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Artificial Intelligence Enabled Laser Fence System for Object Classification

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ABSTRACT
In recent years, security of international borders and homeland have gained momentum. Country like India which has vast border line and is surrounded by many neighbourhood countries requires lot of infrastructure to cover the border by conventional means. Laser fence based network is gaining popularity worldwide. Smart sensor network is one of the potential solutions to protect the border areas. Some other sensors like thermal/day-night camera, underground seismic sensor, Passive Infra-Red sensors (PIR) etc. are also integrated with laser fence to enhance its efficacy during poor visibility conditions and different terrains. Other conditions like rain and atmospheric turbulence may be taken care of by adding ArtificialIntelligence (AI) to networked laser fence.As per published literature, current methodology is innovative as it classifies the real time object intrusion on the basis of temporal data fusion of multiple photo sensors. Velocity, length and height of an object are taken as key parameters to generate the data sets for object classification. In this methodology, multiple data sets for different real-time objects and for different terrains can be generated and stored to achieve better accuracy for classification of objects in human, vehicle and animal.
Keywords: *Laser Fence, Artificial Intelligence, Intrusion detection*

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I. INTRODUCTION

With the advancement in laser diode technology, laser diode based laser fencing is gaining lot of popularity for securing perimeter of vital installations and border areas. Laser fence system is a real-time intrusion detection system [1]. A practical laser fence system should have heat and ambient light management for 24x7 operations. Apart from this, it should be immune to decoy attacks and capable of detecting it. Laser fence is a good detection system but integration of imaging device enhances its usefulness to great extent. Adding multiple beams to laser fence makes it an efficient sensor for height based classification. Integration of wireless modules like Long Range Radio Frequency (LORA), Global system for mobile communication (GSM) and other IOT device gives a new dimension to laser based intrusion detection system [2-4].

Laser based system experience performance deterioration during heavy fog and rain conditions. Laser power may be increased in automated manner to handle the visibility issue to some extent during the fog. During rain, system may switch to simultaneous interception of multiple beams to generate alarm, with reduced discrimination capability. Apart from this, data from other sensors like underground seismic sensor, thermal/ day-night camera can be fused with laser fence data to take collective decision during poor weather conditions [5-8]. This paper aims at highlighting the approach for object detection and classification of man, animal and vehicle using an AI enabled laser fence system. System described in this article is designed to work without any imaging device.

System Description of AI enabled laser fence-AI enabled laser fence is bi-static system comprising transmitter and receiver modules as shown in Fig.1. The transmitter emits multiple laser beams obtained from a single laser diode. The multiple beams are incident on the corresponding sensor of receiver module placed at a distance up to 500 m. Apart from this framework, object detection and classification may be implemented using two arm laser fence design shown in Fig.1. The Pulse Repetition Frequency (PRF) of laser diode beams are coded at a particular frequency. PRF coding introduces a level of security in the laser fence and safeguard it from any decoy laser hacking. In addition to security, the PRF encoding offers an excellent solution to control the thermal load of laser diode module, required for 24 x7 operations. Pulsing with 50% duty cycle reduces the current consumption in same ratio and enhances the life of laser diode by reducing its heat level. Other major challenge of ambient light may be catered by embedding the optical filter in front of photo detector to reduce the solar and shot noises. Intrusion alert can be transmitted to the control room either via optical fibre, copper wire or through radio-frequency link.

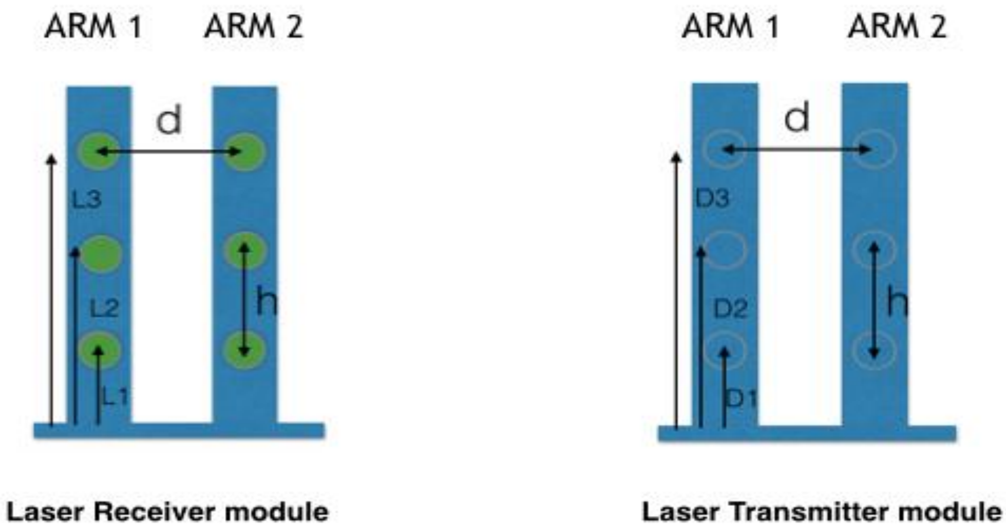

Figure 1: AI enabled Laser Fence system (Two arms)

Classification Methodology-
Classifying an object includes various modes of human and animal movements. Some basic assumptions to classify the objects are as follow:

- Body/target moves with same velocity while crossing the pillars.
- Body can be classified on the basis of its velocity, size and motion pattern and laser beam emerging from laser transmitter is covering corresponding detector on receiver (Laser transmitter has variable collimating length optics).

Some ideal cases have been considered to generate the time response of detectors mounted on receiver side.
Some ideal cases for object classifications- Different test cases have been considered to classify the type of objects as shown in Fig.2. Case 1-5 can be described as follow

- Case '1' : Object is longer than detector separation 'd'
- Case' 2' : Object height covering all detectors
- Case '3' : Object with two legs
- Case '4' : Object with four legs
- Case '5' : Vehicular object

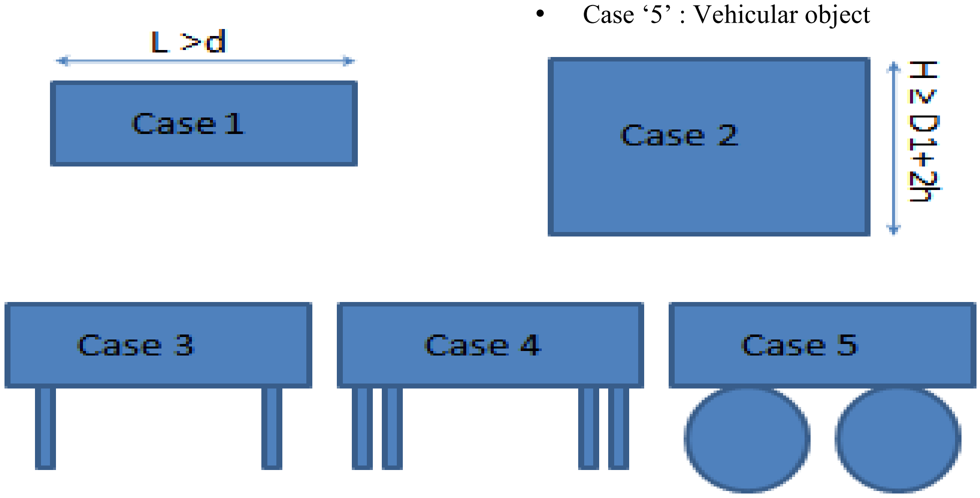

Figure 2: Different test cases for object classification

Ideal responses of different photo detectors (ARM1 or ARM2) in time domain are presented in Fig.3. Detectors outputs remain high in case no interruption of laser beams. In case of intrusion, different detectors will respond according to object patterns shown in Fig.2. In case '1' test object will interrupt only upper two detectors and lower detector will remain high. In case '2' test object interrupts all detectors for same interval of time. In case '3' and '4' objects have 2 and 4 legs respectively so the interruption time by main body will be higher than the interruption time by legs. Timing diagram for case '3' and '4' are combined. Case '3' will have only two timing pulses for the interruption by two legs and case '4' will have for four timing pulses (two extra pulses are shown by doted lines). Case '5' present vehicular object and generates broad timing pulses for wheel movements.

Parameter estimation for classification- Velocity, length and height of an object are important parameters to classify the intruded object. Intrusion timing information captured by the controller is heart of this classification model. Different time instance parameters are presented using T11, T21, T12 and T22 variables as follow

T11: Time at which Front end of object crossing arm 1 of Tx or Rx
T21: Time at which Front end of object crossing arm 2 of Tx or Rx
T12: Time at which Rear end of object crossing arm 1 of Tx or Rx
T22: Time at which Rear end of object crossing arm 2 of Tx or Rx

Velocity estimation- Velocity (V) of an object can be estimated by determining the distance between the arms(d) and T11 & T21 timings as follow:

$$V= d/ (T21-T11) \quad ……….. (1)$$

Length estimation- Length (L) of an object can be estimated by determining velocity (V) from equation 1 and T12 & T11 timings as follow:

$$L= V*(T12-T11) \quad ……… (2)$$

Height Estimation-Height (H) of an object can be estimated by determining the height of topmost detector intercepted by the object as shown in the table below:

Cases	Detector	Height Estimation(H)
Case 1	Detector1	D1≤H≤D1+h
Case2	Detector2	D2≤H≤D2+h
Case3	Detector3	D3≤H≤D3+h

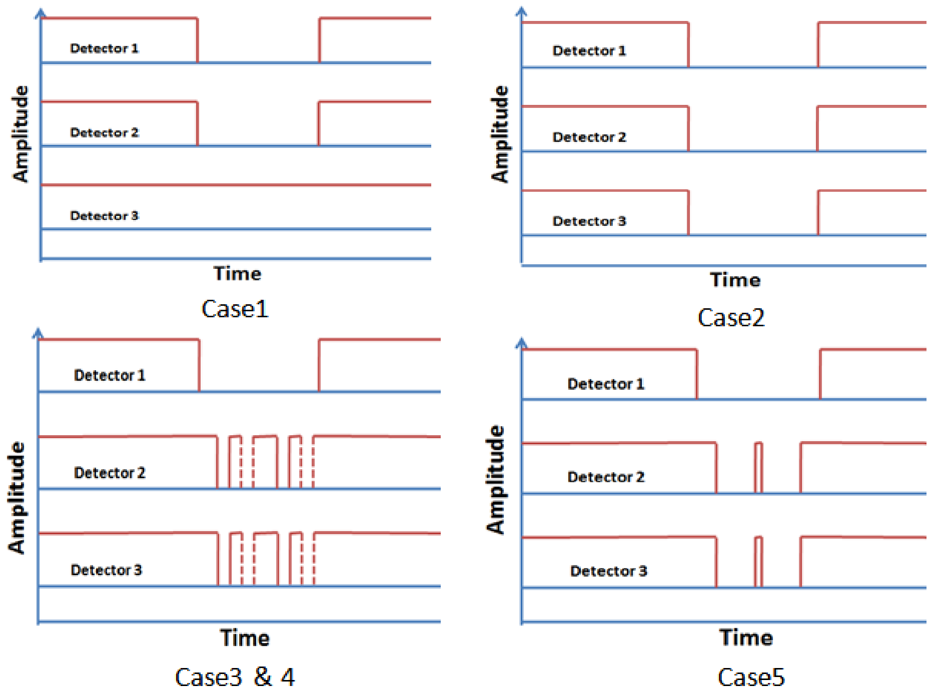

Figure 3: Ideal responses of photo-detectors for test objects shown in Fig. 2.

Detectors Response Pattern

Different detector response patterns are generated when an object intrudes between any of the transmitter and receiver arm. These response patterns are the important database to compare and classify the intruded objects. There will be different response patterns for walking, running and crawling of human in term of velocity, length and height. Similarly there will be different patterns generated for vehicles, small and big animals.

For human crossing the laser fence, the lower-most detector generates two dips due to two legs. The middle detector also have two dips but of varying time duration in comparison to lowermost detector. The uppermost detector shows one dip in complete duration due to abdominal portion. The relative position of dips gives an indication of walking pattern and speed. Distinctive timing patterns in Fig.4 are for real time objects and are stored in library matching to identify and classify the new intrusion event.

Implementation-

AI enabled laser fence system generates two level alarms. First level is the intrusion detection and second level is intrusion classification. Infrared Laser diodes are ideal choice for laser fence development. Optical laser signal can be detected using photo-diode or photo-transistor of suitable spectral response according to the wavelength of laser light. To minimize the impact of ambient light a suitable optical filter must be integrated. Photo-detectors like SFH313 (OSRAM) with in-built filter are optimal choice. A controller like STM32 (STMicroelectronics) with inbuilt ADC will be ideal choice to capture the optical signals from photo-detectors. After acquiring the optical signal, controller will first check for PRF of incoming signal to distinguish between friend and foe. In case of detector saturation or false PRF, alert will be generated in the control room. After completing this mandatory loop, each arm of laser fence will process the signal for intrusion detection and will generate timing information of each detector in respective arm. Data from both the arm will be used to generate the intrusion pattern information. This generated information will be correlated with intrusion pattern stored in library.

Management of intrusion patterns database and their correlation can be implemented on Intel Galileo platform. In case of intrusion pattern matching with the stored pattern of library, an alarm will be raised in control room.

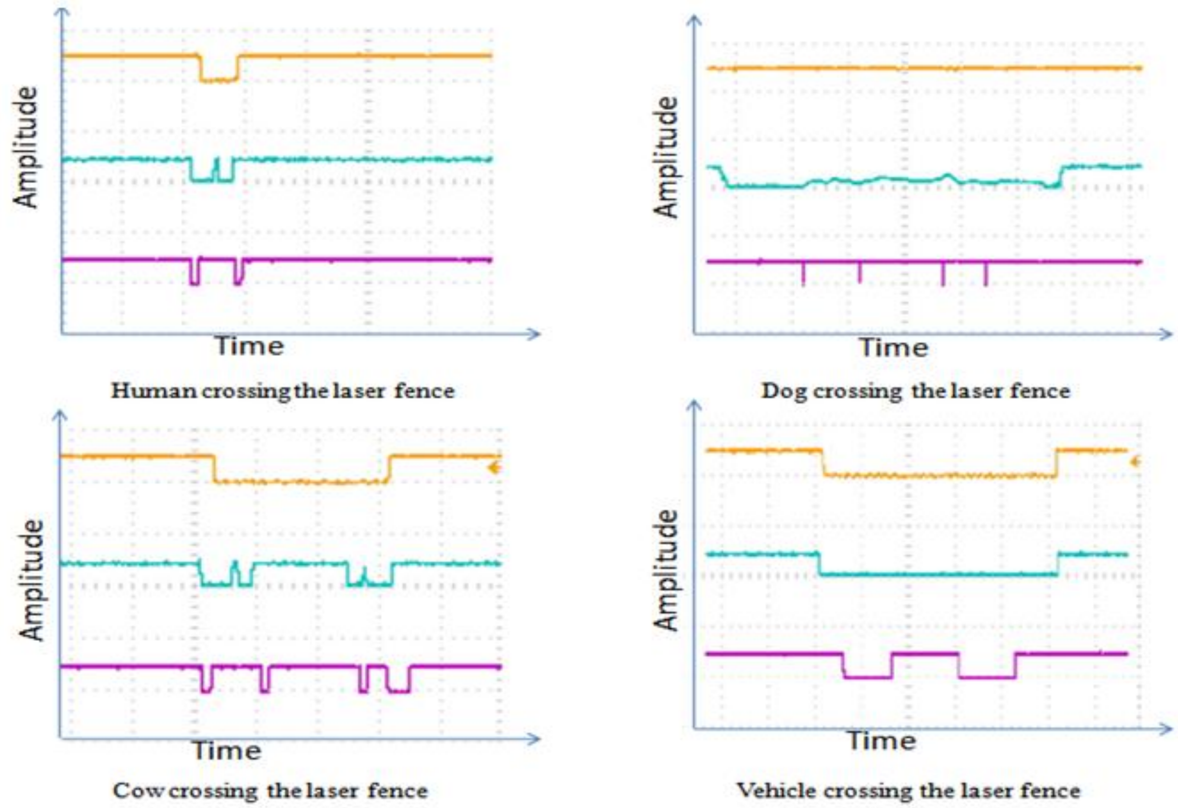

Figure 4: Typical responses of Photo detectors for Human, Dog, Cow and Vehicle intrusion (at one of the Tx/Rx arm).

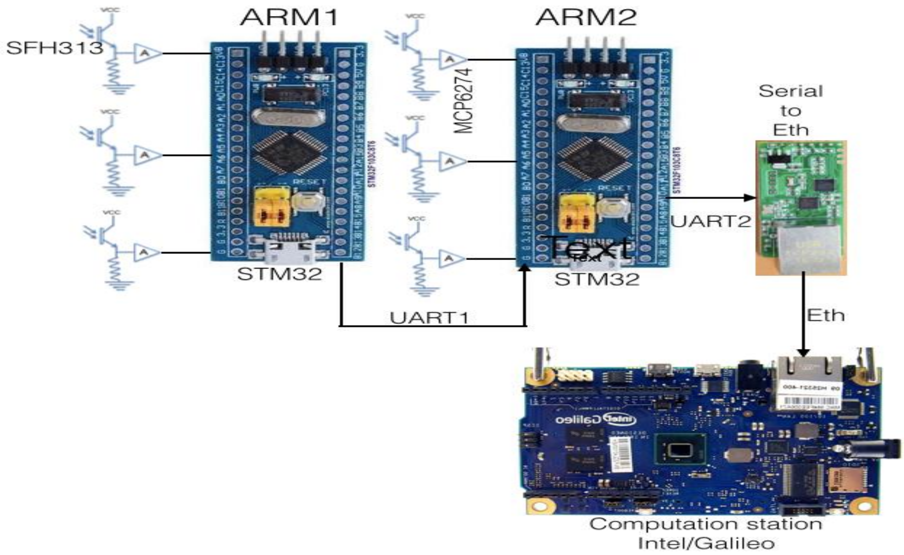

Figure 5: Typical electronics hardware: AI Enabled Laser Fence System

II. CONCLUSION:

AI enabled laser system is capable of object classification into human, animal and vehicle on the basis of its height, length and speed As per published literature, current methodology is innovative as it classifies the real time object intrusion on the basis of temporal data fusion of multiple photo sensors.This classification methodology is applicable throughout the path between transmitter and receiver. This system also identifies the direction of intrusion. Low visibility and heavy rain reduces the system ability for classification. This system can be made all weather solution by integrating Under Ground Senors (UGS) for vibration detection and microwave sensors. Integration of an imaging device with AI enabled laser fence will enhance its capability many folds.

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