



TrackItPipe: A Fabrication Pipeline To Incorporate Location and Rotation Tracking Into 3D Printed Objects

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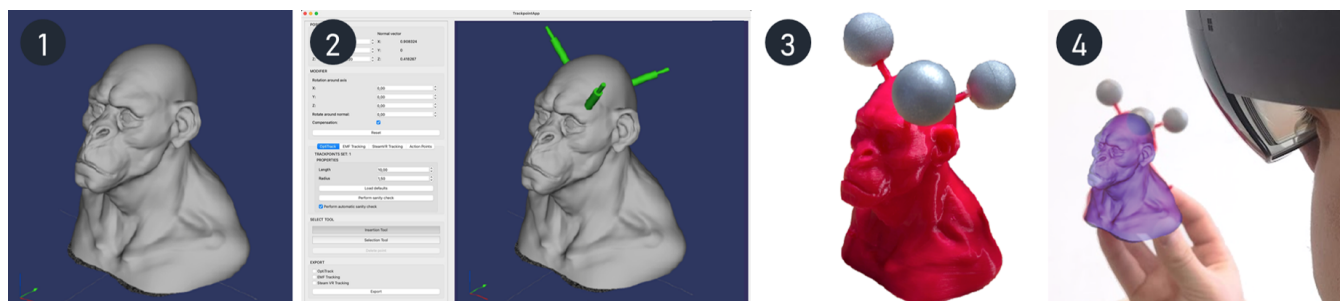


Figure 1: With TrackItPipe, the user (1) loads any 3D printable model into the tool to (2) semi-automatically add modifications for tracking support. The tool then generates (3) a modified 3D printable object and (4) the fully trackable virtual model for Mixed Reality Applications.

ABSTRACT

The increasing convergence of the digital and physical world creates a growing urgency to integrate 3D printed physical tangibles with virtual environments. A precise position and rotation tracking are essential to integrate such physical objects with a virtual environment. However, available 3D models commonly do not provide tracking support on their composition, which requires modifications by CAD experts. This poses a challenge for users with no prior CAD experience. This work presents TrackItPipe, a fabrication pipeline supporting users by semi-automatically adding tracking capabilities for 3D printable tangibles tailored to environmental requirements. TrackItPipe integrates modifications to the 3D model,

produces the respective tangibles for 3D printing, and provides integration scripts for Mixed Reality. Using TrackItPipe, users can rapidly equip objects with tracking capabilities.

CCS CONCEPTS

• **Hardware** → **Tactile and hand-based interfaces.**

KEYWORDS

Tracking, Mixed Reality, Fabrication, 3D Printing

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1 INTRODUCTION AND BACKGROUND

Digital and analog worlds are increasingly converging, consequently merging entirely into one another, particularly in Mixed Reality

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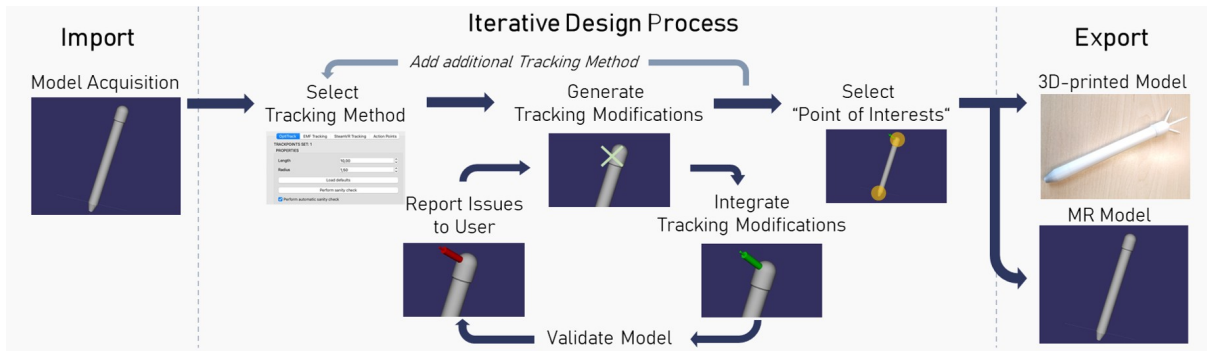


Figure 2: Example workflow for a pen object using the TrackItPipe pipeline. After importing the model, the user can select the desired tracking methods. The application then helps to add modifications to the model to fit tracking hardware. If the results are in alignment with the user’s needs, the points of interest can be selected and the final model can be exported.

Environments (MREs). Integrating interactive and augmented 3D-printed objects transfers tangibility to digital parts in MREs. However, tangibles do not incorporate any tracking capabilities within the object itself, which is required to be tracked by MREs. While already available consumer tracking systems provide sub-millimeter tracking precision, they need to mount additional hardware, (e.g., VIVE tracker) to equip objects with tracking capabilities. Mounting other hardware on objects not designed for specific tracking systems is cumbersome when prototyping and working with customized 3D printed objects. A potential solution is to modify the surface of existing 3D models by mounts facilitating the attachment of tracking hardware. However, changing the 3D models to integrate the tracking components requires CAD expertise that is tedious to achieve by non-CAD experts.

Previous research proposed various approaches to ease the creation of interactive objects. For example, previous work automatically adjusted the looks, structure, and material [2, 27], enabling users to create paper-based electronic devices [14] or ease embedding new interactive functionalities including touch sensing [3, 21, 24] or haptic feedback [20]. At the same time, computer vision-based approaches have been proposed [26, 28] to track multiple [16, 29] objects in 3D space including mobile devices with less performance [6, 19]. To detect an object and compute its pose, some approaches employ instant motion tracking on mobile devices [1], or RGB- and pointcloud-snapshots [15]. For example, past research used pointcloud data, which is typically available on commodity mixed reality devices, in order to create robust tracking for assembly assistance [17] or remote live support [18]. approaches to detect markers invisible to human eyes using infrared cameras [4] or computational imaging method [11]. Another class of approaches use additional hardware to enable external tracking [9, 10], such as RFID trackers For example, Kantareddy et al. [9] integrated RFID trackers to 3D print masks for golf balls.

The most widespread tracking approach uses optical markers [5, 13]. OptiTrack, for example, achieves high precision and sample rates [5]. Compared to the high costs of OptiTrack System [13], SteamVR offers some great budget tracking with comparable results [12, 25]. These two systems are the most widespread used systems for optical tracking and are therefore integrated in TrackItPipe.

However, optical tracking require line-of-sight to track objects. In some situations, however, occlusion might not be preventable. In these cases, magnetic field tracking (MFT) can be deployed. MFT trackers do not need a line of sight and can therefore even be installed hidden in objects. One of tracking systems is AmfiTrack¹, which we also included in TrackItPipe.

Instead of embedding tracking capabilities into objects, we show how necessary support structures for high-precision real-time tracking can be added to 3D models. This work introduces TrackItPipe, a fabrication pipeline assisting users integrating tracking capabilities into generic 3D models. Since TrackItPipe semi-automatically extends any 3D object with support structures for real-time tracking, it does not require any CAD knowledge of the users. Consequently, users can easily extend objects by 3D tracking capabilities for MREs. We contribute a processing pipeline that we showcase using an example object. Furthermore, we present preliminary user feedback commending the simplified and efficient use of TrackItPipe involving CAD experts and novices. Finally, we envision TrackItPipe as a fabrication pipeline that provides an accessible environment for CAD non-experts who aim to prototype trackable objects.

2 TRACKITPIPE FABRICATION PIPELINE

We introduce TrackItPipe, a semi-automatic processing pipeline to transform 3D models into trackable objects. Therefore, we integrated SteamVR, OptiTrack, and AmfiTrack as a sample tracking system, as they represent widespread solutions with different approaches and capabilities.

2.1 Import

2.1.1 Model Acquisition and Loading. TrackItPipe allows users to load any 3D model. Preferred format is 3MF, but STL is supported, too. Users can use their models or acquire models from third-party websites². In the example of Figure 2, the user loaded a pen model.

2.2 Iterative Design Process

2.2.1 Select Tracking System. After loading the 3D model, the user can pick a tracking system. TrackItPipe then assists to apply the

¹<https://www.amfitrack.com/>

²For example Thingiverse: www.thingiverse.com

required modifications to the object to fit the tracking hardware (named *tracking modifications* in the following). TrackItPipe can handle multiple tracking systems for one object and stores their respective tracking modifications in separate files. This enables users to receive various output files for all compatible tracking systems automatically. To select the right tracking solution for each use-case, the user should consider

- *potential occlusion by hands or other objects*
- *physical constraints on weight, size and enough space for the additional tracking hardware*
- *maintaining the object's appearance*

In the example of Figure 2, the user can assure no obstruction in line-of-sight tracking and has plenty of space to add tracking modifications at the back end of the pen. Therefore, the user decides to use OptiTrack as a tracking solution.

2.2.2 Add and Adjust Tracking Modifications. Based on the selected tracking system, different kinds of tracking modifications, such as stand-offs (see Figure 3), threads (see Figure 3) or cut-outs, need to be added to the object. We intentionally did not use a full-automatic approach to place these modifications since they could potentially lead to unwanted obstruction of the object's interaction space. Therefore, our pipeline is based on a semi-automatic approach, where users decide where the modifications should be placed. Using a 3D preview, users can select spots on the model and see the changes with the applied modifications in real-time. This way users can keep the interaction space free of modifications. In our example of Figure 2, the user selected a spot at the back of the pen to add tracking modifications.

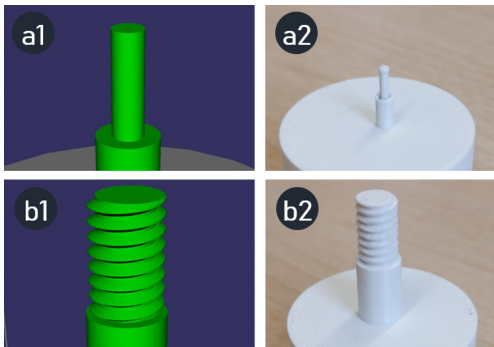


Figure 3: Two tracking modifications to attach markers or hardware to 3D-printed objects. a1 and a2 for OptiTrack Markers, b1 and b2 for SteamVR.

2.2.3 Integrate Tracking Modification into the Model. Once the user places a tracking modification at the desired spot, our application automatically integrates them into the object. For added structures, such as stand-offs or supports, TrackItPipe checks for enough adhesion confirming that the tracking modification is physically attached to the object. In the example of Figure 2, TrackItPipe adds a stand-off structure perpendicular to the surface at the selected spot. The stand-off's tip is chamfered for the OptiTrack markers.

2.2.4 Validate Tracking Modification. After integrating the tracking modification to the object, TrackItPipe checks and validates the placement given the tracking system requirements, the application performs various checks depending on the selected tracking system in Chapter 2.2.1. These checks include e.g. physical clearance, tracking marker count, and placement. Tracking systems with need to attach additional tracking hardware (e.g., SteamVR or OptiTrack), require enough physical clearance. In the example of Figure 2, our tool checks for enough space at the stand-off's tip to fit an OptiTrack marker and for collisions with the object itself.

2.2.5 Report Issues to User. TrackItPipe reports issues detected in 2.2.4 to the user through either warning pop-ups or information labels. Major issues, including insufficient placement, obstruction, or missing clearance, are displayed as a pop-up describing the issue and prompting the user to act. Issues that require no immediate action, such as having too few trackers attached, are just displayed as a status text. This way, the user can perceive them but is not interrupted while working on the object, potentially solving the issues in the next steps. As shown in Figure 2, the validation step did not find any significant issues, therefore not displaying a pop-up.

2.2.6 Select Point-of-Interests. Once the tracking system requirements are met and placed validly, the user can set Point-of-Interests. Point-of-Interests are spots on the object where the user wants to know the location later on. In the example of Figure 2, the pencil's tip and eraser are marked to use their position to draw or erase lines in a Mixed Reality Environment. Defining such Point-Of-Interests directly on the model makes it easier to place them correctly.

2.3 Export

2.3.1 Models. As output, TrackItPipe produces two models with additional meta information. The first model is set up for 3D printing featuring the added tracking modifications ready to be sliced and printed. The second model is for use in Mixed Reality applications containing meta-information, like the Point-of-Interests, for easy Unity Engine integration. As shown in Figure 2, TrackItPipe produces these two models. One for use inside the Unity Engine and one with the added tracking modifications ready for printing. The user can now print this object and attach the OptiTrack markers.

2.3.2 Mixed Reality Integration. The users can import the model produced by TrackItPipe into Unity and use our scripts to connect to the selected tracking system in Chapter 2.2.1. The user can easily access the pre-defined Points-of-Interests and make use of their posture. As shown in Figure 2, the user implements line drawing using the position data from the pen's tip. In addition, the point-of-interest of the eraser is mapped to deletion of content.

2.4 Implementation Details

TrackItPipe uses Qt and OpenSceneGraph. We further rely on the 3MF format as it stores meta-information directly inside the same file, enabling us to closely tie object and tracking modification together. We store the tracking modifications as JSON which allows users to easily alter modifications or add tracking systems later on. After export, the modifications and 3D model are rendered into a 3D-printable model. In addition, the tool creates a unity object,

useful for integration into Unity with the provided integration scripts that connect to the respective tracking system.

Such tools allow non-expert user to grab a 3D model from the internet or other source and turn them into smart objects, being interactable [2, 21, 24] or trackable. This enables researcher to quickly produce and evaluate 3D printed haptic Mixed Reality Objects, allow for faster and more object iterations.

3 LIMITATIONS AND FUTURE WORK

TrackItPipe makes it faster and easier to add tracking capabilities to ordinary 3d printable objects compared. Yet, the introduced tracking modifications are not able to automatically adapt to object changes. Because these modifications are usually placed at locations not used while interacting with the object, their structure will most likely not change much or at all between the cycles. This potentially allows automatic tracking modification carry-over between the object iterations. In future work, we plan to introduce automatic modification adaption on object updates. The user then just has to check if these automation produces feasible results, rather than recreating anything from scratch.

TrackItPipe can be expanded to integrate techniques to interact with the 3D printed object [7, 8, 21–23], which will allow users to not only receive posture information of their object, but also interactions, such as shape or touch input. This enables users to quickly fabricate controller objects for their Mixed Reality application.

4 CONCLUSION

This paper presented TrackItPipe, a tool-supported pipeline for providing tracking capabilities to 3D-printed objects. TrackItPipe empowers designers to quickly modify existing 3D models by semi-automatically adding modifications to integrate existing tracking methods, such as retro-reflective markers or SteamVR tracker. TrackItPipe allows users to export the modified model for 3D-printing, as well as a model that can be directly used within mixed reality applications. To foster and encourage further research in the community, we plan to publish the source code³.

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³<https://github.com/Dominik-Schoen/TrackItPipe>

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