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Inference Engine Design Supervised Machine Learning Method On Electric Feeding System Of Liquid Propellant Rockets

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Abstract— For Indonesia, having greater deterrence from potential threats is the mandate of the Preamble of the 1945 Constitution in the fourth paragraph. Therefore, 7 priority programs (Combat Aircraft, Submarines, Medium Tanks, Rockets, Missiles, Radars, and Propellants) have been launched by the Government of Indonesia through the Ministry of Defense in the field of technology. To support the program, in this paper an inference engine is built by applying the supervised machine learning method on the WSN architecture which is embedded in a liquid propellant rocket electric feed system to obtain the desired rocket thrust. The data used in this research are pump motor speed, valve opening angle, propellant flow rate, propellant pressure, and propellant thrust. The results of this study obtained an inference engine that is able to provide a pressure prediction model with an accuracy value of "r2 = 0.962", a flow rate prediction model with an accuracy value of "r2 = 0.9835", and a thrust prediction model with an accuracy value of "r2 = 0.963".

Keywords— Electric Feed System, WSN, Inference Engine, and Supervised Machine Learning.

I. INTRODUCTION

For Indonesia, having the ability to deter potential threats that will occur is the mandate of the Preamble of the 1945 Constitution (UUD) 4th paragraph, "to protect the entire nation and the entire homeland of Indonesia." This deterrence capability is the core of National Defense, as explained in Law Number 3 of 2002 concerning National Defense Article 1 paragraph 1, "State Defense is an effort to defend the sovereignty of the state, territorial integrity, and the safety of the entire nation from all threats and disturbances. towards the nation and the state." Therefore, the Government of Indonesia through the Indonesian Ministry of Defense as stated in the 2015 Indonesian Defense White Paper (BPPI 2015) in the defense technology sector has launched 7 priority programs, namely fighter aircraft, medium tanks, submarines, rockets, missiles, radar, and propellants. As the Industrial Revolution 4.0 goes, the desire to embed a smart system in a hardware system is a popular thing and has become one of the trends at this time. Various problems in a system that were previously thought to be impossible to overcome, by producing an intelligent environment in the system the solution of the problem is possible, such as research conducted by (Agrawal, 2015) on intelligent systems in agriculture and by (Tuan, 2019) about intelligent systems in aquaculture. To support the 7 priority programs that have been launched by the Ministry of Defense of the Republic of Indonesia, this research will conduct research on intelligent systems in the military defense sector, especially the feeding system on liquid propellant rockets by applying the supervised machine learning method on the Wireless Sensor Network (WSN) architecture embedded in a liquid propellant rocket electric feed system.

II. RESEARCH METHODS

The method used in this study is a computer experimental research method with a factorial design model (Tanner, 2018). This method is carried out by testing the relationship between the independent variables produced by the liquid propellant rocket electric feeding system. In accordance with the factorial design model, one independent variable was searched for its relationship with the Inference Engine Design Supervised Machine Learning Method on the Liquid Propellant Rocket Electric Feeding System | Prawira Nusantara, Rudy Gultom, Achmad Farid| 3 other independent variables by keeping one variable constant (control variable), while the other variables were experimented with (experimental variable). After carrying out research with this factorial design model, data on variations in pump motor speed and variations in the valve opening angular speed will be obtained. From the relationship of these variations, data on pressure and flow rate of the propellant will be obtained. By utilizing the mathematical equation (4) and considering the limitations of the study, the propellant thrust data will be obtained from the pressure and flow rate data of the propellant.

$$F = \dot{m}ue + (Pe - P\ )e \qquad (1)$$

where,

: Push style (N)

$\dot{m}$: Mass flow rate (kg/s)

u : Outflow rate (m/s)

P : static pressure out (Pa)

P : Atmospheric pressure (Pa)

A : exit cross-sectional area (m2)

Furthermore, the mass flow rate can be defined as follows:

$$\dot{m} = \rho Q \qquad (2)$$

where,

$\dot{m}$: Mass flow rate (kg/s)

: Volumetric flow rate (m3 /s)

: Fluid density (kg/ m3)

Then the outflow rate can be defined as follows:

$$ue = Q/\ A_e \qquad (3)$$

From the equation (1), (2), and (3) it can be obtained an equation of the relationship between the pressure and flow rate of the volumetric propellant to the propellant thrust according to the research variables, as shown in equation 3.7:

$$F = \rho Q^2\ A_e / + \Delta P A_e \qquad (4)$$

By knowing the relationship above, mathematically the rocket boost as desired can be obtained based on the volumetric flow rate and pressure data obtained in the study. The data obtained from the volumetric flow rate, pressure, and thrust of the rocket are hereinafter referred to as the actual research data. While the data obtained from running a machine learning model is referred to as predictive data. The data is then stored in a database. By accessing the data contained in the database and using the supervised machine learning method, prediction data will be obtained for each research variable. In this study, supervised machine learning was used with a linear regression model. Actual data and predictive data for each research variable are then analyzed for accuracy. Furthermore, the actual research data and predictive data from machine learning models are analyzed in such a way as possible based on the accuracy of the data so that they can produce a representative intelligent system (Mohammad, 2020). The overall flow of the research, the course of the research can be seen in the following Flowchart:

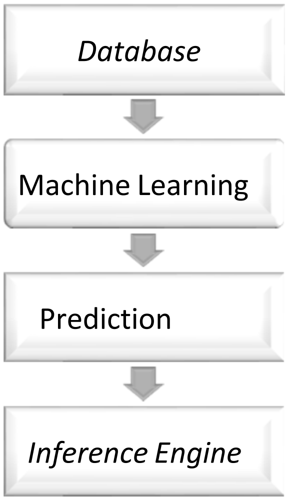

Figure 1. Research Flowchart Source: research results, 2021

III. Results And Discussion

Research Database

In Table 1 and Table 2 below are presented the data acquired by the Wireless Sensor Network (WSN) which is embedded in the electric feed system of a liquid propellant rocket. A good intelligent system, in this case is WSN, must have a knowledge base, database, inference engine, and user interface (Grossan et al., 2011). In this research, part of the intelligent system that is built is the inference engine. To build an inference engine, the system applies a further supervised machine learning method, so that data on motor speed, opening angle, propellant pressure and propellant flow rate are used as a result of the sensor node acquisition that is planted on the WSN. In addition, the rocket boost data obtained by using the mathematical equation (4) is also used.

Table 1. Processing Research Data With Speed Constant Motor And Varied Valve Opening Angle

No.	Motor speed (% Duty Cycle)	Valve opening angle (^{o})	Sampling time (second)	Propellant Pressure (bar)	Volumetric flow rate (Liters/hour)	Push (Newton)
1		30	5	0,93	1848	13,91812
2			10	0,93	1840	13,89992
3			20	0,93	1856	13,9364
4			40	0,95	1848	14,17212
5			80	0,95	1864	14,20876
6			160	0,95	1856	14,1904
7			320	0,96	1856	14,3174
8			640	0,95	1840	14,15392
9			5	1,12	1992	16,6723

10	100 (MAX)	45	10	1,11	2000	16,565
11			20	1,11	1992	16,5453
12			40	1,11	2024	16,62459
13			80	1,12	2024	16,75159
14			160	1,11	2000	16,565
15			320	1,09	1992	16,2913
16			640	1,05	2040	15,90271
17		60	5	1,09	2032	16,39061
18			10	1,12	2016	16,73165
19			20	1,11	2016	16,27167
20			40	1,09	1984	16,5453
21			80	1,11	1992	16,5453
22			160	1,09	2000	16,311
23			320	1,11	2056	16,70514
24			640	1,18	2120	17,75904
25		90	5	1,18	2112	17,73816
26			10	1,18	2104	17,71735
27			20	1,21	2112	18,11916
28			40	1,21	2104	18,09835
29			80	1,21	2104	18,09835
30			160	1,2	2104	17,97135
31			320	1,17	2072	17,50789
32			640	1,2	2104	17,97135

Source: processed by researchers, 2021

Table 2. Processing Of Research Data Using Motor Speed Is Varied And Valve Opening Angle Is Constant

No.	Motor speed (% Duty Cycle)	Valve opening angle (o)	Sampling time (second)	Propellant Pressure (bar)	Volumetric flow rate (Liters/hour)	Push (Newton)
1			5	0,25	640	3,427723
2			10	0,26	640	3,554723
3			20	0,25	632	3,421445

4	25		40	0,29	624	3,923245
5			80	0,26	624	3,542245
6			160	0,27	624	3,669245
7			320	0,27	632	3,675445
8			640	0,27	632	3,675445
9	50		5	0,54	1232	7,794497
10			10	0,51	1216	7,389331
11			20	0,52	1216	7,516331
12			40	0,52	1224	7,528375
13			80	0,49	1232	7,159497
14			160	0,52	1232	7,540497
15			320	0,52	1232	7,540497
16			640	0,51	1248	7,43798
17	75	90 (MAX)	5	0,74	1544	10,86889
18			10	0,7	1552	10,37617
19			20	0,73	1552	10,75717
20			40	0,74	1552	10,88417
21			80	0,7	1552	10,37617
22			160	0,73	1560	10,77253
23			320	0,76	1568	11,16897
24			640	0,74	1592	10,96176
25	100		5	1,18	2112	17,73816
26			10	1,18	2104	17,71735
27			20	1,21	2112	18,11916
28			40	1,21	2104	18,09835
29			80	1,21	2104	18,09835
30			160	1,2	2104	17,97135
31			320	1,17	2072	17,50789
32			640	1,2	2104	17,97135

Source: processed by researchers, 2021

Based on the data available in the database recap and the purpose of this research, the machine learning model used is linear regression type. In building a linear regression model, the data are grouped into two parts, namely some as independent variables and some as dependent variables. What is meant by the dependent variable is the result data that the model wants to predict, while the independent variable is the data that affects or is needed to obtain the predictive data. From the two groups, the data is still further divided into train data and test data. This modeling can also be done by installing and importing the sklearn module in the python script. By utilizing the machine learning modeling functions available on the sklearn module, a data prediction model can be obtained based on the available data. From the available data options and the relationship between each data in this study, a predictive model was obtained for data on propellant flow rate, propellant pressure, propellant thrust, and pump and valve combinations. The prediction data obtained is then compared with the actual data, to analyze how accurate the machine learning model built to predict the predictive data is.

Flow Rate Prediction Model

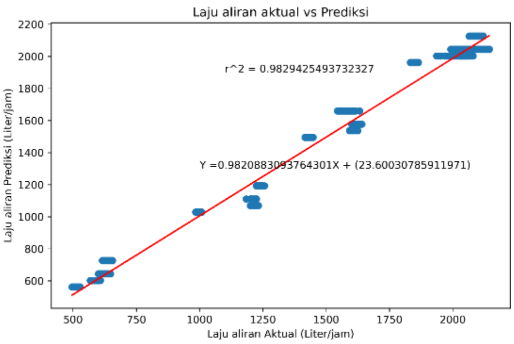

Figure 1. Comparison graph of actual flow rate data and predictions Source: processed by researchers, 2021

Figure 1 above shows how the comparison between the actual flow rate data and the predicted rate data generated by the machine learning model that is built is shown. Based on the graph, it can be seen that the model built produces very accurate predictive flow rate data. This accuracy can be seen from the resulting r2 value which is 0.9835. The comparison gives a linear equation with the value "y=0.982x + 23.6". The obtained model is built using coding as shown in Figure 2 below. Figure 2 shows the coding used to generate a machine learning model to predict the value of the flow rate data. The first step in the coding is to access the required data options from within the database to build a flow rate prediction model. To build this model, we need pump data (motor speed) and valve (opening angle) as independent variables, and flow rate data as dependent variables. By using the "train_test_split()" function from the sklearn module, the previous group of data is divided into "train" data and "test" data. In this study, the "test" data used was 0.3 of the total available data. This means that 0.7 part of the data is used to train the model and 0.3 part of the data is used to test the model. In the coding under the machine learning model that is built, it is declared with the variable "ml1". From the coding, it can be seen that to train the model, the "fit()" function is used and the "predict()" function is used to test it. After the model successfully predicts the data, a graph is formed to compare the actual flow rate data and the predicted flow rate data obtained, as shown in Figure 1 earlier. As for seeing the accuracy of the model in predicting the data, the r2_score() function is used.

```
x=df_ml[['Pompa','Katup']].values
y=df_ml['Dorongan'].values
y1=df_ml['laju'].values
y2=df_ml['Pressure'].values

# model laju aliran prediksi
x_train,x_test,y1_train,y1_test=train_test_split(x,y1,test_size=0.3,random_state=0)
ml1=LinearRegression()
ml1.fit(x_train,y1_train)
y1_pred=ml1.predict(x_test)

akurasi1=r2_score(y1_test,y1_pred)
plt.figure(figsize=(8,5))
plt.scatter(y1_test,y1_pred)
plt.xlabel('Laju aliran Aktual (Liter/jam)')
plt.ylabel('Laju aliran Prediksi (Liter/jam)')
plt.title('Laju aliran aktual vs Prediksi')
plt.annotate('r^2 = ' + str(akurasi1), (1100,1900))
plt.show()
plt.savefig('Lajualir_aktual_prediksi_rev.png',dpi=600)
```

Figure 2. Coding Script to Build Flow Rate Prediction Model Source: Processed By Researchers, 2021

Pressure Prediction Model

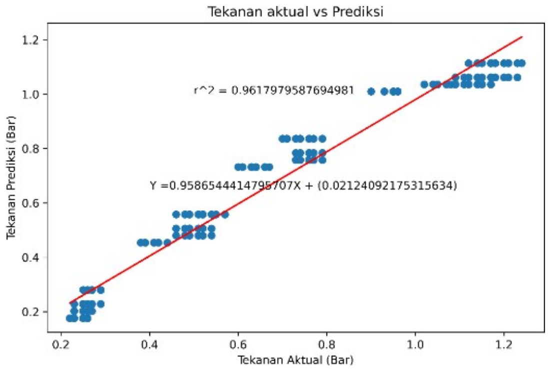

Figure 3. Graph of pressure Data Comparison Actual and Prediction
Source: processed by researchers, 2021

Furthermore, in Figure 3 above, it is shown how the graph of the comparison of the actual and predicted pressure data is shown. The coding method used to build the model that generates the data uses the same method as building the previous flow rate prediction model. As for what distinguishes it is the declaration of the dependent variable used. The accuracy of the prediction model used reaches a value of "r2 = 0.962". This value indicates that the prediction model built is very accurate. In addition, the comparison of the actual pressure and the predicted pressure produces a linear equation with the value "y=0.959x + 0.021".

Model Prediksi Dorongan

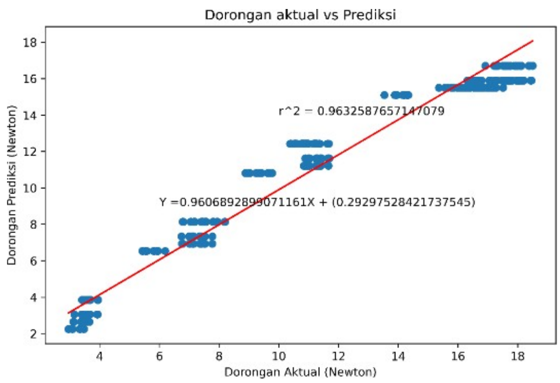

Figure 4. Data Comparison Chart   Actual Push and Prediction

Source: Processed By Researchers, 2021

Then in Figure 4 above, a graph of the comparison of the actual drive data and the predictive impulse data is shown which is generated by the machine learning model. The coding method used to build this model is still the same as the previous methods. It's just that in this model the dependent variable used is the actual propellant boost data. Based on the graph above, it can be seen that the accuracy of this model is very accurate, reaching a value of "r2 = 0.963". In addition, this comparison forms the equation 8 | Journal of Sensing Technology | Volume x Number x Year 20xx (Candara 11) a linear line with the value “y=0.961x + 0.293”. With the acquisition of the three prediction models, namely the pressure prediction model, the flow rate prediction model and the thrust prediction model, then by inputting the pump motor speed and valve opening angle in the WSN system, the desired rocket boost will be obtained. The advantage of this built inference engine is that the thrust of the liquid propellant rocket can be predicted and regulated by adjusting the input pump motor speed and valve opening angle in the electric feed system. The weakness is that it still takes effort to find the right pump motor speed variable and valve opening angle variable to achieve a certain boost value.

IV. Conclusion

The supervised machine learning method that is embedded in providing a data prediction model is able to produce an inference engine on an intelligent system. To obtain the desired rocket thrust, the resulting inference engine provides a pressure prediction model with an accuracy value of "r2 = 0.962", a flow rate prediction model with an accuracy value of "r2 = 0.9835", and a thrust prediction model with an accuracy value of "r2 = 0.963". ". The limitation of this research is the propellant modeling using water. So the "rho" data entered in equation (4) is the density value of water. In addition, the cross-sectional area of the pipe used in the design of this electric feeding system is a PVC pipe with a size of ". And it is assumed that the effect of gravity on changes in the design volume of the electric feeding system is constant.

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