Optical Pressure Sensing for Tangible User Interfaces

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ABSTRACT

In this paper we present a low cost pressure sensing method for Tangible User Interface (TUI) objects on interactive surfaces, using conventional FTIR and DI tracking. While current TUIs use optical tracking for an object's position and orientation, they rely on mechanical or electric enhancements to enable sensing of other input parameters such as pressure. Our approach uses dedicated marker pads for pressure sensing embedded into an optical marker pattern for position and orientation tracking. Two different marker designs allow different precision levels: Number of Contacts (NoC) allows click sensing and Area of Contact (AoC) enables continuous pressure sensing. We describe the working principles of the marker patterns and the construction of the corresponding tangible objects. We have tested continuous pressure sensing in a preliminary user study and will also discuss limitations of our approach.

ACM Classification: H.5.2 User Interfaces: Input devices and strategies.

General terms: Design, Human Factors

Keywords: Pressure, sensing, tracking, tangible user interface, FTIR, DI, DSI, interaction

INTRODUCTION

Tangible user interfaces (TUI) let users interact with a computer through physical objects and provide advantages over pure multi-touch input [4]. Normally, three degrees of freedom (2D position, 1D rotation) are used to control interface actions such as dragging, rotating or zooming. These three DOF properties can easily be tracked in a Diffuse Illumination (DI) setup [11] where the system keeps track of the object's shape or an optical marker.

Current markers are well designed to (1) identify various different objects and to (2) track their position and orientation [7]. However, they do not communicate any other DOF of a tangible object, such as pressure. This severely limits possible interactions, compared to our interaction vocabulary with daily objects and tools, such as knifes, pens or erasers, where different degrees and directions of pressure make an essential difference.

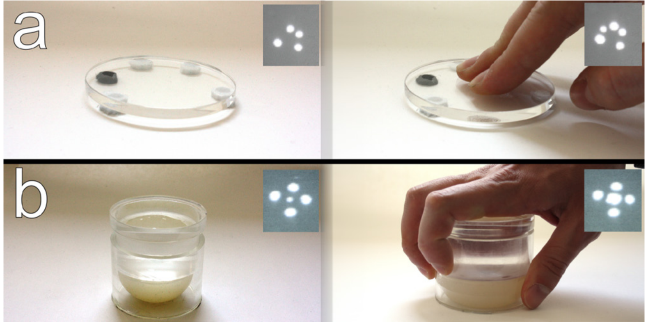

Figure 1: Optical pressure sensing with (a) a Number of Contacts (NoC) marker and (b) an Area of Contact (AoC) marker.

Some electronic devices such as Sony's Jog Dial or the BMW iDrive use a physical element's rotation to navigate lists and menus, while pushing it will select or activate a labeled element. Thus, many users have already learned how to interact via pressure. Even though interaction via (at least stepwise) pressure input is becoming widespread, sensing of push or pressure input with tangible objects is currently only possible by adding complex mechanics or electronics to them. This additional hardware makes the tangible objects complicated, more expensive and potentially error-prone. Another drawback of additional electronics is the energy consumption and therefore the need for batteries or power cables. This results in an increased and decentralized maintenance effort of the entire TUI setup.

We therefore propose two low cost designs for optical TUI markers that allow sensing pressure using FTIR and DI tracking combined in a Diffused Screen Illumination (DSI) setup [15]. Both designs work without electric or complex mechanical hardware enhancements of the tangible object. The first design *(Number of Contacts, NoC)* allows click sensing with a robust felt-based marker (see Figure 1(a)). The second design *(Area of Contact, AoC)* enables inferring and therefore sensing pressure continuously and is based on a deformable silicone hemisphere within the tangible object (see Figure 1(b)).

RELATED WORK

Our approach is related to other work in the area of optical marker and touch tracking as well as existing techniques of pressure sensing with TUIs and pressure-based input.

Optical Tracking Hardware

Various tracking technologies can be used to implement multi-touch input on interactive surfaces. While FTIR [3] and DI [11] both provide touch input, FTIR does not support tracking of optical markers. DSI combines the capabilities of FTIR and DI and is used in our prototype.

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Pressure-sensing Tangible User Interfaces

TUIs based on optical tracking rarely provide a larger interaction vocabulary than position and orientation. Luminos by Baudisch et al. [1] are an approach allow three-dimensional TUI constructions by transmitting a marker pattern through an underlying object with optical fibers. Weiss et al. [16] implemented binary pressure (click) sensing based on optical tracking by mechanically enhancing their SLAP widgets. They also suggested using small silicone pads to possibly allow additional interaction metaphors [17]. Beside this Kakehi et al. [6] presented ForceTile, which allows sensing force as additional input parameter of a tangible user interface.

Other approaches use non-optical tracking hardware for pressure input. The Haptic Tangible Puck by Marquardt et al. [10] uses internal mechanical and electric enhancements to allow pressure input and give haptic feedback to the user, for example. Beside this Leitner et al. [8] used a pressure-sensitive IFSR foil within the surface to enable pressure sensing. Additionally Ramos et al. [14] used a stylus/tablet combination to present the idea of Pressure Widgets.

OPTICAL PRESSURE SENSING

Optical tracking of non-enhanced tangible objects is usually limited to sensing the object's position and rotation. We have developed two optical marker pattern designs to sense pressure: *NoC (Number of Contacts)* and *AoC (Area of Contact)*. While a blob pattern is used for position and rotation tracking, characteristics of one or more additional blobs are used for NoC (appearance of the blob) and AoC (diameter of the blob) to allow sensing pressure. The NoC marker uses felt pads, which behave differently if the marker is pressed against the surface. AoC instead relies on at least one pad within the marker, whose contact area changes under pressure, similar to the finger-based approach by Benko et al. [2] or the malleable surface by Hilliges et al. [5]. This provides a trade-off between a higher pressure sensing resolution (AoC) and simplicity of the marker construction (NoC).

Number of Contacts

The simpler marker design for sensing pressure with an optical tracking setup is *NoC*, which allows two different pressure stages: *pressure* and *no-pressure*.

The marker pattern consists of pads that behave differently in distinct pressure states. This differing behavior is achieved by using white and black felt pads illuminated from underneath. While the white pads reflect the IR light, the black pads do not reflect any IR light as long as no pressure is applied. This results in a marker pattern consisting of only the white pads, which already allows tracking of the object. When the object is pressed, each felt pad underneath the object is pressed against the surface and the FTIR effect at the position of the pads is triggered. While the blobs caused by white felt pads just become brighter, the black pads now also create blobs in the camera image. These additional blobs reveal the object's pressure state.

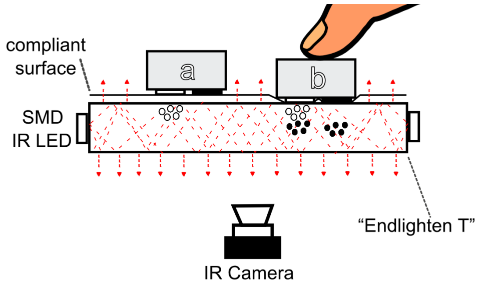

Figure 2: NoC marker pattern: (a) White pads are illuminated with IR light; (b) Pressing the object on the surface results in FTIR-based blobs by both the white and black pads.

Area of Contact

The AoC marker allows continuous optical pressure sensing using the diameter of an additional blob to infer pressure. A deformable pad deforms continuously under pressure and creates the additional blob. This pad is therefore referred to as a *dynamic pad*. Pressing the tangible object against the surface results in a deformation of the dynamic pad and therefore in a larger blob in the camera image.

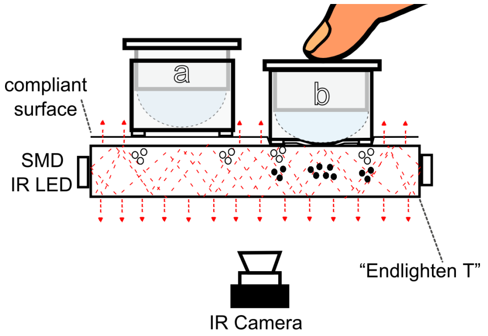

Figure 3: AoC marker pattern: (a) White pads are illuminated with IR light; (b) The silicone hemisphere creating an FTIR-blob with varying diameter.

PROTOTYPICAL SETUP

Our tabletop system uses a combination of DI and FTIR sensing, which can be elegantly combined in a DSI setup: The interactive surface consists of a transparent acrylic late ("Endlighten T"[1], 92% light transmission) and a compliant surface with a silicone-coated bottom side on top of it. The silicone creates FTIR-based blobs already at lower pressure levels than a non-coated screen.

NoC-based TUI

The number of contact (NoC) design simply uses black and white felt pads as described in the previous section. These pads can be used under any tangible object, as long as the object's pure weight does not trigger the FTIR effect. Our prototype (see Figure 4) is based on an acrylic plate.

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[1] We used a combined DI & FTIR setup for our first implementation shown in Figure 6. The DSI setup was later used with a smaller tabletop.

It rests on five felt pads with a diameter of 1 cm each and FTIR is not triggered unintentionally as it weighs 22 grams.

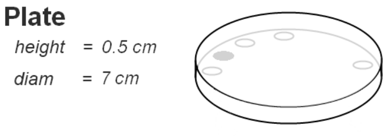

Figure 4: Construction plan of a NoC-based object.

AoC-based TUI

Our AoC prototype consists of only four simple acrylic and silicone parts. The RTV2 silicone (‘ZA-00’) exhibits a Shore A hardness of 0 ShA and a Shore 00 hardness of 55 +/- 4 Sh00 after its curing process. This results in an effective swept volume of 1.2 cm for the height of 2.7 cm of our AoC object. A Piston, a silicone Hemisphere and a Cylinder form the object’s body (see Figure 5), which carries a Marker Foil. The optical marker pattern consists of four white paper pads between the cylinder and the Marker Foil on the bottom side. The silicone Hemisphere is mounted to the bottom side of the Piston and both are inserted into the cylinder with the Hemisphere facing down. The Marker Foil (Rosco translucent projection screen) underneath the bearing Cylinder minimizes friction between the object and the surface while still transmitting the changing blob size of the dynamic pad.

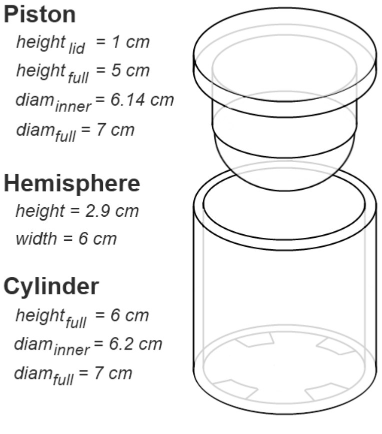

Figure 5: Construction of an AoC-based object.

If the user presses the Piston down, the Hemisphere deforms and creates a larger contact area with the interactive surface, from which the software can infer stronger pressure. To identify the blob of the dynamic pad we use the object’s position, rotation and size to calculate the surface area occupied by the object. Any additional blob in this area is interpreted as a dynamic pad. Due to the object’s construction the contact area varies between 0cm and 5.5cm, which results in a blob diameter between 0px and 28px in the tracking image as our system supports 5px/cm.

Visual feedback

As related work [12, 14] suggests, visual feedback is essential for pressure input in order to support users in accessing different pressure levels. We provide two different types of visual pressure feedback: color and size of a graphical circle underneath the tangible object. Because both NoC and AoC objects happen to be transparent, the interactive surface underneath illuminates them (see Figure 6). While the NoC object is totally transparent and allows detailed visual feedback, the AoC object is too diffuse to display more than color through it.

EXAMPLE APPLICATIONS

We implemented some demo applications that can be controlled with pressure-sensitive tangible objects based on the proposed optical sensing designs. As Li et al. [9] suggested we used personal pressure spaces for each user. Prior to each session the user had to define her personal pressure space. Therefore she had to press the tangible as strong as it is suitable in order to define the upper pressure level. The lower pressure boundary was calibrated with no pressure applied to the tangible The interval between both values was linearly divided into six different levels of pressure as suggested by related work [13]. In analogy to a classic “Ring-The-Bell” game, we built a game in which the user has to apply pressure to let a virtual bar reach a given height and keep this for at least one second (see Figure 6).

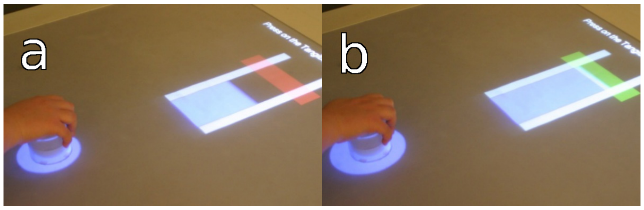

Figure 6: Ring-The-Bell: (a) User’s pressure is too low; (b) User hits the correct pressure level.

First Insights

A preliminary user study provided first insights into usage and grasp of the AoC object. We saw during the observations that there is no uniform way of grasping the object. Some users controlled it with one hand while other users used both hands – one hand to fixate the bearing cylinder and the other hand to press the piston. Our observations, however, showed that our design worked well with all different types of grasp, that there is no difference in terms of precision or fatigue and that after 30 minutes. Beside this the study revealed the importance of a minimum pressure space. Participants with a very low self-defined maximum pressure level performed evidently worse than others as their pressure levels became vulnerable to even small jitter. Contrary to this it is also critical if the user presses to strong as the dynamic blob becomes too large and merges with the marker blobs.

LIMITATIONS AND POSSIBLE EXTENSIONS

Pressure sensing through conventional optical tracking enables new interaction techniques at low cost but it also suffers from some limitations. One drawback of the marker design is that it can only sense pressure directly from above and not on the side of the tangible object.

A varying pressure distribution on the top of an object can't be measured either but several small spherical silicone pads within the marker would allow this [17]. However this would require a higher camera resolution, which would also mitigate another problem of our approach: jittering pressure input due to camera image noise. Especially small pads are critical as even their maximum diameters are rather small making them vulnerable to a jitter of only a few pixels. Considering our low tracking resolution of approximately 5px/cm only a higher tracking resolution can ultimately solve this problem at cost of an increased image processing effort.

Although we were able to encode pressure information, the object's height and the massive silicone hemisphere hamper a more detailed visualization (e.g. text) through it. Additionally they might distort the field of view of other users or cannot be identified using multiple AoC objects. To address these problems the height of each object could possibly be reduced according to different use cases at the cost of pressure scope or pressure resolution.

SUMMARY AND OUTLOOK

We have presented NoC and AoC - two different marker designs which allow inferring pressure from well-known optical tracking technologies. They work with different accuracies and without enhancing the tangible object with any complex mechanical or electric components. As both marker designs do not consume any electric power or suffer from possible mechanical failure, their maintenance effort is very low. Therefore these low cost TUIs can easily be used in many different scenarios (e.g. public installations).

Our next steps are the refinement of the marker design in terms of pressure distribution. Maybe the differing grasps of a pressure-based object observed in the preliminary study may also influence future marker designs. Therefore we hope to gather more information about marker designs, how users interact via pressure with AoC-based objects, and how they grasp them in a more extensive user study.

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