Boresighting of laser range finder or designator systems with and without laser/FLIR synchronization

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ABSTRACT

We have conducted experiments to prove feasibility of a boresighting method between a laser and a Forward Looking Infra-Red (FLIR) system, which has the advantage of working with or without synchronization between the laser pulses and the FLIR scanning. The method is based on the Thermal Target concept (TT); the laser energy is focused on a special substrate which is locally heated and produces a point image on the FLIR screen with respect to the FLIR line of sight which is boresighted. Resistance to laser damage by the required pulse energy densities was established by target lifetime measurements.

The TT method can be also used for real time boresighting of the laser with the FLIR, which means that the boresighting is done while looking at the scenery.

1. INTRODUCTION

The concept of laser boresighting with a FLIR, for weapon delivery systems, has been described in the literature[1-3]. The method is based on focusing a laser beam through a collimator onto an absorbing material (i.e. thermal target), which is heated to high temperature in a small region. The infrared radiation re-emitted by the hot region is collimated in a direction parallel but opposite to the incoming laser and appears on the FLIR screen as a bright spot (Fig. 1 shows a simplified diagram of the concept). Boresighting of the laser with the FLIR can be performed manually or automatically by rotating the laser, the sighting instrument or their electronic crosshairs until the various lines of sight are centered with one another.

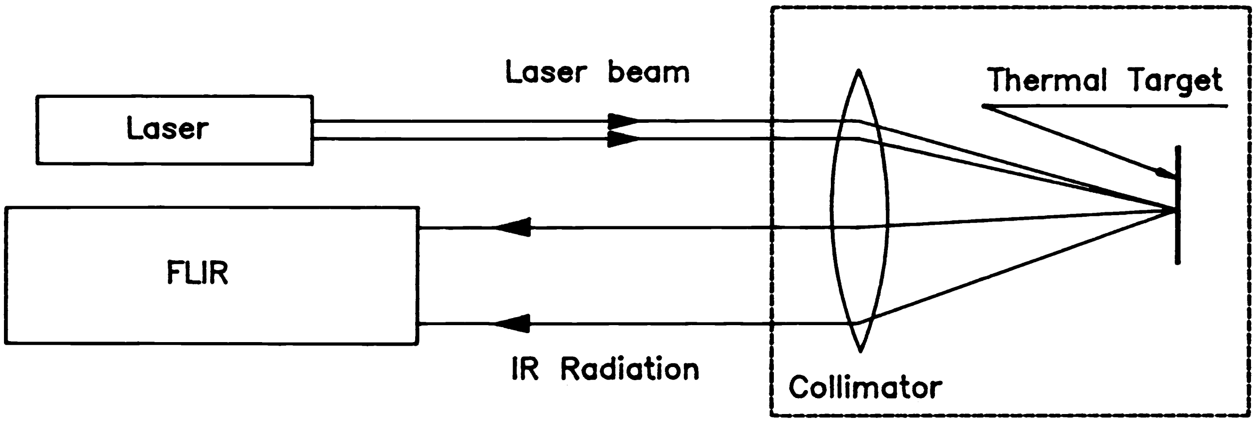


Figure 1. Schematic diagram of boresighting using the TT method.

It has been shown, both experimentally and by numerical analysis, that the effective temperature difference between the heat spot and its surroundings drops below 10C after approximately 30 msec. Such a long decay time is important in order for the FLIR to detect the heat spot with or without synchronization of the laser pulses with the FLIR scanning. The difference between these cases is that by using synchronization, a stronger signal is obtained on the FLIR screen, therefore less energy is required. This ensures a longer TT lifetime. However, synchronization is cumbersome and sometimes impossible in practical situations in which case our method may still prove effective.

The estimated boresight accuracy was predicted to be about 0.1 mrad. The size of the spot is determined primarily by the laser divergence, but there are additional broadening effects which come in to play such as diffraction, quality of the optics used to focus the laser and spreading of the heat spot due to heat conduction in the thermal target.

Lifetime measurements of the thermal target were also carried out by repeated irradiation of a single spot on the thermal target.

2. CONCEPT

Consider the laser-FLIR boresight configuration depicted in Fig. 2. The laser is attenuated by an appropriate ND filter, enters the Boresight Collimator (BC), schematically represented in Fig. 2 by a lens, and is focused onto a small spot on the TT absorbing material. Incident radiation is strongly absorbed (an A.R. coating is used to minimize reflection) resulting in local heating well above ambient.

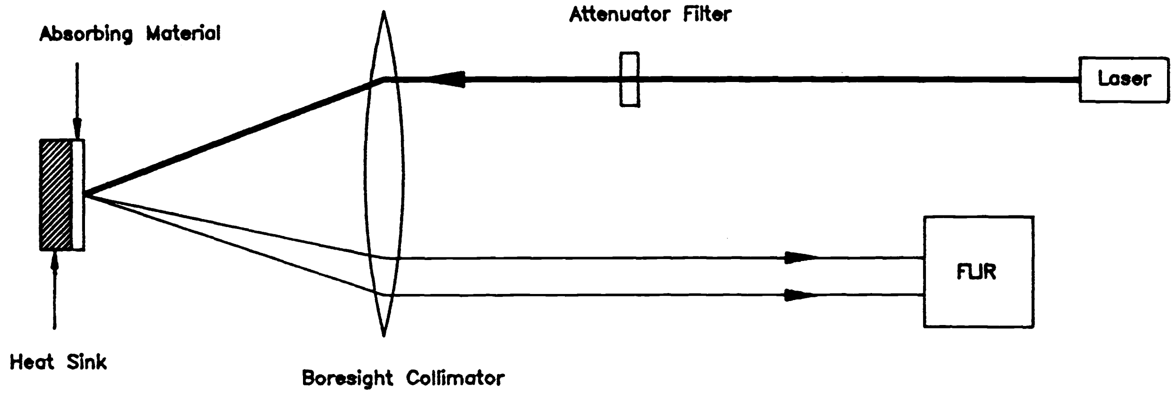


Figure 2. Boresight configuration.

The heat generated in the spot is dissipated, partially by radiation, but mostly by thermal conduction in the absorbing material. Since typical laser pulse durations are short compared with thermal diffusion times, the resulting temporal profiles are characterized by a very steep temperature rise followed by a slower (typically exponential) decay in spot temperature. The amount of infrared radiation which is emitted at any time and detected by the FLIR from the heat spot depends on its temperature and on the TT emissivity in the 8 to 12 μm wavelength range.
In principle the heat spot spreads in all three dimensions, laterally, parallel to the TT surface, and perpendicular to the surface, into the bulk of the material. This effect brings about a fine interplay between the decay time of the heat spot and the lateral spreading: there is a danger that if the lateral conductivity is too large and the decay time too long, the heat spot will appear too large on the FLIR screen and therefore the required boresight accuracy will not be achieved. On the other hand, if the decay time is too short, the FLIR may not see the spot.

In order to minimize these problems, a configuration with anisotropic thermal properties has been developed, which has a low conductivity laterally and high conductivity perpendicular to the thermal target surface. This idea was implemented by coupling two plates of different materials, represented in Fig. 2 by dashed and empty regions. The absorbing side material is the empty region, and is characterized by low conductivity; it strongly absorbs at the laser wavelength, and has high emissivity in the 8-12 μm range. The dashed region is a material of high thermal conductivity, which acts as a heat sink by spreading the heat that reaches it into a large volume in a short time.

The thickness of the absorbing side is also important: it must be large enough to absorb sufficient laser energy, but must be thin enough so that the time taken by the heat pulse to reach the heat sink is not too long. In fact, it should be just long enough to be seen by the FLIR and to cool down before the arrival of the next laser pulse, so as to avoid staircase heating. The thermal target design considerations are summarized in Table 1.

Table 1. TT design considerations

Design consideration	Relevant Parameters
Absorption of laser radiation	Absorption depth at laser λ, A.R. coating
Re-emission of TT radiation	Emissivity at 8-12 μm
Minimal thermal spreading	Thermal conductivity, heat sink
Suitable thermal decay time	" " "
Laser damage	Damage threshold
Durability	A. R. coating

3. EXPERIMENTAL SET-UP AND RESULTS

The experimental set-up used to implement the focusing of the laser and the imaging of the re-emitted radiation is shown in Fig. 3. The laser is first reflected by the two diagonal flat mirrors M1 and M2, then focused by a spherical mirror S and an additional flat mirror M3 onto the TT. Re-emitted IR radiation from the TT is reflected back by M3 and collimated by S into the FLIR.

The BC unit shown in Fig. 3 must be optically aligned so that the thermal target is in the focal plane of S. This ensures the highest possible boresighting accuracy and minimum pulse energy requirement for a given heat spot temperature. The laser pulse train was synchronized with the FLIR scanning using suitable electronics.

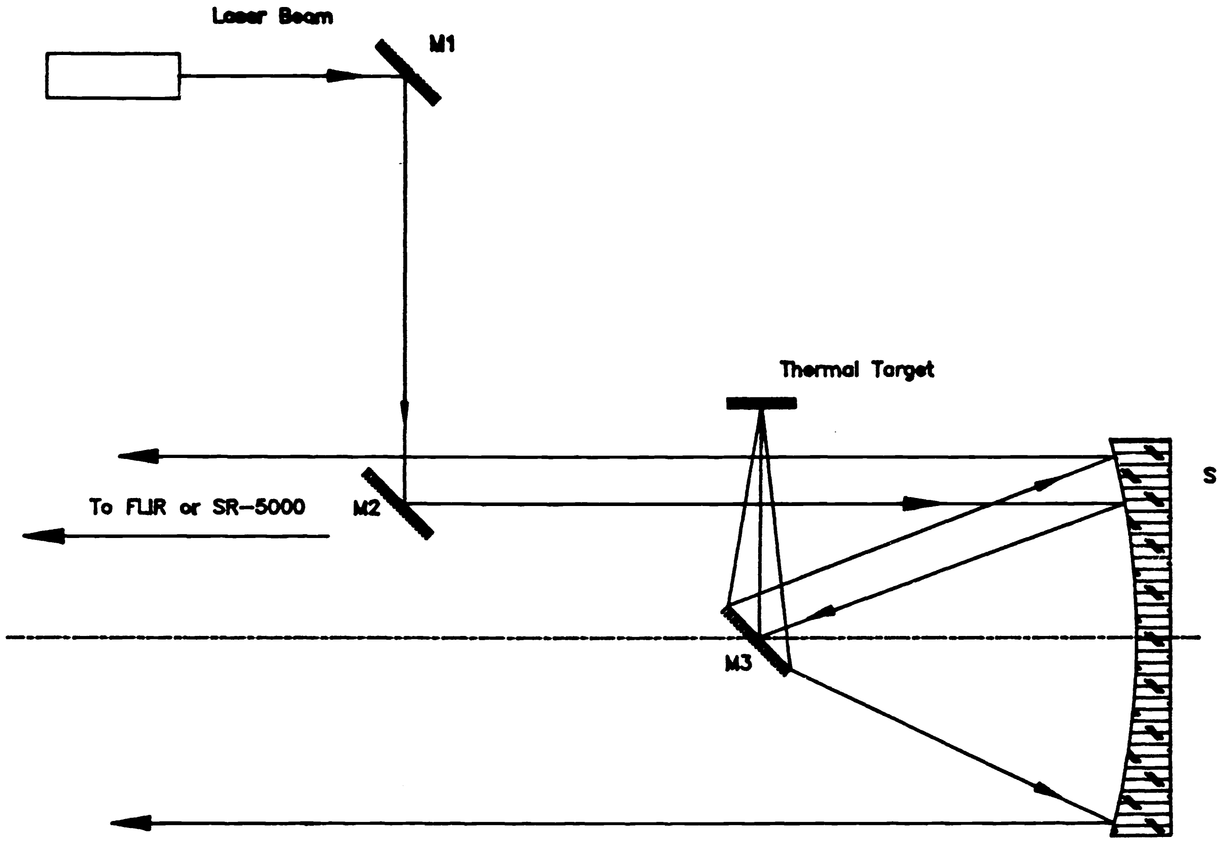
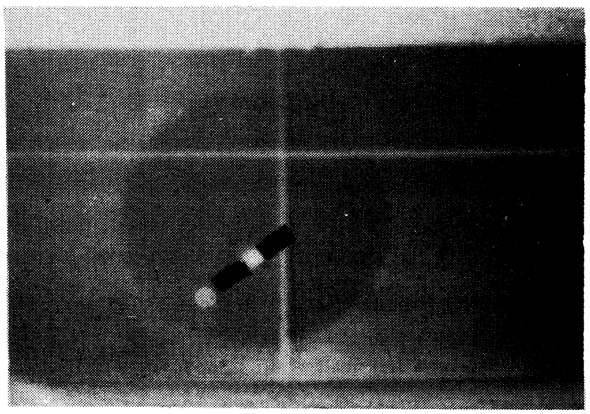
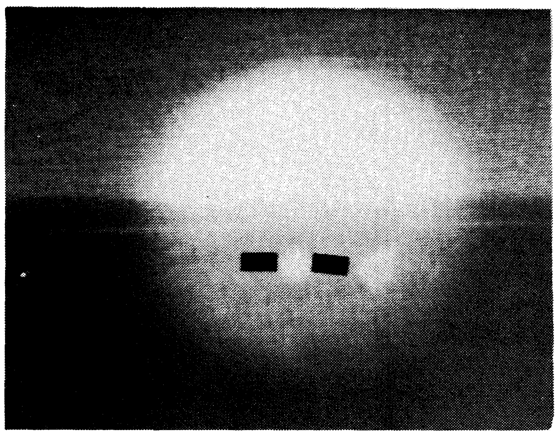


Figure 3. Thermal Target and optics set-up.

Figure 4 shows examples of the images seen by the FLIR.



(a)



(b)

Figure 4. Photographs of the heat spot observed by the FLIR.
(a) Wide field of view. (b) Narrow field of view.

It is possible to see the bright spot on the TT superimposed on the background of the TT substrate material. The heat spot is marked by arrows in both photographs (a) and (b). Fig. 4b shows a spurious imperfection on the substrate material.

Not clearly visible in the photographs of Fig. 4 is a calibrated reticle on the FLIR screen, on the basis of which the exact angular size of the heat spot can be easily calculated. The angular size of the heat spot was determined to be 0.7 mrad, resulting in a boresight accuracy attainable in practice of 0.1 mrad. The factor of seven is somewhat arbitrary, but follows from empirical knowledge and experience in boresighting in the field. A factor of ten is also sometimes used.

An alternative method used to investigate the TT behavior was to radiometrically monitor the infrared output from the heat spot as a function of time. To this end the FLIR as shown in Fig. 3 was replaced by a CI SR-5000 spectroradiometer[4]. Fig. 5 shows the signal obtained in the 8-12 μm range from the SR-5000. For alignment purposes the selected field of view of the radiometer was considerably larger than that of the heat spot, resulting in a somewhat noisy signal. The continuous curve in Fig. 5 is an exponential decay using a characteristic decay time of 19 msec.

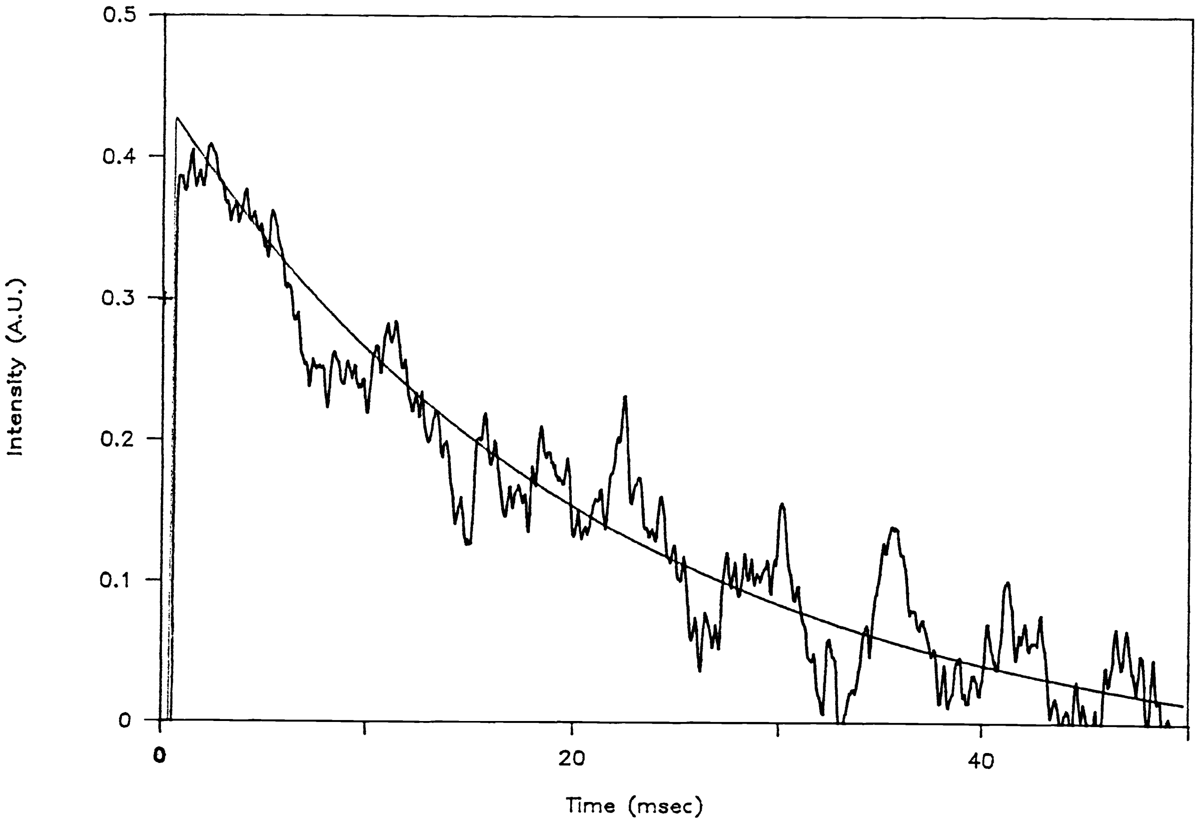


Figure 5. Time dependence of radiometer signal intensity from a single laser pulse on TT. The continuous curve is an exponential.

Lifetime measurements were carried out on the thermal target. Its surface was irradiated with laser pulses of energy three times grater than that required to obtain an image of the heat spot on the FLIR screen. After three hours at a frequency of ten pulse per second there was not perceptible change in either: a. The IR output as detected by the SR-5000 as describe above or b. the reflectivity of radiation spot on the target when inspected using brightfield optical microscopy.

4. ANALYSIS

The total spectral irradiance from a blackbody is, according to the Stefan-Boltzmann law, proportional to the fourth power of its temperature. However in the 8-12 μm range, the integrated spectral irradiance from a blackbody is in fact roughly linear with temperature between 300 K and 600 K. This is the range of spectral sensitivity of the SR-5000 spectroradiometer's MCT detector and so the detected signal is roughly proportional to the TT average temperature over the whole field of view.

As can be seen in Fig. 5, the experimentally measured signal follows quite closely an exponential time dependence, i.e.

$$T(t) = T_o \exp(-t/\tau_e)$$

where T_o is the rise time temperature of the TT at t=0 and the best fit was obtained with a τ_e of 19 msec. This may be compared with the characteristic thermal diffusion time τ of the system which may be estimated by:

$$\tau = l^2/\kappa$$

where κ is the thermal diffusivity of the TT and l is the characteristic dimension of the hot volume. For a beam diameter D and absorption depth α of the laser radiation in the thermal target l may be taken as:

$$l = (D^2/\alpha)^{1/3}$$

Substituting the values of these parameters for the present case yields a value of 18 msec for τ, which is perhaps coincidentally close to the experimentally determined decay time, but nonetheless may be taken as evidence for the validity of this approximate calculation.

To substantiate the validity of the experimental results, finite element analysis was carried out on the TT configuration using the physical parameters of the experiment as input. The beam intensity was assumed to be of Gaussian profile and to decay exponentially with depth (according to α). The pulse time was taken to be very short compared with τ, the characteristic thermal diffusion time. Fig. 6 shows the temperature dependence of the TT surface as a function of time and radial distance from the spot center. At the spot center the temperature decays to 1/e of the initial temperature after approximately 10 msec. However by this time there has been significant lateral thermal spreading and the heat spot radius has increased by a factor of about 1.6. Hence the total thermal emission from the hot spot must decay considerably more slowly than does the maximum temperature as indeed observed in the radiometric measurements.

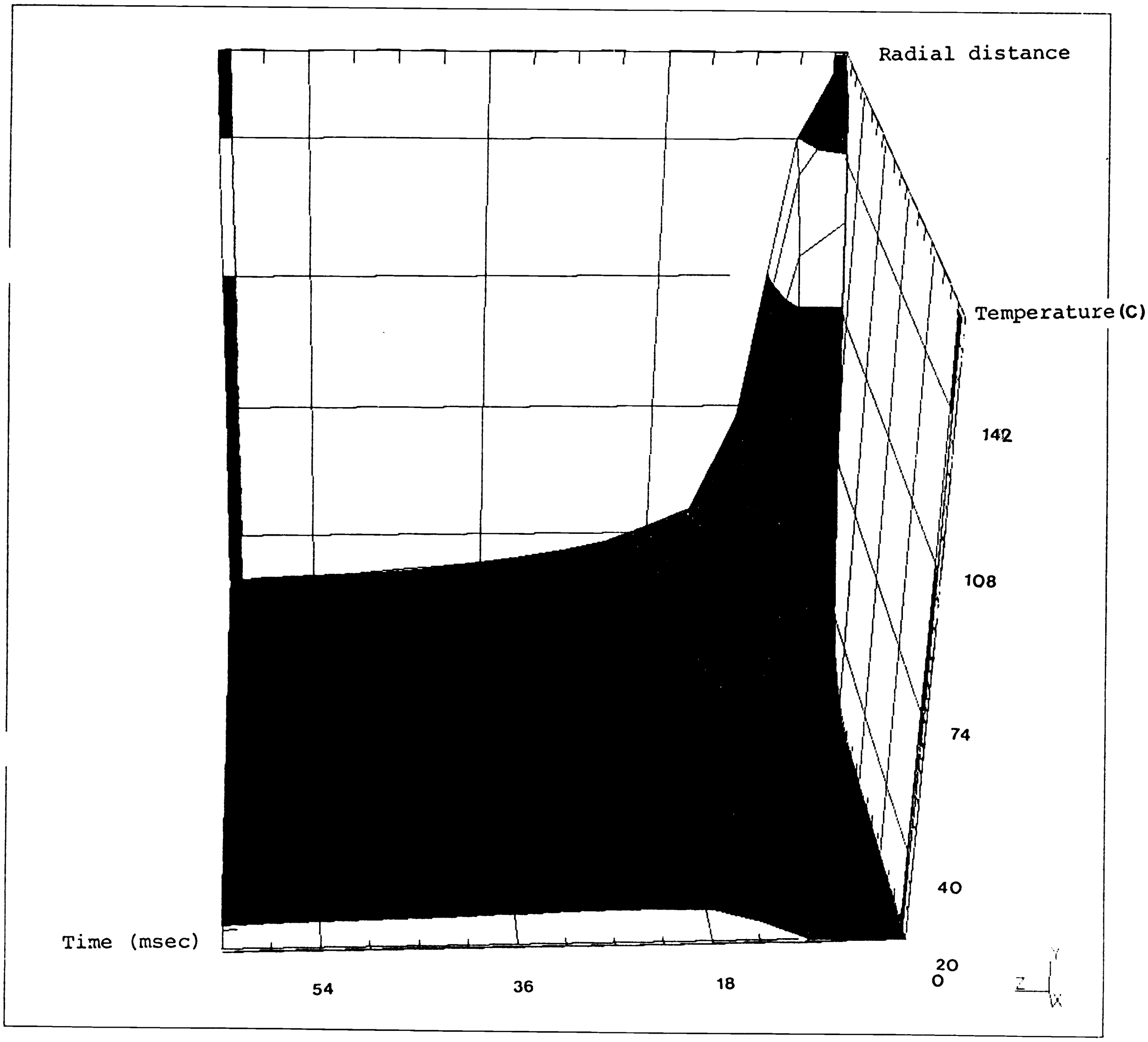


Figure 6. Thermal profile dependence on time and radial distance from heat spot center given by Finite Element Analysis.

5. REAL TIME BORESIGHTING

Fig. 7 shows a possible extension of the optical system, which allows real time boresighting. This means that the laser and the FLIR can be boresighted while the scenery is observed.

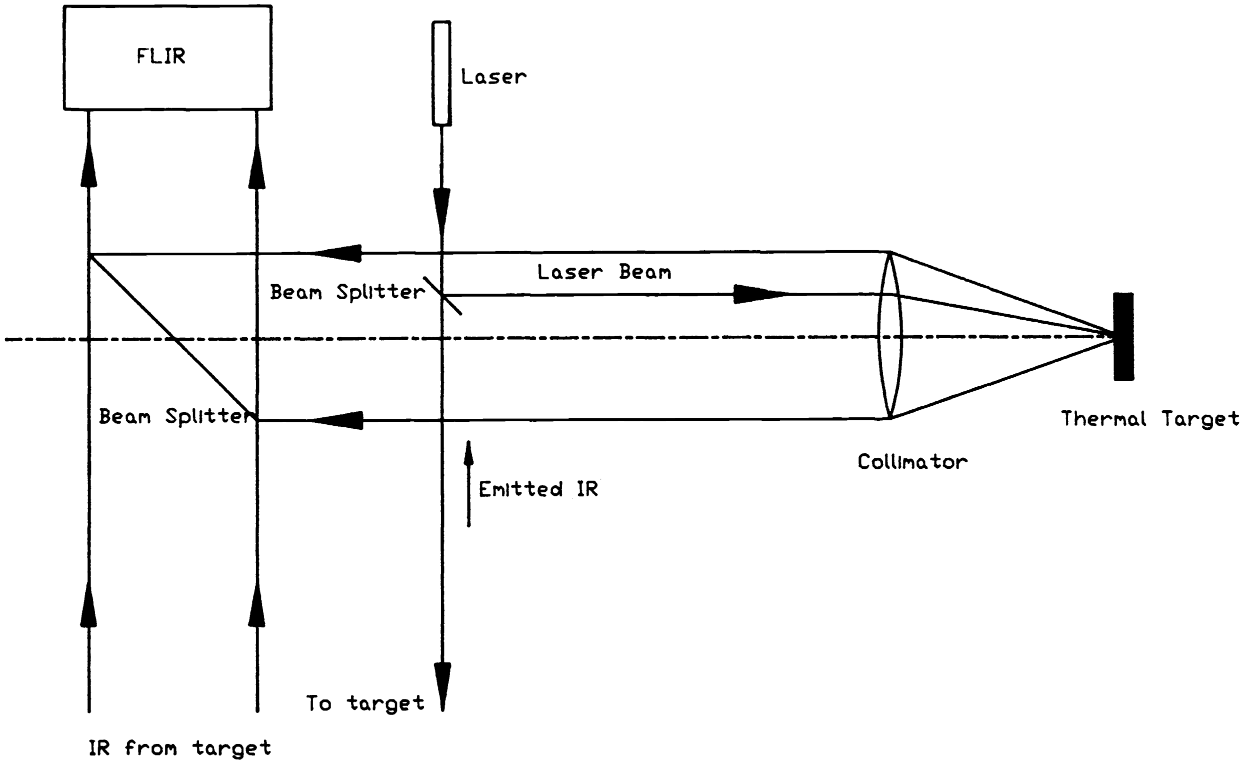


Figure 7. Schematic diagram of the real time boresighting using the TT method.

6. CONCLUSION

In the present work we have shown results of experimental and numerical analysis designed to prove the feasibility of the thermal target concept for laser-FLIR boresighting. It has been shown that using a composite thermal target structure of carefully chosen materials, the resultant temporal and spatial temperature profiles of the heat spot are such that boresighting may be carried out with or without synchronization of the laser pulses with the FLIR scanning.

7. References

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