

Trends in Sighting Systems for Combat Vehicles

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ABSTRACT

Search and tracking in dynamic condition, rapid re-targeting, precision pointing and long range engagement in day and night condition are core requisite of stabilised sighting systems used for combat vehicles. Complex battle field requires integrated fire control system with stabilised sighting system as its main constituent. It facilitates quick reaction to fire control system and provides vital edge in the battlefield scenario. Precision gimbal design, optics design, embedded engineering, control system, electro-optical sensors, target detection and tracking, panorama generation, auto-alerting, digital image stabilisation, image fusion and integration are important aspects of sighting system development. In this paper, design considerations for a state of art stabilised sighting system have been presented including laboratory and field evaluation methods for such systems.

Keywords: Stabilised sighting system; Fire control system; Detection and tracking; Panorama generation; Auto-alerting; Digital image stabilisation; Image fusion

1. INTRODUCTION

Line-of-sight (LOS) jitter induced by moving platform degrades the image quality of a high performance sighting system, resulting in reduced detection, recognition, and identification (DRI) ranges. In the battlefield, depth of surveillance, reaction time and fine tracking are essential requirements for engagement and survival. Stabilised sighting systems facilitate these features on a mobile platform. The basic principle of inertial stabilisation of LOS rate is to sense the disturbance using gyroscope and apply opposite torque based on an appropriate servo controller output to reduce its effect. Stabilised sights provide stabilisation, positioning and tracking functions. Application and host platform governs the configuration of the gimballed sight. Stabilisation can be achieved by mirror stabilisation or mass stabilisation. Mirror stabilisation has advantage of better control but it suffers from the problem of optical doubling effect¹ and image rotation in a plane perpendicular to LOS. Mass stabilisation does not face these issues but needs higher torque for control.

Basically, there are three widely used stabilisation methods²: Mechanical image stabilisation (MIS), optical image stabilisation (OIS) and digital image stabilisation (DIS). In MIS¹, camera or a mirror is mounted in gimbals and whole camera/mirror is stabilised. It is most common method for stabilisation and is used for long range surveillance application. For combat vehicle, MIS is the most suitable stabilisation method. In OIS, an optical component (i.e. lenses) in the camera is moved according to the motion detected by accelerometer or gyroscopes so that its principal axis will be directed towards

the scene. DIS estimates the inter-frame motion in acquired video and corrects it while preserving the intentional motion. OIS and DIS are available in most of the commercial cameras having image stabilisation features. Unlike MIS, both of these methods are effective for small disturbances.

Masten¹ and Hilkert³ have presented different configurations of inertially stabilised platforms in detail. The main function of stabilised sight is to provide vision to the operator for targets of interest at required ranges in dynamic conditions.

Development of stabilised sight is a multi-disciplinary activity. A high precision gimbal design is the core of stabilised sight. Orthogonality, rigidity, balancing of the gimbal dictates the performance of the complete system. Criticality is to achieve stiffness within limited gimbal weight. High performance control system is required for precise and quick motion along with fine stabilisation. Low noise, miniaturised electronics with sufficient computational capability is needed to realise these functions.

Electro-optical sensors provide vision (i.e. Day vision camera, SWIR camera and thermal imager) and ranging (Laser Range Finder). To miniaturise sighting system multi-spectral and compact optics design is required. Target detection and tracking, panorama generation, auto-alerting, digital image stabilisation and image fusion enhances the capabilities of the sighting system.

Generally, ballistics computer is integral part of sighting system. Based on ammunition type, target and host platform dynamics, armament characteristics and environmental conditions (temperature, winds), it provides ballistics offset for accurate target engagement.

Heat management, EMI/EMC, integration and performance evaluations are other important aspects of sighting system development.

2. DESIGN CONSIDERATIONS

The exhaustive knowledge of the mobile platform and the operational scenario are the key issues for the development of stabilised sight.

2.1 EO Sensor Selection

Electro-optical sensors provide vision and accurate ranging capability to the observer. For an all time (day/night) vision capability, multi-sensors i.e., day TV camera, SWIR camera and Thermal Imager are used in sighting systems. These sensors cover a very wide spectral band collectively and increases surveillance capability in term of duration and performance. Camera specification is dictated by target characteristics (Dimension, illumination, reflectivity, and thermal characteristics), target range and environmental conditions (visibility, humidity, temperature, presence of solar radiation and so on). Instantaneous field of view (IFOV) is derived from spatial resolution required for desired DRI ranges. Optics speed and depth of focus are important considerations for EO sensor design. Multi-channel, multi-spectral and compact optics design is persuaded now days. It reduces payload size and subsequently the gimbals size also gets reduced. George Downey⁵, *et al.* have given details of design consideration of sight to be used in electro-optical tracking.

2.2 Gimbal Design

Payloads (Cameras and ELRF) to be stabilised are mounted on high precision gimbals. Gimbals can be of open architecture where EO sensors can be changed within certain limitation of servo system. Here, generally centre drive is used for movement in pitch. This increases the separation between EO sensors placed on both sides. In closed architecture payloads are not directly exposed to the environment. Gimbals can be single axis, two axes or three axes with or without redundant gimbal configuration. In ground based systems, generally 2-gimbal approach is used. In few gimbals, complete payload is stabilised (mass stabilisation) but in some cases only an optical component (i.e. mirror) is stabilised (mirror stabilisation).

3-D model and realised prototype of mass stabilisation configuration has been shown in Fig. 1. Here, complete payloads (cameras and ELRF) have been stabilised. All payloads are individually sealed. It is also an open architecture and its payloads can be easily changed. Similarly, Fig. 2. depicts mirror stabilisation scheme. Here, only mirror is stabilised and payloads receive stabilised scene information.

Size and shape profile of EO sensors; weight, moment of inertia, orthogonality and structural resonance frequency of gimbals are governing factors for design. Gimbals are being made as single line replacement unit (LRU) where associated servo electronics is housed inside the gimbals instead as separate unit. It has made heat management a critical issue.

2.3 Control System Development

LOS disturbances cause motion blur in the camera images.

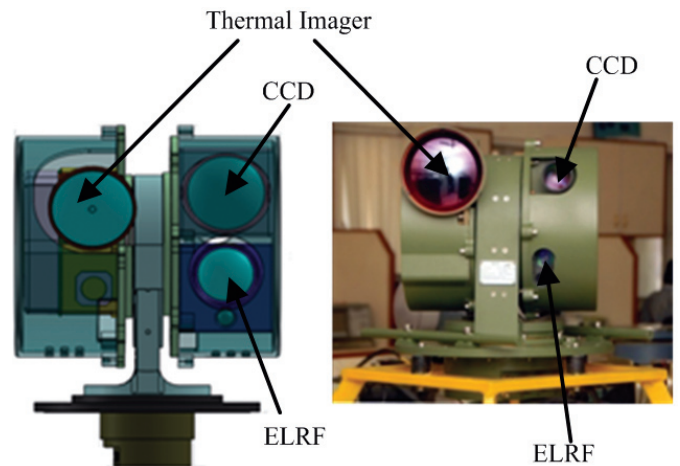


Figure 1. SEOS: Mass stabilisation.

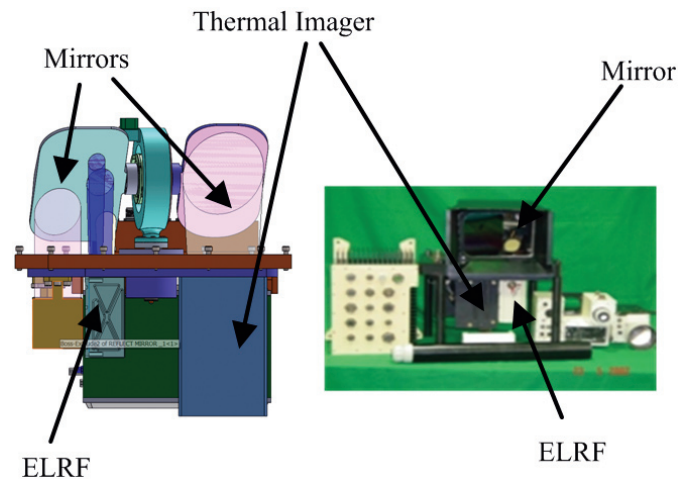


Figure 2. IGMS: Mirror stabilisation.

Image blurring causes degradation in the image resolution. Hence, effective recognition range is reduced and tracking capability is impeded. High gain, wide bandwidth control loops are required to isolate induced motion to the LOS.

Control system has to reduce disturbance to an allowable limit. The allowable residual jitter at dominating frequencies^{5,6} of disturbance spectrum depends on IFOV and integration time of EO sensor.

Control loop goals are derived from the required order of disturbance isolation, LOS rate/acceleration and transient response. Target dynamics and tracking rate/acceleration requirement considerations are very important for its acquisition and accurate tracking. Compensated open loop gains at dominant disturbance frequencies are calculated to achieve required residual jitter.

The basic control loops for the realisation of all the functions of a system are position loop, stabilisation loop and track loop. In stabilisation loop feedback is from gyro, in position loop feedback is from position sensor (i.e. encoder, resolver) and in track loop automatic video tracker provides feedback.

Controllers are used to manipulate the gimbal dynamics to get desired response. Basic control loop for stabilisation and tracking are as shown in Fig. 3.

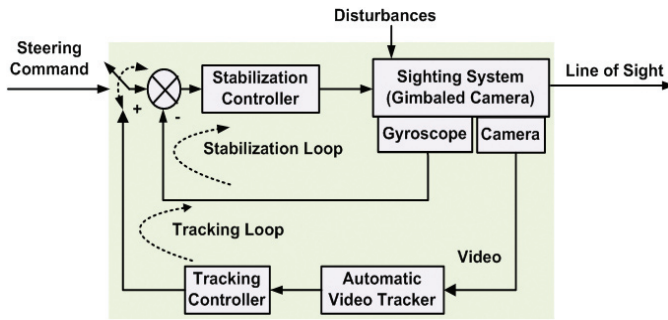


Figure 3. Stabilisation / tracking loop.

For good transient response in position loop, either gyro is used to provide damping or mode switching⁷ depending on the position error is used.

Hybrid image stabilisation⁸ has been proposed where digital image stabilisation has been used along with mechanical (gimbal) stabilisation.

2.4 Embedded System

Embedded system is required for real-time implementation of control algorithms, health monitoring, data acquisition and EO sensor control. Compact electronics hardware is being developed to perform multi-tasking. Embedded software can be real-time operation system (RTOS) based or non-RTOS based. In non-RTOS based systems, real-time operations are implemented based on timer interrupts.

2.5 Digital Image Stabilisation

In digital image stabilisation (DIS) jitter in video frames is removed from the acquired video sequence using image processing. Motion estimation methods⁹ are either in spatial domain or frequency domain. Algorithms have different accuracies and different computational complexities. Search region is dependent on expected disturbances. Larger the search region, higher is the computational complexity. So, for higher disturbance, it is difficult to achieve real-time operation with limited processing power. Also, after motion compensation, large area of stabilised frame is undefined. For estimating, background/global motion, frame is divided into small parts. Motions of these small parts are called local motions. Background motion¹⁰ may be estimated from local motions.

Inter frame motion consists of intentional motion and non-intentional motion. Compensation is done for shaking (non-intentional) motion only. Intentional motion is generally smooth motion (i.e low frequency). This assumption is the basic idea for separating it from non-intentional motion for which high pass filtering, Kalman Filtering¹¹, motion vector integration (MVI)¹² and modified Proportional-Integral (mPI) controller¹³ are most popular methods. During motion compensation, frame is shifted by estimated jitter in opposite direction. Generally, there are two approaches⁴: Frame-to-frame algorithm (FFA) and frame-to-reference algorithm (FRA). DIS can be used along with MIS to have high degree of jitter attenuation^{8,14,15}.

2.6 Image Fusion

Multi-sensor Image fusion¹⁶⁻¹⁷ is the process of combining relevant information from two or more images into a single

image. The resulting image will be more informative than any of the input images. Image fusion enhances the quality of an image. Firouz¹⁸ has presented a statistical based method. Dou¹⁹, *et al.* has presented method to achieve high spectral fidelity.

2.7 Panorama Generation

Image captured by small field of view (FOV) camera are aligned together to have large scene information as wide video frames. It is useful to have comprehensive idea of large field of regard (FOR). Many schemes²⁰⁻²², have been proposed for panorama generation.

2.8 Target Detection, Tracking and Auto-Alerting

Tracking is the process of locating a moving object (or multiple objects) over time²³⁻²⁴. In video tracking, target motion is estimated from video captured by camera. For tracking, detection of potential target is prime requirement. Target detection and tracking feature is incorporated by automatic video tracker (AVT).

Closed loop tracking of target requires EO sensors, set of gimbals with associated embedded control system and automatic video tracker (AVT). Automatic target detection (ATD) helps in quick acquisition of the target. Agile target can be accurately tracked by AVT. Area/phase correlation, centroid and edge algorithms are commonly available tracking algorithms in COTS AVTs. Although complex for real time implementation, advanced tracking algorithms²⁴⁻²⁶ are giving promising performance against low contrast, occlusion and appearance changes.

Tracking range depends on target size (pixels), target contrast, target occlusion and target dynamics. EO Sensors (IFOV and FOVs) are decided based on tracking range for a particular target. Also, AVT should be capable to provide tracking error for available target size/contrast. Target dynamics governs inter-frame tracking rate, error update rate, target state prediction and control loop's bandwidth

2.9 Integration

Sight needs to be integrated with other subsystem to provide integrated fire control solution (IFCS). There are three aspects of integration: Mechanical, electrical and optical. Calibrations are required for accurate engagement of the target.

3. SIGHT EVALUATION

Sights are evaluated in lab/factory during development. After integration on the platform, they are evaluated in the field. Sights are mainly evaluated against control parameters and EO sensors (camera) parameters.

3.1 Lab Evaluation

Thermal Imagers are tested for minimum resolvable temperature difference (MRTD), FOV, focus, etc. Similarly, Minimum resolvable contrast (MRC) of day cameras is tested. Laser range finders are tested for beam divergence, echo, false alarm rate, dual target discrimination, extinction ratio, range resolution, and range capabilities.

A typical testing setup²⁷ for lab evaluation is given in

Fig. 4. Sight is mounted on 3-axis motion simulator, field disturbances are simulated and control system performances (slaving and dynamic slaving) is evaluated by recording gyro and encoder signals.

US resolution chart may also be used to quantify stabilisation accuracy. Positioning accuracy is measured by theodolite. Target dynamics and characteristics (size, contrast) are simulated through dynamic target simulator (DTS) and tracking performance is evaluated.

Factory calibration range, accuracy and retention are also validated. Sights are to be evaluated for EMI/EMC and environmental conditions too.

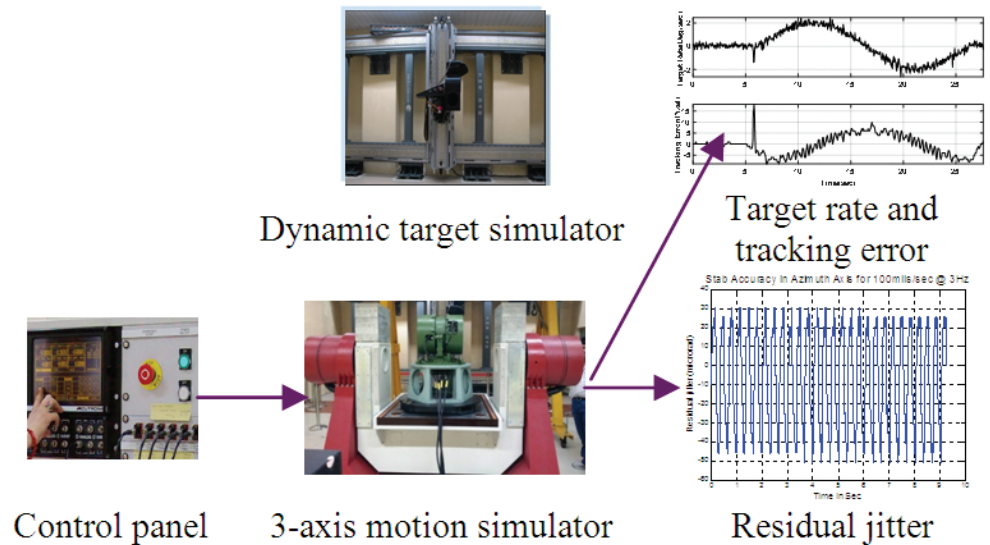


Figure 4. Setup for lab evaluation.

3.2 Field Evaluation

After successful development, sights are integrated on the vehicle and field calibration is done. DRI ranges of all cameras are evaluated. Laser range finder is evaluated against its parameters.

For evaluating servo performance in dynamic condition, combat vehicle is run on Aberdeen proving ground (APG). Vehicles may also be run in cross country for this purpose. Target with different appearance and dynamics are tracked for evaluating tracking performance.

Finally, accuracy shoots during firing trials gives performance of complete sight.

4. WORLDWIDE SCENARIO

Sighting system has evolved all the way from iron sight to much advanced multi-sensor, high accuracy integrated sight. In India many private/government units are involved in the development. Instruments Research and Development Establishment, Dehradun, Aeronautical Development Establishment, Bengaluru are acting as design centers. Bharat Electronics, VEM technologies, Benengg, TATA are involved in design and mainly fabrication. Worldwide SAGEM, Elbit, FLIR and WESCAM are major players in this field. Contemporary sights provide high-performance observation, detection, tracking, navigation and target engagement. Robust discriminative tracking algorithms are used which give good performance in presence of clutter, occlusion, appearance changes and high dynamics in target motion. Sights with quick look mode are also being developed and they have de-blur mechanism for imaging at high steering rate.

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Mr Avnish Kumar received the BTech and MTech in Electronics Engineering from IIT Roorkee. Currently he is working in Instruments Research and Development Establishment, Dehradun and he is guiding a team of scientists for the design and development of line-of-sight stabilisation, electro-optical surveillance and fire control Systems for various platforms. Contribution in the current study, he has consolidated the surveyed trends and given valuable inputs based on his experience in this field.

Mr Rajeev Marathe received the BTech from Madhav Institute of Technology and Sciences, Gwalior and MTech (Control Engg.) from IIT Kanpur. He is working in Instruments Research and Development Establishment, Dehradun and his area of work is payload stabilisation, electro-optical tracking and fire control systems. Contribution in the current study, he has summarised evaluation methods of sighting systems in a concise way.

Dr Madhav Ji Nigam received the BTech (Electr. Comm. Engg.) from Regional Engineering College, Warangal, 1976, the ME (Control and Guidance), in 1978 and PhD (Electr. Comm. Engg.) from University of Roorkee (Now IIT-Roorkee), Roorkee, in 1992. Presently working as Professor in IIT, Roorkee. His area of research includes: Guidance and Controls in navigational systems including high resolution real time intelligent kalman state estimator as well as regulation, tracking and guidance for peace time work and industry. Contribution in the current study, he has consolidated new technologies (i.e. Image Fusion, Panorama Generation etc) of sighting systems.