INTACT: Instant Interaction for 3D Printed Objects

Abstract
The INTACT platform enables the instant addition of interactivity to any 3D printed object, with the aim of enriching and enhancing the interaction design process. This is achieved by eliminating the need to incorporate potentially obstructive sensor technologies. Using a system of force sensing combined with a digital model of the object, the system is capable of detecting a single touch, its position and the corresponding force of that touch anywhere on the object.

Author Keywords
Interaction Design; 3D printing; modelling; touch

ACM Classification Keywords
H.5.2: User Interfaces

Introduction
Prototyping of ideas is a core skill in the field of interaction design, particularly when designing new and innovative interactive objects. This high-fidelity physical prototyping phase traditionally depends on either the craft skills of the designer or a more prolonged fabrication and engineering process. The increasing ubiquity of 3D printers in design laboratories, however, has revolutionized this part of the design phase by enabling the rapid and often iterative production of
tangible objects that the designer can touch, feel and present to potential users or clients. However, for technical novices, the process of moving beyond low-fidelity prototyping towards more technically complex high-fidelity solutions can be challenging since adding interactivity to physical prototypes often involves the integration of technical components and electronics. This is not only time consuming but it can also hamper the design process and increase the complexity of a project as it involves the use of extra engineers or developers.

The INTACT system avoids the need for this extra step in the development of prototypes by enabling the designer to render an object interactive straight from the printer. The object is placed on a surface instrumented with a 6 degree of freedom force sensor and is rendered interactive using the sensed force data in combination with the 3D model used to print the object. Using an algorithm similar to that presented in [1] and employed in [6], we can touch anywhere on the object and recognise the position or gesture/stroke along with the force of the touch. This offers a rapid method of modelling the interaction components of the design that are normally reserved for a later phase in the design process.

Other methods of adding interactivity to tangible objects have included the addition of fiducial markers [2], pressure and magnetic sensing [4], accelerometers [3], piezoelectric microphones [5] and capacitive sensing [7]. Ono et al. [5] present ‘touch & activate’, a system that enables the addition of touch input capabilities to 3D objects using only a vibration speaker and a piezo-electric microphone paired as a sensor. They find that it is possible to recognize five touch configurations involving the touching or gripping of different parts of an object, with good accuracy. These approaches are advantageous in that they can be applied to objects of varying size and shape. However, all still require the addition of hardware components and often rely on complicated signal detection and classification approaches.

The INTACT system

The INTACT system enables interaction with any object that is placed on its surface under the condition that this object has a corresponding digital model. The system works using a 6-axis force sensor (ATI Mini 40) capable of measuring forces and torques in the x, y and z spatial directions. This sensor is embedded in a surface on which objects can be placed, as illustrated in Figure 1.

As the user touches the object placed on the surface, interaction forces are sensed and converted into electronic signals by the sensor and its conditioner. A voltage level shifter then scales and offsets these signals to match with the 0-3.3 V range required by the Arduino analog input pins. The Arduino then converts the signal from analog to digital and sends the data through a serial port to the PC for processing and visualisation in the developed applications.

The system relies on the analysis of forces and torques exerted on a supporting platform, an approach referred to as “intrinsic contact location”, used often in the field of robotics to provide robots with a sense of touch. Forces and torques are measured along the x, y and z axes with the fundamental assumption being that, at any given point in time, the user applies a force with no torque, at a single position on the object. With this knowledge, it was shown by Bicchi et al. [1] that, based
solely on three forces $\mathbf{F} = [F_x, F_y, F_z]$ and torques $\mathbf{M} = [M_x, M_y, M_z]$ measured by our sensor, the contact point must belong to an axis $A$, whose parametric equation is given by:

$$\mathbf{A}: \mathbf{X} = \mathbf{X}_0 + \mathbf{D} p$$

(1)

Where $p$ is a scalar parameter and $\mathbf{D}$ and $\mathbf{X}_0$ are vector quantities given by:

$$\mathbf{D} = \left[ \begin{array}{c} F_x \\ F_y \\ F_z \end{array} \right], \quad \mathbf{X}_0 = \frac{\mathbf{r} \times \mathbf{M}}{||\mathbf{F}||^2} = \frac{1}{F_x^2 + F_y^2 + F_z^2} \left[ F_y M_z - F_z M_y \\ F_z M_x - F_x M_z \\ F_x M_y - F_y M_x \right]$$

(2)

The force and torque measurements alone though do not provide the position of the contact point. Instead they reduce the possible positions of this contact point to a line in space or a point on a flat surface. Further information is thus needed to locate the actual contact point on the surface of the object. Since we know that the contact point must lie on the surface of our object, the contact point position is therefore at the intersection of the axis $A$ and the object surface which we refer to as $\Sigma$.

Finding this intersection point can be a complicated problem for complex shaped objects. The digital model of a 3D printed object however makes this intersection problem straightforward to solve. The STL file format, supported by most CAD software, discretises the object surface into a set of triangle faces, as illustrated in Figure 2-bottom. Finding the intersection of a line, or ray with a triangle is a common problem in computer graphics.

**Examples**

This technology can be applied to any 3D printed object. Below we describe two basic examples.

**TOUCH SENSITIVE STANFORD BUNNY**

In this example we demonstrate that it is possible to rapidly add tactile interactivity to the Stanford Bunny by simply printing it and placing it on the INTACT surface. Figure 2-bottom, shows the finger positions and force vectors recorded during the exploration of the bunny. Because of friction, the tangential component of the force vector to the surface indicates the motion direction, visible on this figure from the bunny’s back to its head.

This demonstrates that any object of arbitrary shape can be printed and placed on the surface, enabling a rapid investigation of the possible interactive capabilities of that design without the need to further equip the printed object with the required electronic components. Touch positions on the surface of the bunny are detected with high accuracy.

**INTERACTIVE SPHERE**

In this example, illustrated in Figure 3 we show that we are not only limited to 3D printed objects.

**Figure 2**: Top - The Stanford Bunny was printed and placed on the INTACT surface. Bottom - Reconstructed trajectory (points) and applied forces (arrows) during a tactile exploration of the bunny.

**Figure 3**: Google earth is controlled using a spherical bowl. The position on the sphere corresponds to the position on earth. Zooming in and out is achieved by varying the force of the touch. In fact it is possible to interact with any object which has a corresponding STL model. This model can be produced by hand or from a 3D scan, for example.
In this case we use a spherical goldfish bowl, to interact with google earth. The user simply touches the part of the vase corresponding to the part of the earth that he wants to move to. A zoom on that particular part of the earth is achieved by varying the pressure. Pushing down on the position causes google earth to zoom in; releasing the pressure causes it to zoom out again.

The sensed position is accurate to the millimetre scale meaning that very fine positioning can be achieved over the full pressure range. Figure 4 shows the finger positions and applied forces during an exploration of the glass sphere. In this sequence the user explored the earth surface, stopped at $t = 8\, \text{s}$, zoomed in and resumed exploration until $t = 12\, \text{s}$.

This accuracy means that it is also possible to detect gestures on the surface of the sphere such as swipes or other shapes that can be mapped to various functionalities in the target application.

**Conclusions and Outlook**

With this initial exploration we have shown that it is possible to easily add interactivity to 3D printed objects without the need to add any extra electronic components that could both hinder the design process and increase the overall costs of a project.

This paper has presented the steps necessary to produce such a system for other practitioners in the field. The next step in this research will involve the production of software application that further enables the design of interaction by allowing the allocation of touch positions, strokes or gestures to application functionality. This will subsequently be tested with potential users of such a system.

**References**

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