# AcuTable: A Touch-Enabled, Actuated Tangible User Interface

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**Abstract.** In this paper we describe AcuTable, a new tangible user interface. AcuTable is a shapeable surface that employs capacitive touch sensors. The goal of AcuTable was to enable the exploration of the capabilities of such haptic interface and its applications. We describe its design and implementation details, together with its strengths, limitations, and possible future applications.

**Keywords:** Tangible user interface · Adaptive interface · Actuated surface · Haptic feedback

## 1 Introduction

Tangible User Interfaces (TUI) are used in a wide variety of modern day appliances, from ticketing machines and information kiosks [1], to music instruments [2] and cars [4]. TUIs differ from standard graphical user interfaces (GUI), as they are developed specifically to perform tasks by touch and manipulation. Humans have highly sophisticated skills for sensing and manipulating the physical environment. However, these skills are rarely used in the interaction with the digital world [5]. This issue has been partially addressed by mobile devices with the wide availability of 2D touch screens for human-computer interaction [5]. Recently, new 3D touch interfaces such as in the iPhone 6s indicate that this type of TUIs may be introduced in other computer devices in a near future.

In contrast to traditional mouse-keyboard based GUIs, TUIs allow users to manipulate information in 2D or 3D by incorporating haptic feedback. A haptic interface creates haptic sensations on skin and muscles. Compared to other types of feedback, such as auditory or visual sensations, haptic feedback is rarely utilised to an equal extent.

TUIs have been applied in multiple applications in different domains, but one significant aspect of these interfaces is in facilitating people suffering from visual impairment. It allows for use of computer systems in a more effective way, since the haptic sensations add an additional way of interacting [1].

In this paper we describe the *AcuTable*, a haptic TUI. We have built a prototype of this TUI to explore its possibilities and part of its design space.

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This paper describes a summary of related work, the *AcuTable* in detail followed by a discussion on the strengths, limitations and applications of *AcuTable*. Finally, it presents some conclusions.

## 2 Related Work

A wide variety of research work has been carried out in the field of tangible user interfaces (TUI) in last decade.

TUIs that have been reported in the literature, vary from the actuated surface *FEELEX* [1] to electronic music instruments such as *ReacTable* [2].

Shaer and Hornecker [3] describe the possibility of a collaborative interaction with other users, as one of the key strengths of TUIs. An example of this is the tangible electronic musical instrument *ReacTable* [2], a system with a round shape that allows having several users at the same time. Shaer and Hornecker state that the way we interact with a TUI is similar to how we use our body. Our bodies are developed for physical interaction and it is natural for us to use our arms and hands without thinking about their placement in the physical world. Users come in direct contact with a TUI-based system without having to think about how to use it [5].

On the other hand, TUIs have their own limitations. Ulmer and Ishii in [6] describe the balance that must exist between physical and digital representations, as one of main challenges in using TUIs. Scalability is also a problem in TUIs, since the primary interaction happens when users are touching a surface. Hence, TUI's size matters since if it is too big, the interface will be perceived as "bulky" by users, decreasing their level of interaction. Additionally, TUIs are also versatility-wise limited [3], as most systems are often created for one specific purpose. In contrast to a GUI, TUIs cannot just be easily transformed into something new, and the creator or user does not have the ability to undo his/her actions. Additionally, TUIs require users to use their body and depending on the size and weight of the system, this might be tiresome or difficult.

Iwata et al. [1] analyse TUIs physical design and its possible application scenarios. These authors created two prototype artefacts that combine haptic and visual sensations in a single interface. Their project *FEELEX* consists of a rubber flexible screen, actuated by a matrix of motors. Each actuator is equipped with a force sensor which senses the pressure applied to the surface by the user's hand. In an alternative prototype, the motor's power consumption is measured to estimate the load. The load value is increased when external pressure is applied to the surface (e.g. a hand pushing onto it).

In [1] it is argued, that resolution and speed of the actuation are vital for an optimal perception of the haptic feedback that the system may provide. This research found that a maximum stroke rate of 7 Hz with a length of 18 mm was sufficient for optimal perception. Resulting from these studies, a group of possible applications of haptic interfaces was compiled. Among these applications are: their use in medical equipment, for 3D modelling, as an enhancement to current touch-screen technology, and finally as interactive art.

## 3 AcuTable: A Programmable, Adaptive Interface

The systems described in previous section are creative and work well. However, *AcuTable* has different goals. One goal is to enhancing the adaptability aspect of the interactive surface by introducing a greater haptic sensation. At the same time, *AcuTable* allowed us to explore the design space of TUIs by experimenting with different materials and techniques in its construction.

Figure 1 shows a block diagram of *AcuTable's* main components. The system is comprised of three major parts: the surface with servo-motors and touch-sensing electrodes, the touch sensing processing system, and the servo motor control system. The surface consists of several layers of foam which can be shaped by the user or the system itself at same time, to produce haptic feedback. A matrix of motors located underneath the surface allows the programmatic control of deformation in the foam. In order to utilise the surface as touch-input, self-capacitive touch sensors were used. A computer and two microprocessors control the motors and sensors.

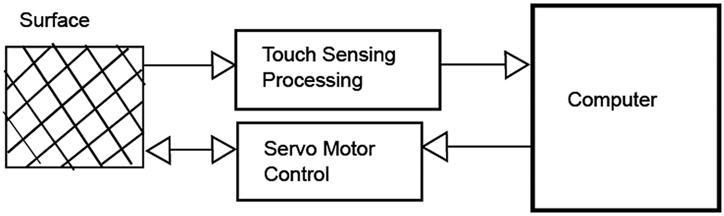


**Fig. 1.** Block diagram of *AcuTable*

### 3.1 The Foam Compound

*AcuTable's* surface is composed of several layers of foam which when compressed subsequently return to its original state. Different kinds of foam were combined in order to obtain the optimal, mechanical properties for the application. These include the ability to be shaped by the motors in the desired way, additionally to the rebound speed and resolution of the actuation. *AcuTable's* surface consists of 2/3 soft foam (17 kPa rated) and 1/3, harder, cold-foam (30 kPa rated) on top. This allows for easy compression of the compound and at the same time, to achieve an even distribution of the force along the surface. In order to further enhance the even distribution and resolution, facets are distributed along the surface (Figs. 2 and 3). These facets provide a more "fluid" sensation of the surface's movement, compensating for the relatively sparse grid of servo motors [7].

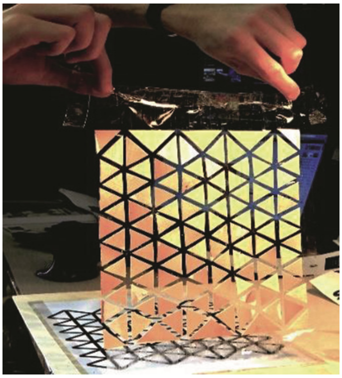

**Fig. 2.** The 1.5 mm thin facets are situated in between two layers of flexible cloth.

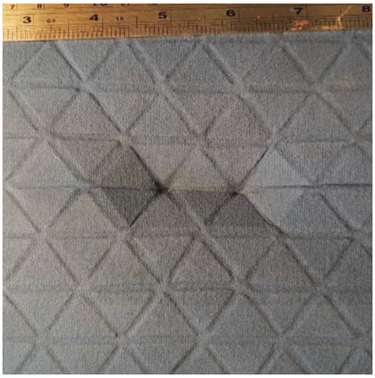

**Fig. 3.** The facets embedded in the surface. Two points are pulled down by the servos.

Finally, nylon strings attached to the facets through the foam, allow the mechanical connection to the servo-motors.

### 3.2 Servo-motors

To compress the surface, the servos wind and unwind the strings attached to the facets. The servos are interconnected in modular rows that can be removed from the system and serviced individually. The motors and pulleys attached to each, are designed to provide the exact amount of force and movement required, in order to actuate the surface. A force of 1.5 kg of pulling strength produces 20 mm of movement. A total of 46 servos are arranged in 7 rows to form a triangular tessellation.

### 3.3 Touch

A capacitive surface, composed of a two-dimensional grid of electrodes, [8] was designed as the input to the system. By measuring and analysing the capacitive properties of the electrodes in the surface, the computational system can determine the three-dimensional position of a human hand or finger on and over the grid. The electrodes are 5 thin strips of aluminium along each axis, and are located below the foam compound. For determining the correct characteristics of these, some tests were performed, whose results are shown in Fig. 4.

### 3.4 Programmatic Control

Four individual software applications running independently enable *AcuTable* to perform all tasks required to function properly. The software running on a microcontroller attached to the touch sensing electrodes, measures their capacitive characteristics. It performs 6000 readings per seconds which are filtered using an integration filter with 60 cycles. Furthermore, it performs calibration in 2 s intervals and normalisation of the

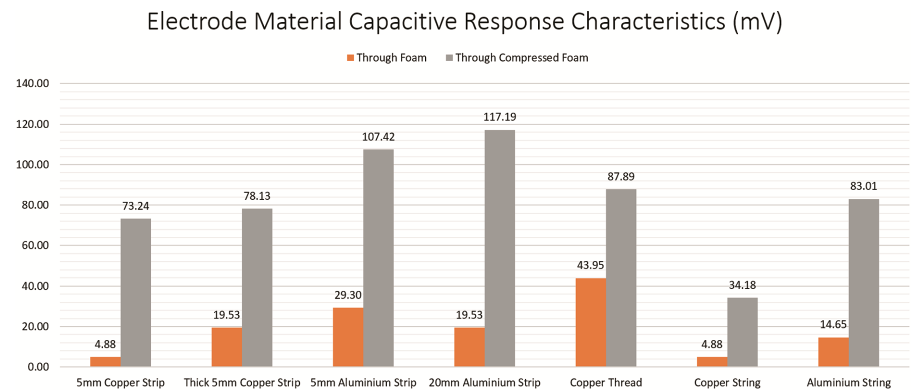


**Fig. 4.** Different types of electrodes tested on the particular setup. The voltages represent the discharge of the electrodes after a given time subsequent to charging the electrode.

readings [9]. A script written in Matlab receives those values through a serial connection. In order to retrieve coordinates from the readings, the position is interpolated as described by O'Conner in [9]. Coordinate filtering is subsequently performed using a rolling average with a 4:1 ratio. The resulting values are broadcasted to a sketch written in Processing. Processing allowed the rapid implementation of several application scenarios. The outcome of this is a map representing the deformation of the surface. The microcontroller connected to the servos receives packages of positional data from the Processing sketch through a serial connection and subsequently generates the electronic signals that control all servo-motors. The full system running can be seen in Fig. 5.

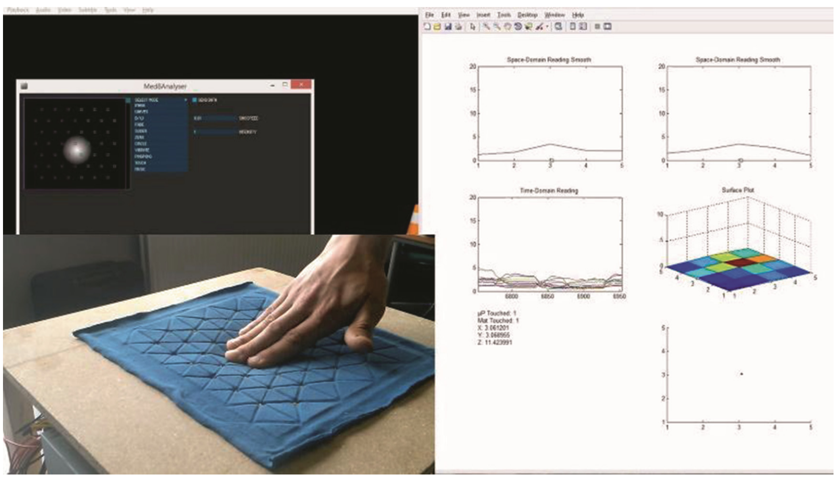

**Fig. 5.** A user interacting with the system. Matlab signal processing is visualised to the left. The Processing sketch is on the top-right.

# 4 AcuTable Strengths, Limitations and Applications

## 4.1 Strengths and Limitations

Similarly to the TUI described by Shaer and Hornecker [3], we found that our system has its own strengths and limitations. The system itself is fairly easy to use, and allows the collaborative interaction of several users at the same time. This is because the system has a near-square shape, so users can stand at each side of the table. As described previously, TUIs often lack malleability, making it hard to give them a new purpose. Contrarily, *AcuTable's* surface allows to adapt its affordances dynamically.

**Table 1.** List of general strengths and limitation of select TUIs.

| AcuTable | ReacTable | Project FEELEX |
|---|---|---|
| *Strengths* | | |
| Easy to use and requires no tools or intrusive devices | Visual and auditory feedback | Robust construction |
| Size and shape offers collaborative interaction | Size and shape offers collaborative interaction | Surface optimized for projection mapping |
| Dynamic surface | | Dynamic surface |
| Safe to use | | Safe to use |
| *Limitations* | | |
| Limited malleability, thus limiting number of potential purposes | Lack of malleability, thus limiting number of potential purposes | Limited malleability, thus limiting number of potential purposes |
| Large number of noisy actuators. Strings can unhinge from servos | Requires skill to use | Physical representation of objects is limited |
| Physical representation of objects is limited | Objects used with the system can be a potential danger hazard | |
| Latency of up to 1 s | Utilises additional devices for interaction | |

*AcuTable* does not require any tools or intrusive devices in order to be operated by the user. This has positive impacts in relation to usability and safety aspects. However, a major disadvantage of *AcuTable* is the complex nature of the implementation in the current prototype. In this implementation, it requires a large number of servos and is relatively susceptible to be used wrongly. Given that the system uses strings to pull on the surface, the strings may unhinge themselves from the pulleys when the servos release strings too rapidly or the user interferes with this action by pushing onto the surface simultaneously. This may cause that parts of the surface could be unmovable. Furthermore, the system is limited in the range of objects it can represent as it cannot represent complex geometric shapes, and will always be shaped with a slope, and not free flowing, like a computer-generated 3D object. Complex, three-dimensional objects are hard to visualise, especially when featuring hard edges. The system is mostly restricted to representing textures of surfaces.

The touch system allows for a rough approximation of the user's hand, but not for recognition of gestures or for mapping it to a virtual cursor on a computer system. Also, the considerable latency of about one second before a touch is recognised by the computer presents some limitations to the naturalness of the interaction. This is mainly due to the fact, that the signal has to stabilise before it could be recognised. This is partially due to the fact that the electrodes have to sense touch through three centimetres of foam.

For a greater understanding of the difference in systems, Table 1 below show a short list of strengths and limitations are listed.

### 4.2 Application Scenarios

**Adaptable interface.** The surface of the *AcuTable* allows it to adapt in some ways, as long as the constraints of the surface are not challenged. Like a touch-screen can dynamically change its visual interface in order to afford the right tools for the current task, the *AcuTable* can change its haptic properties. This just-in-time-affordance opens up for a great amount of possibilities in regards to user experience and productivity. As described by Iwata et al. [1], touch-screens are used in a wide variety of modern day appliances such as automatic-teller machines and ticketing machines. Though intuitive, touch-screens lack haptics feedback. A solution for a touch-screen would be a mapped projection of a visual user interface. The user would be able to see and feel the interface.

**Art installation.** Projection mapping can be used to manipulate a projected landscape or shape of any kind for the purpose of encouraging playful behaviour.

**Music manipulation.** The *AcuTable*, with its adaptable interface, can be used as a means to manipulate a piece of music. By using the touch capabilities of the surface, the user can change both the pitch and tempo individually, or together. Both pitch and tempo have its own axis respectively, with pitch being on the x axis, ranging from low pitch to high pitch, and tempo being on the z axis, ranging from slow tempo to high tempo. By varying the intensity of the actuation in accordance to the beat of the music, the user can haptically sense it.

## 5 Conclusions

In this paper the *AcuTable* TUI has been introduced. The concept of such a new interactive interface has been discussed in relation to relevant, related work. The developed prototype demonstrates the idea of haptic feedback in touch systems and allowed us to explore the design space of the system and the capabilities of the techniques involved. The use of foam as the main material for the surface worked as expected. However, the material introduced some challenges in detecting the changes in capacitance when the surface was pressed by a user.

The use of servomotors presented an accessible and cheap way of actuating the surface with the required force and desired speed. However, the noise generated by these motors turned out to be a downside. Additionally, the shapes generated by *AcuTable* are rather limited, as it cannot represent complex, free floating 3D objects or steep slopes. Finally, the current prototype will present some challenges regarding its fabrication and maintenance.

Future work will include a new design for the pulleys, a different capacitive touch solution and the use of a single, more powerful microcontroller for the servo-motors and touch sensing processing.

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