions or actuating gestures onto the surface. The curent state of the machine incorporates low-level audio processing into a framework which guarantees the stable behavior of the physical system, whilst allowing directed control with regard to the physical representation of observed sounds on the part of the performer/interactor.

1.1 Related Work

The electromechanical component of this project, as developed with a team of student collaborators, is a member of the class of user interface devices that can be described as actuated interactive surfaces, haptic displays, or 2.5D tangible user interfaces. The common characteristic of this class is that a flexible surface can be sensed and/or controlled according to a pixel grid, such that each "pixel" corresponds to a height by which the surface is raised or lowered. Many combinations of sensing and actuating techniques have been explored, including sensors ranging from 3D laser scanners [7] to guitar pickup coils [2], and actuators ranging from an array of motorised pins [6] to pneumatic elastomers [9]. The designers of an elastic display using linear actuators describe an interactive gesture grammar; regrettably, their sensor implementation suffers from occlusions [1]. This class of devices should be distinguished from tabletop tangible user interfaces, in which rigid objects are moved around on a sensing surface. Typical examples include Reactable [4], or previous projects in Cambridge such as Neil Jenkins' and Alex Kuscher's MPhil projects in 2009/10 [5, 3].

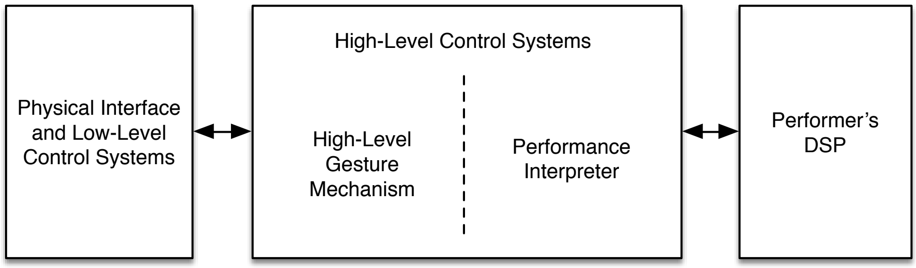


Figure 1: *System Overview of Mephistophone*

2 Hardware

The fundamental definition of the hardware is a tangible, flexible, planar surface, mounted on a rigid structure. Attached to the surface is a grid of nodes comprised of stepper-motor activated elements and sensors for recording the interactions the user exerts on the surface. Additional interaction mechanisms on the surface of the device may be integrated in the controller at a later stage.

2.1 Mechanical Design

Currently, we have implemented an initial prototype design which was sufficiently robust to run for a series of live performances. It is this prototype which is subject of the detailed description to follow. The design is currently limited insofar as the two interaction modes, sensing and acuating, are not simultaneously available.

2.1.1 Interaction Surface

The interaction surface is a flexible sheet which allows the user to impress sensed gestures into the device or for the device to actuate and inform learned gestures to the surface. With the present design, only one of the paired sensors or actuators is active at a given time. Regardless of whether the device is currently sensing a user's control intentions, or actuating the surface to reflect a prior trained gesture, data pertaining to the surface interaction is constrained to an 8 x 4 grid of 32 sensors/actuators, spanning 100cm and 70cm, respecitvely. This surface is connected to the chassis by the attraction between a set of neodymium magnets and magnetized rods. This allows for rapid retensioning of the surface which is necessary given the flexible nature of the surface after prolonged interaction or actuation.

2.1.2 Actuators

The actuators are servos intended for use in remote controlled sailcraft. The 3-pole 6V motors are controlled by PWM and generate up to 2.42 Nm, allowing actuations in both the positive (upwards) and negative (downwards, into the machine) actuations of the Interaction Surface.

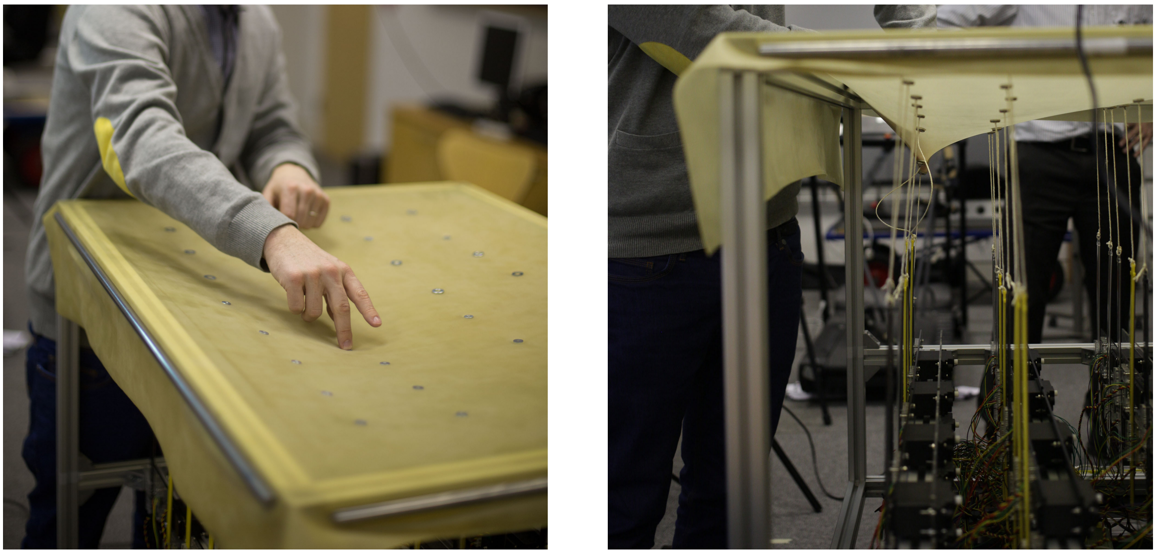
Each of the actuators use a 5cm screw-mounted lever to translate rotational into translational displacement.

The actuators can be connected with rigid acrylic arms to the surface (allowing positive movement but limiting the ability to manually override movement with gestures) or by non-rigid nylon-based connectors that only allow for negative movement, but allow for the concurrent sensing of manual gestures impressed into the surface beyond the movement instigated by the actuators.

2.1.3 Linear Displacement Sensors

Each actuator is paired with a Linear Incremental Magnetic Position Sensors mounted within acrylic sliding fixtures through which a magnetic strip is guided. As the magnetic strip moves through the fixture, the position sensors increment an index counter as each pole pair (spaced at 2mm) travel by the sensor and encode the absolute position within the pole pair. This allows for a resolution of 2μm.

The index counter is direction-independent;



(a) *Interaction Surface* **(b)** *Sensor Design*

Figure 2: *Mephistophone in use*

it increaes independent of the direction of travel of the magnetic strip. Hence, directionality of movement needs to be inferred by two subsequent absolute measurements within each 2mm pole pair.

The sensors allow for both a PWM output as also a quadrtautre pulse, making the subsequent decoding of 32 concurrent movements as flexible as possible.

2.1.4 Chassis

The chassis is constructed from an aluminium space frame which allows the modular construction of a central structure for mounting servos and sensors. The top of the frame holds the magnets in place which are used to attach the surface to the chassis, and the base of the frame includes a platform on which the power supplies, microcontroller boards, and signal distribution circuit boards have been mounted. Servos and sensors are mounted on a series of parallel struts combined with acrylic mounting plates forming an intermediate layer, the height of which can be easily adjusted to accomodate different length attatchments to the surface. Varying these lengths, in the context of actuation, allows the surface to extrude by varying distances, limited primarily by the characteristics of the surface material and, to a lesser degree, the torque available from the motors.

2.2 Electronic Design

Two parallel systems have been implemented to read sensor data from the device in response to a user's gesture informed on the surface, and to drive actuators given an output gesture. In both systems, the interface with the electronics is compiled on arduino Mega2560 single-board microcontrollers [1]. Between all system components, messages are passed using the Open Sound Control (OSC) content format[8] bundled into UDP packets. These can be transmitted either via USB and/or over ethernet, allowing the 5m cable length restriction imposed by USB to be overcome.

2.2.1 Actuator Control

Multiple versions of the actuator control code have been implemented reflecting differing degrees of training for gesture re-creation, however, in all instances, certain facets remain the same. Low level I/O driving all of the actuators requires one Arduino Mega2560 board, with all of the control signals being sent via digital pins. Each actuator is individually addressable and the current state of all other actuators is

[1] http://arduino.cc/en/Main/arduinoBoardMega2560

known. To allow network effect constraints to be placed on the actual actuation values possible given limitations of the surface flexibility and servo torque, actuator control code identifies the states of all adjacent nodes prior to driving a particular motor, and constrains any intended position should it exceed bounds set as a function of the adjacent node states. This has a smoothing effect when playing an output gesture, should that gesture exceed the system's mechanical capacity for re-creation.

2.2.2 Sensor Control

Recording the output from the sensors requires multiple Arduino Mega2560 microcontrollers which receive PWM signals from the sensors on their analog inputs as well as index pulses as described above in Section 2.1.3. As the rigid connections necessary to actuate the surface in playback mode are replaced with flexible connections in sensing mode, the movement of the surface is less constrained in this state. Thus, as the user interacts with the surface, sensed data bounds are tracked to allow for subsequent data normalization. Due to timing constraints, the current sensing code is limited in its capacity to accurately gauge the direction of motion in the course of a user-informed gesture.

2.2.3 Systems Overview and Power

While the simultaneous use of the sensors and actuators has yet to be implemented due to physical constraints regarding the connections with the surface, the low-level I/O for such a system has beeen implemented to run on three Arduino Mega2560 microcontroller boards. The concomittant reduction in power requirements would be negligible. The 32 actuators are each rated at 2A, however, their peak draw, measured on an oscilliscope, exceeded 4.5A; thus the primary power requirements are virtually unchanged with a reduction in the number of controllers. Due to the significant potential power requirements given simultaneous actuation of all 32 stepper motors, four 600W ATX power supplies are used in parallel (note: 5V rails of ATX power supplies are rated << 600W). Power fluctuations and constraints have been overcome yielding a device that, in actuation mode, can run continuously for considerable time without significant heat dissipation issues.

3 Conclusion

In its current state the device is progressing through the proposed design evolution. The conceptual scope has been clarified, although the integration of a number of environmental and physiological sensors has yet to be implemented. An initial prototype of the machine has been built with a chassis simultaneously set up for sensing and actuating the surface although connection constraints currently limit the prototype to be in only one of the two modes at any given time. Initial work has been carried out to determine the efficacy of the prototype as both a sensing and an actuating device.

4 Further Work

Given that the device works as either a sensing controller or actuator at this time, subsequent prototypes will explore mechanisms by which both modalities can simultaneously be incorporated. Additionally, we anticipate the integration of environmental and physiological sensors into the I/O stream.

These interaction mechanisms will fall into two broad classes, those which extend the users control through physiological monintoring, and those which integrate environmental factors into the interaction. Included in the former may be a cardiometer, blood pressure meter, body thermometer and skin humidity meter to assess the impact of changes to the users physiology over the course of their interaction with the device - these will be implemented via the ANT+ protocol.

In the latter category, we anticipate integrating temperature sensors and/or heat exchangers, photodiodes and/or LEDs and surface humidity sensors, for allowing interactions based on surface temperature, surface light occlusions and humidity levels, respectively.

These environmental sensors may be used as modulation methods in a semi-deterministic manner for a range of performance parameters

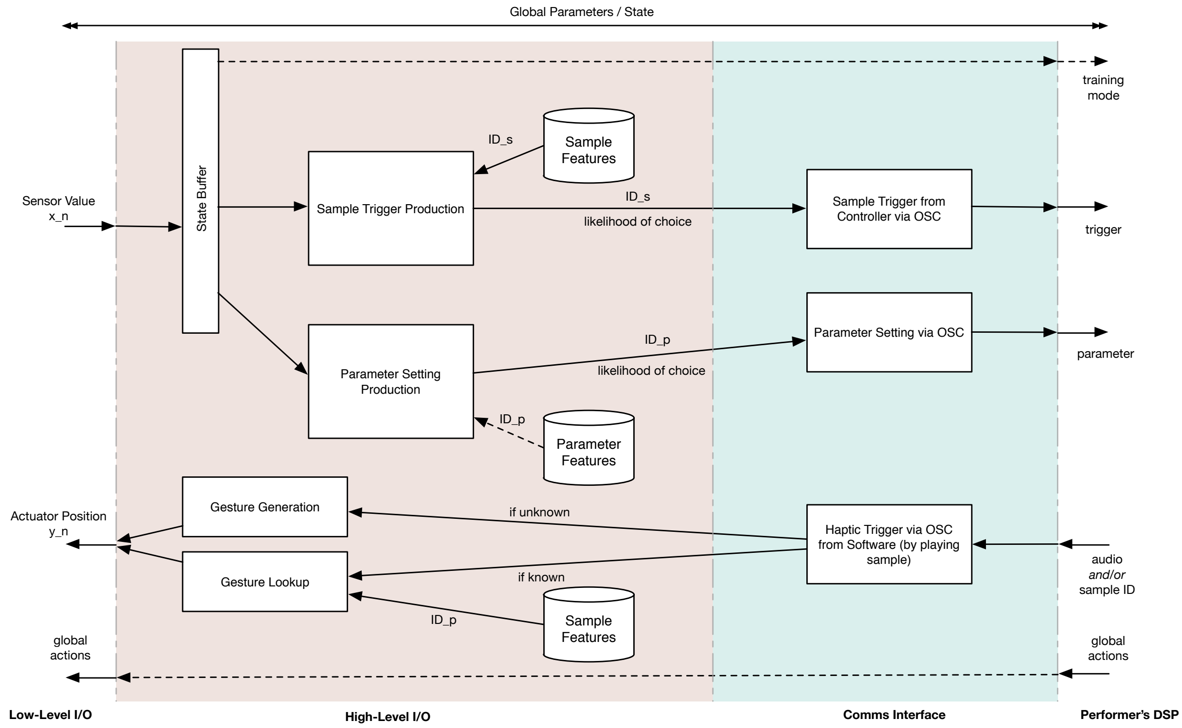


Figure 3: *System Overview of future work relating to the Mephistophone*

and include a barometer, thermometer, humidity meter, and lux meter. Output of the lux meter will be segmented to ranges of the visual and non-visual spectrum in order to be able to eliminate feedback cycles through stage lighting.

Continued iterative design of the physical device will allow us to identify further modularity in order to optimize the production process. A detailed outline of the anticipated use of the Mephistophone can be seen in Figure 3, in which the Device Hardware and Low-Level I/O (on the left) can be seen with respect to the anticipated interaction with High-Level I/O as well as with regard to the performer's DSP.

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