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Design of an Infrared Camera Based Aircraft Detection System for Laser Guide Star Installations

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For laser guide star installations above a few watts in average power, the irradiance of the beam exceeds the ANSI[1] standards for eye safety and an aircraft detection system is required to insure that pilots or passengers are not blinded. Even for powers lower than this level, numerous incidents of temporary flash blindness have been observed[2] and pose a threat to the safety of aircraft. LLNL has deployed two laser guide star systems[3,4] and has obtained permits from the Federal Aviation Association which insure safe operation of these lasers. These aircraft detection systems use a combination of a rotating search radar, a narrow angle, boresight radar and visual observers to provide a triple layer of detection, each with its own access to the laser safety shutter.

For the installation of a 20 W for the generation of sodium-layer beacons at the 10 m Keck Observatory on Mauna Kea, the presence of active radars is not desirable. The reasons for this are possible interference with sensitive optical instruments at or near the Keck telescope and the presence of millimeter wave radio telescopes, also on the Mauna Kea site. An alternative for the active radar are passive near infrared cameras. Such cameras are commercially available using focal plane arrays of either Indium Antimonide (InSb) or Platinum Silicide (PtSi) which are sensitive in the 3-5 micron band.

There are many advantages to passive infrared cameras. These commercial cameras, operating at video frame rates, cannot detect stellar or planetary sources; this greatly reduces and in some applications eliminates altogether the signal processing required. The contrast between the cold night sky background and the hot exhaust emission of jet or piston aircraft engines is high so that the detection range of infrared equals or exceeds many small radars. The possibility of an aircraft not having lights as, for example, in the case of illegal or disabled aircraft, does not affect the detection scheme. Finally, infrared cameras can provide some penetration in haze and light cloud cover which can severely limit the detection capability of a visible camera.

Two infrared cameras have been tested at LLNL, one with a 256x256 pixel InSb array[5], and the other with a 512x512 pixel PtSi array[6]. Tests were carried out in conjunction with a LLNL search radar to provide slant range information on detected aircraft. With both cameras, once the aircraft was resolved across more than one pixel it was easily visible, and even unresolved aircraft could be detected out to ranges of 10-12 miles. The InSb camera could in fact easily detect large commercial aircraft out to ranges of 20 miles or more, and small single-engine aircraft at ranges of 12 miles. Aircraft were somewhat easier to detect from the rear then when approaching. Since air traffic was relatively low during these nighttime tests, and visibility somewhat limited by buildings at the LLNL sight, all possible combinations of aircraft size and distance were not tested. However, the IR cameras detected essentially every target within line of sight that could be detected by the radar. The PtSi camera did have some difficulty with very small aircraft seen from the front at ranges of greater than 6 miles. These tests were carried out with no signal processing whatsoever - aircraft were easily visible on the direct video output of the camera. More sophisticated target-detection algorithms operating on the digital output of the camera would provide even greater detection ranges. Both these cameras are extremely simple to operate, with self-contained closed-cycle coolers and both direct video and digital data readout.

With current technology a trade-off exists between InSb arrays, which are significantly more sensitive, and PtSi arrays, which are available in larger formats (512x512 pixels vs. 256x256.) Careful consideration must be given to selecting the best array for a particular purpose. For our application we prefer the InSb camera for the boresight sensor, to maximize sensitivity over a narrow field of view, and possibly the PtSi array for the wide-angle search application.

For the narrow angle, boresight application, a 7-10° field of view lens is sufficient and is readily available as a commercially supplied item. The camera would be located adjacent to the projection lens of the guide star laser system and would not be required to move. The camera would be enclosed in a box with heaters to prevent damage during cold nights. No software other than a threshold detector is required and the laser shutter would simply be closed if any aircraft entered the narrow angle field of view. The laser shutter system is sufficiently fast as to close the beam before an aircraft enters the center of the field of view where the laser beam is.

For the wide angle search function, there are several options. The camera should be located on top of the dome and would need to be shielded from the elements as well as heated when necessary. To cover the entire sky either the camera or a mirror/lens system could be scanned about the vertical axis. A better option in terms of low maintenance would be to use a hemispherical lens with full 180° coverage or a "panoramic" lens with has full azimuth coverage but has a hole centered about zenith. Most search radars also have this blind spot directly overhead. LLNL has designed both these lenses for other programs and designs at a commercial optical vendor presently exist[7]. Although these lenses are expensive, they may the least expensive option when maintenance and software costs are folded in the estimate.

Even in a low-traffic area such as Mauna Kea the all-sky system could not simply shut down every time it detects an aircraft, since it will be sensitive to aircraft 10-20 miles away that may be in no danger from the laser. Either a human will have to monitor the all-sky display or a more sophisticated algorithm will have to be used, defining a cone or cylinder surrounding the laser beam. One disadvantage of passive infrared systems is that they provide no direct range information. However, once a target is close enough to be resolved (even if it spans only 2-3 pixels) its surface brightness per unit angle can be determined. Surface brightness is of course independent of range, and can be used to distinguish the hotter exhaust of jet aircraft from small propeller-driven aircraft. This classification can then be used together with the angular size of the target to provide an estimate of the range. For this reason we prefer the large-format PtSi array for wide-angle search application. For an all-sky application the PtSi array may be better, since it could resolve targets at a greater range.

The use of passive infrared cameras for aircraft detection has been discussed with officials at the FAA and has received a positive response; the burden of demonstrating the effectiveness of such systems remains, as always, with the laser group. A plan to purchase the InSb camera for the boresight camera and test the concept both at LLNL and the laser installation at the Lick Observatory has been formulated. Simulation of the wide-angle camera system to decide the optimal target detection and laser shutdown algorithms are being conducted. After detailed design, a camera and lens system will be purchased for the wide angle camera and tests will be repeated at the same locations. The FAA will be invited to witness both demonstrations prior to the filing of a formal permit for laser operation.

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