# Geckos: Combining Magnets and Pressure Images to Enable New Tangible-object Design and Interaction

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## ABSTRACT

In this paper we present *Geckos*, a new type of tangible objects which are tracked using a Force-Sensitive Resistance sensor. Geckos are based on low-cost permanent magnets and can also be used on non-horizontal surfaces. Unique pressure footprints are used to identify each tangible Gecko. Two types of tangible object designs are presented: Using a single magnet in combination with felt pads provides new pressure-based interaction modalities. Using multiple separate magnets it is possible to change the marker footprint dynamically and create new haptic experiences. The tangible object design and interaction are illustrated with example applications. We also give details on the feasibility and benefits of our tracking approach and show compatibility with other tracking technologies.

### Author Keywords

Tangible, vertical display, force-sensitive resistance, physical marker.

### ACM Classification Keywords

H5.2 [Information interfaces and presentation]: User Interfaces: Input Devices and Strategies, Interaction Styles

### General Terms

Design

## INTRODUCTION

Tangibles have been used on interactive surfaces for several years and have found their way from research projects into commercial products [11,17]. Despite the widespread use on tabletops [1,2,22,37] and the long history and general acceptance of tangibles [7,20,38], they have not often been integrated into vertical interactive surfaces, i.e. multitouch-wall displays and/or interactive whiteboards.

Guimbretière [6] notes that interactive whiteboard interfaces should bridge the gap between powerful desktop computers and traditional whiteboards that allow very fluid interactions. This, however, does not come without new drawbacks (e.g. *mode problem* [24]). Different attempts have been made to solve this problem [31,39]. Commercial products use tangible objects for different tools [13]. In [8] the authors explore the use of tangible palettes for switching easily between different modes. Their study results show that users prefer the tangible palettes to digital menus. However, some problems like the lack of interactive feedback still remain. Therefore, we aimed to integrate fully interactive tangible palettes into our existing interactive whiteboard setup, cf. [8].

In this paper, we present the resulting tangible object system called *Geckos*. It is based on physical objects augmented with permanent magnets, which are recognized and tracked using *Interpolating Force-Sensing Resistance* (IFSR) sensor technology [30]. While originally designed for the use on interactive whiteboards, *Gecko*-Tangibles are not limited to vertical surfaces and extend tangible object interaction in general.

## GECKOS

Figure 1 shows a photo of a *Gecko* as well as a schematic view of all the layers present in our prototype system.

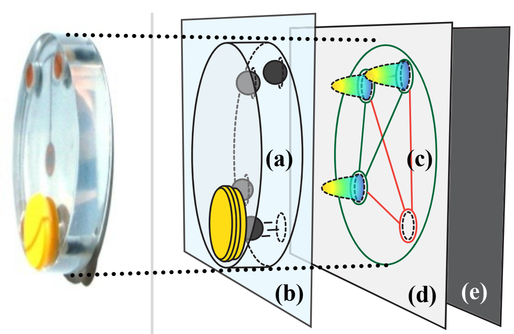


**Figure 1: A *Gecko* (a) placed on the projection surface (b). ID, position, and orientation can be determined analyzing the pressure footprint (c), which is detected using an IFSR sensor (d). Embedded magnets and a metal plate behind the sensor (e) allow the Gecko to be used also on vertical surfaces.**

Geckos are using low-cost permanent magnets to create a constant pressure map (*footprint*) on an IFSR sensor. Analyzing the sensor output – a two-dimensional pressure image – we can support both touch *and* marker tracking. In addition, we can detect interactions (e.g. gestures) on the


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tangible objects themselves. The system is designed to be compatible with our existing interactive whiteboard system, where interactive content is front-projected onto the whiteboard using off-the-shelf short-throw projectors. In our system, the same projectors are used to render interactive graphics on top of the tangible objects. Using transparent FSR sensors, rear-projected setups are possible. Summarizing, the main contributions of this paper are:

- the combination of permanent magnets, pressure footprints and IFSR sensor technology to enable stable and cost-effective marker tracking,
- the use of permanent magnets to enable lightweight, low-cost tangible objects that also work on non-horizontal surfaces,
- new interaction modalities based on pressure-changes as well as dynamically changing contact surfaces, and
- tracking technology agnostic software and marker design which enables the use of our software with different tracking technologies (beyond IFSR sensors).

Additionally, we describe our system, which uses combined features of 2D marker point constellations (footprints) to identify unique objects on IFSR sensors as well as detect user interactions on the tangibles themselves. We compare selected properties of our system with visual marker tracking approaches and give an outlook on future work.

## RELATED WORK

To turn arbitrary objects into tangible interfaces, optical markers (fiducials) are commonly used. Fiducials are easy and cheap to produce, they can be easily attached to arbitrary objects, they are unpowered (passive) and therefore easy to maintain, and they can have a large address range. However, fiducial marker tracking solutions using a rear-facing camera and diffuse illumination (DI) [25] are hard to combine with an interactive, magnetic whiteboard system as a camera cannot see through the non-transparent surface. By drilling holes into the whiteboard surface and combining it with fiber optics, magnetic objects could be tracked with a similar approach as described by Jackson et al. [21]. However, using this approach, the complexity increases with larger screen sizes and higher tracking resolution. Alternatively, a fine metal mesh could be used as a surface for magnets to stick to. Commercial products like STAND BY [14] are advertised as "transparent magnetic surfaces" and could be used together with a rear-mounted camera. Projects like Mechanix [33] have shown that using such a setup fiducial marker can be still detected when captured through the mesh. Rear-camera setups require a considerable amount of space behind the tracking surface.

Front-facing cameras have been used to track physical tools as well as Post-it® notes [23] on whiteboards. In these setups, users often occlude parts of the objects they interact with, prohibiting stable real-time tracking. Systems like Optitrack [18] that use several cameras can deal with occlusions; however, this requires again more tracking hardware, which results in increased system complexity and costs. Optical frames (e.g. DViT, PQLabs) do not require a camera mounted at the back of the surface and can track multiple touch points simultaneously [12]. However, these systems are still susceptible to occlusions when several larger objects are placed inside the frame. Also frame sizes are limited and do not support seamless multi-screen setups.

Electromagnets can be used to hold objects on a vertical surface. Pangaro et al. present an array of electromagnets to move small metallic objects around the surface [26]. A separate camera is mounted above the surface to track the position of the objects. The tracking again is affected by occlusion. Madgets [36] circumvents occlusion problems by integrating the camera directly in the system. However, the system complexity and cost for larger screen sizes are still high. Van Laerhoven et al. [34] use special pins, which can be detected and controlled on a custom designed pin wall. However, objects affixed with pins, adhesive materials or suction cups cannot be dragged around easily on the surface, effectively restricting possible interactions. Other systems that require powered objects [5,35] cause both high component- and maintenance-costs. Systems relying on acoustic tracking [27] or passive magnetic [3] tags can neither determine the object ID nor detect object orientation.

Summarizing, all of the previously discussed approaches were omitted either because of space-requirements, setup cost and complexity or due to limitations in terms of interaction possibilities. Ideally we will get a low-cost large-scale foil that can be integrated in our system and will provide object tracking. For touch tracking, large scale capacitive solutions that offer multiple input points are announced [15], but still no capacitive solution provides both tracking and identification of objects. Digital resistive tracking solutions like the Lemur [16] can provide multitouch-tracking using a special foil with a grid of thin wires. Rosenberg et al. [30] show that by interpolating sensor data, the resolution can be improved. FSR sensor data can be displayed as a two-dimensional "*pressure image*" that can be analyzed. Holzmann et al. [10] show that pressure images can be used to identify and track a limited number of classes of arbitrary objects on the sensor grid. However unique object identification is impossible with their approach.

Resistive-based systems show a lot of promise for object tracking on vertical interactive surfaces. Unlike most camera-based system, they can easily be combined with magnets. They do not require a bulky setup and they can scale inexpensively to large form factors [30]. Moreover, they and can easily be combined with off-the-shelf short-throw projectors.

## OBJECT TRACKING ON FSR SENSORS

Figure 2 provides a brief introduction to object recognition on force sensing resistive sensors. While soft objects (e.g. finger touches) can be tracked easily, a rigid object (e.g. cup) often produces multiple (varying) contact points. As a consequence, it is impossible to reliably detect and identify

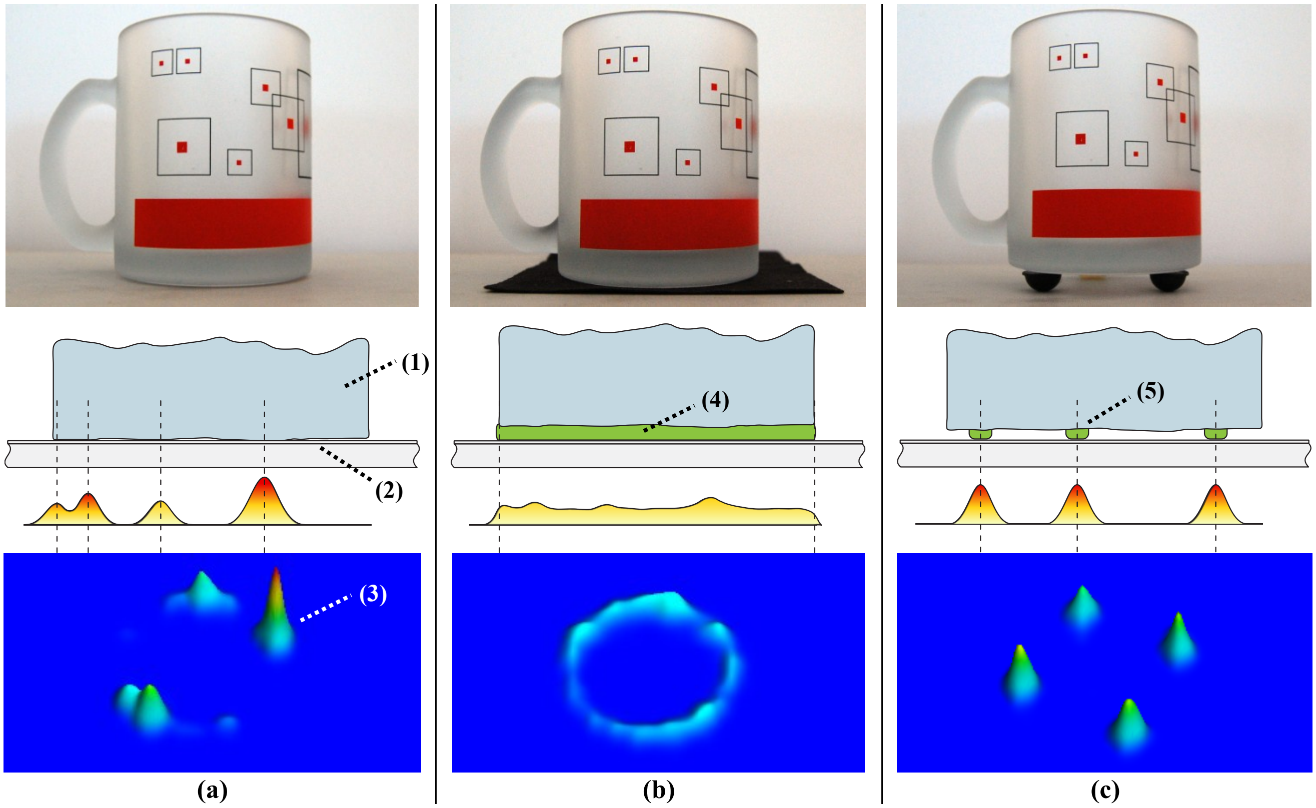


**Figure 2: (a): Due to sensor grid spacing and surface bumpiness placing rigid arbitrary objects (1) on an FSR (2) sensor results in varying pressure images (3) unsuitable for tracking. (b): Compensating for surface roughness through a soft contact layer (4) enables detecting simple contact shapes. (c): By placing dedicated contact points (5) on the object it can be detected and identified using the unique contact point constellation (footprint).**

these objects, cf. Figure 2 (a). To get a better representation of the object's shape, its weight has to be distributed across a larger contact area. This can be achieved by using a soft layer on top of the sensor surface. Figure 2 (b) depicts the resulting pressure image if a piece of cloth is placed between the sensor and the cup. Analyzing these pressure images, contact-shape categories (e.g. circles etc.) can be detected. However, unique objects can still not be identified. It is easy to augment an object to produce the same contact point constellation. Figure 2 (c) shows the resulting pressure image after gluing four rubber dots to the bottom of the cup. These *pressure footprints* can be used to detect and uniquely identify objects. While a similar sensor than the one used in [10] could have been used, IFSR foils can track even very small contact shapes with much higher resolution, making it possible to identify very small tangible objects. One limitation is that – due to the interpolation process – a minimum distance between the contact points has to be maintained, requiring a minimal size of tangible objects. This minimum distance corresponds to the distance between sensing wires. With a higher density of sensing wires, smaller tangibles can be used (but at the same time it increases sensor complexity and cost). FSR sensors require a minimum force to be applied for objects to be detected. Magnets can be used to exert additional force for very small objects to register. Magnets exert a constant force over a longer period of time, which can be used to distinguish even single contact points from input coming from a user's touch. Strong enough magnets also make it possible to use objects on slanted, vertical or even upside-down surfaces. We designed two different types of tangible objects based on low cost permanent magnets and materials.

### Geckos based on a single magnet

The simplest possible way for creating a Gecko tangible is to attach small felt pads to a magnet. Figure 3 depicts two simple markers. The left object consists of four pieces of soft self-adhesive felt attached directly to a whiteboard magnet (with a diameter of 32 mm).

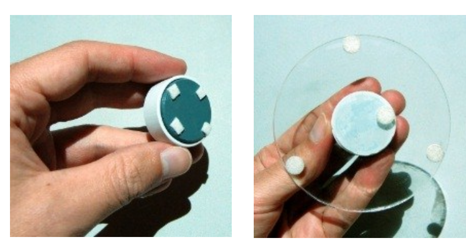

**Figure 3: Magnet markers can easily be attached to the vertical surface.**

The object on the right uses a magnet that is glued to a larger acrylic disc for a larger and hence more stable footprint. It again has a dedicated contact point constellation made of felt pads.

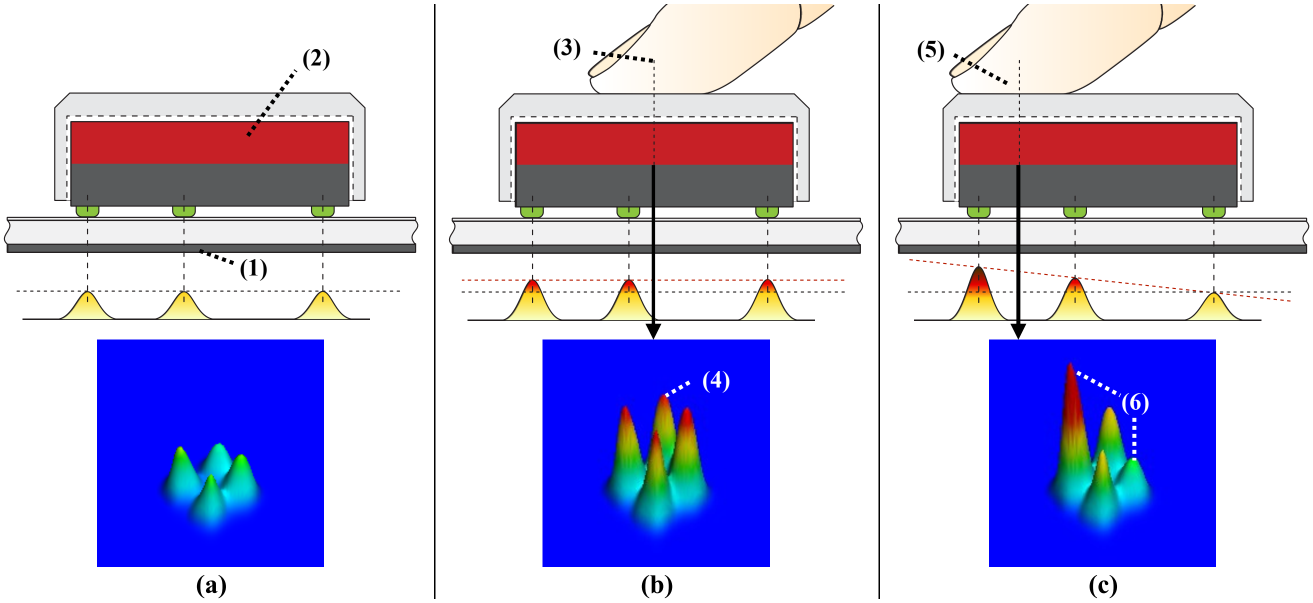


**Figure 4: (a) Placing a metal plate (1) under the IFSR sensor enables the magnetic tangibles (2) to be used also on vertical surfaces. (b) Applying additional force (3) results in higher contact point pressure (4). (c) Applying pressure off center (5) results in different pressure values (6) at different points. This can be used to approximate the position of the applied force.**

Figure 4 (a) shows a schematic of the whiteboard-magnet and the (four) resulting pressure values detected using the pressure sensitive foil. The magnet (2) inside the plastic tangible in combination with the steel plate (1), which is mounted behind the pressure sensor foil, attaches the tangible to (vertical) metal surfaces. When a user presses on the magnet (Figure 4 (b)) the pressure values increase (4). Combining the pressure values can be used to calculate a pressure value for the whole marker, enabling high fidelity pressure interaction. Our setup also can approximate the position of applied pressure on the tangible, regardless of the number of contact points and their positions. Figure 4 (c) shows a user pressing on the left side of the magnet (6), which results in a different pressure map (5). Consequently, users can easily perform single point gestures on the magnet. Using a single permanent magnet together with felt pads is the easiest way to create a tangible object that is uniquely identifiable on a FSR sensor.

**Figure 5: Multiple small magnet balls can also be used to create a unique footprint for a Gecko.**

### Geckos using multiple magnets

Instead of using a single magnet we can augment objects with several magnets (see Figure 5). The tangible itself can be any (non-magnetic) material (cf. Figure 7 (a)). It is also very easy to create markers made from non-rigid materials (e.g. cloth, rubber foam, or silicone), which enables designers to achieve different tactile qualities. One advantage of using multiple magnets is the possibility to change the marker footprint dynamically. A separate magnet on top can be used to lift up a magnet embedded in the tangible object (cf. Figure 6). Consequently, the magnet does not touch the tracking surface and the marker's point constellation changes.

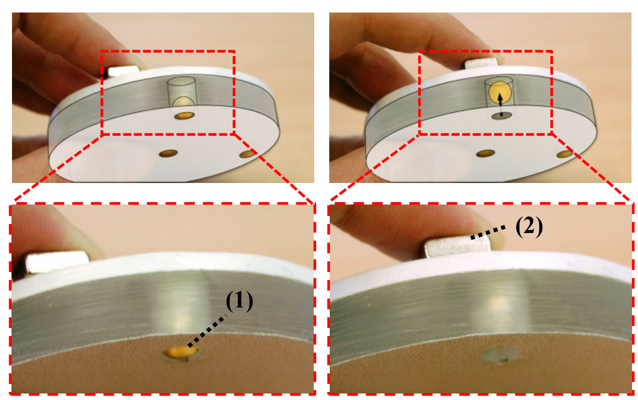


**Figure 6: The magnet ball embedded in the the object (1) gets pulled up as soon as another magnet (2) is placed on top. As a result the lifted magnet does not touch the tracking surface anymore and the marker's point constellation changes.**

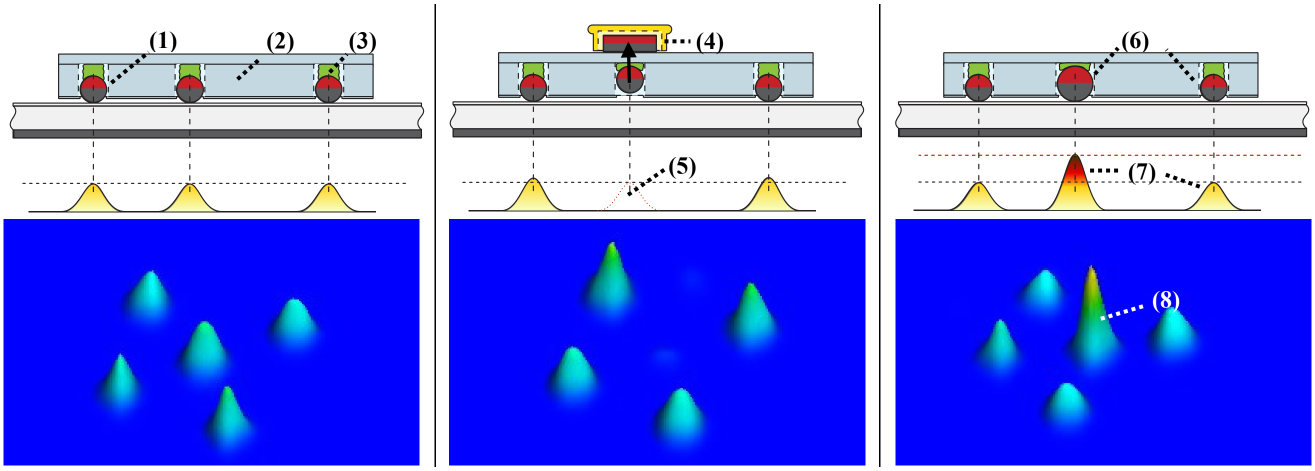


**Figure 7: Placing multiple magnets (1) inside an object (2) enables reconfigurable designs. Soft rubber foam (3) pushes the magnets against the bottom, ensuring surface contact. Placing an additional magnet on top of the object (4) contracts the rubber foam and retracts one of the contact-magnets. The contact point disappears (5). Using magnets of different strength (6) results in different pressure values (7), allowing designers to create a more unique footprint (8).**

Figure 7 shows a schematic view of the process as well as the resulting pressure images. When users re-configure the marker, these changes can trigger specific actions in the application or switch to a different marker entirely.

### *Varying force*

Magnets with different forces result in a different tracking pressure values (see Figure 8) resulting in a more unique footprint and also enabling customizable tangible properties.

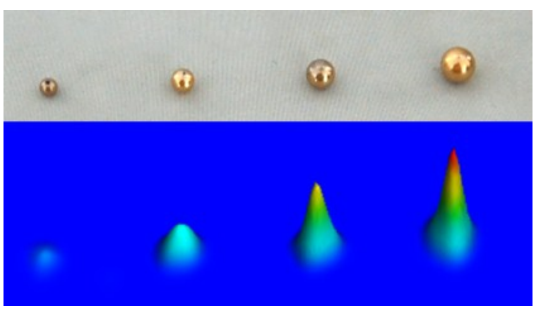

**Figure 8: Increasing magnet size (6, 8, 10, 12 mm) results in increased magnet force (6, 11, 17, 25 Newton respectively), which results in higher-pressure values in the pressure image.**

The figure shows four neodymium magnet balls ranging from 6 mm to 12 mm placed on our sensor foil. It should be mentioned that placing the same magnet on different locations on the IFSR sensor results in slightly different initial pressure values. If a magnet is placed right on top of two sensing wires, we get different results than placed in-between. Our hardware still can distinguish different magnet sizes as seen in Figure 8.

The vertical holding force of the magnet is depending on the friction coefficient between the ground surface and the magnet as well as the magnet force. Since surface properties are the same for all used magnets, surface friction is dependent only on the force of each magnet. Using stronger magnets allows us to create areas of greater friction, influencing how a tangible can be moved on the surface. Figure 7 (c) illustrates the footprint of a tangible object if the magnet in the middle has a higher force. This "primary" magnet ball results in higher friction in this point and is acting as a pivot point for the whole marker, allowing it to turn very easily around this point. Consciously embedding multiple magnets of different strength in a tangible can help create tangibles which encourage certain movements like rotation around a specific point without restricting the overall freedom of movement. This could be particularly helpful for tangible compasses or protractors.

## APPLICATIONS

In this section we present applications to illustrate possible uses of the Gecko tangibles. These applications cover a range of fundamental user interactions like single button clicks and menu interactions as well as more specialized interactions like gestures on tangibles. More common interactions like rotating tangibles are not covered in this section, but can of course be combined with all presented interaction.

### Buttons and Menus

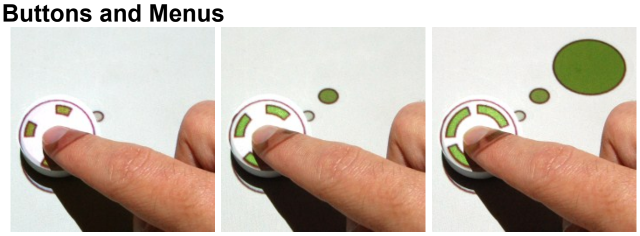

**Figure 9: Continuous pressure information for the whole marker can be given.**

Figure 9 presents a pressure-sensitive button with continuous pressure feedback. To support this functionality no mechanical mechanism is required – the use of a whiteboard magnet as shown in Figure 3 is sufficient. The continuous pressure feedback can be used to show tooltips when pressing only very lightly on the button.

**Figure 10: The marker can detect the position of the user interaction on the tangible and can change color accordingly. A white circle rendered on the approximated interaction position gives feedback to the user.**

Pressure interaction can be extended to approximate the position of interaction on the Gecko by comparing the magnitude of changes in the pressure values of all assigned points. A 2D interaction position can be calculated for all Geckos with more than two visible contact points, independently from the Geckos position, rotation as well as contact point constellation. This can be used to interact with menus rendered on top of the tangible object. The Gecko in see Figure 10 is made out of a 10 mm thick acrylic disc with embedded magnets. Five felt pads on the bottom create a unique footprint. Pressing onto different colors changes the color in the middle of the tangible. Visual feedback about the current interaction position can be provided to the user.

### Gesture Interaction

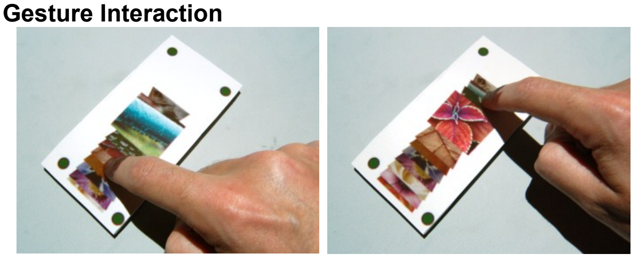

**Figure 11: Single point gestures can robustly be recognized on the tangible objects.**

Tracking the interactions on the Geckos over time allows the use of single-point gestures on the tangibles. An example is the picture browser inspired by Apple's *CoverFlow* shown in Figure 11. Similar interactions could be used to control sliders or to recognize more complex gestures or even characters or words. Drag operations started on the tangible object can be continued off the tangible onto the FSR-foil. Hence objects can be dragged off the tangible object very naturally.

### Menus with physical feedback

In Figure 12, we present a re-configurable Gecko that can detect the position of a separate magnet ball on top as shown in Figure 7 (b). This can be used to switch between different states (e.g. colors) by simply moving the magnet on top. The embedded magnets are placed right under each colored sector. The magnet on top is attracted by the magnetic force and snaps to these positions. The force is felt by the user moving the magnet creating very distinct haptic feedback. It is also possible to place multiple magnets on top or to remove them altogether, providing more interaction possibilities.

**Figure 12: The magnet on top is attracted to the magnets embedded in the disc. Users feel the magnet snap to different positions. It is also possible to flick the magnet to the next position.**

Since the magnet will automatically be attracted to one of the three positions it is also possible to snip the magnet from one position to the other (cf. Figure 12).

### Stacking Geckos

Bartindale et al. [1] and Baudisch et al. [2] show how to overcome occlusion problems in optical systems when stacking markers. Similarly, it is possible to stack magnetic makers and pass on information from the top marker to the tracking foil. As illustrated in Figure 19, the top Gecko with its embedded magnet balls modifies the status of the underlying magnets. Therefore, we can combine markers for new interactions without adding further hardware.

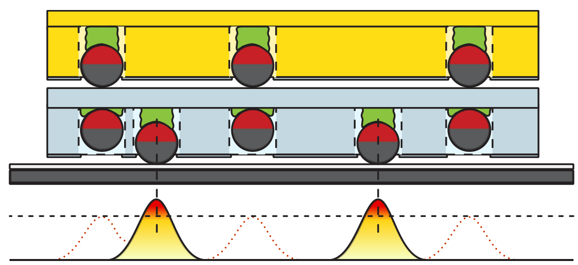

**Figure 13: Schematic view of two markers stacked.**

Figure 20 shows how the rotation of the top tangible influences the magnets of the bottom tangible. The placement of magnets is crucial and will require further research. So far, we only tested the stacking approach with two Geckos.

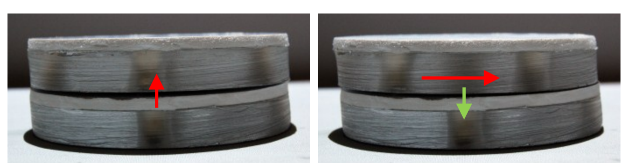

**Figure 14: Rotating the top marker results in a different pressure image of the bottom marker.**

Of course, we can still use active components or mechanical buttons as described in [37] with our system, but *Geckos* enable many similar interactions without additional building cost and effort while also supporting new interactions.

## IMPLEMENTATION

In this section, we discuss the implementation in order to help application designers to develop their own demos. Therefore, we will provide a deeper discussion about the hard- and software.

### Hardware

For developing the felt pad magnets, we simply have to add felt pads onto any permanent magnet. The implementation of Geckos with separate magnets balls is slightly more complicated. In a first version, we experimented with different magnet shapes including cubes, cylinders, and balls. As seen in Figure 15, a magnetic ball will always result in a single point located at the center of the magnet. Cubes or cylinders however often resulted in blobs of varying size making localization more error prone. Also it is possible that a larger contact surface can cause more than one peak. In our setup we used neodymium magnet balls (inner flux density of 1.17 Tesla) with a diameter of 8 – 10 mm and a holding force of 11-17 Newton on the surface.

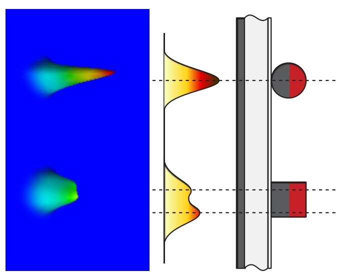

**Figure 15: A magnetic ball will always result in a single contact point located in the center of the magnet. Using flat magnets can result in varying contact.**

Figure 16 shows the most important steps of developing custom Gecko tangibles with multiple embedded magnets. For each magnet, a hole is drilled in an object, in our case an acrylic disc with 8cm diameter. The holes should be just big enough so that the magnets can move up and down freely (a). A thin foil with holes - slightly smaller than the magnets diameter on the bottom of the disc - prevents the magnets from falling out (b). To ensure that all magnets touch the surface, we added small pieces of rubber foam above the magnets, pushing the magnet balls down (c). The rubber foam has the same function as a suspension in a car – enabling the necessary degree of magnet movement to ensure ground contact for *all* magnets. The rubber foam easily compresses whenever another magnet is placed on top of the tangible, lifting the magnet up from the surface. Finally a rigid top is now glued to the top holding the tangible together (d).

### Software

SlapWidgets are registered by the distinctive spacing between reflectors [37]. As Echtler et al. point out in [4], there are limitations with this approach. For example it is impossible to find out whether a set of points belongs to a single object or multiple objects. Hence it is possible that input points from multiple different objects are recognized as a single marker. To minimize these limitations we have to ensure that the probability of ambiguous point constellation is very low. This can be achieved by combining multiple point constellations features to uniquely identify a marker.

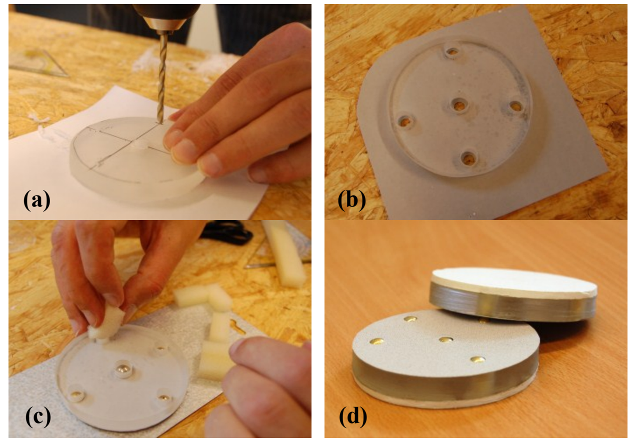


**Figure 16: Even reconfigurable markers can easily be built with common materials and tools.**

We have created a robust *Point Constellation Detection* (PCD) system, which is based on the following features: (i) input type (e.g. touch or pen input), (ii) point distance with controllable thresholds for each point, (iii) point count and (iv) detection timespan. In addition the detection algorithm also ignores points that have already have been assigned to a marker. If required, the system can use additional features like (v) contact shape, (vi) contact diameter, (vii) pressure, or (viii) detection order. Figure 17 shows an example of the marker detection process.

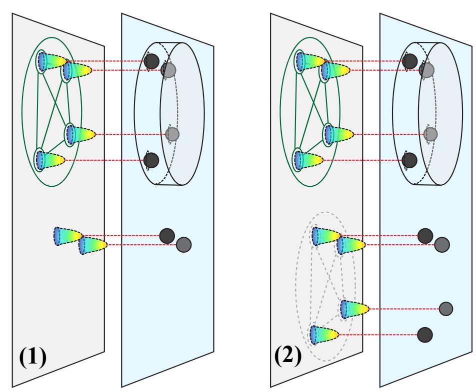


**Figure 17: (1) Looking at all valid input points a predefined point constellation is found. Two points are not assigned to a marker. (2) After a specified delay two new points appear. Even though the distances between the four assigned points match, the timespan between point detection is too large (500ms) so no marker is detected.**

Most tracking data is prone to some calibration error and noise. Instead of only considering one single tracking value, a range of values within certain thresholds has to be considered valid. Finding the optimal thresholds will produce best detection results, reducing the number of false positives/negatives. Thresholds depend on both the tracking hardware as well as tangible object precision.

In contrast to [37], no dedicated *type-, id-* and *state-footprints* are specified for Gecko-tangibles. While dedicated contact point layouts can speed up marker detection, marker detection fails if *type* or *id* contact points are not detected. In contrast our PCD system can be configured so that Geckos can still be detected with any one contact point missing. Our approach also does not impose any restrictions on the physical layout of the contact points; allowing users to quickly design and record own tangible objects. Also no restrictions on tangible object size and shape are imposed. In our system, it is possible to track changes for any contact points currently assigned to the marker. Actions can be triggered if new blobs appear, move or disappear in certain areas of the marker. Figure 18 illustrates the concept.

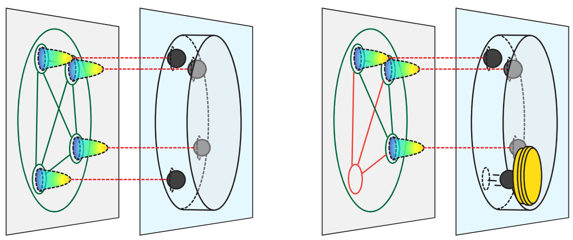

**Figure 18: It is possible to detect changes not only for specific contact points but for any assigned point of a marker. Different actions can be triggered accordingly.**

### System Performance

Our current system is based on a 24” IFSR foil and allows us to localize tangible objects at a resolution of approximately 100dpi. Higher resolutions could be achieved through more accurate build precision. Object rotation can be detected reliably with a precision of 0.1 degrees for tangibles with 8 cm diameter. The constellation detection time varies depending on the number of new input points, but is typically less than 5 ms (Intel® Core™ 2 Duo CPU @ 3.0 GHz). We are currently tracking the tangible objects with an update rate of 100 frames per second. As mentioned before, in addition to common features like position and angle information, we can also add pressure information for each marker. By accumulating pressure information of all assigned contact points and dividing it by the number of currently visible blobs, we can calculate the pressure for the whole marker. Our system currently has similar pressure detection performance on tangibles than state of the art pen tables and can distinguish more than 1,000 different pressure values. Similar to the approach in [32], it is even possible to approximate the position of interaction on the object surface. In contrast to [32], which uses pressure data from the four corners of a rectangle, our system can use any number of randomly positioned pressure points to calculate the interaction position.

## DISCUSSION

Our initial idea was to simply use available marker tracking solutions on the pressure image as they also provide x-y-information on objects. Holzmann et al. [10] have shown that using computer vision techniques on pressure images classes of objects can be identified. Still *unique objects* cannot be identified. Adding fiducial markers allows optical systems to uniquely identify objects. However, just taking markers designed for vision systems and use on FSR foils does not work. Figure 19 shows a marker with a soft contact surface shaped like a simple ReacTIVision fiducial marker [22] and the resulting pressure image.

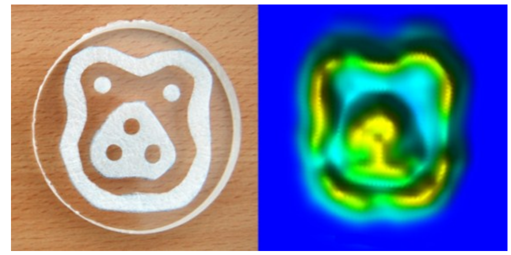

**Figure 19: A ReacTIVision inspired custom contact surface marker and the resulting pressure image. Several features cannot be detected by the sensor.**

Despite the large size (8cm ø) of the marker and the high resolution of the pressure sensor (100dpi interpolated), various features of the fiducial marker are not reproduced correctly in the pressure image. Also it takes considerable force to press the marker against the sensor to produce a pressure image as shown. Therefore, optical marker tracking software cannot be simply used with pressure-sensor-based foils.

IFSR sensors excel at tracking multiple separate input points with very high accuracy. This can be used to specify and detect special point constellations to identify objects. We hence decided to develop the PCD system as described before. Our system offers similar properties like fiducial markers for vision systems, namely (i) low production costs for tangibles, (ii) easy maintenance, (iii) large address range, (iv) flexible object design and (v) high tracking reliability and accuracy. While some limitations like separating ambiguous point constellations exist, there are several benefits of our system that make it unique when compared with fiducial-based marker tracking systems.

### Designing and adding new markers

Both in vision-based systems as well as in our PCD system the quality of tracking results heavily depends on the marker design. Not only similarities with other markers are a problem, but also self-similarity. For vision-based systems, custom fiducials (if supported) are mostly designed in external (graphic) editors and are then integrated in the application. Testing, adding, or changing markers can be time-consuming. In our setup, the registration (adding new markers) and tracking process are included in the same application. This way, we can add new markers on the fly and feedback about marker self-similarities like (rotational) symmetry or similarities with other markers can be given instantly to the designer. This enables designers and developers to quickly iterate through different marker designs getting instant feedback about possible marker design problems. Once finished with the design, the designer can add the new marker to the system by pressing a keyboard button. In our system the marker specification is in an XML-file, which can easily be edited with any text editor.

### Tracking stability

In vision-based systems, motion blur can make it difficult to track markers during fast movements. Our system is neither affected by motion blur nor is it susceptible if single contact points are lost during fast movements. Only for the initial detection, all blobs of a point constellation are required. Once all input points have been assigned to a marker, the tracking is resistant against loosing contact points. As long as two blobs can be tracked, it is possible to calculate the marker's position and rotation. The remaining points also can be used to help re-assigning points. While only two points are required to calculate rotation and position it is possible to use more points and interpolate the results, making the system resistant to position or angle jitter.

### Compatibility with other systems

It might be beneficial (e.g. for data transfer) to use the same tangible object on several interactive surfaces. However, interactive tables are often based on vision based input technologies. Our detection system is separate from the tracking software layer and can accept input from other tracking hardware (e.g. FTIR, DI etc.). Figure 20 shows a marker design using white felt pads on black, self-adhesive velour that can be tracked using an optical system as well as a digital resistive tracking system. We have successfully tested our prototype system with resistive tracking hardware as well as an FTIR based optical system. This will allow new use-cases, where tangible object interactions can start on an interactive table and end on a whiteboard surface and vice versa.

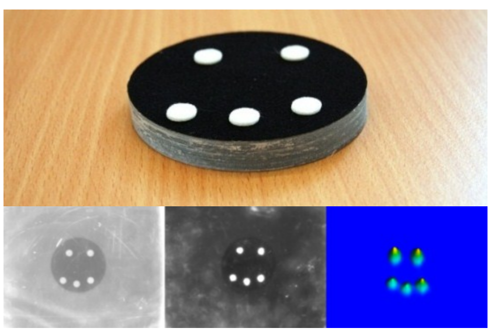

**Figure 20: The same tangible object as well as the same detection algorithm can be used on a DI (1), a FTIR (2) or IFSR based surface.**

In addition to marker detection with our approach it is also possible to detect hand postures to evoke menus or perform gestures. After initial assignment the user can even lift up fingers without losing the assignments for the remaining fingers. We believe that this is also nice addition that sets Geckos apart from fiducial based object tracking systems.

### System imposed limitations

Currently FSR based tracking solutions yet have to find widespread adoption. High-resolution prototypes apart from the solution described in [30] are already available [19]. Given the current interest in touch technology, we believe that more touch tracking foils will become available in the near future.

For our current implementation we had to rely on relatively strong magnets because the sensor was glued permanently to a 5 mm acrylic plate. This results in a 5 mm gap between the magnets and the metallic ground plate. Removing this gap will enable us to use considerably smaller magnets than used for our first prototype markers. Consequently larger numbers of magnets will fit into a single tangible object, offering even more possibilities for dynamic footprints as well as stackable markers.

## CONCLUSION AND FUTURE WORK

In this paper, we have presented the combination of permanent magnets and IFSR sensor technology to enable stable and low-cost object tracking on thin touch tracking foils. We have provided information about the implementation, motivated hard- and software decisions, and we have shown first sample applications of our tracking approach across different platforms. We believe that Geckos are a feasible alternative to fiducial marker tracking solutions that allows users to go beyond horizontal surfaces. For future work we intend to give a more formal description of our software alongside with a more extensive comparison with other marker tracking approaches. Similar to [29], we intend to formulate guidelines for tangible object design with a focus on marker tracking stability, dynamic footprints and stackable marker design.

Future work will mainly focus on evaluating user interaction. How can tangible objects that naturally turn around a certain point guide user interactions? How can magnetic haptic feedback and dynamically changing footprints be used effectively? Our initial goal of bringing tangibles to interactive walls also will open up a new area that will require careful study. How is the movement of tangible objects on vertical surfaces different than on tabletops? Can tangible objects on interactive whiteboards be used to provide suitable feedback for tangible palates? In a further study, we try to find answers to these questions.


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