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Reducing Human Effort of the Optical Tracking of Anti-Tank Guided Missile Targets via Embedded Tracking System Design

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Abstract: Human role reduction in the firing process in the physical military systems is the way to improve the overall system performance and achieve the requirement of operation, especially for the anti-tank guided missile (ATGM). In the second-generation ATGM system, the human operator is responsible for following the target until the missile clash the target (Manual Target Tracking). Achieving an acceptable flight trajectory with getting a minimum miss distance, which is a distance between the center of the target and the impact point, is the factor that used to measure the ATGM performance. This paper is dedicated to designing and implementation of an embedded tracking system capable of dealing with the slow-moving objects, which is carried out as a step to reduce the human operator role during the operation, in addition, upgrade the second-generation anti-tank guided missile system to third generation ATGM system (Automatic target tracking). The present work seeks to take benefits of a System on Chip (SoC) technology, including embedded Linux systems, in the real-time computer vision applications. The nonlinear flight simulation model of the intended missile system is presented in a MATLAB environment. The tracking algorithm is described using Python programing language with the aid of OpenCV library and implemented based on embedded Raspberry Pi system (RPI). Hardware-in-Loop experimental test is carried out to evaluate and validate the methodology of the proposed work to achieve the overall system requirement with an acceptable flight trajectory and minimum miss-distance.

Keywords: Raspberry Pi, Guided Missile, Hardware-in-The Loop, Tracking Algorithm, Computer Vision

1. Introduction

In the second generation of ATGM missiles, the operator has required to track the target by optical telescope manually until clash occurs. In this tracking stage, the skills of the operator are an important factor, which effects on the kill probability of the target. Moreover, the operator training needs so much time, money, and effort. On the other side, from the tactical standpoint, the performance of antitank guided missile systems (ATGM) is measured through many points of view, including achieving the minimum miss distance and the capability of the missile to overcome target maneuver [1, 2]. The edge of science is moving toward having accurate and more efficient systems, especially missile systems by taking advantage of different fields of science, like computer vision.

Computer vision is an area of computer science, mathematics, and electrical engineering. It includes ways to acquire, process, analyze, and understand images and videos from the real world in order to mimic human vision. Also, unlike human vision, computer vision can also be used to analyze and process infrared images [3, 4]. Nowadays, the implementation of the computer vision algorithms on embedded systems provides a wide range of integration with real life applications.

System on Chip (SoC) technology is attracting many researchers for embedded system application especially for computer vision applications all over the world. A single-board computer system is a complete computer on a single board. The board includes a processor (s), RAM, I/O, and networking ports for interfacing devices [5]. Unlike traditional computer systems, single-board computers are not modular and its hardware cannot be upgraded.

The use of single-board computers in embedded systems is very prevalent, and many individuals and organizations have developed and released fully functional products based on single-board computers [5]. Therefore, single-board computers are used as low-cost computers in academic and research settings. For example, popular single-board computers available on the market include, but are not limited to, are Raspberry Pi, Banana Pi, BeagleBone, and Cubieboard boards.

One of development approach methods, that used for evaluation and validation of experimental work is X-in-loop development approach, which has different stages to reach a complete system test finally [6]. These stages are carried out to have a green light to complete system test, in addition increasing the operator experience in interfacing with different analog and digital circuits and saving time and money [3, 7]. In addition, selection of the suitable embedded system for experimental work mainly depends on different parameters such as processing speed, RAM memory, algorithm complexity, and embedded system technology that concerned with software, hardware sensors and their interfaces to the embedded platforms. One of the more suitable embedded platforms is a Raspberry Pi system (RPI), which is used for implementing the proposed tracking system [8].

2. Problem Formulation

The intended missile system is represented as one of a second generation ATGM, surface-to-surface type, wire guided, which depends on thrust to correct continuously the missile spatial motion during its flight. [9]. The block diagram of the 6DOF flight simulation model is shown in figure 1.

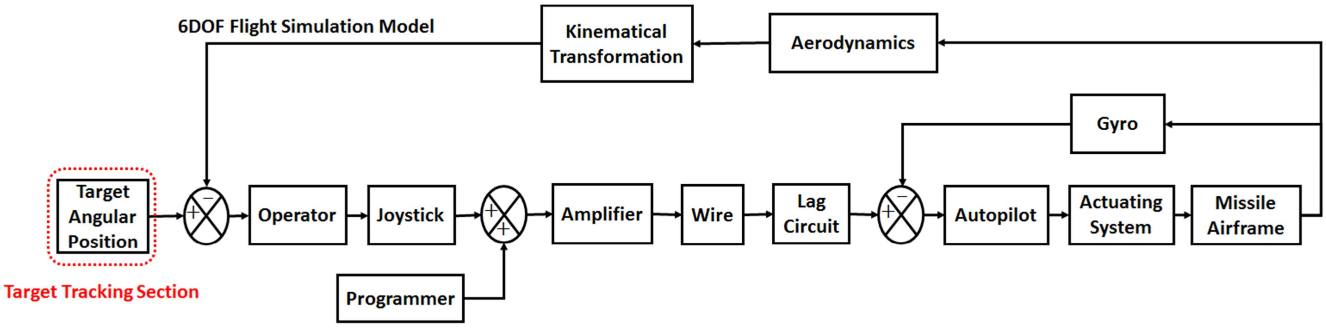

Figure 1. *Non-linear flight simulation model block diagram.*

The intended guidance system utilizes a human eye, usually assisted by a magnifying optic, to track the target until the engagement. In this manner, the missile tracker is usually looking along the line of Sight (LOS). When the missile is launched, as nearly as possible to the LOS, the automatic missile tracker detects any missile deviation from the LOS and passes it to the guidance computer. This computer determines the correct coded command signal and forwards it to the missile via the command link. During that, the operator has to track the moving target to have the correct LOS error between the missile and moving target. This mainly depends on the operator's skills and the quality of the manually tracking devices that may cause a reduction in overall system performance.

3. Experimental Objective

The objective of the presented work is design and implementation of an embedded tracking system to acquire images, detect and calculate target parameters automatically without human interference, which can be considered as the base of target identified system (seeker) for the missile systems. In addition, the proposed system achieves many advantages such as automatic operation, real-time, portable, less weight and size, and less power needed with respect to common systems.

Seeker device is responsible for tracking the required target on board the missile, which used in the third generation of ATGM systems. This upgrading will increase overall system performance and kill probability of the target because once the target is identified by tracking algorithm, the missile needs no further guidance during flight (as Fire-and-Forget systems) and the operator is free to retreat.

4. Experimental Setup

The most widely recognized issue experienced in the object tracking is to discover the region of interest (ROI). The region of interest is the locale in which we find the required object in distinctive video frames. Besides, one of the major difficulties in object tracking is that of noise, complex object shape/movement, partial and full object occlusions, scene illumination changes, continuous processing requirements. For more information on tracking, a comparison between useful techniques can be found in the references [3, 10-12]. This paper deals with the development of real-time object tracking using a color feature and motion to evaluate the overall proposed embedded tracking system.

Figure 2 shows a flow chart of the proposed tracking algorithm in sequential form. Starting from acquiring the video frames, changing the color picture into gray, applying a median filter to expel clamor from images or frames got from the video, selecting the correct feature, and finally tracking the object and locating the properties of the object.

In the proposed approach, tracking the object is carried out utilizing the color feature, particularly red shade. Then track the object using motion, for motion detection and tracking, frame difference technique is used. In addition, bounding box property is utilized to reveal the object.

The tracking algorithm implementation of the proposed work is carried out utilizing the Python programming language with the aid of the OpenCV library in order to design the proposed tracking algorithm.

The hardware connection between the physical part of the proposed system and the main flight simulation model in MATLAB is shown in figure 3 [13-17].

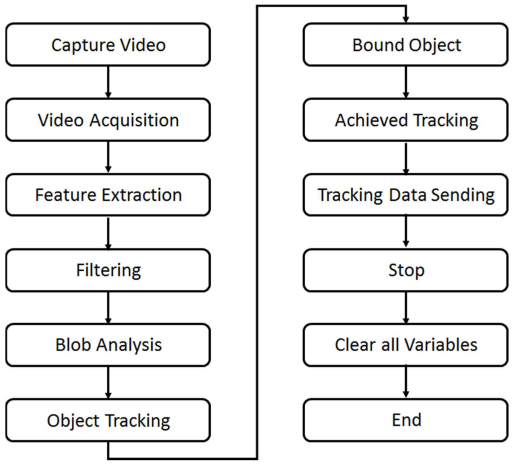

Figure 2. *Flow Chart of the proposed Tracking Algorithm.*

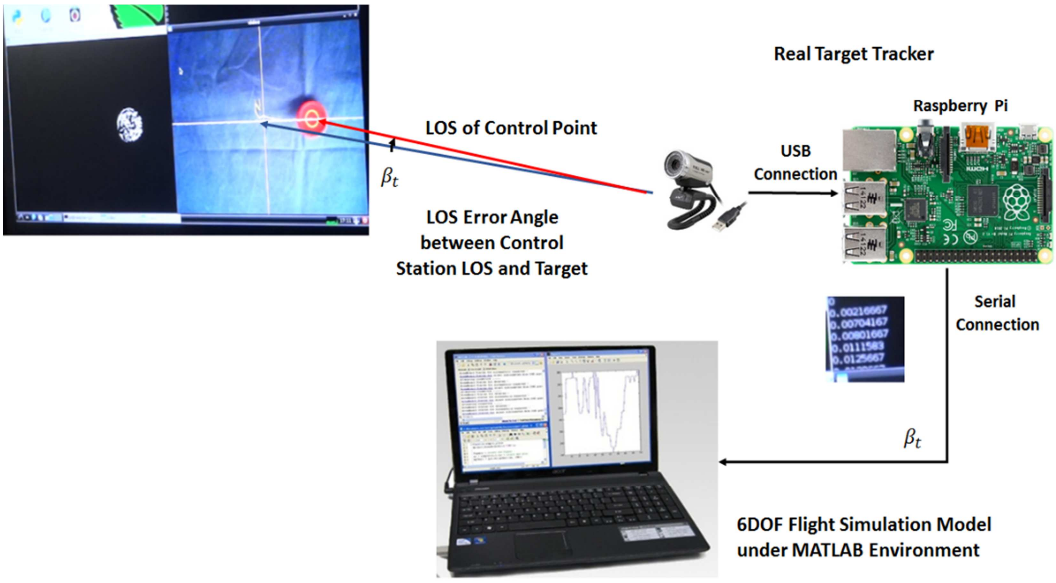

Figure 3. *Hardware tracking system setup.*

The target scenario assumes a moving target in the azimuth plane, toward the positive Y-axis with velocity 5 [m/sec.] at distance 2800 [m] along X-axis. In order to have a full loop, the target parameters are required to close the outer loop of the flight simulation model in both elevation and azimuth plane (ε_t,β_t). According to the target scenario, only the target angle in the azimuth plane (β_t) is required to send from hardware system to simulate the real target angle in the battlefield, which is calculated by the operator. In order to evaluate the proposed tracking system experimentally in the laboratory, the output of the hardware should simulate the target scenario as shown in figure 4.

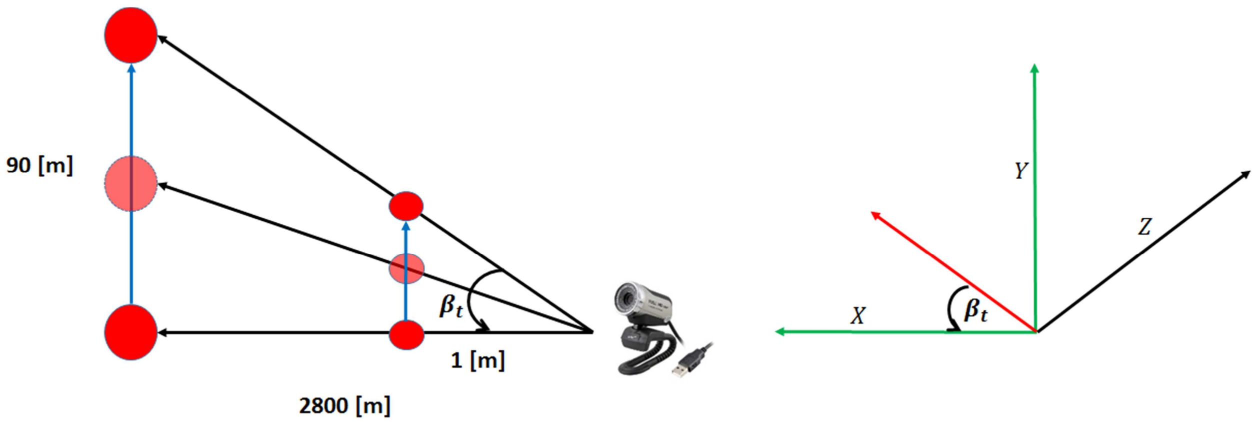

Figure 4. *Target scenario simulation experimental setup.*

5. Hardware-in-Loop Experimental Test

For experimental evaluation, the automatic tracking system connected as a hardware-in-loop (HIL) with 6DOF flight simulation model in the main simulation MATLAB environment as shown in figure 5.

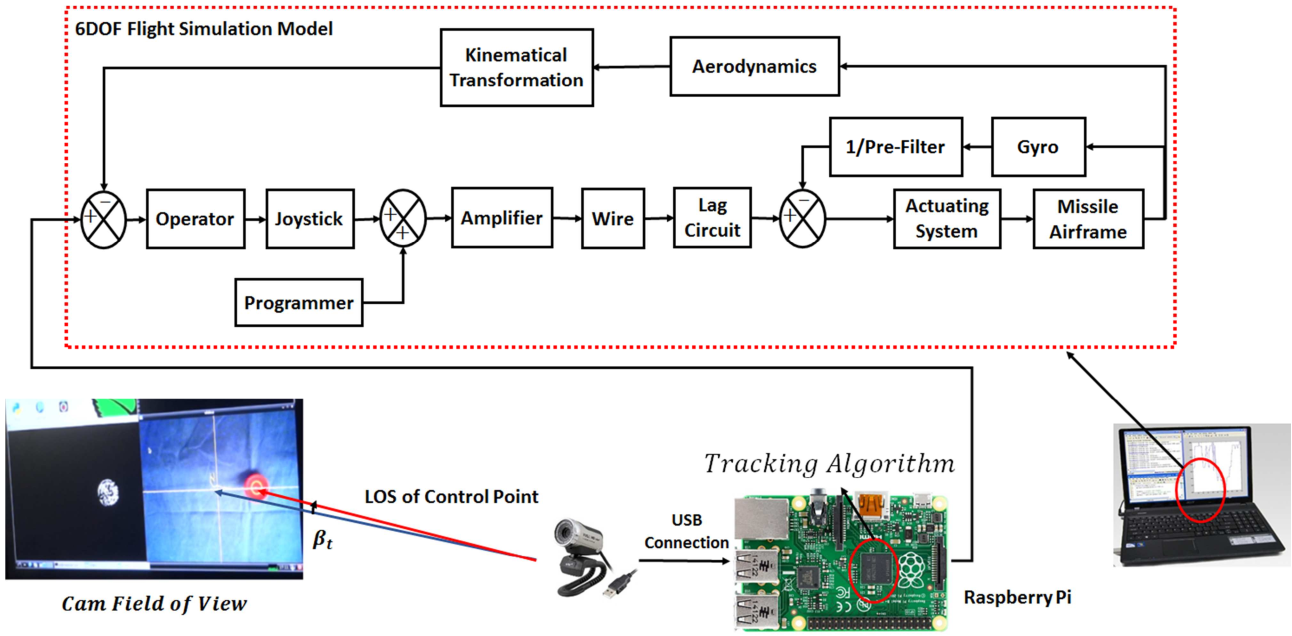

Figure 5. *Automatic target tracking hardware-in-loop setup.*

The target angle variation between simulation and experimental results is illustrated in figure 6. According to the target parameters calculated by the tracking system, the control action is generated to change the actuating system nozzle angle [4, 18]. The variation in nozzle angle causes the change in missile airframe, the nozzle angle variation between simulation and real tracking system is shown in figure 7 and the missile trajectory in pitch and yaw plane represented is shown in figure 8.

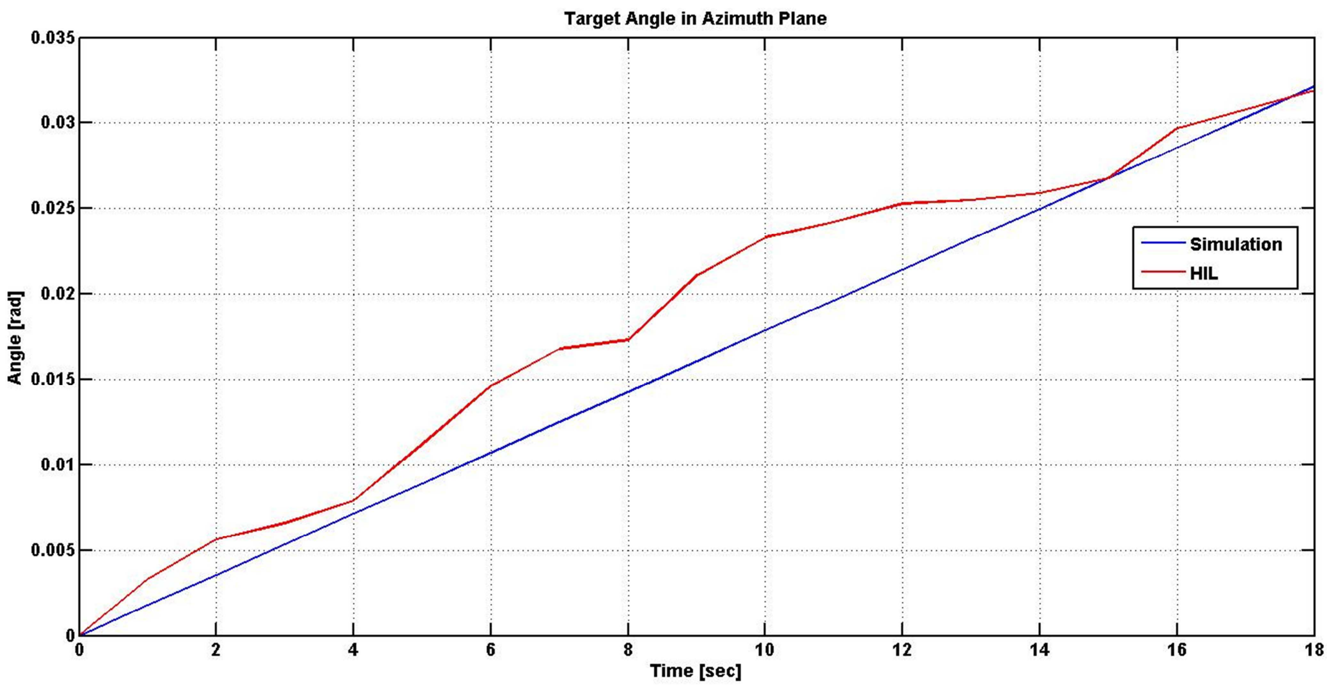

Figure 6. *Target angle in azimuth plane.*

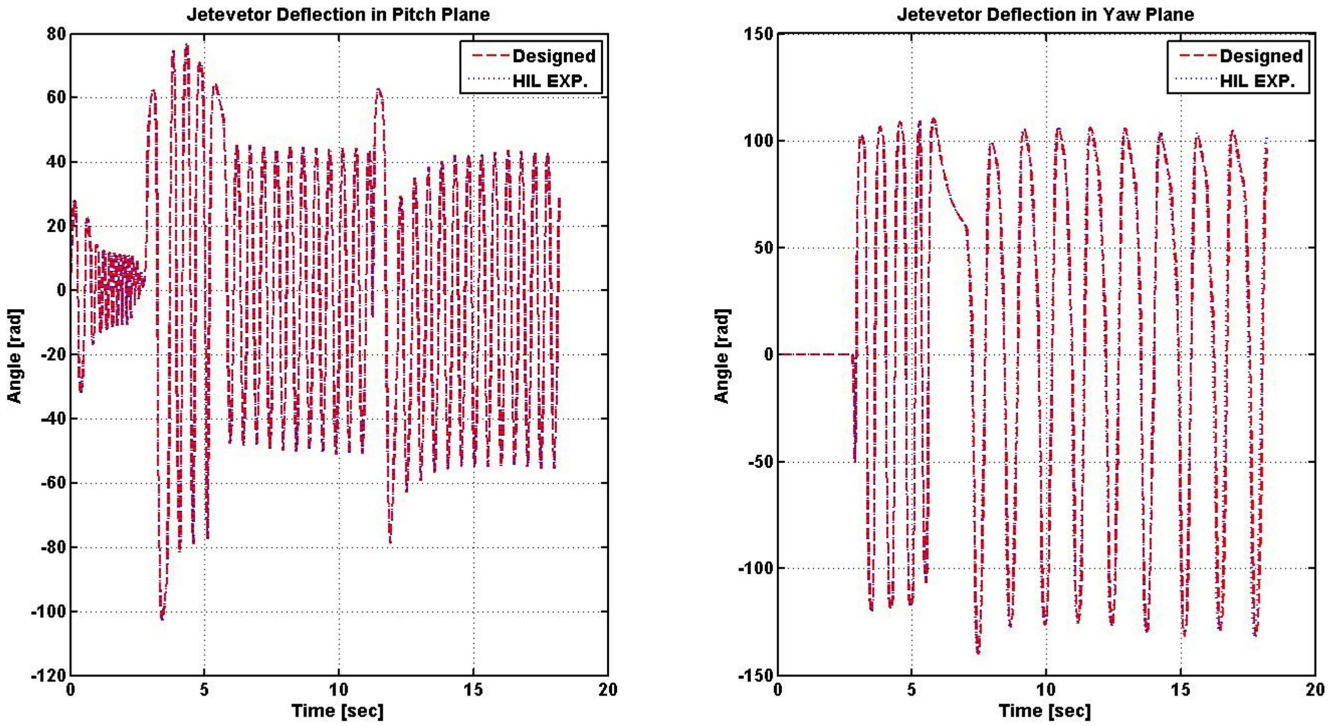

Figure 7. *Actuating system nozzle deflection in pitch and yaw plane.*

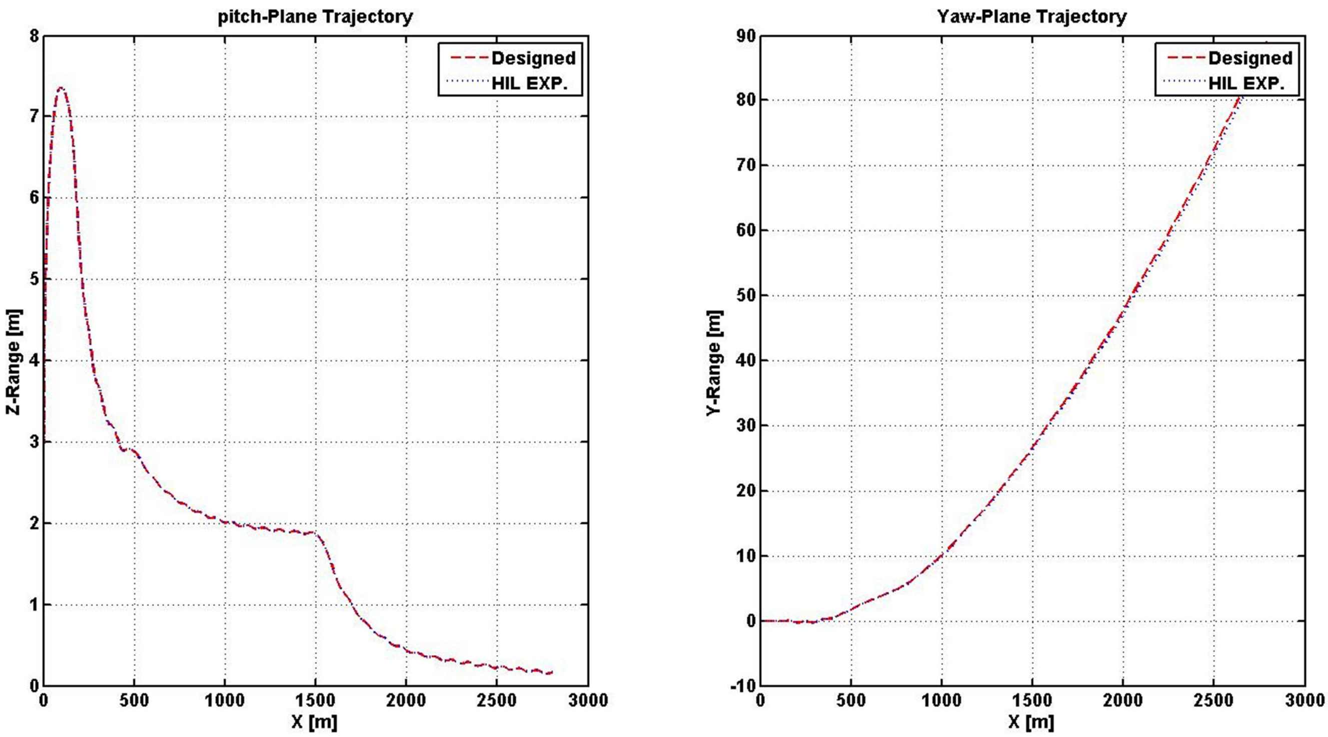

Figure 8. *Missile trajectory in pitch and yaw plane.*

The experimental results show the success of automatic tracking system to detect and calculate target parameters in real time, which are sent using serial communication to main 6DOF flight simulation environment until the missile clashes the target as shown in Table 1. The experiment achieves the missile performance requirement with accepted flight trajectory and accepted miss-distance. The variation of miss-distance has appeared due to a limitation of data size transfer between the embedded system and MATLAB environment [13].

Table 1. *Automatic real tracking hardware-in-loop results.*

Moving Target at 2800 [m] with Speed 5 [m/sec.]	Target Tracker	Miss-Distance	Impact Target
Case (1)	Simulated	1.04731	Achieved
Case (2)	Real	2.2751	Achieved

6. Conclusion

The proposed embedded tracking system introduces an effective step to increase the successful kill probability of the second-generation ATGM systems by reducing the human operator function during the firing process. Moreover, the System on Chip technology provides great facilities for design and implementation real-time tracking systems. These systems have great advantages; include portability, less weight, size, power consumption, easy programming, and rapid development such as the proposed system. In addition, this system helps to understand the real-time conditions of optical tracking systems for moving objects and its challenges.

Therefore, developing systems, like the proposed system, will take several forms, including increasing the processing speed of the intended embedded system, develop advanced tracking algorithms, integrate with different physical systems, and use the edge of science in embedded systems applications.

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