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Multi-Dimensional Interface Based Spatial Adaption

A Prototype For A Multi-Sensory User Interface Employing Elastic Materials

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Patten and Ishii (2000) discovered that people are employing more versatile strategies for spatial distribution when using a tangible user interface (TUI) as opposed to a graphics user interface (GUI) (Patten & Ishii, 2000). Besides, the generated information outputs of conventional two-dimensional interacting screens are currently almost entirely addressing the visual and acoustic senses but lacking in other sensory stimuli - such as haptic, body equilibrium and sense of gravity. With the experiment described here, the multi-dimensionality of both the input on the interface and the output of the human interaction will be challenged. This paper aims to introduce a method to a real world versatile three-dimensional interface actuating a simulated spatial environment that substantiates the more unconventional sensory perception mentioned above. A physical prototype using an Arduino will be assembled to test the feasibility of the structure.

Keywords: *spatial formation, virtual reality, tangible user interface, body equilibrium, physical computing*

ENVISIONED APPLICATION IN THE HUMAN ENVIRONMENT

Spatial Shaping for Virtual Reality

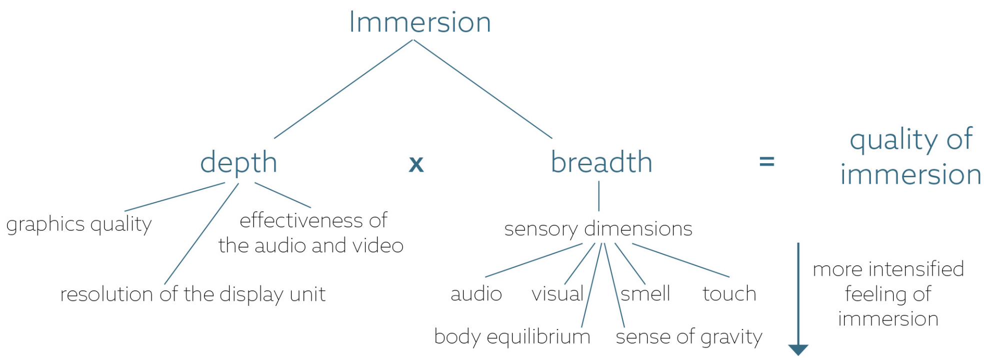
Digital information did not have any visual form until the graphic user interface enabled people to visually interact with information, which could be defined as a somewhat virtual reality in a broader sense. However, Ivan E. Sutherland (Sutherland, 1965) pointed out that the visual interaction between information and humans is only one of the other possibilities using sensory systems such as taste or smell. Sutherland (1965) also mentioned that the ultimate virtual reality system would be able to create virtual tangible and mountable objects; he states "The ultimate display would, of course, be a room within which the computer can control the existence of matter. A chair displayed in such a room would be good enough to sit in.[...] With appropriate programming such a display could literally be the Wonderland into which Alice walked." (Sutherland, 1965).Sutherland's notion of the ultimate virtual reality system is highly relevant to the recent idea of physical computing, which means building interactive physical systems by the use of software and hardware that can sense and respond to the analog world (Sutherland, 1965). The user of the ultimate display in the analog world creates an analog input to the interface, then the ultimate display and finally the hardware does. Following this, it converts the analog input to digital, which is processed in the software to create a physical output in the form of sensory stimuli to the user's body.

This paper investigates a speculative prototype according to Sutherland's "ultimate display" (Sutherland, 1965) in the current world by implementing the physical computing method. In order to realize this vision, the development of a physical human computer interface which provides an internal enclosed space and stimulates multiple senses for a richer spatial experience is necessary. The main focus is on the interface to manipulate body equilibrium and the sense of touch without using equipment directly attached to the body. This attachment to the body could cause a less immersive feeling of the users by requiring them to be conscious of movements that happen attached or detached from the equipment. Our interface can be classified as a virtual reality interface, which generates spatial experience by manipulating the human sensory perceptions with computational interface. On contrary to the so-called augmented reality technology, which alters the perception of the real world environment by overlaying the sensory information onto the real world, virtual reality technology is oriented to completely replace the reality by immersing the user in the virtual environment.

In the Cyberith Virtualizer (Cyberith GmbH, n.d.), a locomotive device for virtual reality that the human uses for immersion by mounting an approximately one square meter platform and being locked in a belt-like frame around its legs and hips. Through the treadmill-like platform properties, the user can walk in virtual reality but does not move off it in reality. The platform does not tilt and through the climbing equipment-like belt straps the human sense of body equilibrium is taken away and held by the belt. At this stage of the project only one person can mount the device at a time in order to test the concept. A sense of communal immersive experiences would add an increase of complexity with focus on multi-agent-interaction; whereby each participant would take on the role of user and human interface to operate the structure.Immersion is the feeling of a physical presence in a non-physical environment. In virtual reality, this immersive feeling is created through the virtual world appearing in the virtual reality medium such as goggles which does not coincide with the space the person is located in.The computer scientist Jonathan Steuer (1992) differentiates between two components that immersion consists of [Figure 1]. One is depth of information and the second one is breadth of information.The depth of sensory information "refers to the resolution within each of [the] perceptual channels" (Steuer, 1992) like the resolution of a screen, the graphics quality, the quality of the audio and video and so on.The breadth of information he defines as a number of sensory dimensions presented simultaneously. Those are the ones addressing the human audio, visual and touch senses to stimulate the human to get entirely focused on the 'new' world they explore and forget their present identity (Virtual Reality Society, 2017).

According to Bricken (1990) the essence of VR is the inclusive relationship between the participant and the virtual environment, where direct experience of the immersive environment constitutes communication. In this sense, VR can be considered as the leading edge of a general evolution of present communication interfaces like television, computer and telephone (Kay, 1984). The telephone has enabled humans to communicate with each other from a distance by transferring analogue audio signal along the wire. The smartphone has enabled humans to virtually communicate using multiple virtual (digital) information outputs such as pictures, videos, or texts, following former interfaces as the telephone or desktop computer. What is observed here is that the communication interfaces have developed to be able to transfer more and more forms of information through history. Smartphones however do not enable users to share information spatially as they do in physical reality; nor do they feel the presence of each other as, for instance by sitting down at a table or running in a park - in the physical reality.

Figure 1
Intensity of immersion



State of scientific space simulation applications

Besides the current interfaces which transform information into visual stimulation, there has been research on interfaces which transform information into tactile sensation to hands, such as inTouch by Scott Brave and Andrew Dahley (1997). InTouch is a haptic feedback technology that transfers manual movement on one side of the tool to the other geographically distant side. Patten and Ishii (2000) discovered that people are employing more versatile strategies for spatial distribution when using a tangible user interface (TUI) as opposed to a graphics user interface (GUI). After all, those interfaces are not able to simulate spatiality induced by unconventional sensory stimuli such as body equilibrium or sense of gravity, because it only targets the tactile sensation especially on hands, thus still lacking in sensory breadth of immersion (Steuer, 1992) of the virtual reality experiences.

One example is the cable-driven parallel robot developed by Fraunhofer IPA (Fraunhofer IPA, 2015) is able to simulate gravitational acceleration up to 1.5 times. In the cable-driven simulator, the motion of the simulator cabin is controlled by eight unsupported steel cables attached to winches. The use of cables makes it possible to reduce the moving mass and to scale the workspace to any required size. A total drive power of 348kW allows the cabin to accelerate at 1.5 times gravitational acceleration along freely programmable paths inside a 5m x 8m x 5m workspace. In addition, the cables can be reattached in under an hour to enable the simulator to be adapted to different cabins and thus used for a range of scenarios.The cable-driven parallel robot has incorporated the flexible interface that the user can be inside. Although the main purpose of the project is to develop an interface for flight simulator, which only needs to concentrate on the simulation of gravitational acceleration, some aspects of the interface could be transferred into the development of a multisensory user interface, such as the simplicity of attachment to the existing space.However, seeing the cable-driven parallel robot as a communication interface to transfer space, it lacks in the freedom of the body of user mounted on it as the user is locked in a seat belt. In addition, the cable-driven parallel robot does not simulate tactile sensation as it is specially developed for the simulation of gravitational acceleration. A synthetic approach combining different sensory inputs and outputs is to be experimented in this paper.

EXPERIMENT SETUP

Component Materials and Interdependencies

Initial form and flexibility experiments were made on the cubic frame by sequentially exchanging each edge of the cube for tensile elastics. The 15cm by 15cm cube is constructed from 5mm x 5mm wooden sections in order to exchange and replicate them easily.Conventional rubber elastics in a thin polyamide cover are fixed to the rods by drilling holes into the ends of them and tying the elastics through it. Testing to exchange multiple rods for tensile elastics, we found a cube of six rods and six tensile elastics most suitable for a high degree of flexibility while keeping two rigid opposite corners [Figure 2].

Figure 2
Working model for the cube with six rods and six tensile elastics Photograph from Fujii

Pulling one of the rigid corners into the X, Y and Z directions from and towards the other one, the space inside the cube transforms. The sides become rhombuses or hyperbolic rhombuses when moving away into two directions.Adding a circular wooden section as the diagonal axis between the two rigid corner frames and turning one around the other, it was examined that the most shape-changing movement of this particular structure is the rotation around the diagonal axis. The tests revealed that there are three fixed states within the 360° rotation of this instrument. Through the tension of the elastics, it is a rather forceful action to rotate one rigid corner around the other as the elastics will collide with each other and the axis rod in the center of the cube.This tension almost dissolves when the rotation hits approximately 120°, meaning the wooden rods on their own form a cube again. The stress in the elastic continues when turning further into the same direction and again decreases when the rotation is at about 240° and then 360°.

In the next step we equipped the sides of the cube with an elastic membrane to understand the spatial formation the twist of the sides causes and their intervention into the cubic inward.Firstly, stripes of a 6% elastane and 94% polyamide thick and tightly knitted fabric were sewed around the rods and tensile elastics and the rotation was performed, but this composition was too inflexible for the underlying stretch.Secondly, conventional 40 denier women's tights from 15% elastane and 84% polyamide were equally applied. Yet, we discovered that this material is not fully elastic according to what is referred to as elasticity.

Landau and Lifshitz (1970) stated: "When an elastic material is deformed due to an external force, it experiences internal resistance to the deformation and restores it to its original state if the external force is no longer applied" (Landau & Lifshitz, 1970).

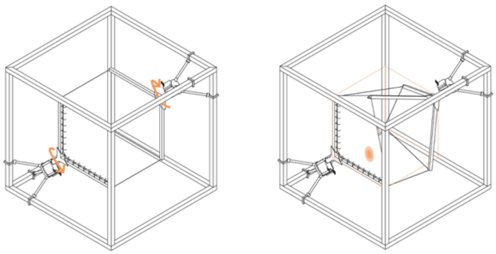


Figure 3
Technical build-up of the prototype

The fabric we used did not fully restore to its original state again, it becomes slightly lose by stretching and builds dents back it the unstretched state. As a final membrane, another again thicker fabric from 16% elastane and 84% polyamide was tested to be stretched in the conditions of the rotational movement and chosen for the final prototype instrument. This membrane was applied to the frame like a trampoline, additional elastic bands tie the membrane to the holes in the frame at an interval of 2cm. Hence, the final experiment instrument for a versatile three-dimensional interface actuating a simulated spatial environment, is a cube of six rods, six tensile elastics and a tangible elastic membrane [Figure 3].

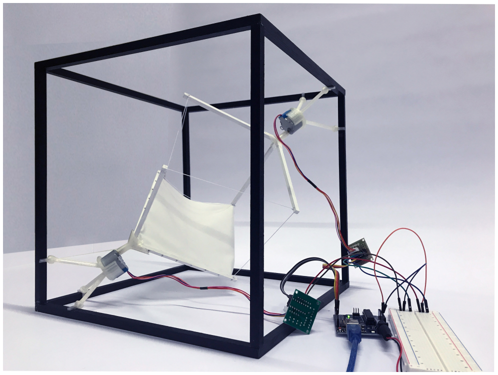


Figure 4
Technical build-up of the prototype with Arduino connection
Photograph from Fujii

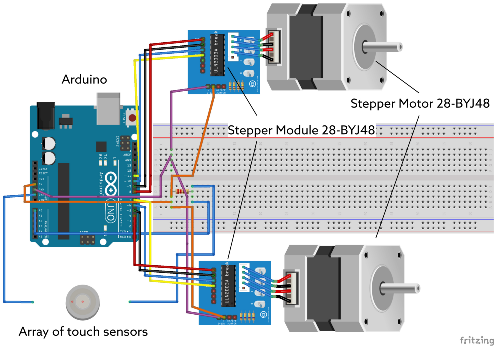


Figure 5
Schematic build-up of Arduino connections

For an initial human interaction test we are investigating two options; a) pressure sensors were applied in a grid to the elastic fabric membrane on the side. The Arduino build-up and mechanism is depicted in Figure 4 and 5. Subsequently the position of the activated pressure sensor and the degree of pressure determines the degree of rotation. b) a stretch sensor made out of conductive fabric such as "Eeonyx Stretchy Variable Resistance Sensor Fabric - LTT-SLPA-20K" by Sparkfun could be incorporated to measure the strength of human touch. However, for our physical build-up proposal of the tool, the membrane stretches through the rotation movement. Thus, the stretch sensor would be stimulated through a false stretch. The rotation will be driven by a 5 Volt step motor on both rigid rod corners. Detailed joints for the wooden 5mm x 5mm wooden strips to fit onto the motor shaft as well as a motor encasement were virtually designed and then three-dimensionally printed. Both motor encasements are also fixed to a bigger cubic frame with a customized joint design so that the instrument can freely rotate inside [Figure 4].

Tangible Manipulation Scheme - Touch Action

According to the pressure and three-dimensional alteration of the membrane caused by a human provoked dent in it, the degree of rotation of the cubic instrument is determined.The step motors on either end of the cube diagonal can both individually rotate clockwise and counterclockwise. An Arduino is used to link the human force pushed onto the elastic membrane for spatial transformation. The pressure measured in the sensors will result as analogRead() values of the Arduino and shown in the computer script. The calculation the pressure is set to a 10% accuracy.The highest pressure the sensor can detect is approximately 600 mbar which translates into 80 ADC (analog to digital converter) in the Arduino script.The slope of the ADC-mbar curve for the pressure sensor is very similar to the slope of the stress-strain curve of the membrane (Arduino, 2018) (Dhar, 2007). They are both initially linear and then continue to be non-linear as the pressure and stretch are easy to apply in the beginning, progressively become more difficult before they reach the plastic region of almost no change in value to the previously achieved anymore [Figure 6, 7]. In the ADC-mbar curve the maximum pressure of about 600mbar is reached after a rather stable run and the pressure read (ACD) measures approximately 58. It is important to calibrate the pressure sensor due to the fact that zero pressure does not translate into zero voltage; there is an offset of

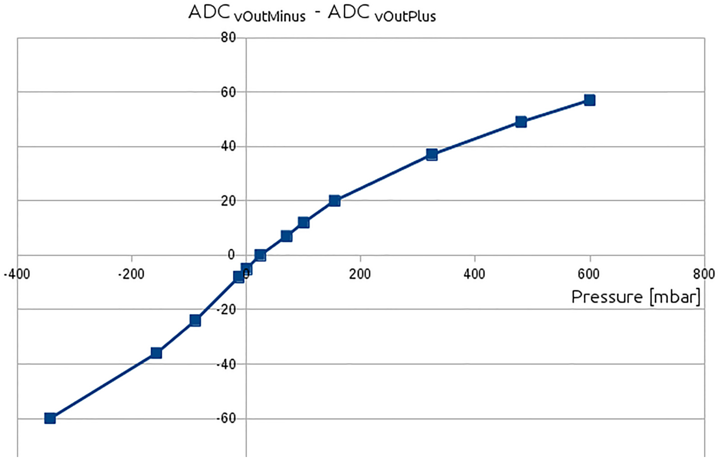


Figure 6
ADC-mbar curve of Arduino pressure sensor Arduino, 2018. Arduino Playground - SPX3058D

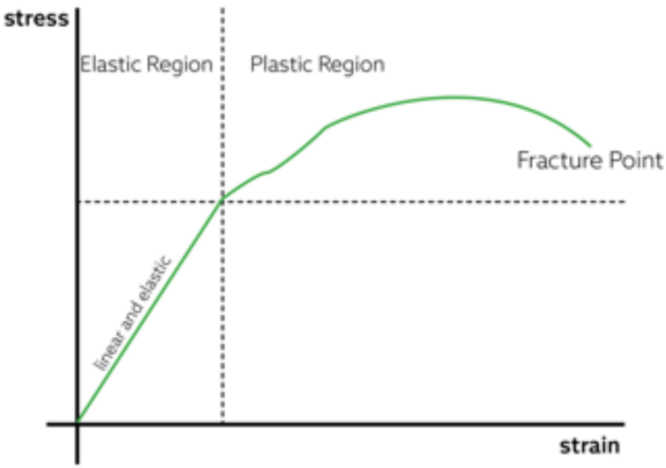
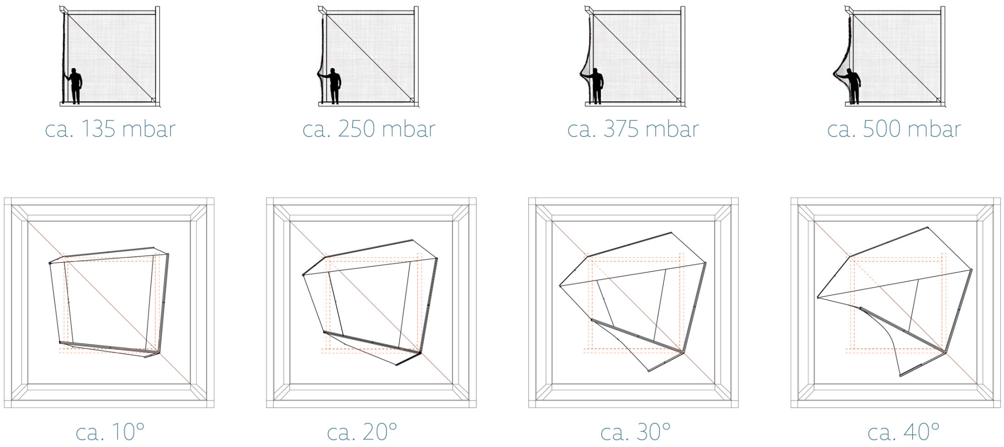


Figure 7
Stress-Strain curve of elasticity

about 20mbar to 25mbar. In the case of the elastic membrane, there is a shared zero point which is only set after the membrane is spanned across the sides of the cubic tool. This probably shortens the initial linear run of the stress-strain curve in the elastic region. After that, the curve undergoes a kink from where the elasticity is becoming weaker and the pure nature of the material continues to employ the strain, therefore it is called the plastic region. For our experiment, the degree of rotation is set to be a linear translation of the force, the graph will be defined through the pressure on the x-axis and the degree of rotation on the y- axis.

At this point of the experiment, the question

Figure 8
Dependencies between pressure applied to the membrane and degree of rotation of the tool.



about the intensified affordance arose.

The term affordance was coined by James J. Gibson (1979) in his book called "The ecological approach to visual perception". He states:" I mean by it something that refers to both the environment and the animal in a way that no existing term does. It implies the complementarity of the animal and the environment." (Gibson, 1979).He pronounced the term to signify the existence between the environment and its actor whether that is a human or an animal. This also means that the same aspect of the environment can create different affordances of different people but also different affordances to the same person but in a different point in time. This means it is not a fixed value to a situation (Gibson, 1979).

Later, Norman (1988) reintroduces the term in a design sense focusing on the distinction between perceived and real affordances (Norman, 1988). To Norman, the inclusion of an object's perceived properties that informs the user about its specified usage, is affordance.Thus, the design and nature of an object or the general environment should imply how it can be used and occupied which depends on the user's ability and state to perceive it but also on the physical, psychological and cultural concepts that influence this perception (Norman, 1988).

Referring to Gibson's (1979) definition of affordance, the user of the multi-dimensional interface cubic tool just has the action possibility available in the space, whereas according to Norman's definition, the user will probably only unconsciously perceive the possibility to move within the space, but not control the affordance actively. The stretch sensor and algorithm as part of the Arduino script initiating the rotation of the tool is more of a perceiver and controller than the human.

Spatial Formation Scheme - Rotation Movement

The elastic membrane changes its three-dimensional form following the rotation on the diagonal axis between the two sets of rigid rods. The twisted membrane surfaces simulate the physical walls and floors in various angles that for example appeal to be downhill for the user inside the instrument. The maximum angle of the diagonal rotation is set to be 40° to avoid extreme imbalance on the human body. [Figure 8]. A sudden fall of the human due to imbalance could cause a decrease in the quality of immersion.

CONCLUSION AND PROSPECTS

As a prospect, improvements of the prototype in terms of structural organization, joinery systems and materiality can be realized to develop a multi-sensory spatial simulation device for virtual reality. In terms of greater variety of spatial formation, additional degree of freedom through movable motor joints rotating along the horizontal plane needs to be incorporated.In order to test the effect of the prototype on the body equilibrium of the user, the prototype needs to be scaled so that at least one person can mount the cubic inside. To track the possible body positions inside the structure, additional equipment such as motion tracking sensors could be incorporated into the further experiment. Simultaneously, the chosen materials need to be reviewed while maintaining the material's properties. For the membrane in order to withstand human weight and movement, the material will be replaced with a trampoline-like polyethylene knit. The horizontal membrane that is mounted by the human will require even higher levels of strength and load bearing which is to be tested in additional experiments.

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