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Research Article

Test System Design and Modeling for Laser Seekers

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Abstract

Flight tests carried out during missile design and development involve high costs. Simulating these tests in a laboratory environment saves companies significant resources and labor. The Electro-Optical Measurement and Test System, where laser seekers are tested, is one of them. In this article, studies have been carried out on designing and modeling a system that can generate the target image required for testing the laser seeker in the laboratory environment. The necessary components for the test system were determined, and their information was given in detail. Labview was used for simulation studies, and the functionality of the designed system was examined with the simulations.

Keywords: Laser, Seeker, Simulation, Labview.

Lazer Arayıcılar için Test Sistemi Tasarımı ve Modellemesi

Öz

Füze tasarımı ve geliştirilmesi sırasında gerçekleştirilen uçuş testleri yüksek maliyetler içermektedir. Bu testleri laboratuvar ortamında simüle etmek, şirketlere önemli ölçüde kaynak ve iş gücü tasarrufu sağlar. Lazer arayıcıların test edildiği Elektro-Optik Ölçüm ve Test Sistemi de bunlardan biri. Bu makalede, lazer arayıcının laboratuvar ortamında denenmesi için gerekli olan hedef görüntüsünü oluşturabilecek bir test sistemin tasarımı ve modellenmesi üzerine çalışmalar yapılmıştır. Test sistemi için gerekli bileşenler belirlenmiş ve bilgileri ayrıntılı olarak verilmiştir. Simülasyon çalışmaları için Labview kullanılmış ve tasarlanan sistemin işlevselliği simülasyonlar ile incelenmiştir.

Anahtar Kelimeler: Lazer, Arayıcı, Simülasyon, Labview.

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1. Introduction

Laser systems are one of the tools used within the scope of target marking in the military. In laser-guided missiles, the direction is determined according to the laser reflected from the target. The laser's energy reflected from the target, its diameter, and angle of incidence provide information to the missile about the target's position [1]. The laser seeker detects the laser reflected from the target in the missile, and the necessary tracking commands are generated. For this reason, seekers also serve as the brains of missiles [2].

Targeted testing in the field is the best method for evaluating laser seeker performance. However, this test is costly and requires considerable financial resources. Moreover, the continuity of the tests is complex due to reasons such as labor costs [3]. For this reason, laboratory tests such as hardware-in-the-loop (HWIL) simulations are performed before actual testing. HWIL tests allow the missile and its components to be tested in various scenarios corresponding to real-life flights. One stage of the HWIL tests is the test for the laser seeker [4, 5]. Laser seeker design and development studies begin with tests in a laboratory environment, and then the field tests under actual conditions start. Simulating the laboratory environment with the field environment at a sufficient level, even if not precisely, enables the designer to develop the design by the field conditions [6]. The laser seeker's parameter calibration, optimization, and performance tests are performed with the test system to be used in these tests. The test system's performance and sensitivity also determine the seeker's quality [7]. In laser tracking applications, a four-quadrant photodetector (QPD) is generally used as a position-sensing element due to its high sensitivity, fast response, and compact structure. The test system moves the laser beams along the X-Y axes to reflect the beams toward the QPD [8].

The importance of laser-guided short-range missiles continues today. For this reason, test system development studies maintain their significance, and companies are developing new devices for this area. Before the installation of the test system, architectural design, modeling, and simulation studies are carried out. In this context, there are studies on different laser seekers in the literature [9, 10]. In this study, the test system's component identification and modeling sections are further elaborated to contribute to existing research.

First, the architectural design studies of the system were made. After the design studies, the components that can be used in the system were determined. Then, modeling and simulation studies were carried out using Labview. At last, simulations were done in different flight scenarios.

2. Material and Method

2.1. Material

The laser seeker follows the laser beam reflected from the target in target detection and tracking. The energy of the laser beams reflected from the target during the flight reaches the seeker at deficient levels at first. The energy reaching the head increases as it approaches the target, depending on the missile's speed and atmospheric conditions. Likewise, the spot diameter of the laser beam detected by the head also changes [11].

The main element of the test system is the laser source. The Q-switch laser was chosen as the laser source in the system. Q is the initial of the word "quality" and means switching the laser from low quality (low energy) to high quality (high energy). The pulsed laser emits in small condensed packets. These small concentrated packets of lasers are more potent than a continuous laser beam [12]. A Gaussian beam is emitted from Q-Switch lasers. The profile of the beam is given in Figure 1 [6].

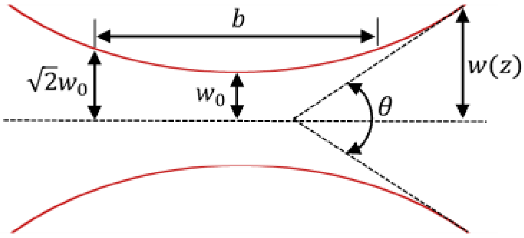


Figure 1. Gaussian beam profile

The equation of density belonging to the Gaussian beam is given below. Beam intensity varies in proportion to the square of the diameter ratios to each other [13].

$$I = I_0 (w_0 / w(z))^2 e^{-2r^2/w^2(z)} \tag{1}$$

$$w(z) = w_0 \sqrt{1 + (z / z_R)^2} \tag{2}$$

I_0 is the central density, r is the distance from the center ve $w(z)$ is the beam radius. The Rayleigh equation finds z_R [13].

$$z_R = \pi w^2{}_0 / \lambda \tag{3}$$

The following equation finds the power of the laser beam passing through the aperture [13].

$$P = P_0[1 - e^{-2r^2/w^2(z)}] \tag{4}$$

$$P_0 = 1/2\pi_0 w^2{}_0 \tag{5}$$

The second element of the system is the filters that will weaken the laser energy to simulate flight. In this context, the internal attenuator of two laser sources can be used. But in general, the resolution of these attenuators may not be sensitive enough. The attenuator of the laser source given as an example is 8 bits so energy adjustment can be made in a range of 256 steps. Another method is to use an external filter. These filters usually consist of an adjustable half-wave plate and a polarizing beam splitter, and energy exchange can be done quickly with a rotary motorized system [14]. The polarization process is given in Figure 2.

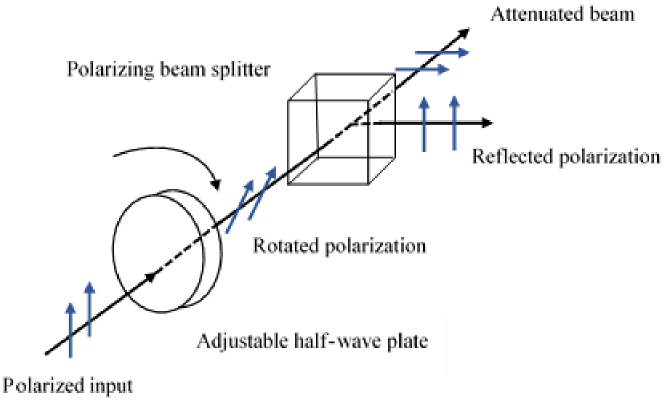


Figure 2. The polarization process

There may be slight scattering in the laser beams emanating from the source. Especially in the first moments of the test, these scatterings can disrupt the desired flow since the energy is small. At this point, it is necessary to use a sensor to adjust the energy level. The energy value received from the sensor is transferred to the control system as feedback [15].

The beam diameter of the laser source is 5 mm. It is aimed to enlarge this diameter up to 100 mm for test requirements. The beam diameter must be variable to simulate the moment of flight fully. In this context, a lens system is positioned before the laser source. The beam diameter expansion process is given in Figure 3.

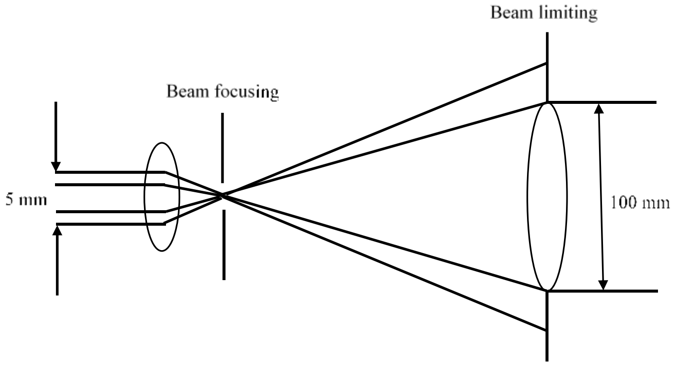


Figure 3. The beam diameter expansion process

A remotely adjustable diaphragm between 0 and 100 mm diameter is placed after the lens system. Thus, the energy and beam diameter required for the flight scenario can be adjusted as desired. After the beam diameter is modified, it transmits to the target. In this section, a motorized scanning system can direct the laser beams along the X-Y axes [16].The block diagram of the X-Y scanner is given in Figure 4.

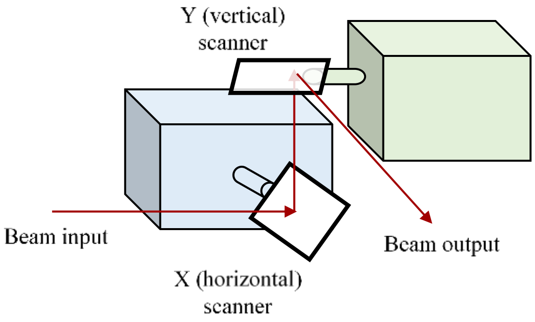


Figure 4. X-Y scanner

The architecture of the system is given in the Figure 5.

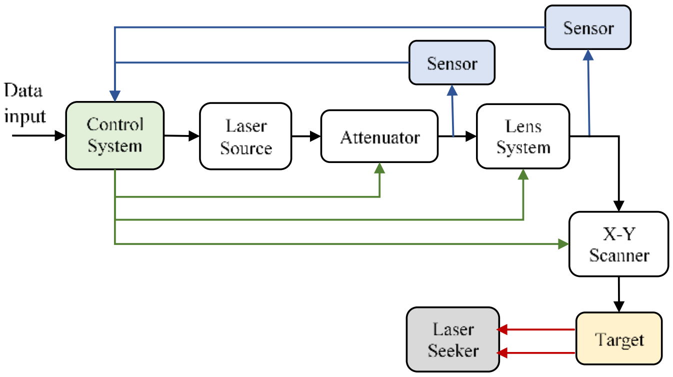


Figure 5. The architecture of the system

2.2. Method

In this study, modeling and simulation studies were carried out using Labview. Labview is short for Laboratory Virtual Instrument Engineering Bench. It uses the graphical programming language, also known as parallel programming. [17].

The simulation creates the laser's energy, beam diameter, and X-Y positions according to different flight scenarios. In the program, firstly, the data reflected from the target for the missile flight is received. In the simulation, the data is taken from the excel file with the "Read From Spreadsheet File" block. In the example scenario, there is data of 500 steps. Energy values vary between 10 and 50 mJ, and beam diameter values range between 0.2 and 100 mm.

The task of the first subsystem in the program is to receive the incoming data collectively and give it separately to the relevant sections. The diameter size is adjusted by transmitting the beam diameter information from these data to the diaphragm. At the same time, X-Y data is transferred to the scanner system. The energy change originating from the diaphragm is calculated, and the required attenuation value is transmitted to the attenuator according to the scenario. Finally, the laser source is activated. These operations are also done in the second subsystem. This cycle continues until the last data is received. The program's control panel is given in Figure 6, and the block diagram is in Figure 7. The white frame on the left side of the control panel simulates the target. On the right are the attenuator and diaphragm settings and the energy output.

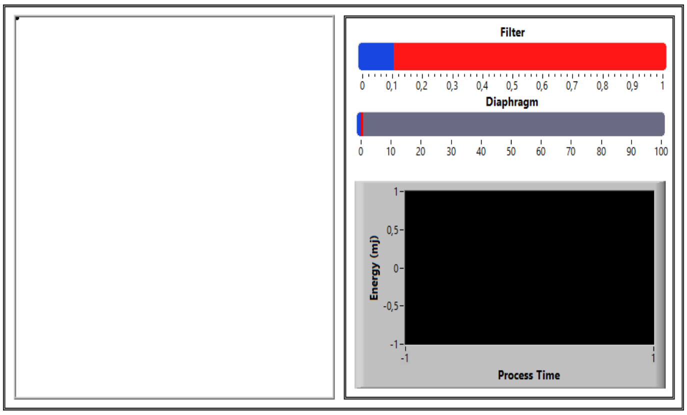


Figure 6. The control panel

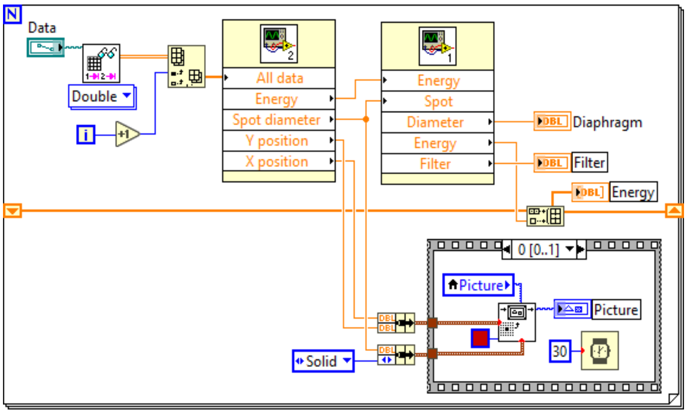


Figure 7. The block diagram

3. Results and Discussion

Firstly, the simulation was performed without an external attenuation filter. The energy outputs of the first 50 steps of the simulation are given in the Figure 8. The data in blue in the graphs are the energy values from the scenario, and the data in red are the energy data obtained from the simulation. As a result of the simulation, there was a 1% difference between the energy values. This situation is due to the sensitivity of the internal attenuator (8-bit - 256 steps attenuator). In the second simulation, an external attenuator is also added. With the effect of the external filter, the 1% error was eliminated. The energy outputs of the second simulation are given in the Figure 9.

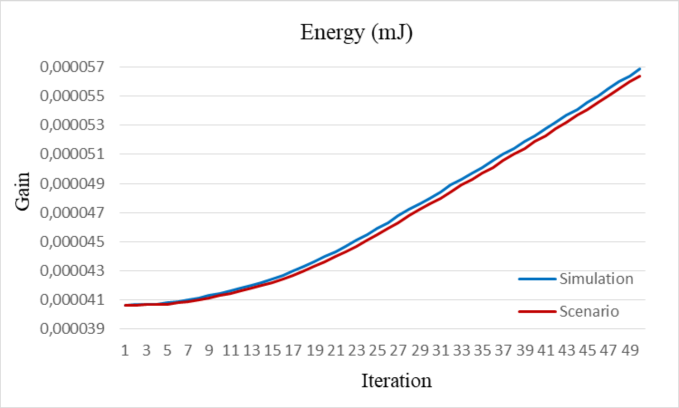


Figure 8. The energy outputs with internal attenuator

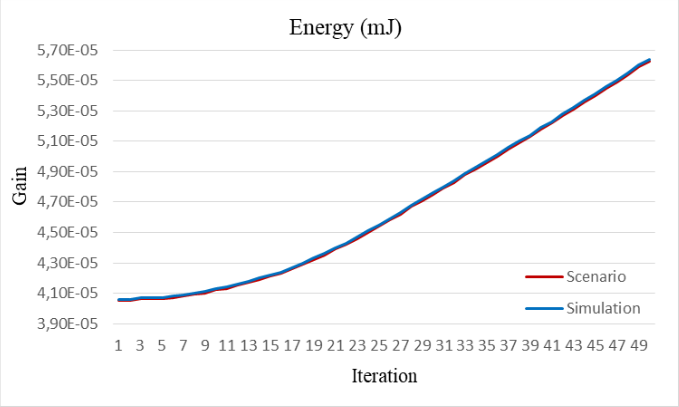
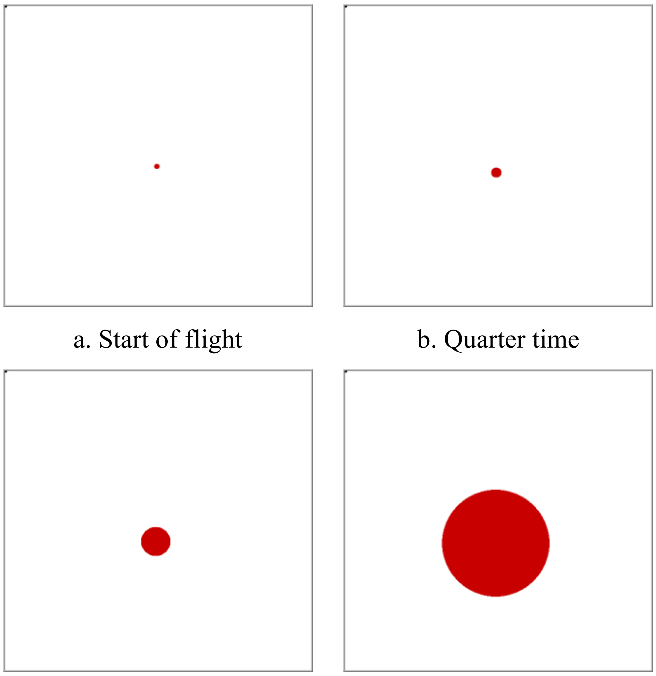


Figure 9. The energy outputs with external attenuator

The laser outputs sent to the target of an example scenario are given in Figure 10. Since the system is far from the target in the first period, a low energy and diameter laser beam arrives (Figure 9, a and b). As time progresses and gets closer to the target, the energy and diameter will increase, as seen in c and d. At the end of the flight, the laser energy and diameter will reach the maximum level in the closest position to the target.

4. Conclusions and Recommendations

As a result, this article explains studies on the design and computer modeling of an electro-optical test system that can be used in the tests of laser seekers. To be a system that can be implemented in design studies, up-to-date technologies have been preferred. The system's operability was tested with the simulation performed in the computer environment. Laser scattering and external factors are neglected in the simulation environment. In the actual process, there may be deviations in energy and diameter changes due to such factors. In this context, sensors are integrated into the system design. The control system can make necessary error corrections by receiving feedback from these sensors.



a. Start of flight b. Quarter time

c. After half d. Last moments

Figure 10. An example scenario

5. Acknowledgement

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References

[1] Stary, V., Krivanek, V., & Stefek, A. (2018). Optical detection methods for laser guided unmanned devices. Journal of Communications and Networks, 20(5), 464-472.

[2] Pu, X., Du, Y., & Dong, Q. (2020). Design and analysis of optical system of semi-active laser seeker. In Journal of Physics: Conference Series (Vol. 1650, No. 2, p. 022059). IOP Publishing.

[3] Zhou, W., Zhang, C., Wang, S., & Ran, L. (2020, March). Design and achievement of hardware-in-the-loop simulation system for strapdown semi-active laser seeker. In IOP Conference Series: Materials Science and Engineering (Vol. 793, No. 1, p. 012065). IOP Publishing.

[4] Todić, I., & Kuzmanović, V. (2022). Cost-Effective HWIL testing methodology for SALS guided missiles. Materials Today: Proceedings, 62, 2509-2515.

[5] Zhu, Y., Cui, X., Wang, Q., Tong, Q., Cui, X., Li, C., ... & Peng, Z. (2016, November). Analysis of laser energy characteristics of laser guided weapons based on the hardware-in-the-loop simulation system. In Semiconductor Lasers and Applications VII (Vol. 10017, pp. 127-134). SPIE.

[6] Sahin, M. (2008) Development of Electro-Optic Test and Measurement System for Mıssıle Hardware in the Loop System Tests. Master Thesis, Ankara University, Graduate School of Natural and Applied Sciences, Department of Electronics Engineering, pp. 14-18.

[7] Xin, H., Aijing, W., Mengyu, W., & Baoxiang, X. (2019). Time-varying periodic disturbance suppression of laser seeker testing system based on spatial iterative learning control. Infrared and Laser Engineering Journal, 48(9), 913002-0913002.

[8] Ferdjali, A., Stanković, M., Manojlović, S., Madonski, R., Bujaković, D., & Djenadbia, A. (2022). Systematic design of nonlinear ADRC for laser seeker system with FPGA-based rapid prototyping validation. Aircraft Engineering and Aerospace Technology, pp. 1087-1099.

[9] Maini, N., Sabharwal, A., Sareen, K., Singh, A., & Kumar, P. (2014). A User Programmable Electro-optic Device for Testing Laser Seekers. Defence Science Journal, 64(1).

[10] Dong, K. Y., Lou, Y., He, J. Y., Tong, S. F., & Jiang, H. L. (2012, October). Research on simulation system with the wide range and high-precision laser energy characteristics. In 6th International Symposium on Advanced Optical Manufacturing and Testing Technologies: Optical Test and Measurement Technology and Equipment (Vol. 8417, pp. 748-755). SPIE.

[11] Ünal, A. (2022). Semi-active laser seeker design with combined diffractive optical element (CDOE). Journal of Optics, 1-13.

[12] Tian, Y., Yan, H., Sun, G., Lv, L., Wang, X., Zhang, L., & Li, Z. (2015). Semi-active laser/millimetre wave beam combiner design and test. IET Microwaves, Antennas & Propagation, 9(8), 830-836.

[13] Saleh, B. E., & Teich, M. C. (2019). Fundamentals of photonics. John Wiley & Sons.

[14] Levy, C. D. P., Pearson, M. R., Kiefl, R. F., Mané, E., Morris, G. D., & Voss, A. (2014). Laser polarization facility. ISAC and ARIEL: The TRIUMF Radioactive Beam Facilities and the Scientific Program, 165-172.

[15] Maini, A. K., & Agrawal, V. (2012). Test system for comprehensive evaluation of infrared-guided missiles. Iet Optoelectronics, 6(5), 255-262.

[16] QS-30 Open Frame 2-Axis Scan Head. (2023). https://www.nutfieldtech.com/qs-30-open-frame-2-axis-scan-head-2/. Nutfield Technology, New Jersey, United States.

[17] Mühendis, A., & Kulaksiz, A. A. (2020). LabVIEW Based Modelling System Applied in Maximum Power Point Tracking Techniques. Avrupa Bilim ve Teknoloji Dergisi, 445-454.