only once per device (Figure 3). Additionally, by comparing two frames' color delta we can measure the smartphone to screen distance reliably up to 15 cm.
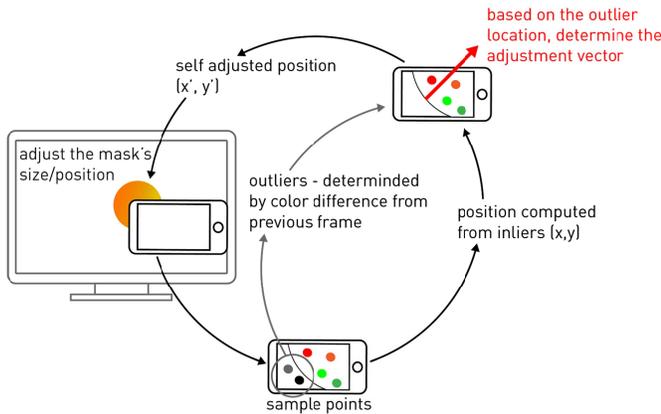

Figure 3. Sequence diagram of the tracking algorithm

Non-invasive Tracking
One advantage of using a dynamically displayed tracking pattern is its adjustability. It is sufficient for the pattern to only be visible in the camera's FOV to achieve continuous tracking. Therefore, we can hide the pattern in the area occluded by the phone, which allows tracking without sacrificing valuable information space.

INTERACTION
Here we present a framework for classifying possible interactions with our system (Figure 4). The phone can be used as a physical token to directly interact with digital entities based on their relative positions (Figure 4(a-b)). It can act as a lens for controlling or augmenting objects on a computer screen (Figure 4(c)) and also offers an additional space to be used for extended control or as a physical clipboard. (Figure 4(d)). The presented interactions can be used in combination or interchangeably, thus enabling variable combinations of tangible interaction and see-through augmentation.
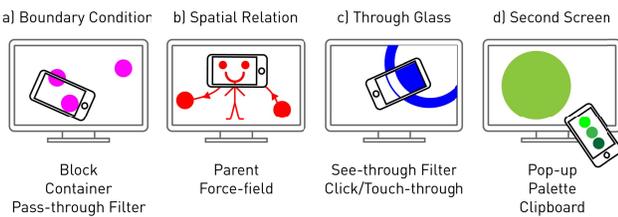

Figure 4. Categories of interaction

DEMO APPLICATIONS

See-through Mouse
We use the phone as an advanced see-through mouse tool. The phone serves both as a tangible clipboard and a see-through touch tool, enabling intuitive drag/drop or copy/paste of digital content (Figure 5). This largely extends the modality of a conventional mouse, enabling more sophisticated functionality such as opening a web link on the mouse or performing kinetic gestures.

Figure 5. Seeing and touching through the smartphone

Game
We developed a simple game in which the goal is to help the character reach the flag. The smartphone acts as an active controller that can be used to physically intervene in the gameplay (Figure 1). Players have to choose different strategies to clear each stage, which is designed to showcase a specific interaction or a mix of interactions of our framework. It is notable that, in each stage, the phone is perceived to have versatile physicality through showing different uses of visual augmentation and interactions. This potentially promises countless more novel gaming scenarios than the ones presented here.

CONCLUSION
In this paper, we proposed an easy to deploy technology as well as interaction scenarios to better utilize the near-range interaction space on and above computer screens with smartphones. The combination of AR and Tangible User Interfaces (TUI) enables versatile user interfaces for context-aware seamless interactions. As a growing number of people own these two complementary devices, we believe that our system can unlock the potential of those collocated technologies in the immediate future and contributes an easy to deploy near surface interaction technology.

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