Merging Tangible Buttons and Spatial Augmented Reality to Support Ubiquitous Prototype Designs

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Abstract

The industrial design prototyping process has previously shown promising enhancements using Spatial Augmented Reality to increase the fidelity of concept visualizations. This paper explores further improvements to the process by incorporating tangible buttons to allow dynamically positioned controls to be employed by the designer. The tangible buttons are equipped with RFID tags that are read by a wearable glove sensor system to emulate button activation for simulating prototype design functionality. We present a new environmental setup to support the low cost development of an active user interface that is not restricted to the two-dimensional surface of a traditional computer display. The design of our system has been guided by the requirements of industrial designers and an expert review of the system was conducted to identify its usefulness and usability aspects. Additionally, the quantitative performance evaluation of the RFID tags indicated that the concept development using our system to support a simulated user interface functionality is an improvement to the design process.

1 Introduction

This paper describes a methodology that provides designers with an interactive physical user interface that is employed for mock-up creation. The initial concept of using RFID tags for dynamically positionable buttons was presented by Thomas et al. in 2011 [21]. The novel contribution of this paper is the development and evaluation of an interactive design system employing Spatial Augmented Reality (SAR) for appearance presentation, tangible buttons for enhanced user interface fidelity, vision tracking to capture placement of user interface controls and our wearable RFID enhanced glove with fingertip read resolution to support emulated button presses. Our methodology allows designers to *dynamically* refine a design by rearranging the physical components of a user interface, virtually change the appearance of the tangible user interface, and emulate user interface functionality. This approach allows the designer to instantiate their ideas in a haptically rich form as early as possible in the design process. Figure 1 shows a non-planar white surface with a blue projected SAR appearance, movable tangible buttons and the wearable RFID glove in use.

Initial explorations into combining Spatial Augmented Reality into the industrial design process have shown promising results by extending currently employed design methodologies [15, 22]. A common SAR prototyping practice employs an approximate physical model that is augmented with perceptively correct projected digital images to enhance the appearance. The projected digital images provide fine-grain details of user interfaces such as virtual buttons, dials, annotations and finishing effects. A significant benefit to using SAR over a CAD software system is that the physical models of SAR systems provide simple passive haptic feedback, allowing the user to touch

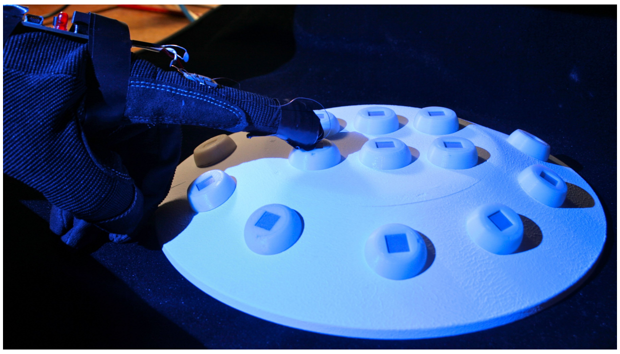


Figure 1: RFID glove used with SAR projected dome mock-up.

the computer generated mock-up while it is being created. Also, unlike pure physical mock-ups that are painted for presenting finishes, the SAR appearance can be modified instantly by modifying the projected image. This is particularly powerful for industrial designers since they can maintain the hands on nature of physical prototyping and also gain benefits, such as unlimited undo operations, that computer systems provide.

In the above description there are a number of limitations that our collaborating industrial design experts have identified that curb the use of SAR systems for design the of mock-ups. For example, a stove appliance may initially be modelled using a rectangular box as the SAR substrate, but design mock-ups would at some stage require physical buttons and dials for the client to feel and experiment with. A drawback to previous SAR design systems is that the fidelity of the haptics felt by the user is limited to fixed surfaces and shapes. For example, in a previous study that validated the use of virtual SAR controls for design, Porter et al. reported that participants collectively perceived projected virtual buttons as less realistic than physical buttons [15]. Participants of the experiment commonly identified the need for improved tangible feedback so that they knew they had actually touched and activated a button. This indicates designers of physical interfaces would benefit from merging the configurability of a purely virtual design with the tangibility of a physical design tool.

This paper reports on our work on improving the fidelity of the haptics in SAR systems by using a wearable RFID technology to combine functional tangible buttons with projected SAR mock-ups. By using unattached individual tangible buttons, the designer maintains the ability to re-configure aspects of the mock-up design but unlike previous implementations they can physically pick up the tangible buttons that compose the user interface and re-configure them until the desired layout is reached. While RFID readers have previously been embedded in gloves [9, 14, 18, 20], the novelty of this use of a glove-based RFID reader is its ability to emulate tangible button presses.

We envision mock-up designs may use hundreds of potential tangible buttons of different sizes and shapes, for example a mock-up audio equalizer board. Using this new technology approach, this is easily achievable and cost effective using RFID tags. For each unique design that is created using this methodology, only the physical substrate (a white blank), the textures used for the appearance and the logic behind interactive controls need to be developed. Application software optionally may be constructed with our API to simulate the design's functionality. The system reported in this paper provides the following features that address the challenges outlined above:

1. Employing tangible buttons for improved haptic fidelity.
2. Provides easy to move physical controls to the designer for mock-up layout (3DOF with the current system).
3. Presents an easy to change SAR appearance projected on the buttons.
4. RFID button presses used by the SAR design system to simulate user interface functionality.
5. Inexpensive and easy to create tangible buttons.

The paper starts with a description of the critical related research and technologies. Following this, the concept of employing the technologies of SAR and RFID for dynamic tangible button interactions for prototyping is presented. The design of the wearable RFID glove system is then presented. Proceeding this, the system implementation details. The remainder of the paper presents a performance evaluation of the finger tip read resolution and an expert review evaluation.

2 Related Work

This section describes the four areas of supporting work for this system including; industrial design methodologies, augmented reality, physical user interface control prototyping and RFID technologies.

2.1 Design

Pugh's total design is an example of a readily employed methodology employed for the creation of prototypes. This approach consists of six fundamental design and development steps; market (user need), product design specification, conceptual design, detail design, manufacture, and sales [16]. The SAR design investigations presented in this paper focus on providing new methodologies for the concept and detail phases. In the concept phase, designers brainstorm approaches, sketch ideas and form potential designs. A selection process is then performed that rules out many potential designs. Following this, mock-ups are created for the selected designs and are shown to the customer.

2.2 Augmented Reality

Augmented Reality (AR) combines a real-world view with computer generated graphics registered to the environment, AR commonly uses head mounted or hand-held displays to present the computer generated information to the user. One limitation of these display techniques is that they do not provide the users with any haptic feedback for the computer generated information. Spatial Augmented Reality [4] is a novel form of AR that uses commercial off the shelf projectors to change the appearance of everyday objects. Since the physical objects are the display surface, the user experiences tactile feedback that provides a more immersive and stimulating experience. The SAR display technology presented in this paper is based on the Shader Lamps [17] technology. An extension of this technique, Interactive Shader Lamps [3] enables a user to digitally paint graphics onto a physical object.

Previous research has explored the use of SAR to enhance the industrial design processes. For example, the WARP [22] system projects onto foam models to allow designers to explore different material properties and finishes for a design prototype. Augmented Foam Sculpting [13] allows designers to simultaneously create 3D virtual and physical models by sculpting foam with a tracked hot-wire cutter. The HYPERREAL design system [11] employs SAR to visualize virtual deformations of the surfaces of physical objects. DisplayObjects [1] is a system that allows designers to project user interface controls on a prototype, this work shows the potential benefits of using SAR to improve the ability to iteratively design the visual aspects of the interfaces.

2.3 Physical User Interface Control Prototyping

There are a number of systems that have provided dynamically configurable physical environments. Pushpin Computing [5] provides wireless input modules that are pushed into a foam substrate, with power pins connecting to conductive planes beneath the foam. This makes the placement of the nodes very simple, but their size and shape cannot be dynamically changed. Additionally, a flat plane for the foam substrate is required, which limits their use on complex surfaces. Phidgets [10] provide a variety of electronic input controls and sensor modules that can be combined to create complex physical interfaces. The Calder Toolkit [12] builds on this concept with wireless input modules that can be attached to product design mock-ups.

While toolkits such as these make high fidelity prototyping faster than with entirely custom electronics, they are still inflexible compared to virtual prototyping. For example, for each module that requires a new shape (i.e. a new button form factor) another physical node and new electronics must be constructed before it can be added to the system. Avrahami et al. developed a system that employed RFID tags to provide interactive controls for industrial design prototypes. Their system did not use a glove based reader, rather an antenna was placed on a table in a fixed position and used in conjunction with switched RFID tags to create button events. One limitation of this approach is the working volume of the system is limited to the range of the antenna [2].

2.4 RFID Technologies

RFID readers have been incorporated into gloves and used to study application spaces spanning business, education, entertainment and medicine. One of the earliest examples of a glove mounted RFID reader system was developed by Schmidt et al. It was used to associate objects with machine generated events when handled including the ability to invoke components of an enterprise resource management system used for business logistics [18]. Muguira et al. developed a similar system intended for conducting warehouse inventories and activity recognition [14]. Another example was developed by Tanenbaum et al. [20] where objects that are touched invoke further interaction between the user and the object. These examples all use glove mounted 125 Khz RFID readers where the aim is to recognize an entire object that is being touched or held. The spatial reading resolution of the RFID system is the entire hand and not a single finger. Systems have also been designed that operate at 13.56 Mhz, a good example is the iGlove [9]. This device was described in two versions with the first version having the antenna on the palm of the glove, and was also used for identifying objects held in the hand. The second version was for medical applications where there was a need to know what was being held in the fingers. This version is notable for having an antenna implemented with conductive paint in the fingertip of a latex glove, and the RFID reader was also moved to the user's wrist. Although this solution provided sensing at fingertip resolution, it was reported to have poor durability.

3 Dynamic Tangible Button Interactions

As previously discussed, the interactive design system presented consists of four major technologies, a SAR prototyping system [15], RFID enhanced tangible buttons, a purpose built wearable glove with an embedded RFID reader, and a computer vision tracking system to determine the tangible button's position. The *dynamic* nature of the tangible buttons is their support for the designer to change a button's appearance and position in a design. This section describes the process a designer would take when developing design prototypes with tangible button interactions.

The tangible buttons we present in this paper address two basic requirements, haptic feedback and dynamic configuration. They allow the designer to physically move parts of the user interface and re-position them to obtain an optimal layout. The tangible buttons are a neutral color to allow SAR images to be projected onto them. Consider the example of designing a calculator where the designer would like to compare different button layouts and spacings. A predefined set of colors and textures of the tangible buttons can be altered via an interface to the SAR system. The designer may iteratively change appearances and placements of the tangible buttons. The movement of a tangible button is captured by our computer vision system, and the texture is projected onto the tangible button in the new location.

The functionality of the tangible buttons is supported through an embedded RFID tag in each button and the RFID reader embedded in a wearable glove with a fingertip antenna. The user interface consisting of the calculator buttons and display can all be made functional. This approach made it possible to avoid using traditional electronics embedded in the physical buttons. Instead the RFID tags provide a generic solution and do not require any wires or a power source to be used. The tangible buttons are activated by touching the antenna finger on a button, and the RFID reader sends an ID to the simulator application. The simulator application may change the appearance of the buttons and update the display on the calculator. This process more closely simulates the interactions required for using the interface and allows the designers to assess usability aspects. Our system allows the development of new shapes and sizes of tangible buttons with technologies readily available to designers such as CAD software, 3D printers, and RFID tags. Currently this is a difficult process with systems such as Phidgets [10], as it requires knowledge of electronics design and construction.

3.1 Modes of Operation

The industrial designer uses the system by following three functional phases. These are the pre-design phase, the initialization phase and the design phase. During these phases the industrial designer will collaborate with clients to provide specialized design considerations and functionality to the product concept.

There are four entities required in the pre-design phase before the concept design process may start. Firstly as with any SAR process, a physical substrate to project upon needs to be constructed. This can be as simple as a white piece of paper or as complicated as a wooden framed prop. Secondly, an application is required for coordination between the SAR system and the glove reader system, which could be a generic or custom application. Thirdly, the tangible buttons with embedded RFID tags is required. Finally a set of virtual 3D graphical models for the different finishes of the device and UI controls are constructed.

The second step is the initialization phase. Firstly, the projector and camera need to be calibrated. Secondly, the computer vision system must be informed of which RFID tag is associated with a particular tangible button. To make the tracking of the tangible buttons more robust, the buttons are not uniquely visually identified. The process is to prompt the designer to pick up a tangible button, read the RFID tag with the glove, and place the button on the prototype device for a camera to start tracking its position. This process is repeated for each tangible button employed in the mock-up. Lastly the 3D virtual models and textures for the physical artifacts are loaded into the application.

The final design phase is where the prototype application displays textures associated with each tangible button, particular textures for the device itself, and purely simulated UI controls. An example of a purely simulated UI control is the output display in the calculator example described in the Scenario Section. During the design phase, the designer may rearrange the physical positions of the tangible buttons one at a time, but they may make as many changes as desired. The designer can also change the appearance of any tangible button with a pre-loaded texture by sliding the button onto a pre-defined region. The application developed supports three different textures and displays them in this dedicated area separate from the mock-up design. We call this area the texture-loading pallet. Figure 4 shows tangible buttons being used with SAR projections.

The shape of the tangible buttons can also be changed as desired. To achieve this, a new model is designed using a CAD system and constructed with a 3D printer. The designer uploads the new tangible button 3D model, new button textures, and new textures for the device itself to the application. The designer repeats the second and third phases throughout the design and evaluation processes.

4 Designing a Wearable RFID Glove System

Several characteristics of RFID systems need to be taken into account in order to successfully implement a tangible button system. Important RFID system characteristics that affect design decisions are summarized in the following list; 1) inductively coupled and operate in the near field in order to confine activation to a single button 2) antenna should be deployable on the user's fingertip, 3) minimal power should be used during communication, 4) read range is established on fingertip contact, and 5) the tag protocol should be simple with low latency.

4.1 Inductive Coupling

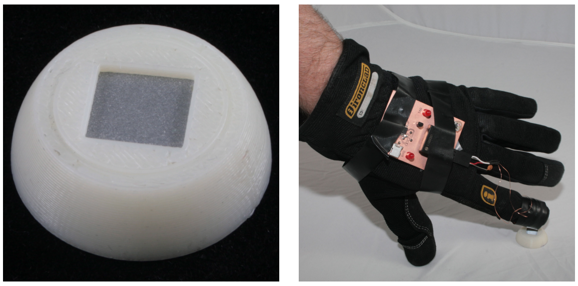
For a tangible button system, near field operation is desirable in order to generate a RFID read event from the user touching or virtually pressing the tangible button. The relatively long range of radiative RFID systems covering up to tens of meters are not appropriate for this compared to inductively coupled RFID systems that operate over a much shorter tag to reader distance.

4.2 Deployable Antenna

For use in a tangible button system, a useful reader to tag distance would range from direct contact up to a few millimeters. Most inductively coupled RFID systems can easily cover such a range, so the choice of technology will depend on cost, power and practical deployment considerations. Several frequency ranges below 50 MHz have been identified as suitable for inductive RFID systems [8], but not all of them are internationally approved for use. The two most common carrier frequency ranges in commercial use are those at 125 KHz and 13.56 MHz.

4.3 Power Consumption

The electrical current required to generate an acceptable magnetic field strength is directly related to the power needs of the system, and indirectly related to cost. In inductive RFID systems, reader to tag communication is accomplished by magnetic field coupling between antenna inductors on both the reader and the tag. The value of an inductor is chosen such to create a resonant circuit on both the tag and the reader. The coil in the tag is encapsulated together with the rest of the tag electronics, but in the case of the tangible button system, the cylindrical reader antenna coil must be constructed on the fingertip of the glove. A typical value of an inductor used in a practical resonant circuit at 125 KHz could be 1mH representing dozens or hundreds of turns of wire around a glove fingertip, while for a circuit at 13.56 MHz a typical value could be 3uH, which is only a few turns of wire around a finger tip. In this regard, a 13.56 MHz system would seem to be preferable to a 125 KHz system because the inductors are physically much smaller. However, this has an undesirable effect with respect to power requirements. The magnetic field strength produced by a cylindrical coil measured at the center of the long axis of the cylinder is given by [8]: $H = IN/2R$. Where H is the magnetic field strength in amperes/meter, I is the current in amps, N is the number of wire turns in the coil and R is the coil radius. As the field strength is directly proportional to the coil current and the number of wire turns in the coil, a coil with more turns results in a power advantage. Because at 125 KHz, the number of wire turns in a practical coil is between 1 and 2 orders of magnitude more than the number of wire turns used in a 13.56 MHz system, the amount of current required for the same magnetic field strength is substantially less. From this power viewpoint, the 125 KHz system is preferable.



(a) (b)

Figure 2: (a) Top view of tangible button with retro-reflective marker. (b) Glove with RFID reader.

4.4 Read Range

Also important is that the area over which the tag is read should not be more than approximately the area of a finger tip so that it does not appear that more than one tangible button is being pressed at a time. This can be accomplished if the antenna coil can be made to closely wrap around the glove fingertip, but still have a suitable number of turns in the coil to reliably generate a usably strong field. This is possible using a 125 KHz system. In comparing 125 KHz and 13.56 MHz systems in these regards, both systems can deploy reasonable coil sizes around a glove fingertip, however the 125 KHz system has a power advantage as previously discussed.

4.5 Protocol

We are also interested in the latency of the RFID system selected. In general 125 KHz RFID systems have less available communication bandwidth compared with 13.56 MHz systems, and often they are simpler systems usually designed without the ability to generate tag sub-carriers, or to perform anti-collision or other tag addressing protocols. A simple, read only identifier sent by the tag is sufficient as long as there are enough unique codes for the intended tangible button system. The absence of complex protocols and a simple data format are advantages in this regard, again indicating a preference for using a simple 125 KHz system for the tangible button system.

5 Implementation

This section describes the implementation of our tangible buttons, RFID glove and computer vision system. We employed a SAR system consisting of two NEC NP200 ceiling mounted projectors, one Sony XCD-X710CR camera (with IR filter removed), a workstation computer (AMD Athlon 64 Processor 3200+, 512 MB RAM, Ubuntu 10.10) and a white SAR substrate.

5.1 Tangible Buttons

We have constructed a custom tangible button with a retro-reflective marker and RFID tag. The 27mm diameter tangible buttons were modeled on a CAD system, and printed using a Dimensions uPrint plus printer. Figure 2(a) shows the printed tangible marker. The top surface is fitted with a square 1cm x 1cm retro-reflective marker that is used by the vision system to identify the location of the tangible button. The underside of the tangible button that is fitted with a 15mm in diameter circular RFID tag allowing each button to be identified with a unique identification number.

5.2 Wearable Glove Input

The RFID system used with the glove is realized using an inductive RFID reader module manufactured by ID Innovations[1], model number ID2. In addition to having a carrier frequency of 125 Khz, the module was also chosen because it has no internal or included antenna allowing a custom antenna to be designed for the glove. The module's operating protocol is extremely simple as it supports no user commands, and simply reports data when a tag is read. The data rate from the tag is found by dividing the carrier frequency by the number of carrier periods to encode 1 bit, which in this case is 64, giving an overall data rate of 1.953 kilobits per second. Tags send 64 bits of data, of which 40 bits are their unique tag ID. With a reader data rate of 1.953 kbps, the time necessary to send the 64 tag data bits is 32.77ms. User latency for each tangible button event will be this time plus the time necessary for the ID2 module to process and transmit the data to a computer host. It is a simple circuit that allows the ID2 module to be read over a USB connection to a computer, and includes a activity LED that flashes when a tag is read. The power consumption of the circuit is calculated to be 140mW, of which 65mW is taken by the ID2 module itself.

In addition to the module, the other components are the connection to the host computer and the antenna. The ID2 reader is interfaced to the computer host using a FT232R asynchronous to USB interface circuit made by Future Technology Devices Ltd. As the ID2 has no control interface, there is only a read data path from the ID2. The FT232R can be easily substituted by a wireless device such as a Bluetooth or Zigbee radio device.

The final component of the design is the antenna inductor. It should have an inductance of 1.08mH in order to form a resonant circuit at 125 Khz. The ID2 module provides an internal 1500pF capacitor to form the resonant circuit with the coil, although the implementer can add external capacitance to allow other coil designs to be used. The 1.08mH coil used with the glove consists of 275 turns of #33 enameled magnet wire scatter wound by hand on the index finger tip of the glove, which forms an ideal orientation for the generated magnetic field lines to be used in a tangible button application. Although easy to make, the exact number of turns needed for such coils are difficult to compute, and usually are made by winding until the desired inductance as measured using an inductance meter. An Agilent Technologies inductance meter model number U1731A was used to measure the inductance of the coil. The choice of #33 gauge wire is not critical, and a physically smaller coil can be made by using finer gauge wire. The complete RFID module and finger mounted antenna are shown in Figure 2(b).

5.3 Computer Vision

There are two major computer vision approaches for object recognition; appearance based and feature based. Our tangible buttons did not have any distinctive features or textures so we employed an appearance based approach in order to detect the retro reflective markers on the tangible buttons (shown in Figure 2(a)).

Our appearance based approach utilizes edges extracted from the images obtained from IR cameras. Edge based recognition was previously used for detecting markers in ARTag [7]. Performance of this edge based method was better in recognition accuracy than threshold based methods, especially when illumination conditions change. The edge based approach was also stable and jitter free, which are important for overall system performance and usability. In SAR environments, illumination changes even more dynamically than in marker based AR. With this consideration, we used edge based method instead of threshold based ones. We used Canny edge detection algorithm [6], which is widely used for its accuracy and performance.

After edges were extracted, contour information was obtained by using the method suggested by Suzuki and Abe [19] from the binary edge images in order to differentiate tangible buttons from objects of other shapes. Tangible buttons were assumed to be brighter than the background and in square shape. Contours and holes could be determined by the gradient difference between the inside and the outside of the closed curve. The shape of the contour was approximated by Douglas Peucker algorithm [6] for eliminating noise and jitters. Finally, by traversing contour vertices, convex, square shape buttons were identified.

6 RFID Finger-tip Read Resolution Performance

The goal of this evaluation is to firstly understand if false activations occur when using our RFID activated tangible buttons and secondly to quantify what error rate to expected during prototyping. For example, when waving the glove near buttons without touching them do button press events occur? and how close is the glove when events occur? This will allow us to better understand their operation and provide a comparison to traditional push button functionality.

We conducted two performance tests to determine the read resolution of the finger-tip mounted antenna during use. The purpose of the first test is to measure the distance from the centroid of the finger mounted antenna to the center of the RFID tags (shown in Figure 3(f)) that is required to registered an event. The purpose of the second test is to challenge the results of the first test and demonstrate that closely located RFID buttons can be recognized uniquely. Additionally, the test demonstrates that RFID buttons are suitable for supporting interactive user interface functionality.

6.1 Read Distance Experiment

To measure the activation distance, we prepared a radial measurement apparatus with a series of concentric rings around an RFID tag (shown in Figure 3(a)) to allow the distance to be recorded upon event activation. Each ring had a measurement unit assigned to it, ranging from 9mm to 40mm from the centre of the RFID tag. A natural finger orientation, of 45 degrees from vertical, was used throughout the measurement process.

6.1.1 Procedure

To capture the activation distance from different directions we repeated the following procedure from three approach directions, along the X-axis (left-right motion when facing the RFID tag), the Y-axis (vertical motion when facing the RFID tag) and the Z-axis (forward-backward motion when facing the RFID tag). With the reading software operating, the user's finger started on the outside measurement ring. It was then slowly moved towards the center of the RFID tag until an event from the system was registered. The resting position of the finger was recorded. This process was repeated ten times for all three approach directions.

[1] ID Innovations. 21 Sedges Grove, Canning Vale, W.A., 6155 Australia

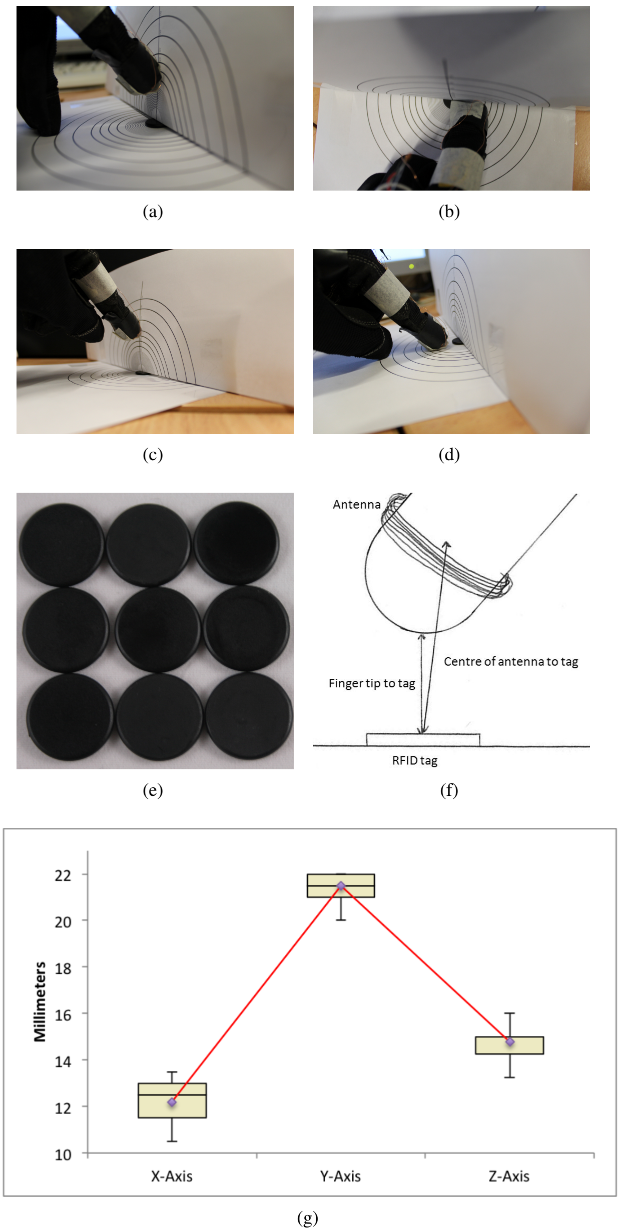


Figure 3: (a) Pose and measurement markers used. (b) Testing pose of the X-axis moving the finger towards the RFID tag. (c) Testing pose from the Y-axis. (d) Testing pose from the Z-axis. (e) 3x3 grid of RFID tags used for proximity testing. (f) Demonstrate measurement locations from center of fingertip and center of antenna to the RFID tag. (g) Summary of statistical results showing event registration distance across three axis.

Figure 3(a) shows the finger angle pose and measuring apparatus used for the evaluation.

6.1.2 Summary

For each approaching angle we describe the distance between the tag with two values, the first is the measurement between the center of the antenna to the center of the RFID tag. The second distance describes the gap between the closest edge of the RFID tag and the users finger (both shown in Figure 3(f)).

The first approach angle measured the activation distance when the finger was moved along the X-axis (as shown in Figure 3(b)). The mean distance recorded between the center of the antenna and the RFID tag was 12.2mm (or touching the side of the RFID tag).

The second approach direction measured the activation distance of the Y-axis (as shown in Figure 3(c)). The mean distance recorded between the center of the antenna and the RFID tag was 21.5mm (with a distance of 8.5mm between the edge of the finger and the edge of the tag).

The third approach angle measured the activation distance of the Z-axis (as shown in Figure 3(d)). The mean distance recorded between the center of the antenna and the RFID tag was 14.8mm (with a distance of 1.8mm between the edge of the finger and the edge of the tag). Figure 3(g) provides a statistical summary of the activation distances for all three axis using a box and whisker plot.

6.2 Grid Array Experiment

To challenge the results of our initial test we performed a second experiment that uses a grid of closely located tags. For this test we placed nine tags in a 3x3 grid with each tag touching its neighbour (shown in Figure 3(e)). The goal of the closely located tags was it increase the chances of incorrect readings to indicate how user interfaces with tightly packed buttons would perform using our system.

6.2.1 Procedure

The finger mounted antenna was worn and the user repeatedly pressed the center button. The software was configured to display the unique ID of a tag when it was touched. When the event was registered we compared the displayed ID with the expected ID. This process of touching the middle RFID tag was repeated 20 times. Three conditions were recorded, correct read, incorrect read and no read occurred.

6.2.2 Summary

A summary of the results can be seen in Table 1. Our results showed that 16 of 20 (or 80%) of button presses were recorded correctly, 2 of 20 (or 10%) were incorrectly identified and for 2 of 20(or 10%) there was no event registered.

6.2.3 Results

The goal of these tests is to validate that RFID tags are a useful tool for capturing tangible button presses without the need for electronics that required wired switches and micro-controllers like traditional prototypes. Specifically the aim was to demonstrate the button presses can be emulated using RFID tags and that groups of RFID tags can be placed relatively close to each other and be used to successfully capture events. These results of the first test show that the use of RFID tags is suitable for identifying closely located tangible button with our glove mounted reader. This is supported by the results of the second test that challenged the scenario of closely located RFID tags during operation. Our result of 80% successful button clicks is not as reliable as a traditional button, however we consider this acceptable for an early prototype that has a flexible form with interactive function.

We also observed that with our current configuration RFID event registration can occur before the user physically touches the tangible buttons.Although haptic sensation and button press event synchronization is desirable, the pre-touch button press event allows for the RFID tags to be embedded inside tangible buttons without preventing button press event registration. This suits the re-configurable nature of our purpose, to allow dynamic, quick re-configuration for exploring different user interface layouts. In addition, some tuning can be performed

Table 1: Read results of the group of nine RFID tags

Correctly Identified	Incorrectly Identified	No Read Recorded
16	2	2
80%	10%	10%

to increase or decrease the read resolution of the glove antenna on the glove, allowing, if necessary, a higher read resolution to be setup.

7 Expert Review

To validate our new dynamic SAR design tool, we undertook a qualitative expert review of the design process with professional designers. We wished to understand the impact of our new SAR design tool on the design process. The expert review evaluation methodology allowed us to better understand the overall effectiveness of the design tool in context with a real design task. This section describes the experimental design, and then outlines the design scenario presented to the professional designers. The results of the expert review are also discussed.

7.1 Experimental Design

We approached the evaluation of the process using a qualitative expert review. Selection was done by picking participants who have extensive design training and experience. We grouped the participants into pairs to stimulate open discussion of the design process with our new SAR design tool. The participants were divided into two teams of two senior designers that have worked in both industry and academia for over 30 years, one team of industrial designers and second team of two architects.

7.2 Scenario

To put our design process in context for our participants, we selected a scenario that is familiar but also a new design problem. We selected the design of a simple calculator to evaluate our design methodology. For our scenario, a basic calculator consists of the sixteen buttons: ten single digit numeric keys, the five basic operators and a clear function. Traditionally, calculators have a square layout (akin to the numeric keypad on a computer keyboard) however, to challenge the designers we provided a number of shapes that made it difficult to use a traditional layout. We provided two scenarios the first was the design of a bone shaped (letter H shape) calculator (as shown in Figure 4). The second scenario was a long skinny bar shape. Both these scenarios were designed to stop the designers falling back on the standard square configuration.

7.3 Protocol

The protocol for this experiment is as follows:

1. We received the participants in pairs (a team) in a separate location to that of the experiment. This allowed us to concentrate on the experimental procedure without being distracted by the aparatus. The nature of the review was discussed and permission was gained for audio and photographic recording.
2. The aim of the project was explained making sure that the explanation did not introduce bias into the participants minds. Participants discussed their experience in the domain of the review.
3. Instructions were given in how to perform the experiment such as ensuring they speak aloud as they work through the scenario.

Table 2: Participant Question

Q1	Is this a useful tool to you for design?
Q2	Would the tool or the process interfere with your current design process?
Q3	What aspects of this tool are useful or not useful in the design process?
Q4	Does this allow you to do something you could not do before? If so what does it allow you to do?
Q5	Where in the design process would you use this technique?
Q6	Which features are useful in the system?
Q7	What needs to be improved in the system?
Q8	If we addressed your concerns. Could you see this being used in industrial design?

4. The survey questions were read out and discussed before the actual design process so that the participants knew what would be expected of them at the end.
5. The participants were led through to the experiment location and an introduction was given on how to use the system.
6. The design scenario was then described.
7. They progressed through the two scenarios to create layouts for the calculator.
8. As they proceeded through the design the observer was instructed to ask questions to stimulate the participants' conversation.
9. Once completed they were given a verbal survey.

The scenario was supported by the SAR design tool by providing the participants with sixteen tangible buttons that can be re-configured into different arrangements. Each button retained its functionality during this process. The sixteen tangible buttons could be moved around a 22cm X 34cm surface to create a variety of different arrangements. The loading texture palette was configured to display the available appearances on the left hand side of the work area allowing the designers to quickly change the appearance by placing the tangible button in the predefined area. The basic calculator functionality was provided by an application with a display texture used to present a simulated output as a virtual text box to provide the output for the calculator's display.

7.4 Results

Overall the feedback from the expert review was very positive. The survey questions are listed in Table 2. A summary of the responses for each question is discussed.

Question one (useful for design?) was designed to validate if the design tool was worth using. Industrial designers pointed out that the 3D design will improve the thoroughness of the product design. That is by having a real physical artifact they can get a more complete representation of the final product. The architects were more circumspect but felt that the physicality of the tool meant

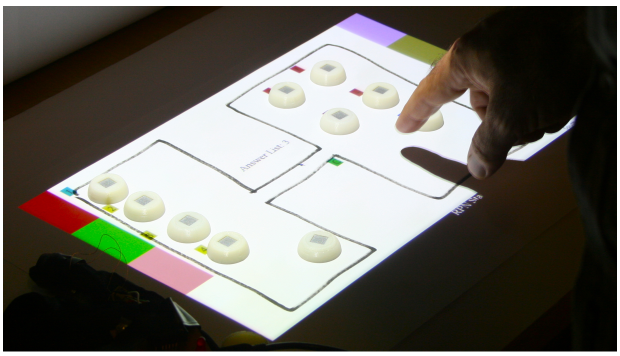


Figure 4: Calculator example using RFID enabled tangible buttons.

that users could gain a better feel for a design early in the process.

Question two (interfere with current process?) was constructed to get the designers to think about whether this would fit into their natural design process or would it slow down their creative process. A common feedback across both groups on this question was that the physical structures may interfere with the design process if the basic shapes had not been established. The groups both agreed that if the shapes have been decided (or are fixed) then the tool would aid in the process.

Question three (aspects useful for design process?) was designed to get the participants to focus on the best features from the tool. The participants pointed out that this would be useful in conjunction with the limitations pointed out previously. One participant expressed this by noting that it "allowed the users to put some air in the balloon". In other words allowed a quick first cut design to try out some ideas which is the exact goal of our overall system.

Question four (could it do something not possible before?) had some clear consistencies between the participants, in particular it allowed early design iterations to be quickly examined. One group pointed out that the design tool could be used to overlay various layers of the design (imagine the wiring routes in a car) so that a designer could get a good idea of the design in their head quickly.

Question five (where in design process?) was designed to further encourage the participants to think about how this would fit into their natural design process. Feedback for this was very consistent between not only separate groups but also the individuals in each group. It was agreed that this tool would fit best into the early design process. The industrial designers also pointed out that the design tool would reveal ergonomic and drafting errors early in the design.

Question six (what features are useful?) got the participants to pick features they thought were useful. Participants said that working on a physical prototype gives a more natural feeling to that of being on a screen with a wire frame and tools. One group of the industrial designers identifed some of the opportunities that the combination of plain paper and SAR together offered and said that simplicity felt good. This was not intended to be part of the tool but it is easy to see the freedom that adding the sketch feature adds to the design tool.

Question seven (what needs to be improved?) got them to isolate features they thought were less useful. The participants were concerned about having fixed sized objects enforced on them. Both groups reiterated that the design tool would be useful if the shapes were fixed or decided and the design was more about the surface design of the product. For example toasters are generally of very similar shape but the controls, style and aesthetics are the variant part.

Question eight (could this be used in industrial design?) showed that the users were generally very positive about the possibilities of this technology. They could see a place for this in their design processes. The industrial designers believed that this process would be good in customization part of the process where the basic shape and use of the product has been designed but final stylistic and operational features were needing to be decided.

7.5 Discussion

Overall while not suitable for the entire design process the designers saw significant advantages in using the tool for early design stages. For instance the design of a number of similar products such as variations on radio fascias would benefit from this approach. One designer stated, "Having a tool box of controls would allow you to rapidly layout a radio, save the design, then have a number of working variations quite quickly". Another designer commented "Anything which provides a more true to life three dimensional simulation of the design intent will allow more thorough investigation of alternatives and better verified outcomes." This indicated to us that the designer liked the physicality of a SAR tool that implemented real physical controls that could be held, arranged and explored.

An unexpected use for the tool that was pointed out was the evaluation of ergonomics. An industrial designer stated "It could also provide a quick and effective rig for evaluation of various ergonomic configurations." The industrial designers were also excited about the opportunity to realistically represent reach, texture and scale which they normally do not see until the final prototype. The architects indicated that the use of the tool for generating briefs (requirements and constraints) by modeling scenarios in the tool would be very useful in their field. Overall, a consistent theme was that the tool was useful in the early phases of a design; in particular after the initial concept was done but before the finalized design was set. Both teams agreed that this tool would be useful in a professional environment.

7.6 Improvements

There were three notable improvements suggested by the reviewers; firstly, grouping of components that would allow moving multiple tangible buttons concurrently that would aid in quick modifications of the design. This is the equivalent of a group select and drag in more traditional user interfaces. Secondly, the ability to draw on the projection and have the shape transferred back to the design software. This is desirable as it brings the design tool back into the designers process. Thirdly, allow designers to place annotations on the design so that design decisions can be recorded. The last two improvements can be seen to smooth the transition between the designers process and the design tool.

8 Conclusion

This paper has presented a novel user interface methodology to be used for product design in a SAR environment. Tangible buttons are leveraged to provide a physical interface that allows the designer and end user to re-configure the layout of the user interface during development. To implement the system, we employ spatial augmented reality for appearance details, vision tracking to capture the physical movement of tangible buttons and a custom fingertip resolution RFID reader to capture tangible button presses. The performance of the read resolution was evaluated and the results validated the use of RFID tags for interactive product designs.

The system was evaluated by professional designers via an expert review. Our initial qualitative evaluation has shown that the concept of incorporating tangible buttons to overcome the simplified haptic feedback of SAR visualizations has been improved. The expert review indicated the tool is useful for industrial designers and architects. They stated that the haptics of being able to move physical objects around gave a solid connection to the final product and provided a number of future directions.

In the future we will explore the localized read area of the fingertip mounted antenna as it would be possible to place antenna coils on all of the fingers of the glove allowing a multi-touch model to be used. This would be relatively easy to add to the current design by placing identical coils on each finger and suitable electronics. We would also like to extend the electronics to support a push and hold button model. We would also like to develop additional UI controls, such as sliders and dials. Finally, in the future we could also incorporate a mechanical clicking mechanism which will further increase the haptic sensation complexity.

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