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Can You Hit What You See?

Dr. Szeto Ching Ho
Wong Tai Sin Hospital
Hong Kong SAR
szetochingho@yahoo.com.hk

***Abstract*—Hypersonic missile travels to the space and then falls back into the atmosphere creating an infrared emitting fireball. The locus of movement of missile can be converted into a line image by cylindrical plano-convex lens. By using an infrared (IR) homing device, a proper alignment and orientation directed to this fireball can be achieved. The plano surface can be made perpendicular to the incoming IR by a ring of solar panels at the periphery of plano surface. The difference at the angle of incidence of IR at opposite solar panels creates a potential difference, which drives an activator, until each solar panels receives the same amount of IR. Detection of fireball irradiation by IR homing will follows Inverse Square Law. Once there is a sharp rise of illuminance in the homing device, a signal will be sent to the firing system that fires immediately.**

Keywords—cylindrical plano-convex and concave lens, infrared homing, lens-maker formula, solar light tracking with Arduino, Robotic Arm Control by Arduino.

I. INTRODUCTION

On the Cartesian coordinate system, the missile horizontal and vertical position as a function of time t can be presented by

$$\left(x = v_0 \cos\theta\, t \;,\; z = v_0 \sin\theta\, t - \frac{g}{2} t^2 \right)$$

where V_0 is the initial velocity making an angle Θ with the horizontal. In this design, only the x- coordinate will be considered because cylindrical plano-convex lens compresses a 3D image into a line on the focal plane (fig 1), making the tracing of missile locus much more easier.

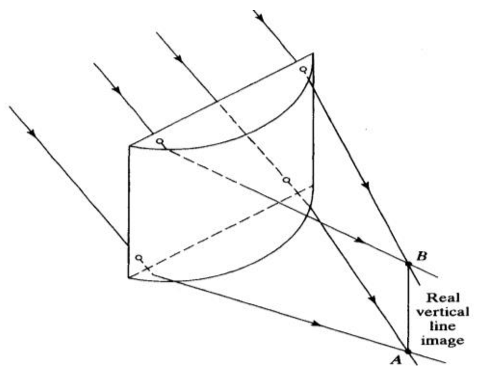


Fig 1. 3D movement of missile can be converted to 2D image by a cylindrical plano-convex lens

II. PROPER ALIGNMENT AND ORIENTATION

In order to achieve the aiming and firing of the target, the plano surface is adjusted to be perpendicular to the incident IR irradiation. This can be achieved by a palisade of solar panels at the periphery of the plano surface of the lens. When the incident IR irradiation is not normal to the plano surface, there is a difference in the illuminance at the pair of solar cells lying opposite to each other. The potential difference across the solar cells drive the Arduino microcontroller until the IR irradiation is perpendicular to the plano surface.

III. PRINCIPLES INVOLVED IN THE DESIGN

A. Photovoltaic effect

Light is converted into electrical energy by the solar cells, that are made from semiconductors like silicon and selenium. The electrical energy can be presented with a current when the circuit is completed. Inside the solar cell, there are holes serving as the positive charge carriers, and electrons carrying negative charges.

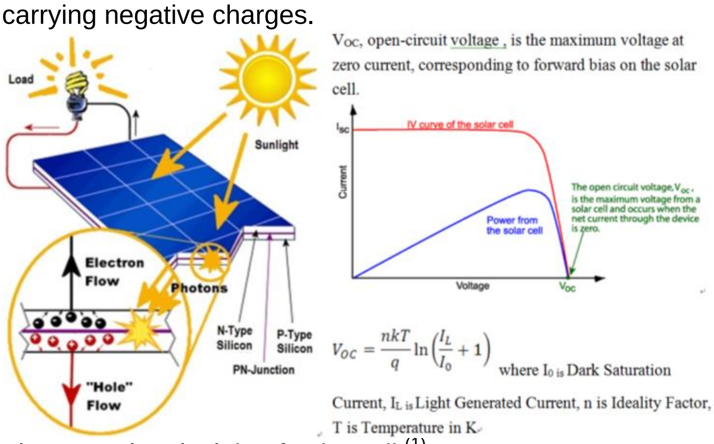


Fig. 2: Basic principle of solar cell [(1)]

B. Illuminance

The amount of light received will be altered by the distance from the center. The electrical energy produced by the solar cells will be different in different positions, as guided by the principle of illuminance. The light intensity, as measured by the **luminous flux I**, is the number of light rays passing through a surface perpendicular to the direction of motion. It falls with the square of the distance r from the light source—the inverse square property of light.

$I_1 r_1^2 = I_2 r_2^2$ or Ir^2 is a constant

Illuminance Ep in lumens/m^2 measures how the light rays from source illuminate a surface at a distance d from the point source.

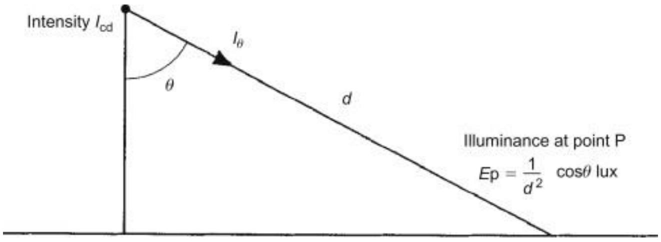


Fig. 3. Illuminance from a point source [2]

C. Infrared (IR) homing [3]

IR homing (figure 4) detects the infrared radiation from hot body with temperature above the absolute zero. Multiple transparent optical filters of total thickness equal to λ/4 resulting in constructive interference at the detector. **Reticles (optical modulators)** are placed between the target and the detector determine the position of target and differentiate the target from its surroundings (figure 5).

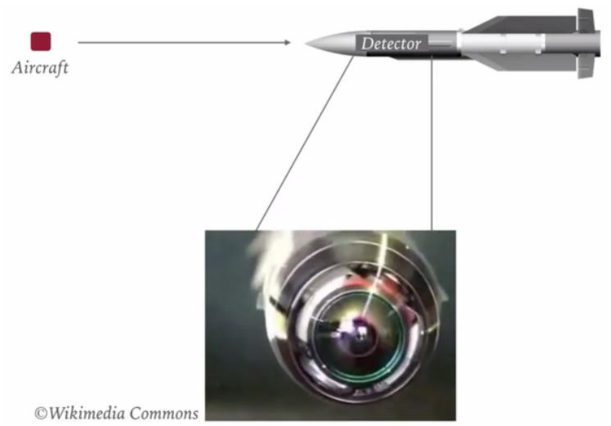


Fig. 4. Infrared homing detector

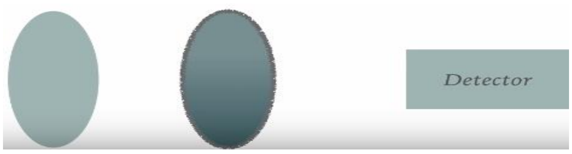


Fig. 5. Reticles are placed between the target and the detector

Reticle A determines whether the IR radiation comes from a point source or from the background. If IR comes from a point source, the IR will be transmitted or blocked by the transparent and the opaque sectors (figure 6). **Reticle B** spinning determines the angular position of 2 objects through the phase difference in the pulse tracing that can be quantified into different angular separation (figure 7). **Reticle C** can be visualized as a combination of both reticles A and B and perform the functionality of both (figure 8).

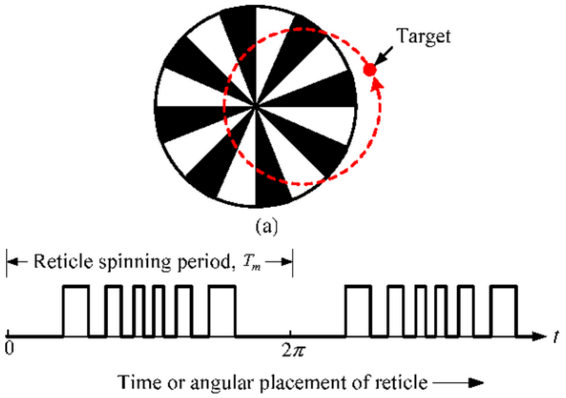


Fig. 6. Reticle A spinning and its detector output pulse

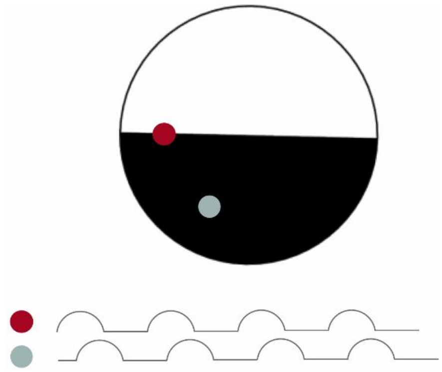


Fig. 7. Different positions of different objects can be differentiated by the phase difference in the tracing

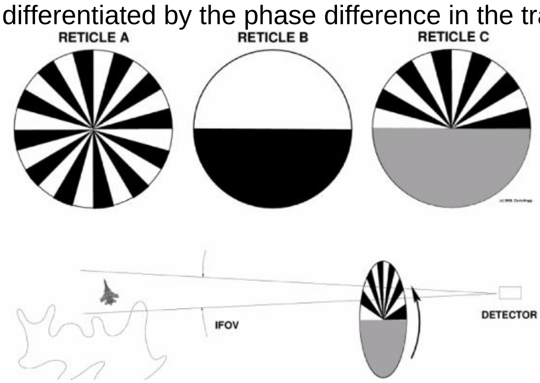


Fig. 8. Reticle C is the combination of both reticles A and B

In IR homing, IR is detected by semiconductors Indium Antimonide (InSb) or Mercury Cadmium Telluride (HgCdTe). The band-gap between the valence and the conduction band in these compounds matches the energy of IR, so these semiconductors absorb IR and generate electrical signals. The semiconductors are kept at very low temperature, or the electrons in the semiconductors will swamp the effect of the detected IR radiation.

Aiming design

A **tube contains an IR** homing device, which is placed behind the cylindrical plano-convex lens but in front of a cylindrical plano-concave lens. Light from distant objects can be seen as parallel rays that converge after passing through the plano-convex lens. IR homing detects and follows the locus of missile. The orientation of IR homing aligns with orientation of the tube.

Just before the maximum IR illuminance is detected by the IR homing device, signal is sent to the firing system. Parallel lasers are emitted, diverge after passing through a cylindrical plano-concave lens, coincide the path of IR rays coming from the missile.

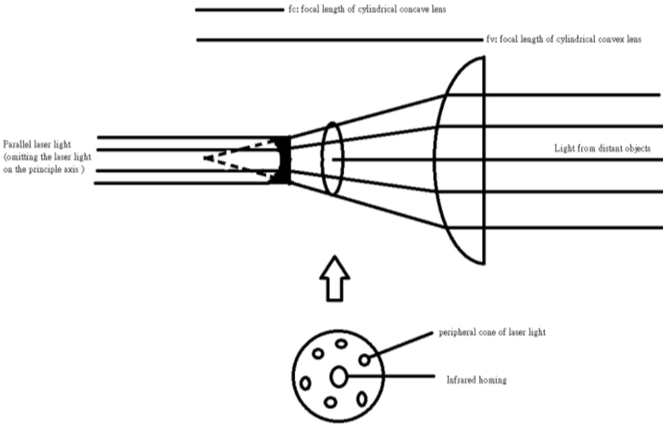


Fig. 9. IR homing detects the IR from target. It lines up the above system with the incoming IR irradiation. A signal is sent from the IR homing to the firing system of parallel laser light.

In the Lens Maker's formula
$1/f = (n-1)\ (1/R_{curve} - 1/R_{flat})$,
f is the focal length of the lens, n is refractive index relative to the medium, R_{curve} and R_{flat} represent the radii of curvature of the curved and flat surfaces.

For plano-convex lenses,
$R_{curve} > 0$ and $R_{flat} = \infty$
$1/f_{convex} = (n-1)\ /R_{convex}$

Similarly, in plano-concave lens,
$1/f_{concave} = (n-1)[(1/R_{curve}) - (1/R_{flat})]$
where $R_{curve} < 0$ and $R_{flat} = \infty$. So
$1/f_{concave} = (n-1)\ /R_{concave}$

Distance between the lens
$= f_{convex} - f_{concave}$
$= (R_{convex} - R_{concave})\ /\ (n-1)$

By using the Arduino light tracking, this lens system is made to be perpendicular to the incident IR rays. The IR homing device fine-tunes the angulation of the tube through movement along a circular arc to detect the maximum IR radiation. This signal will be sent to the firing system to trigger the parallel laser emission.

In order to have real-time correct alignment and orientation of the aiming tube device, the following 3 steps should be carried out simultaneously.

<u>Step 1: Direct the plano surface perpendicular to the light source (solar tracking system)[4]</u>

A scientist has designed an autonomous solar tracking system using 4 solar panels partly behind the 4 edges of the cylindrical plano convex. The opposite solar panels are wired to the motor with opposite polarity. When the IR irradiation shines at an angle to the system, a current will flow through the motor such that the solar panel tends to move under the shade.

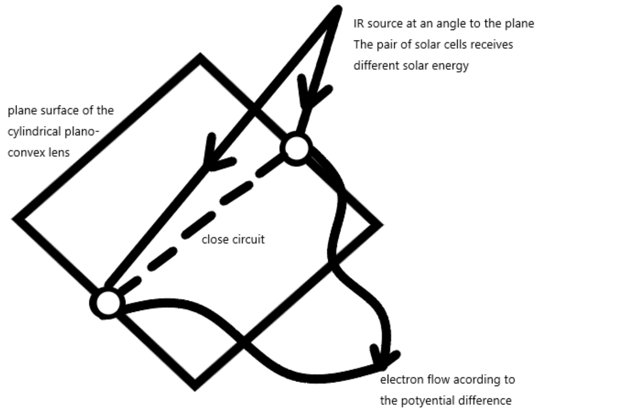
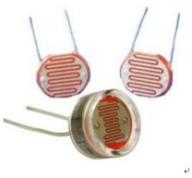


Fig. 10. Potential difference across the opposite solar cells if the plane is not perpendicular to the incident IR irradiation

IR source shines at an angle to the plane. The pair of opposite solar panels receives different illuminance. By the principle of the photovoltaic effect, the solar panels convert the IR radiation into electric potential. The potential difference across the opposite pair of solar cells creates a current that drives the actuator and tilts the 4 edges of the surfaces according to the potential difference. The speed of actuator must be fast, regardless of the overshooting. The laser firing of occurs in milliseconds between every two shaking movements of the plane.

The actuator will stop moving when the incident IR is normal to the plano surface of the lens.

There are similar commercial models using Light Dependent Resistor Sensors available, like the solar light tracking with Arduino [5]. However, modification is required in the current design. The central part is made transparent to allow the aiming and firing systems to work.



<u>Light Dependent Resistor (LDR)</u>
Resistance ↓ with ↑ in light intensity. Provide analog input to arduinoyo

<u>Arduino microcontroller control</u> the position of motor. *At mega 328p* consist of 6 analog inputs and 14 digital i/o ports. 6 of them acts as pwm signals. It also consists 16 MHZ crystal oscillator, a USB cable through which program is dumped. Power jack provides power.

<u>Solar panel:</u> Photovoltaic cell converts light energy into electrical energy.

<u>Servo motor:</u> Two motors (3 wired dual-axis, rotates upto 180 degrees) for east-west and north-south movements, with power received from arduino.

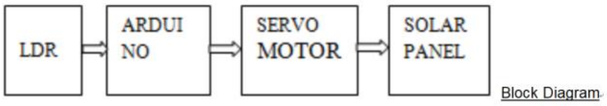


Fig. 11. Components of Arduino light tracking system

Four Light Dependant Resistor (LDR) are connected to Arduino analog pin AO to A4. The analog value of LDR is converted into digital. Inputs : analog value of LDR. Arduino: controller. DC motor: output. LDR1 and LDR2, LDR3 and LDR4 are taken as pair .If one of the LDR in a pair gets more light intensity than the other, a difference will occur on node voltages sent to the respective Arduino channel to take necessary action. DC motor will move the solar panel to the position of the high intensity LDR that was in the programming [6].

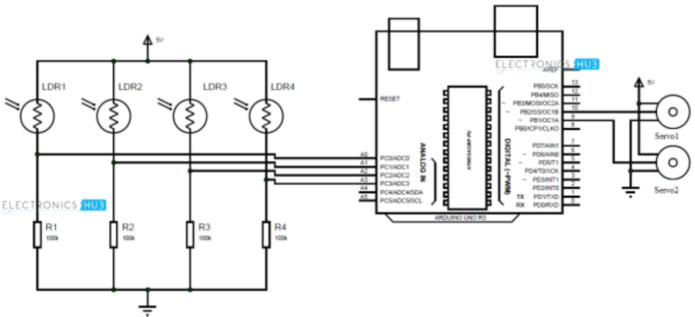


Fig. 12. Circuit diagram of Arduino light tracking system

Step1	start the program
Step2	initialize all the values
Step3	calculate the difference of ldr
Step4	if ldr1>>ldr 2,3,4,5 motor go towards right
Step5	if ldr2>>ldr 1,3,4,5 motor go towards centre
Step6	if ldr1>>ldr2,3,4,5 motor go towards right
Step7	if ldr1>>ldr2,3,4,5 motor go towards right
Step8	if ldr1>>ldr2,3,4,5 motor go towards right
Step9	End the program
Table 1	Algorithm for servo motor movement

Step 2 Direct the IR homing to the light source

The same principle can be applied to the actuator carrying the IR homing device in a horizontal direction.

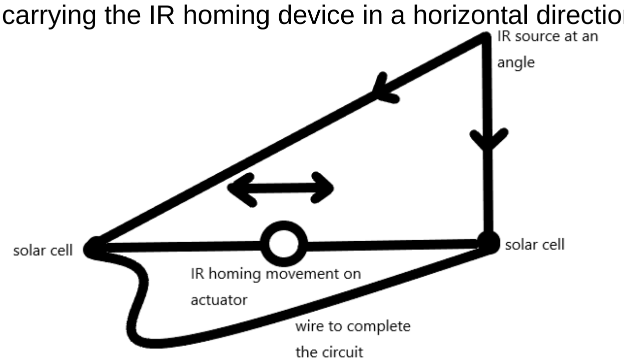


Fig. 13. Potential difference created on the pair of opposite solar cells drives the IR homing device towards the light source.

Again commercial linear actuator is available making use of Arduino and photoresister [7].

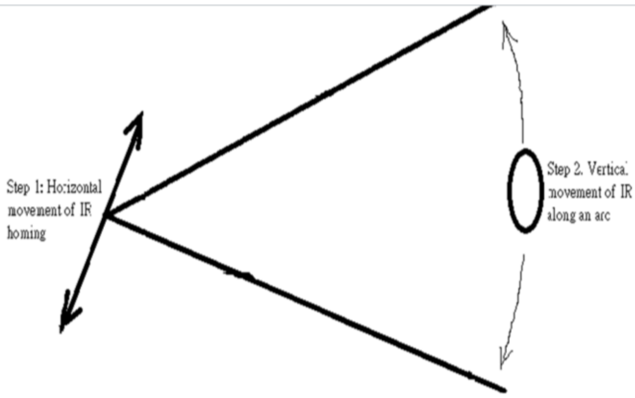


Fig.14.movement of IR homing

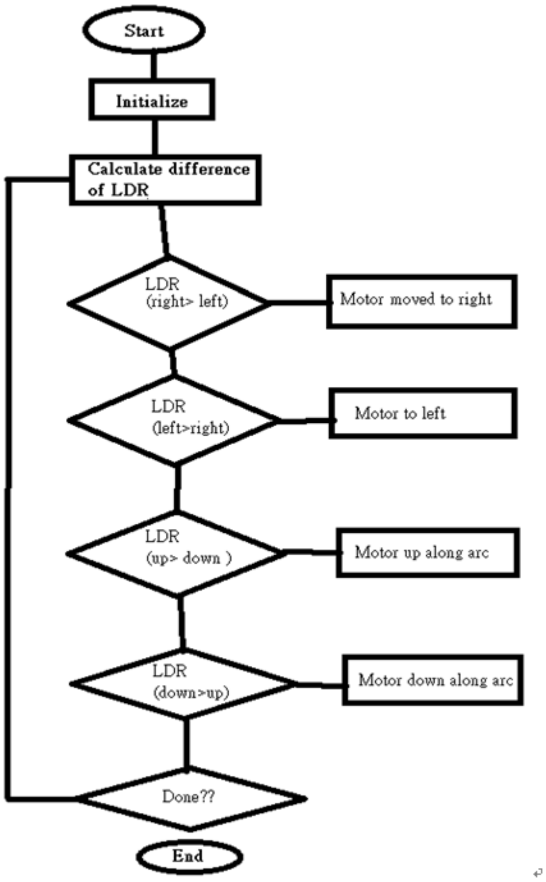


Fig.15. flow chart for the movement of IR homing

Step 3

The orientation of IR homing device is translated to the orientation of the aiming tube by issuing commands to the servoes in the control section

The servoes in the control section actuates the control surfaces to achieve the desired angulation of the aiming tube. It just likes the 3D Printed Robotic Arm Controlled by Arduino Mimics Human Movement. A microcontroller and ESP8266 based WeMos D1 Mini is used which is controlled by the Arduino IDE.

In the blender, the 3D design of aiming tube was driven by servo motors, and controlled by accelerators and magnetometer attached to the IR homing device. Accelerometers measure the orientation of the IR homing relative to the gravity vectors that determine the angles of the servo motors. Since regular movement also creates acceleration, the trajectory of the robot arm will differ at higher movement speeds. Magnetometer (compass) is used to measure the arm yaw. The measured position on the startup of the micro controller is measured and taken as the reference forward direction later.

Since the orientation of the waist between IR homing and the supporting rod needs to be subtracted from the compass vector to get the absolute world orientation, all transformations from IR homing and the supporting rod are back transformed using matrices multiplication in the *calculateAngles* function.

Communication is through I²C wiring. Two GY-521 sensors are addressed by wiring either GND or VCC to the ADD pin of the sensor boards. The code is uploaded to the WeMos D1 Mini micro controller (esp8266 core) from the Arduino IDE. Support for the ESP8266 is provided by the corresponding extension from the bards manager

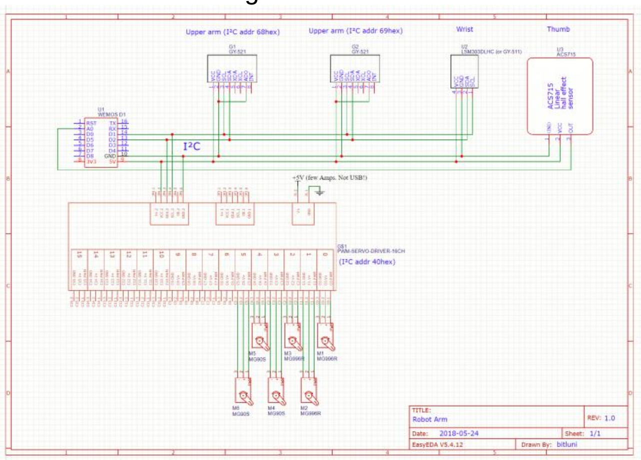


Fig. 16. The wiring involving the transformation of movement [(9)]

The 'eye' of IR homing swings 'to and fro' to detect the target so it can detect the maximum illuminance. However, firing should be started before the maximum.

When the IR device is nearly 'looking at' the target, the illuminance will rise suddenly according to the inverse square law. Laser is fired at this moment rather than fired at the maximum illuminance because there is a time lag between detection and firing. This point is extremely important to avoid missing the target—hypersonic missile.

Increase the range of coverage

The **range of defence** can be increased by using several aiming tubes, arranged along a circular arc centering at the focus of another cylindrical plano-concave lens. Parallel laser source will diverge and supply the aiming tubes after passing through the lens.

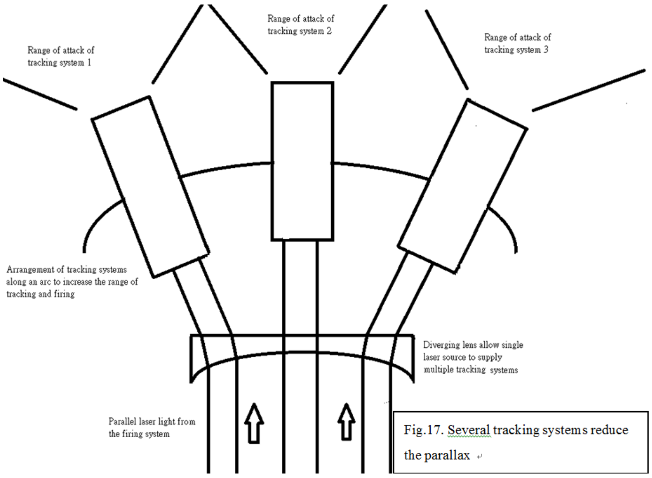


Fig.17. Several tracking systems reduce the parallax

CONCLUSION

Bearing in mind that light travels faster than sound and the target can be traced back along the path of electromagnetic emission that it emits, different designs are possible. Laser has the advantage of not seeing by the target, which otherwise can evade from the attack.

Lag time consideration is particularly important in such a fast moving missile. Here, steps 1,2,3 should be carried out simultaneously. The firing threshold can be adjusted according to the rate of change of illuminance. And firing should ideally occurs before, at, and just after the maxmum illuminance detected.

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