Glint system integration into an IFE target tracking and engagement demonstration

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Abstract. In the High Average Power Laser (HAPL) program, we are developing an integrated target tracking and engagement system designed to track in three dimensions an IFE target traveling 50-100 m/s and to steer simulated driver beams so as to engage it at chamber center with ±20 μm accuracy. The system consists of separate axial and transverse target detection techniques, and a short-pulse "glint" laser to provide final steering instructions for beamlet alignment and target engagement by using the target itself as the final reference point.

The glint laser overfills the target with a pulsed illumination beam 1-2 ms before chamber center, thus reflecting a "glint" off the target in all directions. The glint return propagates back through the driver beamline and is collinear to the outgoing driver beam except for an offset determined by a wedged dichroic mirror. The wedged mirror accounts for the predefined transit distance of the target between the glint location and the driver beam arrival. This technique allows both the glint return and the driver beam to share a common path. Thus, the glint return represents the target's final position, but at a small discrete offset from chamber center, and therefore can be used to steer the driver beams to intercept the target at chamber center.

We are currently prototyping this tracking and engagement system on the tabletop at reduced speeds and dimensions to verify feasibility. All subsystems have been characterized and currently we are integrating the glint system into the tabletop demo and using the glint return signal to provide the final steering instructions for the mirror. The glint system's integration into the tracking and engagement demo and current engagement results are reported.

1. Introduction

In a direct-drive IFE power plant, targets must be injected into the chamber several times a second with a placement accuracy of ± 1 mm at a ~20 m standoff distance. An array of ~60 driver beams, each composed of 50 beamlets, must engage the target with an accuracy of ± 20 μm in three dimensions to generate favorable fusion conditions. Due to the possible variation in target placement accuracy, as well as the anticipated drift of the main driver beams, there must be a means of steering the beams onto the target, as well as a way of aligning all beams with each other.

Over the past few years we have developed new, in-chamber target tracking and engagement concepts [1] from the initial design [2] to meet these requirements and have assembled a tabletop experiment to demonstrate engagement of an injected target on-the-fly [3]. The tabletop experiment will demonstrate proof-of-principle at reduced speeds and distances and will establish the concepts' feasibility for a working power plant. Each subsystem has been verified and characterized separately, the final goal being to integrate all subsystems and to present a hit-on-the-fly demonstration that meets the ± 20 μm accuracy requirement.

2. System integration design

Figure 1 depicts the entire integration of the target tracking and engagement system for our tabletop demonstration. The glint system consists of the pulsed glint laser, wedged dichroic mirror, focusing mirror, and coincidence sensor. It should be noted that, while some systems and devices are useful for diagnostic and characterization purposes, they are not necessarily required for an operating power plant.

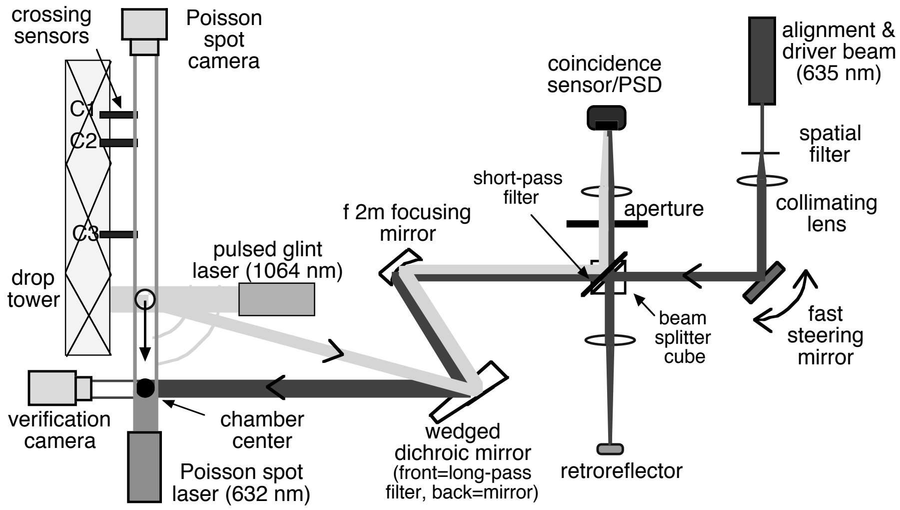

Figure 1. Integrated target engagement demonstration diagram

3. Tracking and engagement scenarios

There exist numerous tracking and engagement scenarios, each calling for different requirements on various subsystems [3]. One "ultra-fast" steering mirror scenario assumes that the chamber is relatively free of gas (<1 mTorr) and that the target can be injected/positioned to within 1 mm in all dimensions at chamber center. Consistent with these assumptions, the glint system alone may be able to provide the final steering information to the steering mirrors 1-2 ms before the target reaches chamber center. This, however, requires the mirrors to be capable of steering each beam possibly up a full 1 mm, and settling, in 1-2 ms. This is a difficult task for current mirror steering technology, especially with large (13x13 cm) mirrors likely needed for a power plant.

In our demonstration plan, we have also considered and pursued means of "pre-steering" the mirrors using information of the target's transverse position from the continuous Poisson spot tracking system [3]. This approach anticipates the target's trajectory during flight and pre-steers the mirrors to the target's predicted location, with the glint system providing a small, final correction to the mirrors. At the same time, the glint also closes the steering loop and aligns all the beams with one another by referencing them to the target itself. We are primarily pursuing the glint-only demonstration but are still continuing our effort on pre-steering since the final requirements of a power plant are not yet defined. In either case, a combination of tracking systems will aid in trouble-shooting and in initialization of a power plant.

4. Hit-on-the-fly tabletop demonstration sequence

The target is accelerated downward by gravity off the 1.5 m drop tower collinearly along the Poisson spot illumination beam (figure 1). The low-power diode laser (635 nm) serves two purposes – as the CW alignment beam, then as the pulsed simulated driver beam. Beginning in alignment mode, the laser passes through a spatial filter and collimating lens, which creates the simulated beam. Next, the alignment beam reflects off an Optics In Motion, 1 inch-diameter, fast steering mirror (FSM). It then passes through a beam splitter cube where half the light continues straight ahead to chamber center while the other half goes into a cat's eye retroreflector, which reflects the beam directly back upon itself and into the coincidence sensor tube. A lens focuses the alignment beam onto a 4mm-square position sensitive detector (PSD). The center of the PSD is key in that it represents the center of the chamber, so the outgoing remainder of the beam will be pointed exactly at chamber center. In alignment mode, the FSM keeps the alignment beam centered on the PSD through an active feedback steering loop in LabView to mitigate any thermal fluctuations or vibrations.

As the target falls through the crossing sensors, the timing and trigger system computes its instantaneous velocity and an on-the-fly timing prediction as to when to fire the glint laser in order to overfill the target (accurate to 45 μm, 1σ). For our demonstration, this occurs 3 cm before chamber center. By this time, the target has reached a velocity of ~5.5 m/s, which allows ~6 ms to perform the glint operation, computer the necessary steering, and steer the FSM. Before the glint laser fires, the alignment beam is turned off and the FSM holds its last steering command. The glint laser, a New Wave Orion 1064 nm 35 mJ Nd:YAG laser, is pulsed to overfill and illuminate the falling target, and as a result, light is reflected uniformly over 4π steradians. A portion of the glint return propagates backward through the driver beam line by reflecting off the back surface of the wedged dichroic mirror. The simulated wedge is composed of a long-pass filter backed by a 2-inch aluminum mirror. The wedged dichroic mirror is designed in such a way that the small angle precisely compensates for the offset distance between the target at the glint location and at chamber center. The glint return signal, which is common path to the driver beam except for the fixed wedge, represents the target's location *as if* it were at chamber center.

The glint return is collimated after reflecting off the focusing mirror, is reflected off the short-pass filter into the coincidence sensor, and is then focused onto the PSD. Here, the sharply-peaked temporal voltage readings portraying the x and y location of the glint return are analyzed by an analog averaging and holding circuit, which averages them for 10 μs to reduce the noise and then holds those values for LabView to read. The circuit is employed because it is crucial that the voltages are consistently read off the PSD in the same manner and at the same time every shot.

The disparity between the glint return and the alignment beam centered on the PSD represents how far off the target will be from chamber center. The system now has ~6 ms (the time it takes for the target to fall from the glinted location to the chamber center) to compute and steer the driver beam to coincide with the glint return signal, i.e. steer the driver beam to the location the target will occupy at chamber center. The steering command is issued from LabView via a calibration curve that has been computed beforehand by moving a stationary target on a stage, glinting it, and applying the necessary steering voltage to reengage the target. The FSM steers the required amount and settles to the step response in ~5 ms. Now, at the appropriate time in the timing sequence, the driver beam is pulsed (now in driver beam mode) to engage the target. At the same instant, the verification camera is triggered to take a snapshot of the engagement at chamber center as shown in figure 2.

5. Target engagement verification system

For our hit-on-the-fly demonstration, we cannot use a thermo-nuclear explosion to rate engagement success, so it becomes imperative to have a means for verifying accurate target engagement. We have devised a verification system (incorporating the aforementioned driver/verification beam), which uses a triggerable Basler camera to take a snapshot of the simulated driver beam pulse overfilling the falling target at chamber center (figure 2). By comparing the centroid of the driver beam to the centroid of the shadow of the engaged target, we can verify engagement with an accuracy of 12μm (1σ) over a range of 1 mm using LabView Vision software.

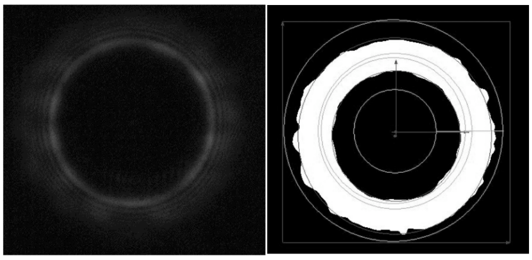

Figure 2. The centroid misalignment of the driver beam and engaged target provide engagement rating

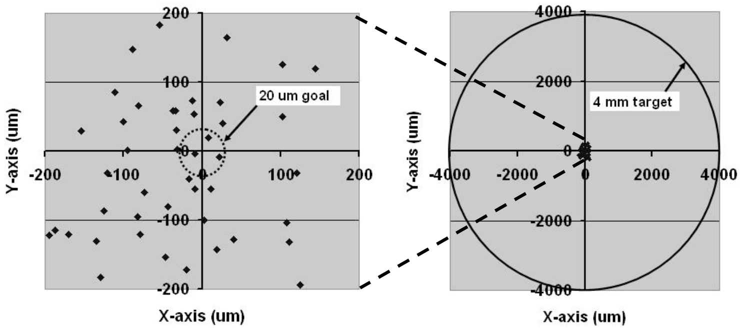

Figure 3. X,Y scatter plot of targets engaged by driver beam

6. Engagement results

We are currently able to engage targets to 150 μm (1σ) when their placement accuracy is ±1.5 mm from chamber center (figure 3). When only those targets with a placement accuracy of <1 mm are considered, then the engagement accuracy is 110 μm (1σ). This does not meet our 20-μm engagement goal, but the methodology remains promising as we continue to identify and eliminate all possible errors and uncertainties.

One crucial benchmark for quantifying engagement progress is to consider the glint return signal variation for a stationary target. Initially it was found that the glint return varied considerably from shot to shot. We have improved upon this variability by identifying and minimizing a host of effects that contribute to this error. We have considered and addressed such inconsistencies as thermal fluctuations and drift, ambient air disturbances, laser energy output variation, optic cleanliness, PSD response as well as FSM response and settling time. Additional factors such as the target's out-of-roundness and surface roughness, and the wedge angle also influence the glint return and must be accounted for.

7. Summary

The target tracking and engagement demonstration is fully integrated and operational for tracking and engaging targets, and is on the verge of meeting the accuracy requirement of a laser fusion facility, albeit at reduced distances and target velocity. The glint-only scenario has given encouraging result and we are striving now to improve upon the systems' inconsistencies to meet the ± 20 μm accuracy requirement. Long-term effort will focus on adding additional driver beamlines and integrating the system with a more powerful injector to achieve a prototypic target velocity of ~50 m/s.

Acknowledgments

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