Demonstrating *BrightMarkers*: Fluorescent Tracking Markers Embedded in 3D Printed Objects

Mustafa Doga Dogan
MIT CSAIL
Cambridge, MA, US
doga@mit.edu

Raul Garcia-Martin
MIT CSAIL
Cambridge, MA, US
raulgm@mit.edu

Patrick William Haertel
MIT CSAIL
Cambridge, MA, US
phaertel@mit.edu

Jamison John O'Keefe
MIT CSAIL
Cambridge, MA, US
jjokeefe@mit.edu

Raul Sanchez-Reillo
Universidad Carlos III de Madrid
Leganes, Madrid, Spain
raul.reillo@uc3m.es

Stefanie Mueller
MIT CSAIL
Cambridge, MA, US
stefanie.mueller@mit.edu

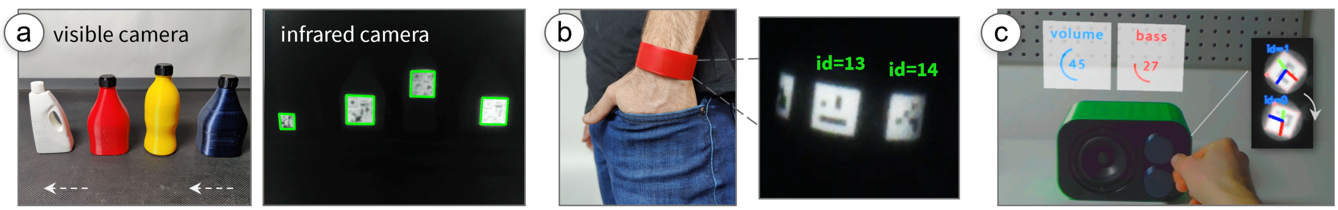

Figure 1: *BrightMarkers* are embedded into objects using a NIR-fluorescent filament. (a) When viewed with a NIR camera with the matching filter, the markers appear with high intensity, which allows them to be tracked even when the objects are in motion, e.g., on a conveyor belt. (b) *BrightMarker* can be used to fabricate custom wearables for tracking, or (c) for transforming physical controls into precise input methods in mixed-reality environments.

ABSTRACT

In this demonstration, we showcase *BrightMarker*, a fabrication method that uses fluorescent filaments to embed easily trackable markers in 3D printed color objects. By employing an infrared-fluorescent filament that emits light at a wavelength higher than the incident light, our optical detection setup filters out all the noise to only have the markers present in the infrared camera image. The high contrast of the markers allows us to robustly track them when objects are in motion.

We also demonstrate a software interface for automatically embedding these markers for the input object geometry, and a hardware module with a high-speed camera that can be attached to existing AR/VR headsets. We developed an image processing pipeline to robustly localize the markers real-time from the captured images. We illustrate applications for fabricating wearables for motion capture, tangible interfaces for AR/VR, and enabling rapid product tracking, as well as privacy-preserving night vision.

CCS CONCEPTS

• **Human-centered computing** → *Human computer interaction (HCI).*

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KEYWORDS

3D printing; digital fabrication; fluorescence; infrared imaging; marker tracking; invisible markers; object tracking

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1 INTRODUCTION

Existing methods for invisible object tagging have several limitations that impede their widespread adoption. One significant limitation is their low signal-to-noise (SNR) ratio, i.e., the poor resolution and clarity of the imaged marker. Because invisible markers are embedded in the interior of objects, the markers are imaged from a weak signal, which needs to be amplified by optical and digital processes [2, 8, 9, 11]. These processes result in long capture or decoding times, typically ranging from seconds to minutes per frame. This deteriorates further when objects are in motion, i.e., the captured markers appear blurrier and are thus unidentified in most frames. In addition, existing invisible tags are often limited in terms of the variety of object colors they can be used with. For example, *InfraredTags* [4, 5] embedded 3D printed codes in black objects, and *AirCode* [8] in white objects.

To address these limitations, we present *BrightMarker*, a fabrication method for passive invisible tags using fluorescent filaments that emit light in a specific near-infrared (NIR) wavelength, which NIR cameras can robustly detect. By isolating the markers from the rest of the scene using the matching filter, we are able to robustly track markers even when objects are in motion. Our work builds on *InfraredTags* and addresses the limitations in regard to marker resolution and object colors by enhancing detection. We were inspired by the motion capture system *OptiTrack*, which uses passive retro-reflective markers that reflect the shined IR to the camera.

We demonstrate the potential of *BrightMarker* by showcasing various applications, including product tracking on conveyor belts, flexible wearables for motion capture, tangible and haptic interfaces for AR/VR, and privacy-preserving night vision. Our technical evaluation shows that the markers embedded in a variety of surface colors can be detected robustly and in real time as they move.

We believe that *BrightMarker* is a promising approach that could significantly improve the performance and versatility of invisible object tagging and have a wide range of potential HCI applications.

2 APPLICATIONS

In this section, we show several applications of *BrightMarker*, in which the tracking of object locations is an integral part of a process.

2.1 Rapid Product Tracking

Because *BrightMarker*s can localize and track embedded objects, it can be used for industrial or commercial applications in which items need to be processed in a swift manner. This can be especially useful for product and packaging logging where, although the external labels may be intentionally or unintentionally removed, it is still crucial to keep track of the item origin and other supply chain or inventory-related data (e.g. the bottles in Figure 1a).

2.2 Wearables for Tracking Human Motion

One of the applications of *BrightMarker* is 3D printing custom wearables for tracking human motion. Figure 1b shows flexible wristbands printed with embedded markers. Embedding unique markers allows us to digitize the user's motion and distinguish between right and left hands.

Such tracking wearables can allow various use cases unobtrusively, such as creating digital twins and animations, increasing safety in human-machine collaborations, posture correction warnings, or device control. Compared to existing tracking methods, the use of *BrightMarker* preserves the user's privacy since the camera only captures the marker, not the user's face or environment. Furthermore, current methods, especially those based on machine learning, are usually tuned for able-bodied people's hands. Wearables with *BrightMarker* could support applications for people with limb differences or hand impairments. In our current implementation, we produced the black wristband using PLA and the red one using ABS. Both wristbands have a small thickness, thus allowing them to be bent. In the future, more custom wearables could be printed using more flexible materials such as TPU or by utilizing FDM-based textile fabrication methods [7, 10].

2.3 Tangible Interfaces for MR Experiences

*BrightMarker*s can be embedded into objects to turn them into tangibles with more precise tracking capabilities for mixed reality (MR). For instance, opportunistic tangible interfaces enhance AR/VR interactions by utilizing objects as anchors or placeholders [1, 3, 6].

Appropriating physical parts as precise AR input tools: Figure 1c shows a loudspeaker that has been unused in an office. The user wants to make use of the unplugged speaker by transforming it into a passive tangible interface for controlling the volume and bass of his AR glasses. This allows him to have a more natural and tangible input method, while touching small buttons on the glasses can be cumbersome.

BrightMarker has the benefit that the marker objects also include the part's identifier, i.e., the top and bottom knobs can be distinguished and assigned unique functionalities. Further, since the knobs have a uniform color and shape, it would be difficult to precisely track their rotation without the embedded *BrightMarker*s.

Real-life objects as VR haptic props: *BrightMarker* allows users to make use of the physical shape of existing real-world objects (e.g., toys, gadgets, sports gear) as haptic proxies in VR. For example, a "lightsaber" toy could come with integrated *BrightMarker*s, so it can be used as a different object in games. As shown in Figure 2, the lightsaber's hilt is used as a haptic placeholder for a sword to slice fruits in a game. Another benefit is that the objects are fully passive, while typical VR game controllers contain infrared LEDs that need to be powered up.

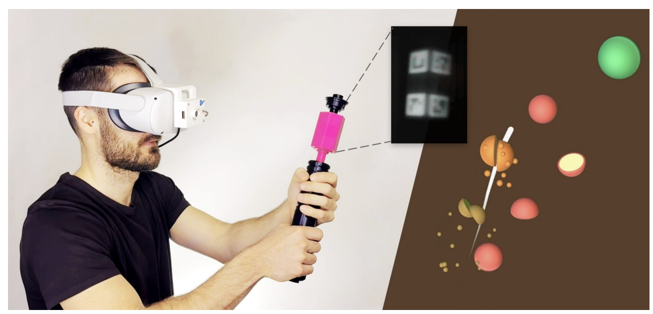

Figure 2: Using a lightsaber as a prop to slice fruits in a game.

3 CONCLUSION

We demonstrated *BrightMarker*, a novel method for embedding and tracking hidden high-intensity markers using fluorescent 3D printing filaments. Our approach offers easy-to-use solution for marker-based tracking without affecting the object's look or shape. We showed that *BrightMarker*s can be embedded in various object colors, and can be easily localized using a light source and camera filter that match the fluorescence characteristics of the material. Our CAD tool allows users to add markers to their 3D models before printing, and our optical detection hardware can be attached to existing AR/VR headsets for marker tracking. Our image processing pipeline uses the captured images to robustly localize the markers.

Our applications demonstrate rapid product tracking, custom-fabricated wearables, tangible interfaces in AR/VR, and privacy-preserving night vision. Our evaluation shows that markers of different colors can be detected from afar, and at various object speeds. We believe that our work demonstrates the potential of using fluorescence as an effective and versatile method for embedding invisible markers, and we hope it fosters further exploration and innovation in this area by the HCI and fabrication community.

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