Application of Coherent Laser Ranging to Characterize Object Geometry Changes in Large Fires

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Abstract: Coherent laser detection and ranging is applied to capture 3D images of objects placed in or behind large fires. A ranging precision of 300 µm through natural gas flame at a 6-meter stand-off is achieved.

OCIS codes: (280.3400) Laser range finder; (280.2470) Flames; (030.1670) Coherent optical effects; (110.6880) Three-dimensional image acquisition

We present coherent laser ranging as a measurement method that can 'see' through flames and capture in a contactless way three-dimensional (3D) shapes meters away at high precision and high update rate [1]. Prior to this study it was not clear how laser ranging in the form of FMCW LiDAR (Frequency Modulated Continuous Wave Light Detection and Ranging), which excels in high precision at meters of stand-off ranges [1,2] is affected by larger fires. Here we find that beam steering due to flames is mostly caused by the first air-flame interface in the beam path and that despite signal loss due to up to 1 meter of fire FMCW LiDAR is still able to capture 3D point clouds with a precision of 300 µm. Such measurements are critical to study the influence of fire on structures and to identify research, technology and regulatory needs to improve structure performance [3,4]. Such measurements are also of interest to determine flow resistance through vegetation canopy [5] where volumetric loss measurements are vital but so far cannot be obtained by existing means during the burning process.

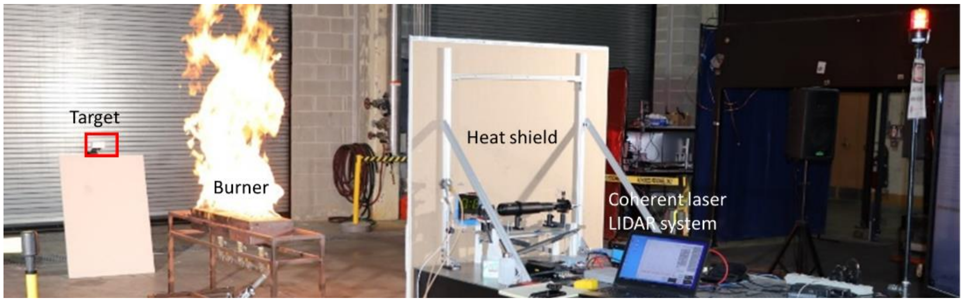

Fig. 1. Experimental setup. Target objects are placed either behind or in the flames produced by a natural gas burner. The FireLiDAR is protected by a heat shield with a quartz glass window. The laser light around 1550 nm from an FMCW LiDAR is coupled into free-space with a beam expander and is scanned across an object with a steering mirror.

The experimental setup is shown in Fig. 1. We use a commercial FMCW LiDAR unit from Bridger Photonics, Inc.[1] with an update rate of 4 kHz. An object (target) is hidden behind a wall of flames of up to ≈ 1 m. A fast steering mirror is scanning the laser over the target capturing a point cloud, that is then calibrated in x, y, and z to undo geometric distortions due to the beam scanning.

Figure 2 shows the influence of a big wall of flames of almost 1 meter on laser ranging. We apply spatial averaging, here on a 1 mm spatial grid to alleviate the beam steering of a 300 kW fire and can hence still extract step heights of 300 µm, which is only an order of magnitude less than in the case of no fire.

[1] Commercial products are identified in this paper to specify the procedures employed. In no case does such identification imply endorsement or recommendation by NIST, nor does it indicate that the products are necessarily the best available for the purpose.

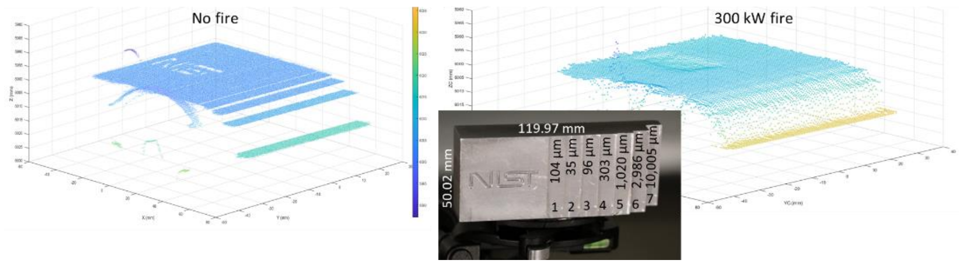

Fig. 2. Point clouds of aluminum stepped-block target at 6 m distance (false color for range). Middle part: block and indicated step heights. In the absence of fire each step down to 35 µm is captured (point cloud consists of 358,807 points). Through almost 1 meter of flames some steps are washed out but the overall shape is still visible. Here the shown point cloud consists of 12,000 points, obtained from spatial averages on a 1 mm grid to alleviate the influence of beam steering when ranging through flames.

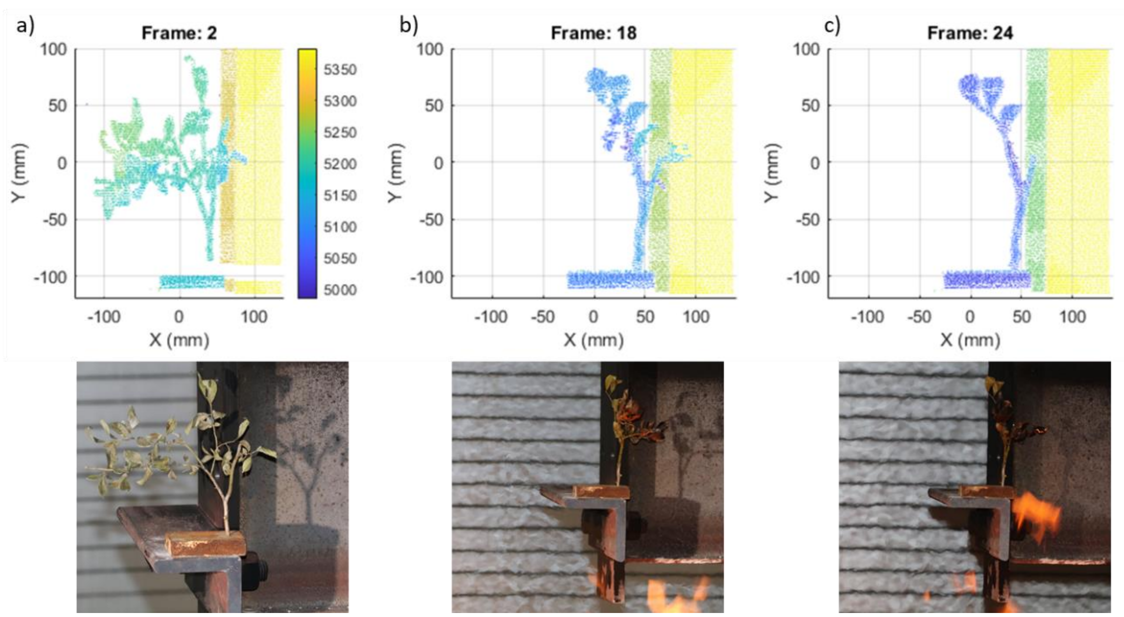

Fig. 3. Point clouds and photographs of a blueberry bush branch heated over a 100 kW fire (false color for range). a) 66 s after fire ignition. b) 600 s after fire ignition. b) 800 s after fire ignition.

Figure 3 shows a proof of principle measurement of how the shape in x, y, and z of burning vegetation can be captured at an update rate of 33 s per frame. We estimate the volume of the pre-burn bush to 25,946 mm^3 while illuminating from different angles. Even though our current laser ranging setup is not capable to capture volumetric shapes in real time, coherent laser ranging can show the relative loss of area in the field of view as burning progresses providing valuable information about the effect on wind drag, which is important to understand wildfire spread rates.

In conclusion we show that coherent laser ranging is applicable to precise contactless imaging through fire and when applying spatial averaging we can still achieve a precision of 300 µm. These results are obtained at longer stand-off distances and higher precision than other methods that can also measure distance through fire [6,7]. The update rate is sufficient to capture burning vegetation in real time and volumetric estimation can be achieved with the same setup before and after burning.

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