Catch Me If You Can: Demonstrating Laser Tethering with Highly Mobile Targets

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ABSTRACT

Conventional wisdom holds that laser-based systems cannot handle mobility due to the strong directionality of laser light. We challenge this belief by presenting Lasertag, a generic system framework that tightly integrates laser steering with optical tracking to maintain laser connectivity with high-velocity targets. Lasertag creates a constantly connected, laser-based tether between the Lasertag core unit and a remote target, irrespective of the target's movement. Key elements of Lasertag include (1) a novel optical design that superimposes the optical paths of a steerable laser beam and an image sensor, (2) a lightweight optical tracking mechanism for passive retroreflective markers, (3) an automated mapping method to translate scene points to laser steering commands, and (4) a predictive steering algorithm that overcomes limited image sensor frame rates and laser steering delays to quadruple the steering rate up to 151 Hz. We demonstrate Lasertag's tethering capabilty with various mobile targets, such as a VR headset worn during active game play, a remotely-controlled moving robot, and more. Lasertag paves the way for laser applications in highly mobile settings.

CCS CONCEPTS

• **Hardware → Sensor applications and deployments**; **Sensor devices and platforms**.

1 INTRODUCTION

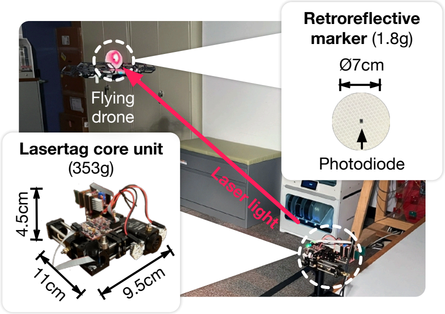

Figure 1: Lasertag maintains constant laser alignment with a flying drone equipped with a passive retroreflective marker.

The physical properties of laser light make it an excellent medium for communication [5, 7, 9], sensing [4, 8, 20, 23], and power delivery [10–12, 22]. Despite its potential, the inherent directionality of laser light has precluded its use in highly-mobile settings due to the difficulty of maintaining constant beam alignment. While diffusing the beam can mitigate this issue, it inevitably sacrifices supporting range and requires high-power laser diodes. On the other hand, scanning the narrow laser beam in search of the target [2, 14, 21] entails noticeable delays (e.g., hundreds of milliseconds[3]) or periodic breaks in the laser link [2, 13, 17–19], which is problematic for tracking fast motions (up to 100 m/s for large drones and up to 780 °/s [6] for human head motion).

A more efficient approach is to *separately* track the target's movement and then steer the laser beam directly to the target's location. While object tracking and laser steering are well-explored endeavours on their own, their integration is nontrivial on multiple fronts. First, the narrow-beam nature of laser light leads to a extremely low tolerance for localization errors. Even if the target is perfectly tracked, it is challenging to translate the object's 3D location to the 2D reference frame used by the laser-steering device. Additionally, mapping the steering device's input to an outgoing beam angle entails measurement overhead which is susceptible to human error. This is further complicated by additional optics (e.g., wide-angle lenses) used in portable laser-steering systems [2, 3, 15, 16], which affect both the tracking unit's perception of the scene and the laser beam's outgoing angle.

In this work, we present Lasertag, a reconfigurable system framework that addresses the above challenges. Lasertag tightly integrates laser steering and optical tracking in support of high mobility applications. As shown in Figure 1, Lasertag provides a laser-based tether between a laser diode emitting from the core unit and an arbitrary object, irrespective of the object's movement. Lasertag's contributions lie in a novel optical design that superimposes the optical

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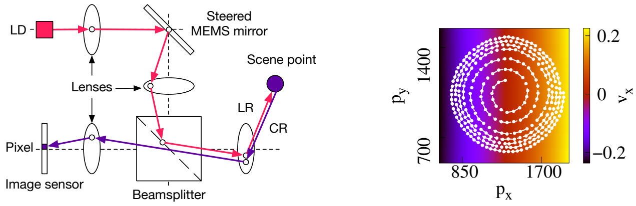

(a) Optical design (b) Mapping function

Figure 2: The optical design (a) of Lasertag enables outgoing laser light (red) to be mapped 1:1 to incoming scene light (purple). During calibration, Lasertag automatically steers the laser to each white dot and fits a polynomial surface to obtain *mapping functions* (b) capturing this relationship.

paths of a steerable laser beam and single image sensor, a lightweight optical tracking mechanism with retroreflective markers, an automated precise mapping between any point in the scene and the laser steering's input drive signal based on the physics of fluorescence, and a predictive steering algorithm that forecasts the target's location to boost the tracking rate. A demonstration video [1] of Lasertag is available at: **https://youtu.be/9JUNwBC88Ms**.

2 LASERTAG DESIGN OVERVIEW

Lasertag's design consists of four elements which together solve the aforementioned challenges facing the integration of object tracking with steering of a narrow laser beam.

Efficient Optical Path Sharing. To tackle the challenge of translating the localization reference frame to the laser steering reference frame, Lasertag incorporates a novel optical design that intrinsically fuses the two together, efficiently sharing the optical path between the outgoing laser light and a single image sensor. As shown in Figure 2a, we overlay the laser's outgoing optical path with an image sensor's incoming optical path ($CR+LR$) using a beamsplitter, which reflects laser light out of the system and transmits incoming scene light onto the image sensor. This optical arrangement creates a one-to-one mapping between image pixels and laser steering angles, enabling a streamlined approach to achieving 2D laser steering in 3D space.

Fluorescence-based Optical Mapping. To determine the relationship between pixels (p_x, p_y) and MEMS mirror voltages (v_x, v_y) specifying a laser steering angle, Lasertag performs an automated, one-time calibration process (Figure 2b). Notably, this calibration process leverages the physics of fluorescence to avoid internal interference and shift the outgoing laser's wavelength to one always visible by the image sensor.

Fast Tracking with Retroreflective Imaging. Upon deployment, the target object is equipped with a passive retroreflective marker with an embedded light sensor. The core unit illuminates the scene with infrared light, which the marker retroreflects back to the image sensor. In general, these retroreflections will be significantly brighter than other objects in the scene. Lasertag's custom computer vision-based marker detection algorithm leverages this characteristic to rapidly determine the pixel location of the target in each frame. The pixel location is then translated to a steering command via the mapping established during calibration.

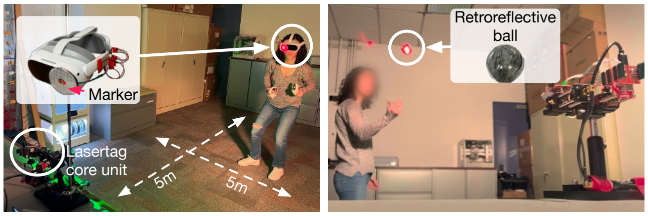

Figure 3: Demonstration setup, visualized in the contexts of laser VR and tracking of a retroreflective ball.

Predictive Steering for High Mobility. Finally, Lasertag employs a predictive steering algorithm to overcome (a) the limited frame rate of low-cost image sensors and (b) the non-negligible delays of laser steering devices. The predictive steering algorithm forecasts the target's future location, interpolates its intermediate locations, and proactively steers to the interpolated points until a new sensor reading is ready.

3 LASERTAG DEMONSTRATION

We will demonstrate Lasertag's ability to tether to (a) a VR headset during active gameplay, (b) several retroreflective objects (e.g., a ball and yo-yo) moving at high speeds, and (c) a remote-controlled robot (Figure 3). The calibrated Lasertag core unit will be connected to a laptop computer, and placed on a table facing an open space. Retroreflective markers will be attached to the various mobile objects, and Lasertag will maintain a laser tether with the objects as they move within the space. In the first application, the marker will be placed on a VR headset to demonstrate laser tethering during fast-paced gameplay. In the second scenario, the marker will be added to a ball or yo-yo, which is then moved by participants at various speeds with arbitrary trajectories. In the third scenario, a remote-controlled robot will be equipped with the marker and piloted at speeds up to 5 m/s. In all scenarios, the core unit will be equipped with a low-power visible laser, such that viewers can safely observe the beam's movement and gauge the system's tethering efficacy. We will also demonstrate Lasertag's robustness to ambient light interference and crowded backgrounds.

4 ACKNOWLEDGMENTS

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