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Smart guided missile using accelerometer and gyroscope based on backpropagation neural network method for optimal control output feedback

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Abstract

As a maritime country with a large area, besides the need to defend itself with the military, it also needs to protect itself with aerospace technology that can be controlled automatically. This research aims to develop an air defense system that can control guided missiles automatically with high accuracy. The right method can provide a high level of accuracy in controlling missiles to the targeted object. With the backpropagation neural network method for optimal control output feedback, it can process information data from the radar to control missile's movement with a high degree of accuracy. The controller uses optimal control output feedback, which is equipped with a lock system and utilizes an accelerometer that can detect the slope of the missile and a gyroscope that can detect the slope between the target direction of the missile to follow the target, control the position, and direction of the missile. The target speed of movement can be easily identified and followed by the missile through the lock system. Sampling data comes from signals generated by radars located in defense areas and from missiles. Each part's data processing speed is calculated using a fast algorithm that is reliable and has a level of accuracy and fast processing. Data processing impacts on the accuracy of missile movements on any change in the position and motion of targets and target speed. Improved maneuvering accuracy in the first training system can detect 1000 files with a load of 273, while in the last training, the system can detect 1000 files without a load period. So the missile can be guided to hit the target without obstacles when maneuvering.

Keywords: smart missile; backpropagation; neural network; optimal control; output feedback; lock system.

I. Introduction

Air attacks become a severe problem in the military world. Air attacks can come in the form of cruise rockets, short-range rockets, warplanes, drones, and others. The observatory results by Anthony D'Amato in his research entitled retrospective measures of Israeli air attack against the Osiraq reactor [1] which explains that Israeli airstrikes are considered understandable and legitimate defenses. So that in warfare, airstrikes can be categorized as a method of self-defense that can be allowed even if it has an enermous impact and a large number of victims. Technological advances in the field of air defense must be developed along with the development of technology in air attack systems. The air defense, which has the most potential in counteracting airstrikes is missiles with a high level of maneuvering accuracy accompanied by an auto-pilot system that can guide missiles to hit targets in the air. Eloy Garcia *et al.* describe the effectiveness of air defense, with the theme of the cooperative missile guide to active defense of air vehicles [2]. About active countermeasures against missile attacks that lead to the aircraft as a target, with the aim of airstrikes can be anticipated to the maximum and can avoid casualties and material damage.

One of the most needed air defense systems is a missile that can be launched and controlled automatically. Missile targeting system by knowing the target location of the guidance system such as inertial navigation system (INS), and terrain contour matching (TERCOM) or global positioning system

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(GPS). The use of the INS method mathematically developed by Castro Toscano M, J, *et al*., the theme is methodological use of inertial navigation systems for the task of strapdown navigation [3], which presents mathematical descriptions for inertial navigation systems and integration of device implementations. The virtual sensor can detect the weight of changes in the object (target), calculate variables such as speed, position, and attitude on the mobile body of the navigation system. So this system can guide the missile by knowing the missile position and target position, then calculate the distance and position of both. As for the TERCOM radar (on missile bodies) use a height gauge algorithm. Research on the TERCOM radar was developed by Zhang Hua and Hu Xiulin with the theme of a height gauge algorithm applied to the TERCOM radar altimeter [4] which serves to measure the distance of the object. So that it can provide feedback on missile maneuver performance. One method of locking the missile system in TERCOM is using infrared. As developed by Ab-Rahman and Mazen R., the locking system using the infrared method utilizes a detector that can detect high temperatures at the target to respond to missile defenses [5]. Missile design with an infrared system was used in France during World War I [6]. Missile's responsibility for targets has been developed by Kerem G *et al.* with the theme response surface-based performance analysis of an air-defense missile system which aims to reduce the computational burden in each detection process when missiles are maneuvered [7].

The missile test launch system has been developed by Baoquan Li *et al.* about the measurement system and automatic testing of several surface-to-air autopilot missiles, which focus on the use of computer control and multimedia technology, to increase the speed and accuracy of measurement and testing to the maximum and reduce the training work time [8]. Research that discusses defense missile architecture has been discussed by Ender. T *et al.* with the theme of system-of-systems analysis the effectiveness of ballistic missile defense architecture through substitute modeling and simulation [9], using modeling and simulation that supports architecture-level analysis on defense missiles including the sensitivity of operational-level metrics to the formation (overview) tracking integration and making the right decisions. The launching path for surface-to-air missiles has been developed by Guo-Min and Hui Gu on simulating the availability of surface-to-air missile weapons systems that focus on estimating target points [10].

The smart system on missile control provides innovation in determining the direction of missile movement towards a target by utilizing an accelerometer sensor that functions to control the tilt of the rocket and the gyroscope sensor to detect the tilt of the target to the missile. The lock system is obtained from the data sent from INS and TERCOM. Research on missiles utilizing INS radar has been developed by Xinqi Fu and Meirong Chen [11] about missile allocation based on SAR bistatic-borne missiles, which utilize INS without relying on TERCOM, so Missile maneuvers are less accurate in chasing target because missiles have difficulty detecting targets when missiles and targets are at a certain height. Automatic control by utilizing sensors has been developed by Faqih. K *et al.* with the theme of smart grid photovoltaic system pilot scale using sunlight intensity and state of charge (SoC) battery based on Mamdani fuzzy logic control [12], about control systems that utilize sensors for automatic control performance on power sources.

Significant progress has been achieved in the design of optimal control output feedback using the RL algorithm by Modares *et al* [13]. Optimal control is applied to develop the control system. Meanwhile, frequency domain analysis in classical control theory is also used to verify system frequency performance, including crossover frequencies, phase margins, and profit margins, bringing restrictions on performance values. The controller obtained is the optimal output feedback controller for a simplified model with certain durability. Optimal control theory and frequency domain analysis are combined to get fast tracking performance, small error conditions, and certain durability [14]. Optimal control for missile guidance systems has been developed by Jingliang Sun *et al* with the theme "robust optimal control for missile-target guidance systems via adaptive dynamic programming", focusing on the effectiveness of a strong optimal control method for intercepting maneuvers with feedback using the adaptive dynamic programming (ADP) technique [15].

To reduce the error rate in determining the meeting point between missiles and targets, the smart missile system utilizes the Kalman filter in estimating state variables from a linear discrete dynamic system that minimizes the estimated error covariance [16]. Another estimate is the extension of the Kalman filter called the ensemble Kalman filter (EnKF). In the EnKF method, the algorithm is executed by producing many specific ensembles to calculate the average and error covariance of state variables [17]. In using the EnKF method, some schemes can be implemented in the EnKF method, which is the square root scheme that can be implemented in EnKF. This scheme can affect the estimation results, both in terms of accuracy and computational time [18], so it can be applied to estimate the missile position and simulated with Matlab software.

The autopilot design on air defense missiles has been developed by Delin Luo *et al.* [19]. Target identification is carried out to test the performance of the missile autopilot, but it is still unable to detect the direction of the target which changed drastically, so the need for a more accurate maneuvering system on missiles equipped with intelligent algorithms. There is also a missile control study with a bank to turn (BTT) system that can detect changes in the target direction, this study is represented by Mehta S.S with the theme of adaptive vision-based missile guidance in the presence of avoiding target maneuvers [20]. With a focus on minimizing maneuvering errors with targets whose speed is unknown and can change. The BTT system still requires operators to control missile direction. So the guiding process is still too manual, so a microcontroller is needed to automatically adjust the missile body to the target.

Smart missile maneuver system is divided into several types of clusters according to the target direction, research on the missile direction cluster has been developed by Jan Farlik [21]. The theme is a simulation of surface-to-air missile units. The cluster system implemented by Jan Farlik is not yet equipped with an intelligent algorithm, so the target accuracy can be less stable in some circumstances. Missile maneuver requires prediction of a meeting point between missile and target, research on missile maneuver prediction has been developed by Lee S. *et al.* with the theme of missile guidance based on tracking the predicted target path [22] focusing only on determining missile maneuvers. So there is still no solution available if the missile is interrupted when maneuvering. Intelligent algorithms can be a solution to minimize interference on missile maneuvers.

Backpropagation is an effective method for learning neural networks and has been widely used in various applications. The accuracy of the learning result, despite other facts, is highly affected by the volume of high-quality data used for learning [23].

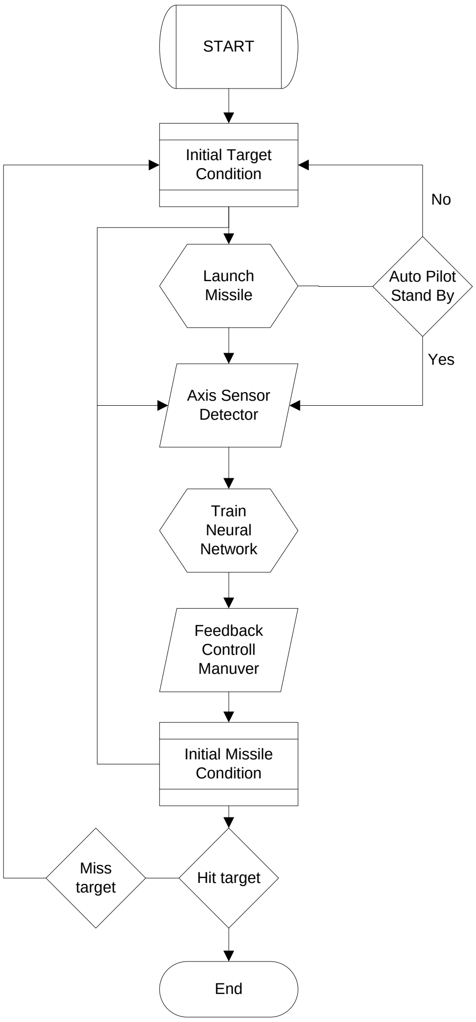


Figure 1. Smart missile architecture flowchart

Neural network planting is one of the methods developed for air defense missile technology. As has been developed by Deyun. Z and Feng. Z with the theme of data fusion control and surface-to-air missile guidance under complex conditions based on neural-net technology [24] using a group method for data-processing to increase the effectiveness of land-to-air missile weapons systems based on filter data tracked with a looping system. The amount of data trained is 500 so that it can be developed by adding the number of iterations at the training stage, as well as a more optimal looping system.

Research that has been developed by Delin and Mehta still utilizes BTT manual control on missile maneuvers. So it can be more efficient if the missile maneuver control system is equipped with sensors and microcontrollers that are sufficient to guide the missile to the target automatically. While research has been developed by Jan Farlik and Lee. S, the cluster system, and its prediction maneuver are still not equipped with an intelligent algorithm to handle files on missile maneuvers. Embedding intelligent algorithms on missiles can be a solution to minimize vibration (fail) when missiles maneuver.

This research aims to develop a system for air defense missiles that can maneuver chasing targets automatically with optimal feedback control that utilizes accelerometer sensor readings for automatic control. This system can minimize vibrations by utilizing the backpropagation neural network algorithm on the sensor detector which can control regular missile maneuvers based on the sensor value cluster. So that the missile maneuver can be better without the need for manual control.

II. Materials and Methods

A. Missile architecture

The missile performance architecture has been prepared about device specifications not damage the missile launcher and body before and during the missile maneuver. The smart missile system has an operating flow as shown in the flowchart of Figure 1. The operation flow starts when the radar gets the target info until the missile can reach the targeted object.

Data maneuvering is processed using MATLAB software, which is equipped with neural network tools to conduct training from data generated by sensors, with backpropagation neural network training methods. The training results become a reference for automatic control on the nozzle. With the embedded sensor in the automatic control on the smart algorithm for nozzle activation control, the smart missile maneuver process is more organized and accurate in chasing targets.

B. Backpropagation neural network missile algorithm

Neural network systems can help accurate maneuverability of automatic control of smart missiles. Because the neural network can recognize an object non-linearly. Neural network control learning provides feedback with many conditions,

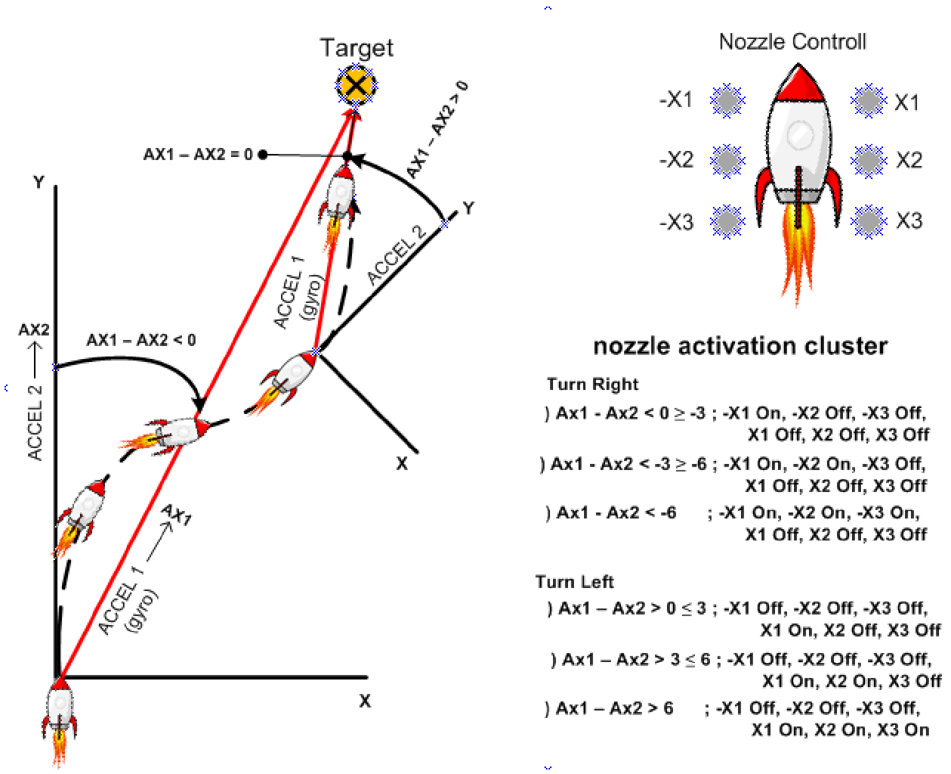


Figure 2. Smart missile algorithm

making it easier to map the input to a result, able to adapt to the recognition of an object, has tolerance for an error in the recognition of an object, can be implemented on hardware, and can be implemented in parallel [25].

Artificial neural networks are usually composed of elements in layers that are connected and weighted. This network modifies these weights based on a series of inputs given from outside the system, to produce consistent and similar output to the given inputs. Usually, each element will process based on mathematical operations that have been given to each element [26]. Smart missile systems use the backpropagation neural network method. Where backpropagation is a supervised learning algorithm and is usually used by perceptron with many layers to change the weights that are connected with neurons in the hidden layer [26]. The implantation of the backpropagation neural network algorithm in missiles has been developed by Da Huang et al. Regarding activation controls on the missile tail to match the exact spectrum volume with strong resistance [27]. The backpropagation algorithm uses error output to change its value. To get this error, neurons are activated by using an activation function that can be differentiated.

As shown in Figure 2, smart missile maneuvering is weighted according to the target slope angle and the missile tilt. The weight that can be achieved is recorded at -10 m/s^2 to 10 m/s^2. The greater the weight of the target slope, the nozzle performance will be maximized with the shortest delay possible. The weight value is obtained from the comparison of the target lock system tilt periodically and the missile tilt periodically. The equation produced in the smart missile represents each neuron as shown in Figure 3. Each neuron is arranged by grouping several clusters based on the smart missile sensor's weight to guide the missile to the target. The neuron continues to work until the detected target can be hit by a smart missile.

The data axis is grouped into 72 clusters as neurons, so the missile can detect and chase targets coming from any direction. The neurons variables are paraded to focus on the movement of the missile tilt by minimizing the readout of the vibrations so that nozzle activation is more regular. In addition to neurons, control maneuvers as hidden layers are also grouped (cluster) according to target and missile conditions. Clusters in hidden layers are arranged in nine clusters to control 24 nozzles as shown in Figure 4.

Nine hidden layers arranged to condition the nozzle activation as follows;

- Low maneuverability; if one nozzle is activated
- Medium maneuver; when two (in a group) nozzles are activated
- Hard maneuvers; when three (in a group) nozzles are activated
- Low & low maneuverability; when two (in two groups) nozzles are activated
- Low & medium maneuvers; when three (in two groups) nozzles are activated
- Low & hard maneuvers; if four (in two groups) nozzles are activated
- Medium & medium maneuvers; if four (in two groups) nozzles are activated
- Medium & hard maneuvers; if five (in two groups) nozzles are activated
- Hard & hard maneuvers; if six (in two groups) nozzles are activated

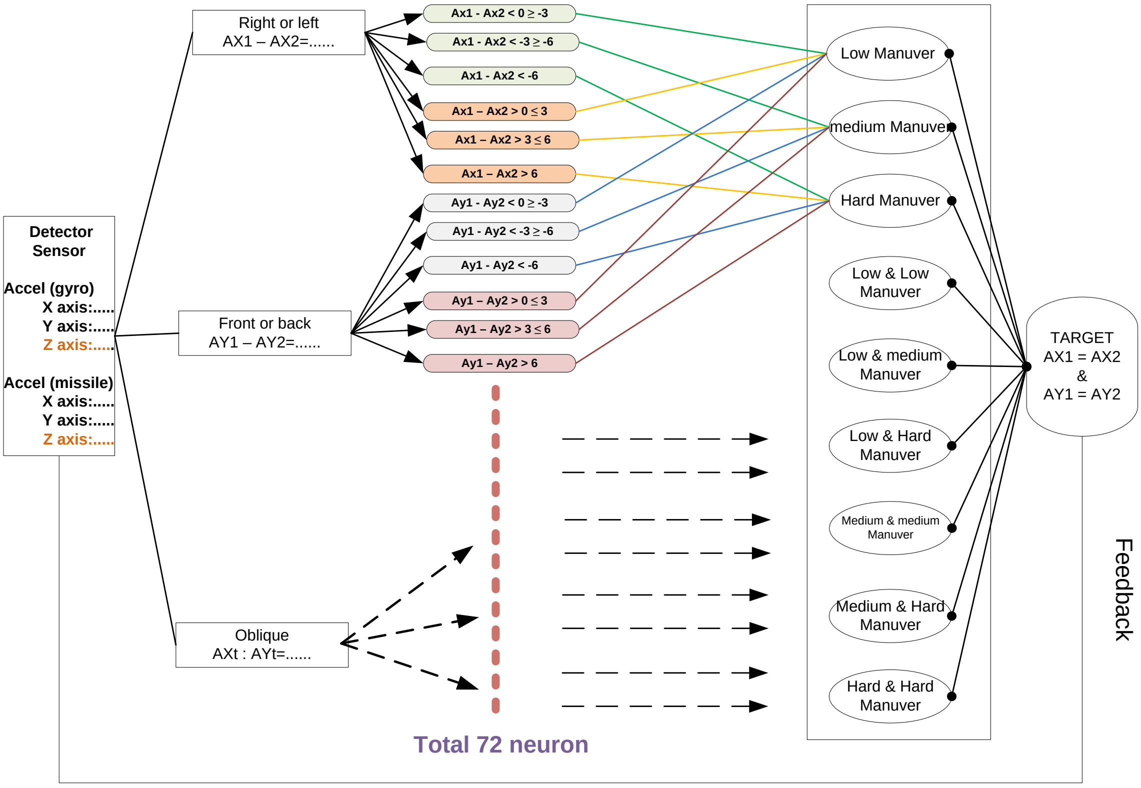


Figure 3. Backpropagation neural network – feedback missile system

There is an equation for the number of nozzles that are activated, namely medium & medium maneuver and low & hard maneuver, totaling four active nozzles. The difference is, if medium & medium each group activates two nozzles, while for low & hard, the first group activates one nozzle and the second group turns on three nozzles (or vice versa). The hidden layers on the smart missile act as a control nozzle that can change the direction of the missile according to the neurons guidance, to increase the accuracy of the missile during the maneuver.

C. Missile maneuver guidance system

The missile guidance system functions as a determinant of the direction of the missile towards the target by adjusting the slope of the missile to match the target position. The scheme developed

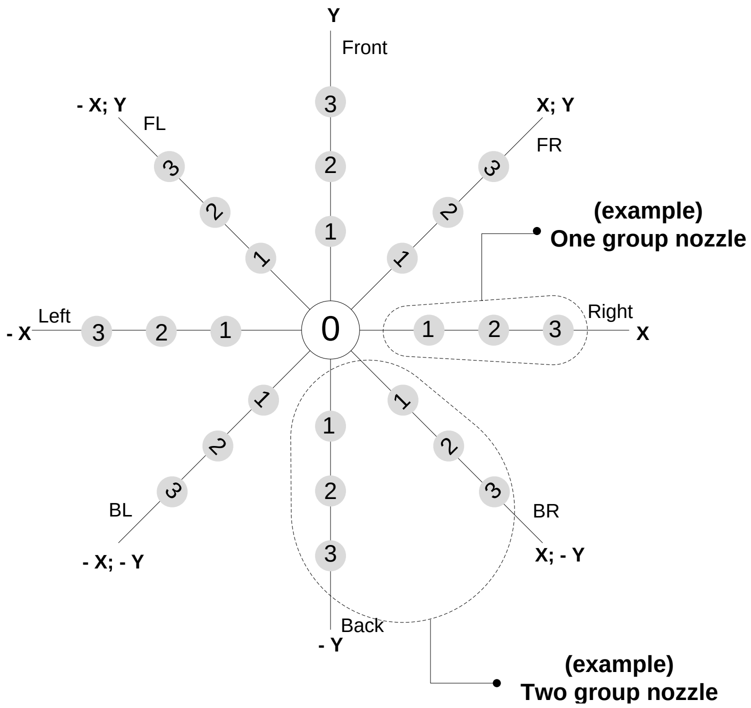


Figure 4. Nozzle position hidden layers

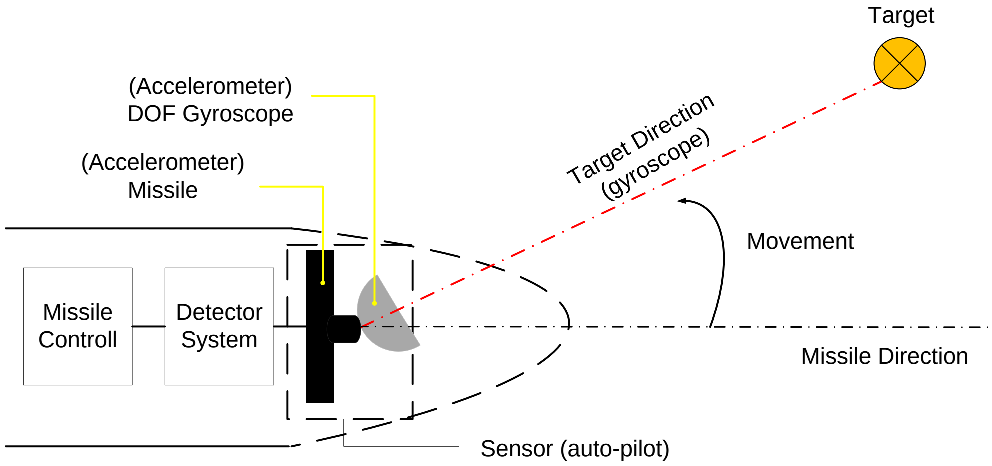


Figure 5. Auto-pilot missile scheme

can control the missile direction against randomly coming targets by utilizing the neural network. The missile uses the degree of freedom (DOF) system on the gyroscope by calculating the axis data from the accelerometer.

By using DOF dynamics as a variable calculation, the technology of the nozzle on the missile body allows the missile to maneuver perfectly towards the locked target and can minimize disturbance from air pressure. There are 24 nozzles attached to the missile body as shown in Figure 4. The number of nozzles that are activated depends on the data obtained by the sensor. Nozzle technology is very commonly used in missiles, both as the main booster and control attitude body missile. The target direction and missile condition are processed by the autopilot system as shown in Figure 5 which is embedded with an intelligent backpropagation neural network algorithm to optimize missile maneuvers' accuracy.

The autopilot system works after the missile leaves the launcher until it reaches the target, so there is no friction between the missile body and the missile launcher. The auto-pilot system continues to work even though the target changes direction (outwit), and the data from the sensor is continuously processed using the intelligent backpropagation neural network algorithm so the maneuverability is much better and the missile's accuracy level is getting higher.

III. Results and Discussions

The weight produced by the X-axis and Y-axis of the missile and target accelerometer is calculated by calculating the ratio and difference of each axis. The training data results show the performance, training state, and gradients of the smart missile system.

A. Training data results

The accelerometer data calculation is trained with the backpropagation neural network algorithm. The algorithm is assembled with 72 neurons of equation neurons connected to nine hidden layers, as well as two types of target data axes (X-axis and Y-axis). As in Figure 6, the network is trained by entering 1000 max files at each stage.

The calculation between the dependent variable and the independent variable on a smart missile sensor is the main target of this research. So that the neural network training method using backpropagation gives high accuracy results and minimal vibrations to maneuver smart missiles towards the target.

The increase in maneuver accuracy can be proven by looking at the results of the first training until the last training recorded, in the first training the system only took 9 seconds to detect 1000 failures, while in the last training the system took about 1 minute to detect 1000 failures, this indicates that the system is getting worse. Often trained, the errors are minimal, so the system is difficult to find 1000 files in the last training.

B. Neural network performance

The neural network performance on a smart missile displays a train, validation, and test graph as shown in Figure 7. The neural network performance graph displays several training stages with a different performance at each stage. The validation graph uses the mean square error (MSE) method to hold the test graph so that performance is more stable during training. MSE is obtained from the lowest point on the validation graph.

When minimizing vibration in missiles, it produces a very significant change from the beginning of the training to the end of the training.

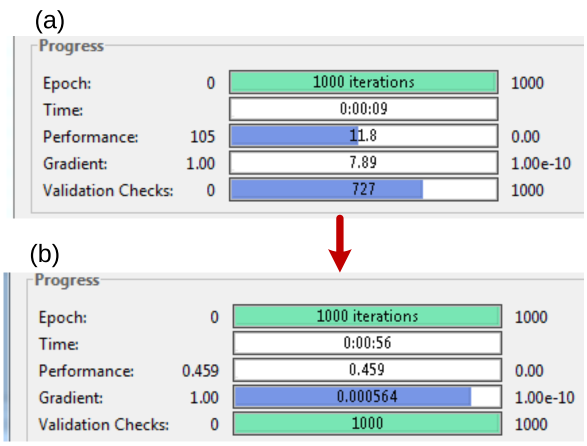
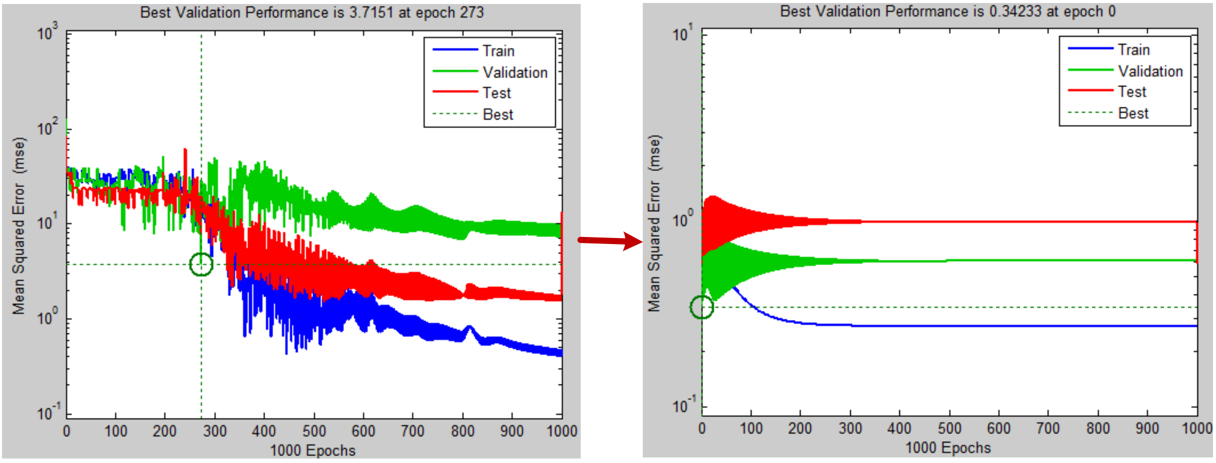


Figure 6. Train progress: (a) First train; (b) End train



(a) (b)

Figure 7. Perform neural network: (a) First train; (b) End train

This can be proven at the initial training with a mass load of 273 to 0.

In the final training, and the best point of validation performance was 3,715 (around $10^{0.57}$) in the initial training, to 0.3423 (about $10^{-0.46}$) in the final training. Besides that, the initial training chart shows fluctuating shapes, while the final training graph shows a constant form. This can indicate that the system can minimize vibration waves on smart missile systems.

C. Training state neural network

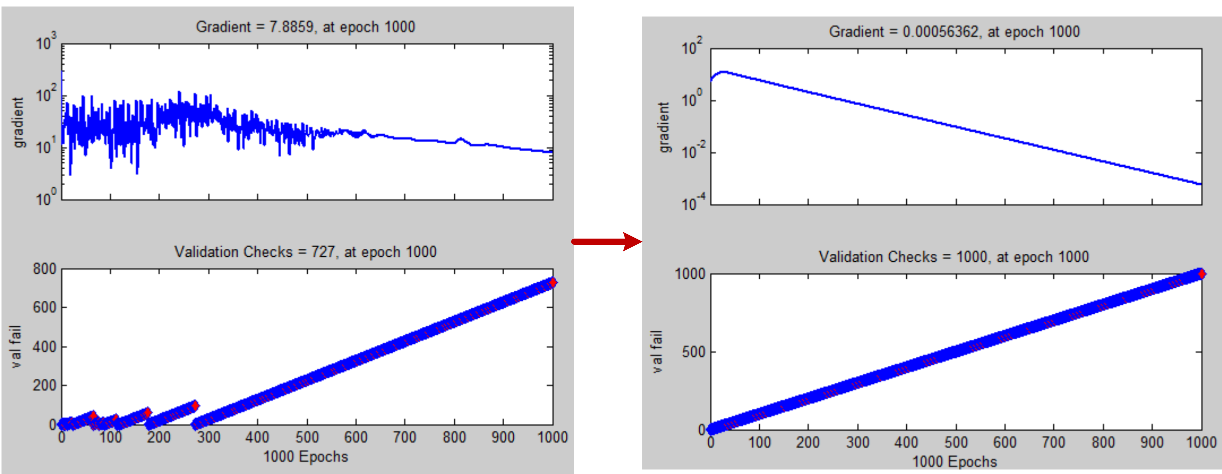
The neural network training state on the smart missile displays a gradient graph and a check validation graph as shown in Figure 8. The neural network training graph displays several training stages with different statistics at each stage.

Gradient graphs and fail graphs that experience changes at every stage of the training. The resulting changes indicate that the gradient value of 1000 iterations is getting smaller and fluctuations are getting smaller too. Where the initial gradient value of 7.88 becomes 0.00056, and in the end, the fluctuation disappears in the final training. Failure graphs in the training state also display changes in shape at each stage, in the initial stages of a discontinuous graph form with a validated period of 727 out of 1000, then at the final stage of the training state, the shape of the failure graph is not interrupted (continued) with a period of validated by 1000 out of 1000. this indicates that the training stage of the smart missile can guide the missile so that it can maneuver with minimal vibration, so that maneuvers (fail) can be minimized or overcome.

D. Neural network regression

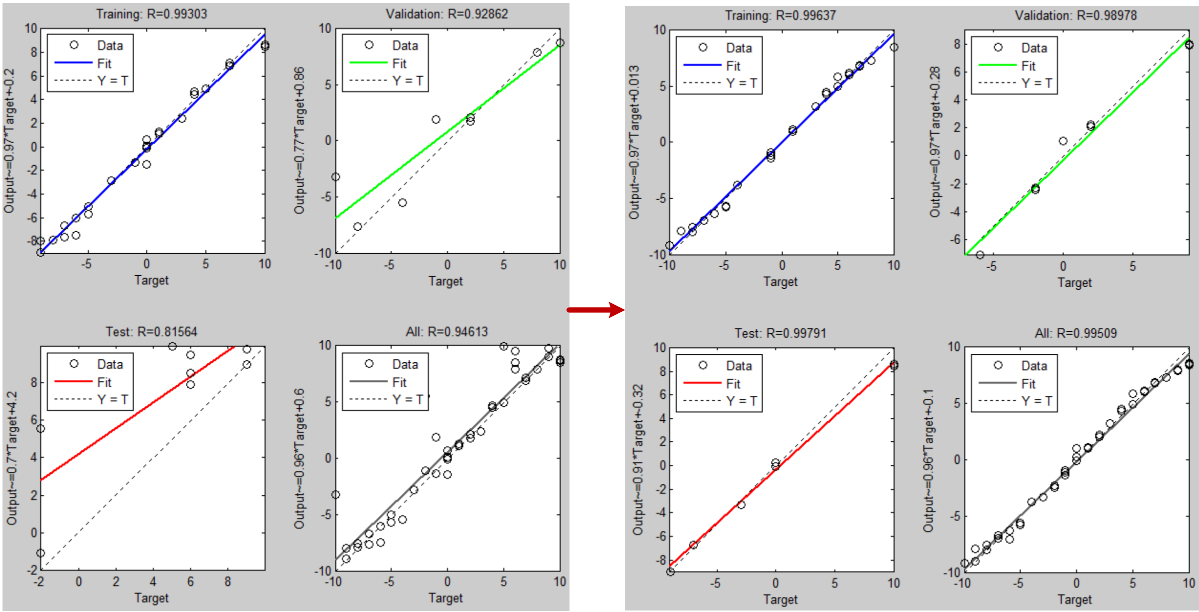
Neural network regression in the smart missile to the target displays a single line of perception of training line intercept, validation line intercept, test line intercept, and all line intercept. As shown in Figure 9, each training stage displays the different conditions of each line intercept.

Line intercept in neural network regression shows changes in the independent variables that are increasingly close to the dependent variable from the data of the smart missile sensor results. The most significant change at each stage of the training was shown by the line test, with the difference in



(a) (b)

Figure 8. State neural network training: (a) First train; (b) End train



(a) (b)

Figure 9. Neural network regression: (a) First train; (b) End train

variables of 4.2 at the initial stage of the training being 0.32 at the end of the training. This indicates that the difference between the slope of the target as a fixed variable, and the missile as the independent variable, results in a comparison that approaches the similarity of the axes. So the missile can be in the right maneuver to hit the target.

IV. Conclusion

Smart guided missile system using the accelerometer and gyroscope, can guide the missile to the target with a highly accurate difference in variables. The slope between the missile maneuver against the target can be reduced by a difference of 0.32 m/s^2. Backpropagation neural network with optimal feedback control makes this system able to minimize vibration up to 0.34 m/s^2, so that missile maneuvers are much better with minimal zigzag movement. Fail that can be detected and validated as a whole, namely 1000 files out of 1000 times (epoch) so the autopilot system can be more regular in adjusting the missile body when maneuvering towards the target.

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Declarations

Author contribution

The simulation of the research data was developed by K. Faqih. Sujito founded the idea of the research and supervise the work. Improvement of the English language and structure of the paper was supervised by S. Sendari. Data collection and layout submission by F. S. Aziz.

K. Faqih, Sujito, S. Sendari, and F. S. Aziz contributed equally as the main contributor to this paper. All authors read and approved the final paper.

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Conflict of interest

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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