TMotion:Embedded 3D Mobile Input using Magnetic Sensing Technique

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ABSTRACT
We present TMotion, a self-contained 3D input that enables spatial interactions around mobile using a magnetic sensing technique. Using a single magnetometer from the mobile device, we can track the 3D position of the permanent magnet embedded in the prototype along with an inertial measurement unit. By numerically solving non-linear magnetic field equations with known orientation from inertial measurement unit (IMU), we attain a tracking rate greater than 30Hz based solely on the mobile device computation. We describe the working principle of TMotion and example applications illustrating its capability.

Author Keywords
3D Input; Embedded Interaction; Magnetic Sensing; Mobile Interaction; Sensor Fusion

ACM Classification Keywords
H.5.2. [Information Interfaces and Presentation]: User Interfaces. – Input devices and strategies

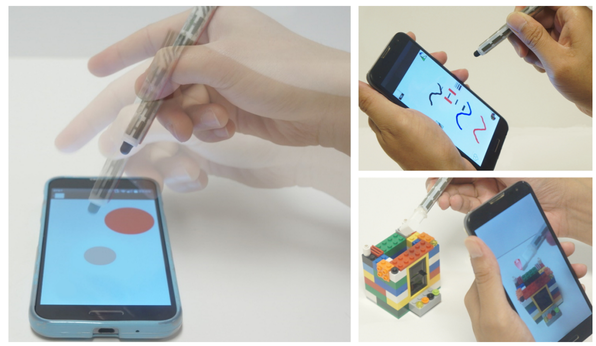

Figure 1. TMotion enables a real-time 3D position tracking using embedded permanent magnet and IMU with mobile device.

INTRODUCTION
Recent developments in smartphone displays and sensors have resulted in enhanced visual experiences such as mobile augmented (AR) and virtual reality (VR). To support these 3D interfaces, it would be helpful to provide natural correspondence such as human motion in 3D space from the input device. Current 2D input modalities cannot fully reflect the user's intent in a 3D space. Moreover, using 3D input offers a more intuitive and quicker way to interact with 3D context interfaces. Our prototype provides a real-time 3D position tracking which utilizes fine-grain information for seamless interaction with physical environment [3].

Acquiring input data from 3D mobile space has been investigated through vision and magnet-based techniques. Occlusion and lighting conditions still limit the use of vision-based techniques in mobile environments. On the other hand, the magnetic sensing techniques which are free from occlusion and light conditions have been also investigated [1, 4]. These works show high 2D/3D tracking accuracy in real-time operation, but they require either a desktop computation, or extensive modifications on the mobile device.

In our work, TMotion enables mobile to track an input device embedded with a magnet and an IMU. Specifically, the algorithm calculates the magnets position relative to the mobile using the magnetic field vector and the orientation of the embedded magnet. We achieve a 3D position tracking rate greater than 30Hz possibly with an unmodified device. As a 3D mobile input, TMotion provides rich interactions in above/behind device spaces.

TRACKING PRINCIPLE
2D and 3D position tracking using multiple magnetic sensors have been explored [2]. However, they require either hardware modification on the mobile device or processing through a desktop PC to overcome the lack of sensing capability or the computational load. From theory of the magnetism, 3D position of the permanent magnet in the mobile's magnetic sensor oriented space ($\mathcal{F}_{mobile}$) can be computed using Eq.(1)

$$\mathbf{H}(\mathbf{r}) = \frac{K}{r^3}\left[\frac{3\mathbf{r}(\mathbf{m}\cdot\mathbf{r})}{r^2} - m\right], r = |\mathbf{r}|, K = \frac{M}{4\pi} \tag{1}$$

Here, H refers to the magnetic field vectors, M denotes for the magnetic moment, **m** is the directional vector of the magnet, and **r** is the location vector of magnet relative to the sensor. Given known **m**, M, and H, **r** can be solved.

We assume magnet is located at (x, y, z) resulting in **r** to be $(-x, -y, -z)$. The directional unit vector of magnet is ($\mathbf{M}_x$,$\mathbf{M}_y$,$\mathbf{M}_z$). We perform space transformation from IMU

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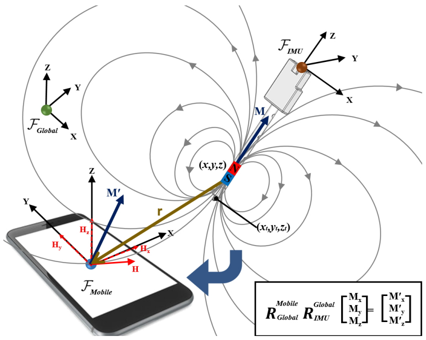

Figure 2. Magnetic vector (H) is generated by magnet. Magnetic directional vector from TMotion (M) is transformed to mobile's frame (M').

space ($\mathcal{F}_{IMU}$) to mobile space ($\mathcal{F}_{mobile}$). Figure 2 illustrates the transformation of the directional unit vectors (**M**) from TMotion to the mobile space (**M′**). Additional transformation has been applied to denote the 3D position of the tip.

By taking known orientations from attached IMU (**M**) and 3-axis magnetometer readings (**H**) from mobile device as inputs, we employ Newton's method to solve nonlinear equations. We observe that position tracking succeeds when the prototype operates within 160mm×160mm×200mm volume around the mobile device. Our approach enables a real-time computation by iterating the numerical analysis once with known orientation from IMU.

SYSTEM OVERVIEW

Figure 3 illustrates our prototype in detail. It holds multiple form factors embedded with magnets of various orientations. To avoid the magnetometer saturation, we configure the sensor stick and the embedded magnet in distinct locations (>5cm) in our prototype. With the streamed mobile's magnetometer data (75Hz), we update the tip position from the latest computation. We subtract average magnetometer readings before the prototype gets into the interaction volume to compensate geomagnetic field. For capacitive sensing, we inkjet-printed a sheet of electrodes using *AgIC* ink.

EXAMPLE APPLICATIONS

Multi-level menu interface: Users pop up a designated menu placed along the edge by hovering around the device. This is followed by moving along the z-axis for choosing sublevel menu. Final selection is confirmed with changing the grip. We utilize find-grained 3D input around the mobile device to augment traditional 2D UI capability. By taking same approach, we can improve user experience with other 2D UI applications. This also demonstrates richer interactions using discrete spatial zones around the mobile device.

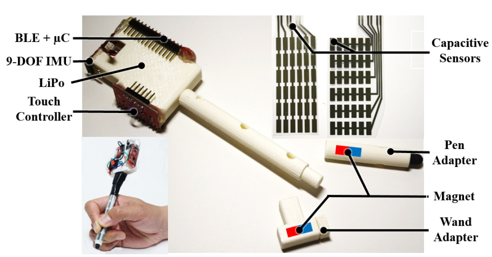

Figure 3. TMotion prototype and breakdown of its components. Permanent magnet and 9DOF-IMU are embedded for 3D position tracking.

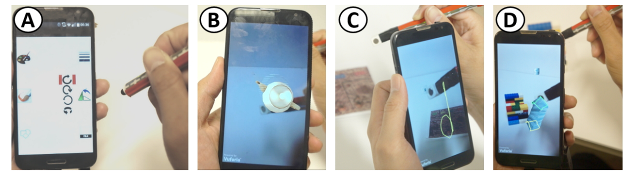

Figure 4. Example Applications: (a) Multi-level menu interface and spatial interactions including (b) 3D manipulation, (c) 3D sketching, and (d) 3D modeling in mobile AR

Spatial interaction for mobile AR: We demonstrate four tasks in mobile AR environment: 1) 3D model manipulation, 2) physical environment referenced 3D sketching, 3) sweeping sketch in 3D path, and 4) superimposition of the virtual creation over a physical object. We use capacitive sensing as an interaction delimiter to shift between different input modes including 'Translation' to/from 'Rotation', and the start & end of the modeling or sketching operations. Through this application, we showcase the possibility of providing rich spatial interactions behind the device.

CONCLUSION

In this paper, we present an embedded 3D mobile input using magnetic sensing technique. With the known orientations from 9DOF-IMU, we explicitly solve the position of the embedded magnet through numerical solver. We achieve a real-time position tracking without altering the hardware setup. With capacitive sensing based interaction delimiter, we utilize TMotion for a seamless embedded interaction. As 3D mobile interfaces develop, the needs for better methods to handle and exploit richer user inputs also increases. We demonstrate that TMotion potentially fulfills these requirements by presenting a real-time 3D input.

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