

# THREE DIMENSIONAL FLASH LADAR FOCAL PLANES AND TIME DEPENDENT IMAGING

ROGER STETTNER, HOWARD BAILEY AND STEVEN SILVERMAN

*Advanced Scientific Concepts, Inc.*

*305 E. Haley St.*

*Santa Barbara, CA 93103*

*[ASC@advancedscientificconcepts.com](mailto:ASC@advancedscientificconcepts.com)*

3-D flash lidar, herein defined as obtaining an entire frame of 3-D lidar data with one laser pulse, is an emerging technology with a number of advantages over conventional point scanner systems. Probably the most obvious advantage is the higher data rates possible and the potential for much higher data rates with increases in the associated 3-D focal planes array (FPA) format. High data rate means that topographical mapping, for example, can be obtained more rapidly decreasing the amount of flight time required. This paper investigates the clear but perhaps not-so-intuitive use of the high data rate: time dependent 3-D movies can be acquired at the repetition frequency of the associated laser. Data is taken using 3-D flash lidar cameras fabricated by Advanced Scientific Concepts, Inc. The paper concludes that there are a number of advantages and unique applications of the time dynamic 3-D flash lidar, including 3-D collision avoidance and object tracking.

## 1. Introduction and Instrument Description

The literature contains descriptions of developments in terrestrial and underwater 3-D flash lidar<sup>1,2,3,4</sup>. We summarize the most salient features: 3-D lidar imaging, using a single laser pulse for each frame of data requires 3-D focal plane arrays (FPA) incorporating rows and columns of pixels, similar to 2-D FPAs that are common in digital cameras today. Fig. 1 illustrates the 3-D FPA. Flash lidar cameras operate and appear very much like these conventional 2-D digital cameras with smart pixels substituted for simple signal integrators; each pixel can accurately and independently count time to the target. A broad area, short, laser pulse replaces the flash of the 2-D camera. The out-going laser pulse, passes through transmission optics, is reflected from a target and focused on the 3-D focal plane by means of a receiver lens where the independent pixel clocks are stopped. The time between the launching of the pulse and the return is proportional to the range via the velocity of light. Fig. 2 illustrates the size and function of a hand held 3-D flash lidar system that could be gimbal or vehicle mounted and was used to collect most of the data presented in the paper. Fig. 3 is an example of a 3-D image taken with the Fig. 2 camera. There are six 128 x 128 frames, taken with six laser pulses, stitched together. Bore-sighted 2-D visible data is overlaid. The value of 3-D imaging and reconnaissance is evident in the images: the 3-D image contains far more quantitative information than is present in the 2-D image

Photons focused, by the receiver optics, on the detector array chip of the FPA hybrid in Fig.1 generate electron hole pairs proportional to the number of photons. The resulting detector current, which has the time dependence of the photon pulse, passes through the detector array into the Readout Integrated Circuit (ROIC) chip unit cells through the metal bumps. This current is converted to a voltage by the unit cell input amplifier and sampled after a clock is stopped when a threshold is reached. The latter process is carried on independently in each pixel. In an alternate operational mode the pulse is sampled at a programmed time in all pixels simultaneously.

Fig. 2 illustrates the ASC 3-D camera configuration. The Fig. 1 FPA is located behind the receive optics just as in a conventional 2-D camera. The volume of the vented air-cooled laser compartment is largely taken up by fans and associated cooling components. The laser itself is very compact and lightweight. The electronics compartment containing the laser power supply and output electronics is behind the laser compartment. A laser pulse is triggered from a laptop through control software and the pixel clocks are started when the laser pulse is emitted through the transmitter optics. The laser pulse strikes an extended target and the reflected pulse enters the receiver optics and is focused on the FPA pixels associated with the target. Both digital and analog data is readout during the laser interpulse period and transferred to the laptop computer where the data processing is completed, the data stored and the image displayed, if desired. The software can display the data time slices as a sequential movie and various operations can be implemented; elimination the imaged objects based upon range for example. It should be noted that the camera design was not optimized for low weight or low volume and could be lighter or smaller; the glass lens weighs over five lbs for example. Two-dimensional cameras are typically boresighted with the 3-D camera for higher resolution 2-D texturing. Although more difficult to design and expensive to fabricate, it is obvious that a single aperture could suffice for both the 3-D and 2-D cameras and even the laser.

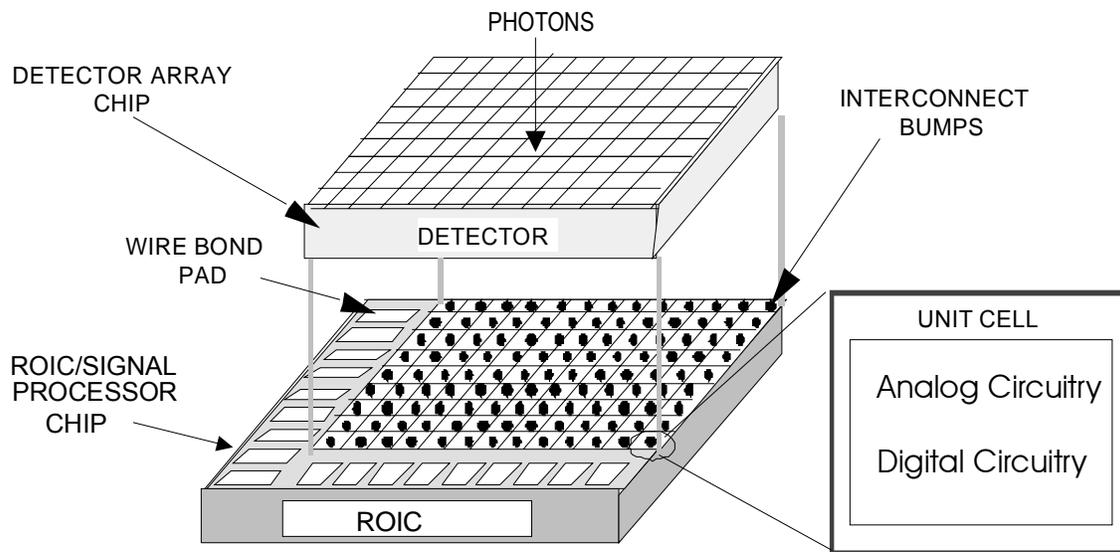


Fig. 1. 3-D FPA Hybrid Design. ASC-designed ROIC (Readout) bump bonded to detector array chip (Detector).

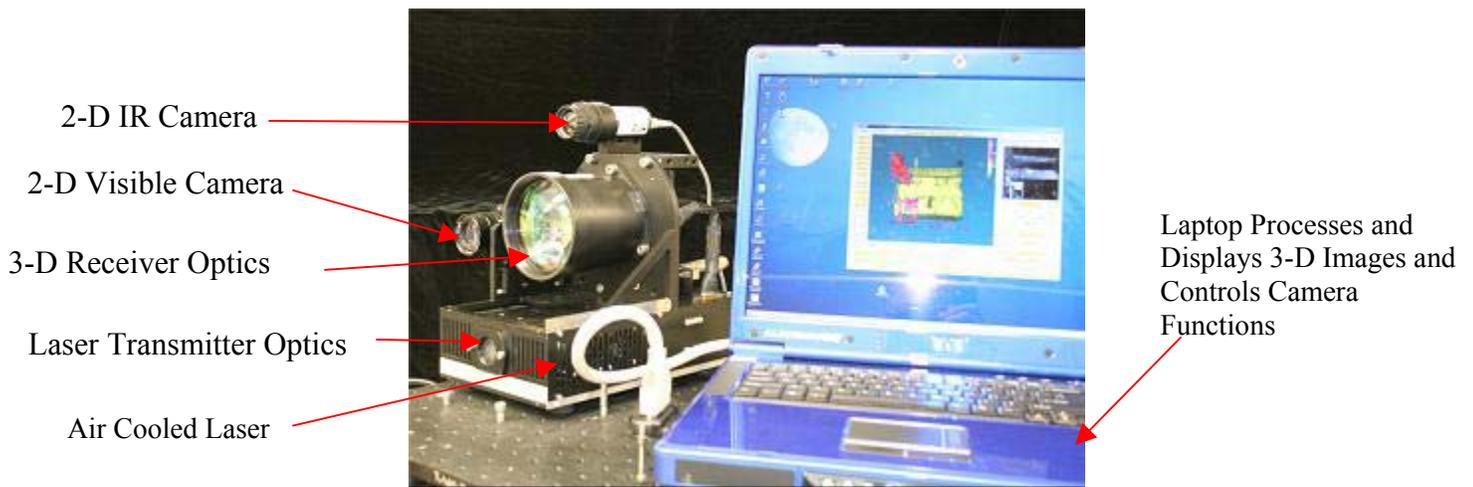


Fig. 2. Handheld ASC 3-D Flash Ladar Camera, 22 mJ, 30 Hz, 1.57  $\mu$ m Laser. Lenses are interchangeable with a total camera weight of 12 lbs. Capable of 1 km Range. Camera power requirement is less than 50 Watts. No attempt was made to minimize volume, weight or power. Field of view is determined by the optics just as in a 2-D camera.

Various operational modes of the ROIC can be implemented by means of the control software: the trigger mode where all pixels operate independently, a delay-trigger mode where the trigger mode is made operational only after a specified range and a gated mode where the trigger is suppressed and only the pulse sampling occurs in all pixels simultaneously after a programmed range. This latter mode is appropriate for penetrating water and obscuration where the return from the obscuration's surface could trigger all the pixels. For the data discussed in this paper only the trigger mode was used.

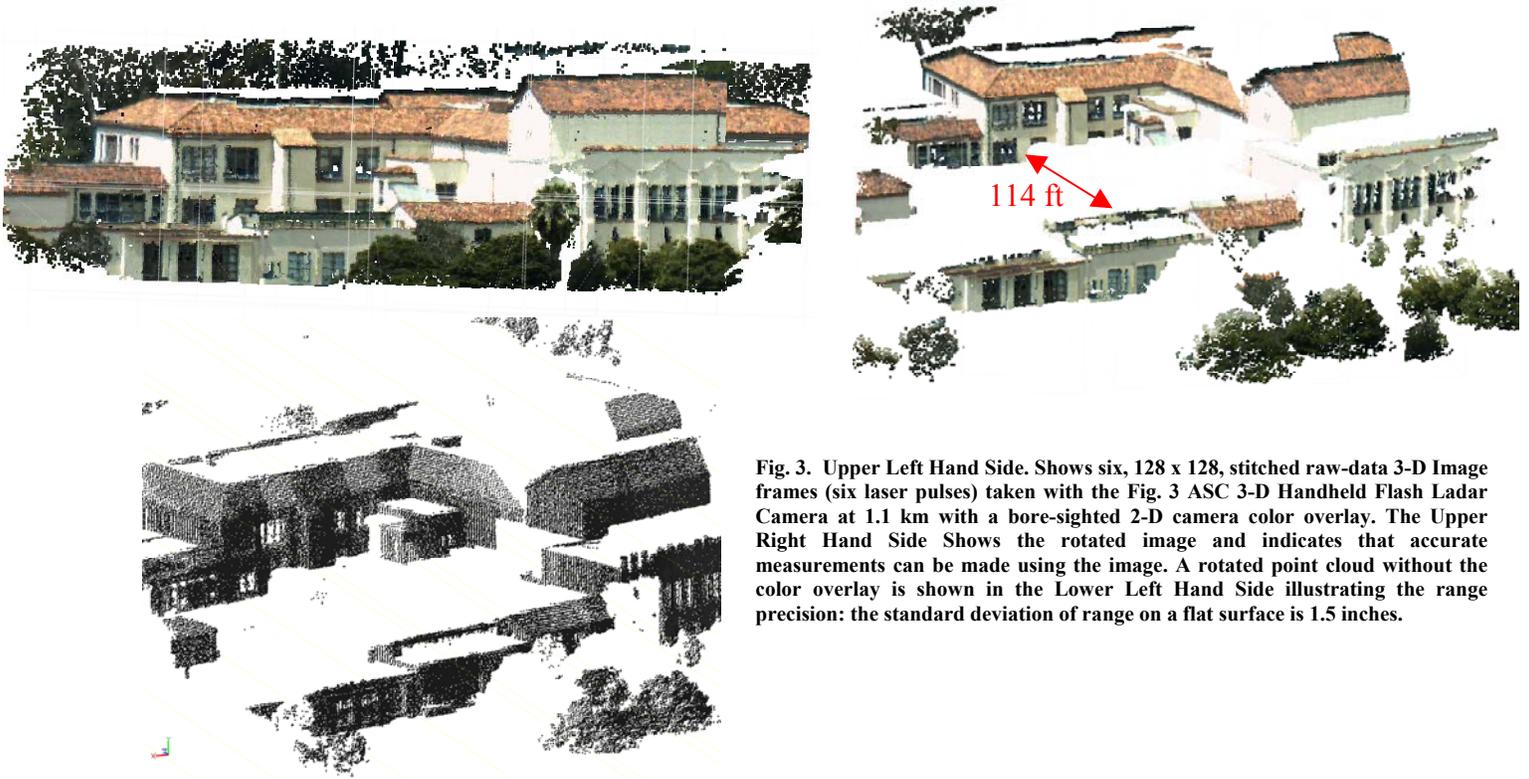


Fig. 3. Upper Left Hand Side. Shows six, 128 x 128, stitched raw-data 3-D Image frames (six laser pulses) taken with the Fig. 3 ASC 3-D Handheld Flash Ladar Camera at 1.1 km with a bore-sighted 2-D camera color overlay. The Upper Right Hand Side Shows the rotated image and indicates that accurate measurements can be made using the image. A rotated point cloud without the color overlay is shown in the Lower Left Hand Side illustrating the range precision: the standard deviation of range on a flat surface is 1.5 inches.

Fig. 3 is a static 3-D image generated by six laser pulses: The upper left hand side shows what would be available from just a color 2-D photograph. The upper right hand side shows how much more information is contained in the 3-D color-textured image: all the dimensions and accurate spatial relationships among the objects in the image. The lower left hand image shows 3-D image without color texturing. Fig. 3 also illustrates how 3-D data will be represented in this paper: two of the infinite 2-D orientations of the 3-D volume are presented.

## 2. Dynamic Data

The Fig. 2 camera can operate at 30 Hz and as a result can capture time dependent or dynamic scenes in three dimensions. Fig. 4 shows a few frames of a birds-in-flight 3-D movie at two different orientations and not only illustrates full four dimensional capture (x,y,z and time) but multi-object tracking capability: the x, y and z coordinates of each bird can be plotted and trajectory extrapolations developed in software. Furthermore the orientations of each bird with respect to the others can be ascertained. Sub-inch range precision is measured for foreground objects and is assumed for the moving objects. Although 30 Hz is certainly not adequate for very high-speed objects, higher speed FPAs and lasers can certainly be designed.

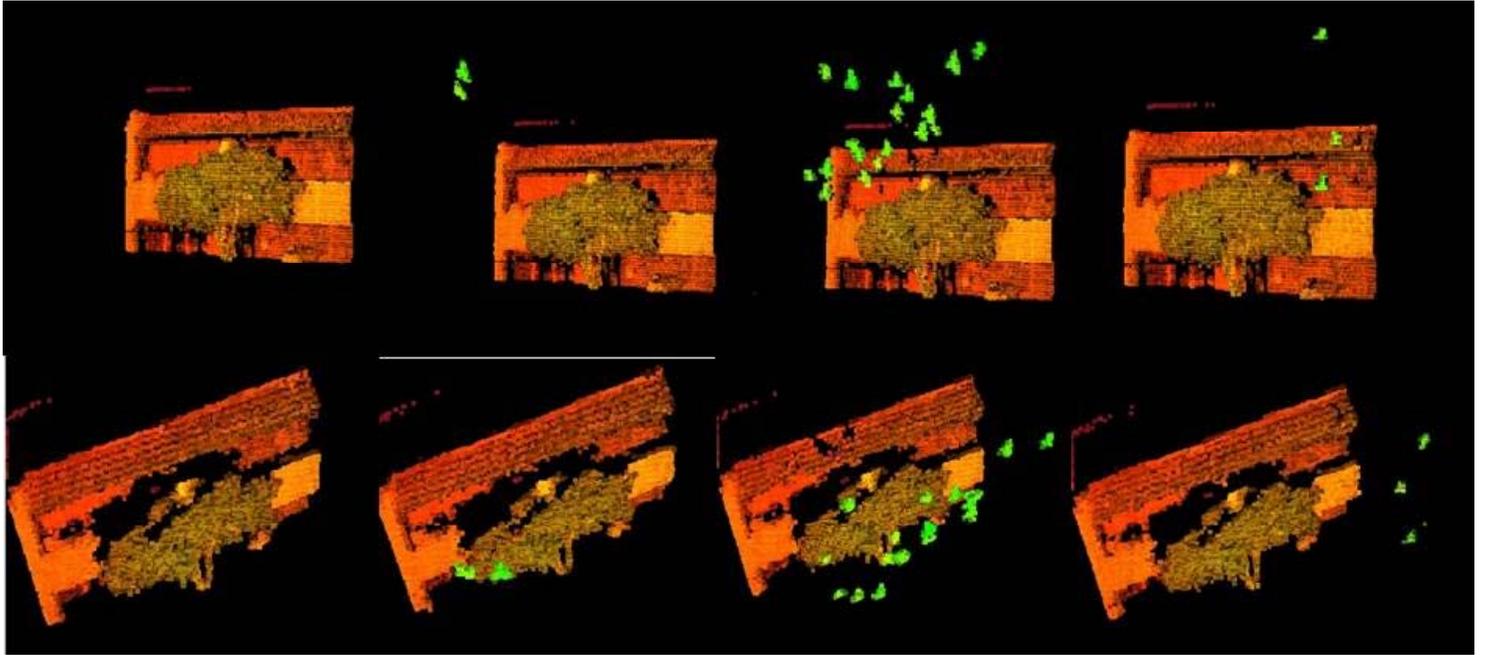


Fig. 4. Tracking a Flock of Birds: Four selected sequential 3-D frames, two orientations, side and top of the same 3-D 128 x 128 array data. Raw unprocessed data where range is color coded. Range is approximately 100 m. Fig. 5 is a 2-D color image of the foreground.



Fig. 5. 2-D color image of the Fig. 4 and Fig. 6 foregrounds.

Fig. 6 Illustrates the three-dimensional capture of objects common to collision avoidance circumstances within the same foreground as Fig. 4.

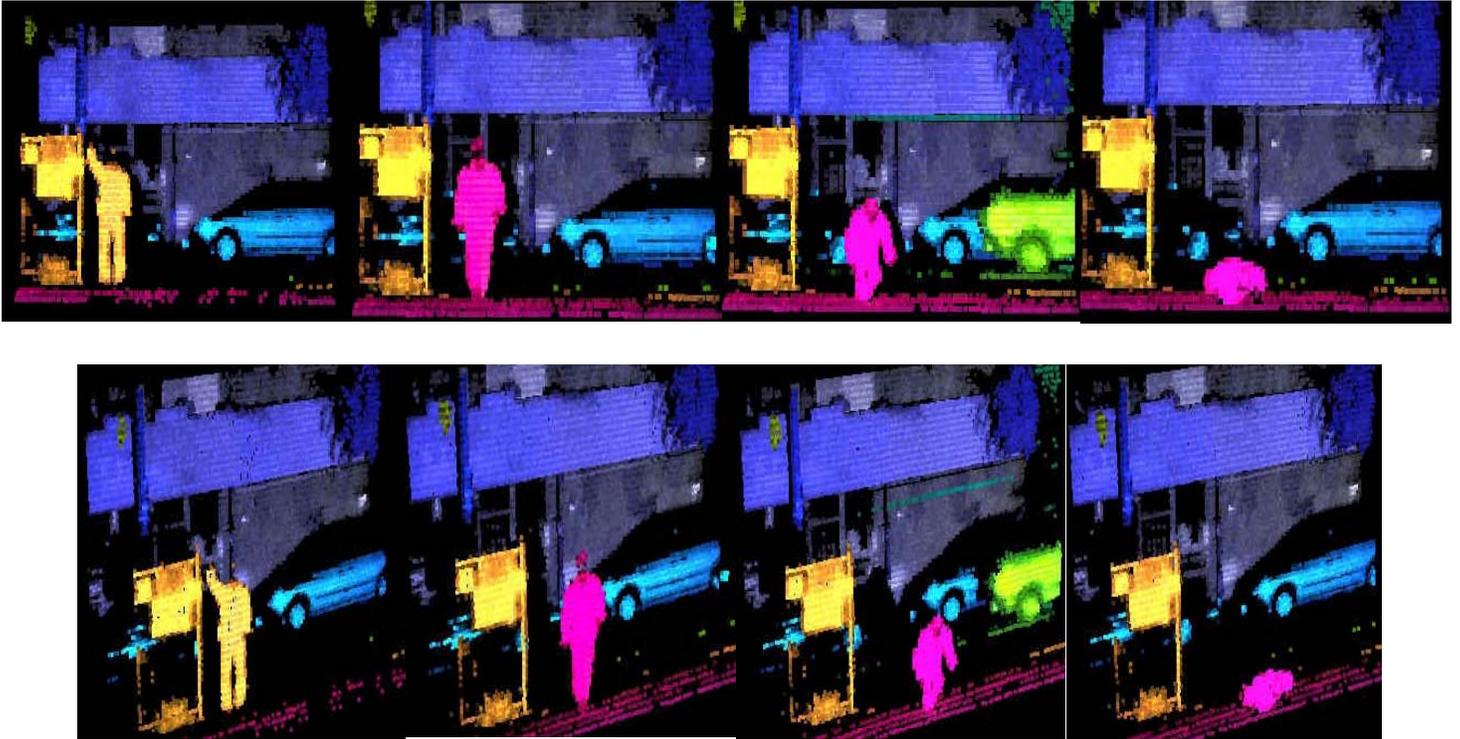


Fig. 7. Person Walking: Four selected sequential 3-D frames, two orientations, front and side of the same 3-D 128 x 128 array data. Raw, unprocessed data where range is color coded. Range is approximately 50 m. Fig. 5 is a 2-D color image of the foreground.

### 3. Conclusions and Recommendations

In this paper data is presented which clearly indicates that accurate three-dimensional data can be acquired a frame at a time with frame rates of at least 30 Hz using a flash lidar 3-D camera invented and fabricated by ASC. Each frame of data is acquired instantaneously with respect to the mechanical motion of the objects within the 3-D flash lidar camera field of view. Although only 50 – 100 m time dependent data was presented, the static image at 1 km suggests that this data could also be acquired a many kms. The current camera has an FPA of 128 x 128 pixels but there is no technological limitation restricting the array size. Furthermore, although in general larger arrays take longer to readout, 30 Hz is certainly not the upper bound frame rate and the camera can quantitatively describe high-speed or rapidly contorting objects.

Applications of the 3-D flash camera abound and are seemingly limited only by imagination. However, the camera appears to offer an immediate breakthrough in collision avoidance or navigation of unmanned or manned vehicles. Vehicle motion can distort the 3-D image of conventionally scanned lidar system which collect a full data frame over time rather than instantaneously. By making a precision scanner unnecessary, 3-D flash lidar systems offer low weight, small size, high reliability, optical zooming and eventually low price.

### 4. References

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