Generic Method for Crafting Deformable Interfaces to Physically Augment Smartphones

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Abstract

Though we live in the era of the touchscreen (tablet PCs and smart phones providing a rigid and flat interface) people and the industry are getting excited about the world of tangible 3D interfaces. This may be explained for two reasons: first, the emergence of cheap vision-based gestural interfaces conquering the space above and below the screen (but without haptic feedback), and second - and perhaps more important for the present discussion - the explosion of the 3D printing industry and the possibility for the end user to not only customise the layout of icons on a screen, but also of *designing their own physical, deformable interface from scratch*. Mass-produced smartphones could then be seen as bare-bone electronics devices whose shape can be physically augmented, personalised and crafted. Now, in order to introduce DIY techniques in the world of deformable input-output interfaces, it is necessary to provide a generic manufacturing/sensing method for such arbitrarily designed shapes. The goal of this paper is to demonstrate a minimally invasive method (i.e. no wiring) to physically augment rigid tablet PCs or smartphones. By putting a deformable object over the front or rear camera - this 'object' can be part of the smartphone case itself - and by making the inside of the object partially transparent, the complex light reflections can be used to recognise patterns of deformation/grasping and map them

to different UI actions. A machine learning algorithm allows object shape and deformation to be designed arbitrarily, bringing the device *physical personalisation* at a level never reached before, with minimal interference with its original hardware.

Author Keywords
Deformable Interfaces; 3D Interfaces; DIY

ACM Classification Keywords
H.5.2 [Information interfaces and presentation (e.g., HCI)]: User Interfaces.

Introduction
Touchscreen interfaces have been the object of extensive study [1]. However, obvious limitations of this sort of interface stem from the physical constraints of a flat and rigid surface. If one could instead freely design/change the shape of the interface, then it would be perhaps more adequate to start by thinking about the required affordances for an effective (application-dependent) physical manipulation of the digital content, instead of adapting an existing technology which lacks these physical affordances in the first place. These affordances may be elemental (e.g., motion, rotation, twisting), or more abstract (e.g. possibility for an "emotional" interaction with an anthropomorphic avatar mapped to high-level actions, like rejecting a phone call or sending specific emoticons, etc.). Attaching self-designed props (without modifying the smartphone I/O hardware) will encourage users to explore their potential usability first hand and with fun. Some smartphone cases already possess eyes or protruding rabbit ears for instance, effectively making them sophisticated dolls or fashion accessories. Emotional attachment may lead to a more *intuitive*, pet-like interaction with the device (for instance, by twisting the ears, poking the eyes, or caressing the device, etc.). The advantages of anthropomorphic or at least pet-like interfaces have not been integrated into a unified UI designing scheme (although there have been numerous studies in particular in the field of interaction with anthropomorphic robots). We believe that crafting arbitrarily shaped interfaces can be a good opportunity to place the end-user at the center of the interaction design and critique. Now, interaction implies that the interface is capable of output (which can be done though sound or change of color of the semi-transparent object, and of course the smartphone screen), but also of input. In traditional interactive displays (such as multi-touch flat displays or tablets), the input is provided through touch, usually guided by a GUI. However, the future of interactive displays lies beyond flat, touch-sensitive interfaces [19]. The display, being itself a physical object, already provides a set of physical affordances that can be exploited in a meaningful way to extend the range of possible interactions with the displayed content. For instance, a rigid, untethered display provides 6DOF that can readily be used to explore volumetric data [6]; however, a *deformable* display may provide much more degrees of freedom [13]. By leaving the end-user design her own physical interface, we run the risk to generate useless degrees of freedom; however, the goal here is not efficiency but creative freedom. For instance, 3D sculptures can represent objects or people guiding or suggesting very specific or idiosyncratic interaction scenarios [8].

Related work
Recently, flexible display have been developed (in particular using OLED technology). This technology will soon find its way into the world of smartphones and smart watches [3, 2]. Deformable displays increase interaction

potential. Cassinelli et. al have developed a screen-based interactive-art installation called The Khronos Projector [5]. In this installation, the user is able to send parts of the image forward or backwards in time by touching different portions of a deformable projection screen made of spandex. Watanabe et. al propose an interpretation for the projected deformable screen as a membrane between the virtual and the real world and have developed a new digital 3D workspace under this metaphor called Deformable Workspace [21]. Deformable *and actuated* screens [7] or devices (including smartphones! [11]) bring an additional level of output and interaction capabilities.

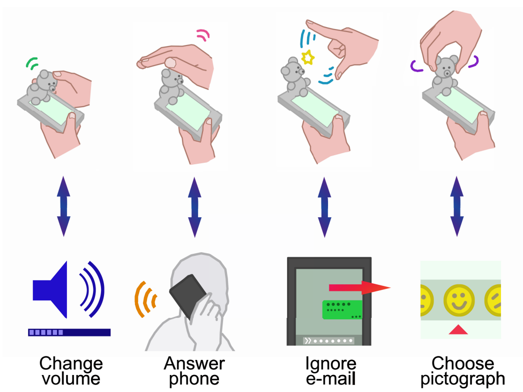

Figure 1: Interaction scenario

Augmented Reality / Mixed Reality can also be used to project patterns and virtual handlers directly over physical objects, so that any flat or non-flat surface in the real world can work as a user interface. For instance, sand [12] and clay [17] can work as both display and input to "sculpt" virtual objects. It is also possible to project onto mobile surfaces as in Sixth sense [16] and Omnitouch [9], or on highly deformable and dynamically changing surfaces, such as the surface of the body (Skinput [10], Skingames [4]). Invoked Computing [22] proposes to capture the imagination of the user in order to use everyday objects as interfaces. We also find inspirational examples of deformable controllers beyond the joystick, although they do not include the function of display. In [20], the amount of the pressure when pushing a soft body in the shape of a cushion is detected by measuring light reflectivity. GelForce is an interface that measures the distribution and magnitude of forces by using a patterned flat elastic body [14]. Another close related work is [18], which also uses a single camera to sense the manipulation of a 3D printed device, although it imposes some constraints on the design. Those examples are very close to our work but they do not propose a specific interaction scenario and also require additional hardware; our contribution here is to propose a way to physically augment smartphones with minimal hardware invasiveness, easy of design and fabrication (the models can be made by hand) so as to maximise the space for creativity. Diversification of display shape obviously affects interaction styles; we are interested in approaches that maximise opportunities for DIY and a personal, open exploration of these interaction styles.

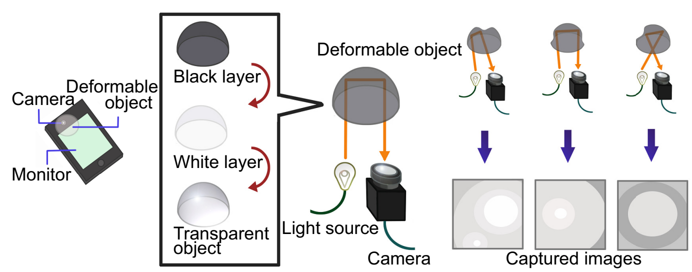

Figure 2: System configuration

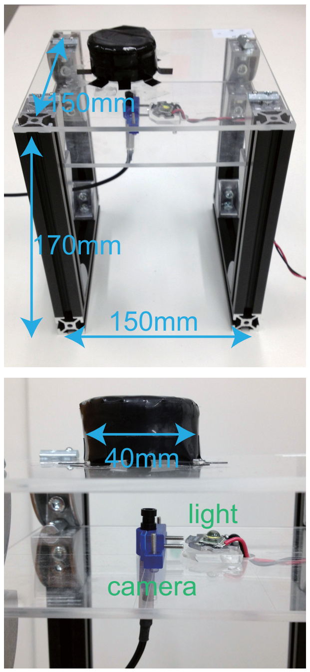

Figure 3: Experimental setup

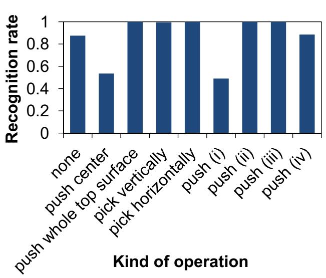

Figure 4: Experimental results

Crafting Deformable Interfaces to Physically Augment Smartphones

Our goal is to provide a way to create a personalized interface extension to smartphones and tablet PCs by providing them with a certain degree of physical flexibility or deformability, without having to add any kind of additional sensor. As described above, users can already personalize their devices by "clothing" or "disguising" them inside a self-designed case - with rabbit ears for instance. We would like to go beyond the simple disguise, and use that shape to enable more meaningful interactivity. In a word, we consider that mass-produced smartphones are no longer complete products, but instead bare-bone electronics that can be physically augmented, personalized and crafted.

Two interesting issues to consider when crafting the interface are potential for emotional attachment and intuitive interaction. We considered both are complementary: complex interactions involving emotions are highly idiosyncratic, and are therefore a good candidate for personalization. Attachment reinforces the connection between the device and its user - attachment may come from the shape of the interface (e.g. a teddy bear) as well as the highly personal way of interacting with it. In the proposed scenario, the user attaches a deformable object over the camera and uses it as a controller (as explained above, the object can be the smartphone case itself, or an extension of it). This object can be arbitrarily shaped, and each deformation (pulling, pushing, stretching, etc.), can be mapped by the user to a specific action. For instance, if the prop has the shape of rabbit ears, by twisting them we could control the audio level. Anthropomorphic or animal shapes may enable more subtle or personal interactions; in this case, the action performed on this physical puppet may be mapped to complex actions (like sending a specific message or emotion, deleting an email, etc.). Figure 1 illustrate some possible interaction scenarios. This design requires a novel technique which can recognise various gestures created by the deformation of an object with arbitrary shape. We propose a generic method for this UI by utilising the light reflected inside the objects. The object needs to be partially transparent in its inside, and some part of the object has to cover a tiny portion of the screen to be used as a controlled light source as shown in Figure 2 (for instance, the pawn of a small bear could "step" on the screen). The captured reflected pattern acts as a fingerprint for each deforming gesture. The object can be made of any flexible material: the requirement is that it has to be partially transparent in its inside. To create arbitrary shapes, the object can be crafted in three-steps: first, a 3D mold is designed by hand or using a 3D printer; second, opaque silicon rubber is deposited to create an outer, empty shell. Finally, transparent gel can be used to fill the inside.

Experiments

In this paper, we evaluate the proposed UI feasibility using the developed prototype shown in Figure 3. The prototype consists of a camera (640 $\times$ 640 / 42 fps), a white LED light and deformable object. In this experiment, we used a cylinder-shaped object. This object is made of transparent elastomer. This transparent body is covered by white sheet in order to reflect the light come from the bottom of the object. This covered body is covered by the black sheet in order to avoid the environmental light coming into the object as shown in Figure 5.

The captured image is separated into $N \times N$ regions. In each region, a color histogram is calculated whose number of bins is M. The feature vector for the recognition is the collection of these values whose number of dimension is $N \times N \times M$. First, user puts the crafted object on the camera and learning step is activated. In this step, user deform the object and make the machine learn the gesture. Once this step is finished, user can start using this crafted UI. The parameters for recognition method is set as $N = 8, M = 5$. We employed Support Vector Machine (SVM) as a classifier. 9 different gestures are classified. The gestures include (1) inaction, (2) push center of the top surface by a single finger, (3) push whole top surface by a palm, (4) pinch lateral face from both ends in the vertical direction, (5) pinch lateral face from both ends in the horizontal direction, (6) push the point (i) on the top surface (Figure 6), (7) push the point (ii), (8) push the point (iii), (9) push the point (iv). The training data consists of 900 gestures (100 samples $\times$ 9 gestures). After training, the 900 gestures are classified. The recognition rates are shown in Figure 4. Actual image and the classified results are shown in Figure 6. Note that even if the object in this case seems to be axially symmetric, pressure at different places produce different light patterns because of the rough internal structure (hence the different results between push (1) and push (2)). As shown in the results, almost all the explored gestures are recognised with a high success rate (about 7 different gestures have a recognition rate $>$ 80%). Gestures in which the pressure center is less than 1cm apart are difficult to identify, but this could be solved by making more complex 3D shapes.

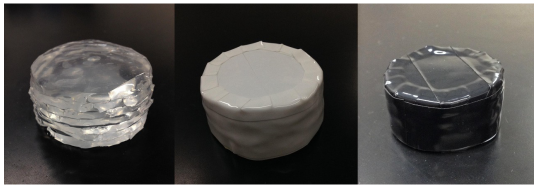

Figure 5: Crafted deformable objects

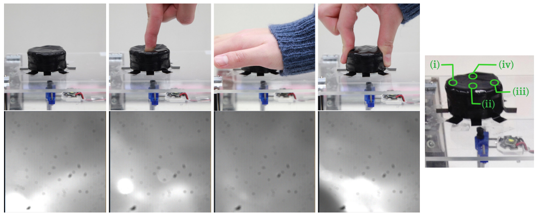

Figure 6: Four example gestures and captured images

Conclusion and further works

We have demonstrated a simple (and minimally invasive) way to physically augment a smartphone or tablet PC by placing a deformable object over the camera that acts as an input controller with many degrees of freedom. This work is primarily motivated by the possibilities of crafting, personalising and appropriating consumer products with imagination and affect. Although efficacy and precision were not in mind, our results demonstrate that for a set of simple gestures, the detection is extremely robust. Our next step is to try this strategy on a real smartphone, and integrate the deformable object with the smartphone case. An obvious disadvantage of the proposed technique is occlusion of the camera and a (small) section of the screen. This is not really a problem though, since the main prop over the camera can be detachable. It could also be possible to overcome this issue by using a completely different detection technique, for instance by inserting magnets into the figurine and using the smartphone magnetometer (i.e. the compass) to detect and learn different magnetic field configurations (in the line of the work [15]), while retaining the possibilities of arbitrary design of anthropomorphic 3D interfaces. Other interesting directions to explore are the possibility of coupling light into the whole smartphone case, so as to detect the grasping gesture; or inspecting the spectrum of the ambient light coupled inside the object in order to infer things about the place and time of the interaction.

Ambient light and coupled light from the screen can be easily separated by using a known temporal sequence of colors on the screen for instance.

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