Artificial Intelligence in Industry 4.0: The future that comes true: AI

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Application of Advanced Technologies of Artificial Intelligence in the Optimization of Product Quality in Industry

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Abstract: *This paper investigates the application of advanced technologies in the optimization of product quality in a dedicated industry. As the demands for high-quality products in this sector are increasing, so is the need for efficient optimization methods, which encourage the development and implementation of innovative technological solutions. Focusing on artificial intelligence, soft computing and related techniques enables improvement of the production process, identification of problems in early stages, prediction of potential defects and optimization of production parameters, with a deep consideration of how to improve quality control, reduce costs and achieve greater competitiveness in the market. The aim of the work is focused on the research of the input factors that influence the quality of the product. An analysis of literature and practical studies investigates how these technologies can improve processes in industry, exploring how they bring benefits and what challenges they can represent. Through this work, the door is opened for further development and implementation, to create more efficient processes and superior product quality.*

Keywords: *Advanced technologies, Quality, Artificial intelligence, ANFIS, Industry.*

1. Introduction

In the modern age, the dedicated industry faces increasing demands for high-quality products that must meet strict standards and specifications. To remain competitive in the market and meet the needs of their customers, companies in the dedicated industry are increasingly turning their attention to advanced technologies that allow them to optimize the quality of their products. Through the implementation of artificial intelligence, soft computing, and other innovative tools, these companies are creating new approaches to quality control, defect prediction, and manufacturing process improvement. This paper explores how advanced technologies are used in a dedicated industry to achieve superior product quality, reduce costs and increase market competitiveness. Through the analysis of the application of these technologies, we investigate how they are integrated into production processes, and identify key challenges and obstacles, as well as opportunities for further progress. This topic is essential

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in the context of modern industry, where technological progress is becoming a key factor in achieving success and long-term sustainability.

The importance of digital technologies for manufacturing services is often highlighted, but the current literature does not sufficiently address how companies can use digital methods to improve their service offerings. This article contributes to current theory by exploring how digitization can enable the development of servitization for manufacturers [1]. Digital technologies are increasingly becoming a key resource for the future competitiveness of modern organizations [1].

With the ever-increasing consumption of natural resources and growing market demands for high standards, the focus on sustainable development is becoming increasingly important in modern process industries, especially when it comes to product quality. Therefore, manufacturers are extremely interested in implementing new process monitoring techniques to improve product quality and process efficiency [2]. Product quality is the result of a combination of properties and characteristics that determine the extent to which the product can meet customer needs. The main goal of this study is the analysis of factors that influence purchase decisions, which includes the assessment of product quality and competitive prices [3].

2. Theoretical Settings of the Research

Software that uses the principles of soft computing, unlike traditional computing, is focused on using approximate models and providing solutions to complex real-world problems [4].

The application of soft computing explores the integration of artificial intelligence tools such as neural networks and fuzzy technologies into a comprehensive hybrid framework for solving real problems [5]. ANFIS training includes determining those parameters through the application of optimization algorithms. In the first ANFIS model, developed by Young, a hybrid learning approach was proposed for training [6]. Adaptive neuro-fuzzy inference system (ANFIS) is one of the most popular representatives of hybrid neuro-fuzzy systems [7][8]. Using neural networks, we can develop a fuzzy inference model that is used to estimate membership function parameters based on available input-output data. In the ANFIS network algorithm, the data is forwarded through four layers, applying the least squares method to determine the appropriate parameters [9].

In this research, the bell membership function was chosen because of its capacity to model non-linear data. The bell-shaped membership function is defined as follows:

$$\mu(x) = bell(x; a_i, b_i, c_i) = \frac{1}{1 + \left[\left(\frac{x - c_i}{a_i}\right)^2\right]^{b_i}}$$

Training and evaluation of the ANFIS network was performed using the Matlab software package. Input-output data from experimental tests were collected to identify key parameters for a given output data using an ANFIS network, along with an estimation of the prediction error (RMSE). In this research, the accuracy of the prediction is evaluated through the least squares error, which can be expressed by the corresponding equation.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(P_i - Q_i)^2}{n}}$$

Where Pi and Qi are experimental and calculated data [9].

2.1. Methodology and data

The subject of research in this paper is the analysis of the impact of various input factors on the quality of products in the dedicated industry. Then identify the key factors that have the most significant impact on product quality and explore ways in which the application of advanced technologies can contribute to the optimization of these factors to achieve better product quality in a dedicated industry.

This research paper aims to investigate the influence of various input factors on product quality in a dedicated industry and to identify which of these factors contribute the most to improving or reducing product quality. To achieve an optimal solution and improve product quality, which is the main goal of this research, it is necessary to consider the influencing factors that will be key to the analysis. Various factors can significantly affect product quality, as shown in Table 1. Some of these factors include:

- Starting material - The casting as a starting material has a key influence on the quality of the product. Its purity, homogeneity and mechanical properties play a vital role in the final product. Any irregularities or impurities in the casting can result in a reduction in the quality and performance of the product, which can have negative consequences for the end user and the company's reputation. Therefore, it is important to carefully control and optimize the casting production process to ensure the high quality and competitiveness of the product on the market.

The range of 0 to 100 percent for starting material affecting product quality describes the spectrum of material quality from the lowest to the highest level. At 0% there is a material with numerous impurities and variations in structure, while at 100% it represents a material of high purity and homogeneity.

This range allows precise measurement of the quality level of the starting material and its influence on the quality of the final product.

- Cutting tool - The choice of cutting tool has a significant impact on the quality of the product. Parameters such as cutting tool material, blade geometry, cutting speed and cooling directly affect the accuracy, surface finish and durability of the product. Using the appropriate cutting tool with properly set parameters ensures efficient material removal without damage, resulting in high-quality products and reducing the need for additional processing. Therefore, careful selection and quality maintenance of cutting tools are key factors for achieving the desired performance and competitiveness in the market.

The range of 0 to 100 percent for a cutting tool that affects product quality covers the spectrum of tool performance and characteristics, starting from the lowest to the highest level. At 0% there may be poorly maintained or inappropriate tool material, leading to poor processing and lower product quality. On the other hand, at 100% there is a high-quality cutting tool with optimal geometry and material, which enables precise and efficient material processing and results in high-quality products. This range allows the evaluation of the performance level of the cutting tool and its impact on the quality of the final product.

- Operator - The operator's influence on product quality is undeniably crucial. Their experience, skills and attention during the production process play a crucial role in ensuring a high standard of quality. Through precise machine setup, proper execution of operations and constant monitoring of processes, operators ensure that products are manufactured according to specifications and standards. Their ability to recognize and respond to potential problems or defects during production can have a significant impact on preventing unwanted defects and improving product quality. Therefore, operator training, motivation and support are vital to maintain a high level of quality and competitiveness in the market. The range from 0 to 100 percent for the operator reflects different levels of skill, experience, and efficiency in the production process, starting from the lowest to the highest level. At 0% there may be novice or poorly trained operators who may cause errors or defects in production. On the other hand, they can be 100% expert operators with rich experience and skills.

- Digitization - Digitization has a profound and comprehensive impact on product quality. Through the application of digital technologies such as automation, artificial intelligence and data analytics, manufacturers can optimize production processes, identify potential defects and improve quality controls at every step of production. This enables more precise control of production parameters, reducing quality variations and improving product consistency. Also, digitization enables proactive prediction of potential problems and faster resolution of possible irregularities, which significantly contributes to increasing product quality and user satisfaction.

Digitization range: 0% - Low digitization. Absence or minimal use of digital technologies in the production process. 100% - High digitization. Full implementation of digital technologies such as automation, artificial intelligence, and data analytics in the production process.

- Machine - The impact of machines on product quality is extremely significant. The efficiency and accuracy of the machines directly affect the production process, which ultimately results in the quality of the final products. Accurate calibration and regular machine maintenance are key factors in achieving production consistency and minimizing quality variations. Modernization of machines with advanced technologies enables automatic process monitoring and control, reducing the possibility of human error and increasing precision. Also, innovative technologies such as 3D printing machines enable the production of complex components with high accuracy and finish. Therefore, investing in high-quality machines and their continuous improvement are key steps towards achieving superior product quality.

The range of 0 to 100 percent for a machine ranges from poorly maintained and inefficient machines to high quality and reliable. At the lower end of the range, machines can be imprecise and cause machining errors, while at the higher end, they provide accurate and efficient material processing. This range enables the evaluation of the efficiency of the machines in production and the impact on the quality of the final products.

- Manufacturing time - The manufacturing time of a product plays an important role in determining its quality. The speed of the production process can lead to too frequent omissions, insufficient control, or lack of attention to detail, which can result in low product quality. On the other hand, products made too quickly may not have enough time for complete processing or drying, which may also affect the final quality. Therefore, manufacturers need to determine the optimal manufacturing time for each product, taking into account the required steps, processes and time required to achieve the desired quality. The balance between the efficiency of the production process and ensuring a high standard of quality is key to successfully meeting the expectations of users and maintaining competitiveness in the market. The range of 0 to 100 percent for manufacturing time indicates the spectrum of time frames required to complete the manufacturing process, ranging from minimum to maximum time. At the lower end of the range, there is rapid production that can lead to reduced attention to detail, while at the higher end, it allows for thorough machining and precision, ensuring high-quality final products. This range makes it possible to estimate the optimal production time to achieve the desired level of product quality.

Table 1: Input and output parameters

Input and output	**Parameter description**	
	The name of the input parameters	***Range***
Input 1	Starting material	0% - 100%
Input 2	Cutting tool	0% - 100%
Input 3	Operator	0% - 100%
Input 4	Digitization	0% - 100%
Input 5	The machine	0% - 100%
Input 6	Build time	0% - 100%
Output	Product Quality	0% - 100%

3. Results and Discussion

Table 2 shows the results of applying the Anfis method, including the mean error value, the mean deviation, the root mean square error, and the root mean square error for the training and test data. Table 3 also shows the reliability coefficient of the obtained model for the input factor that has the greatest influence on the output size.

Table 2: The impact of one input on the output

INPUT 1
TRAINING – ERROR SV = -0.000000 SD = 0.175803 MSE= 0.030718 **RMSE**= 0.175266 TEST – ERROR SV = -0.013962 SD = 0.091634 MSE= 0.008302 **RMSE**= 0.091117 ALL DATA – ERROR SV = -0.0020983 SD = 0.1658 MSE= 0.02735 **RMSE**= 0.16538

Table 3: Reliability of the model

Reliability of the model
TRAINING DATA R=0.99998 TEST DATA R=1 ALL DATA R=0.99998

Input 1, which corresponds to the starting material or casting, shows the lowest root mean square error (RMSE) value compared to the other inputs. This indicates that the starting material has the most significant influence on the quality of the product.

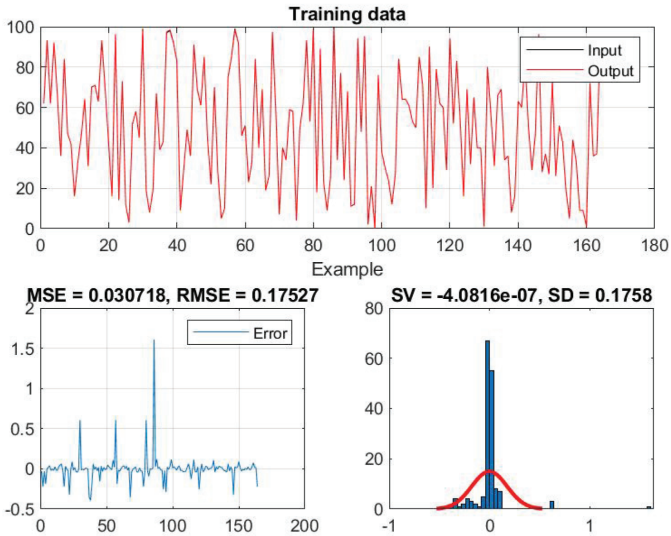

Figure 1. ANFIS network training - one input - achievements

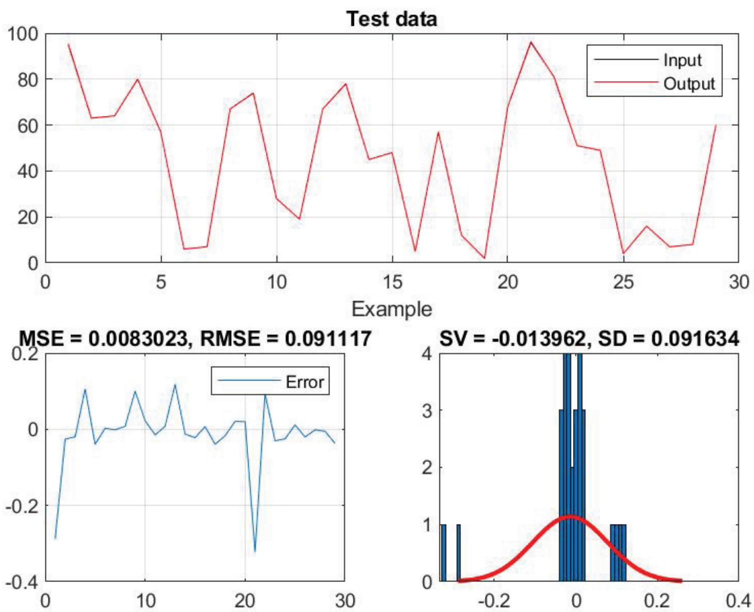

Figure 2. ANFIS network test - one input – achievements

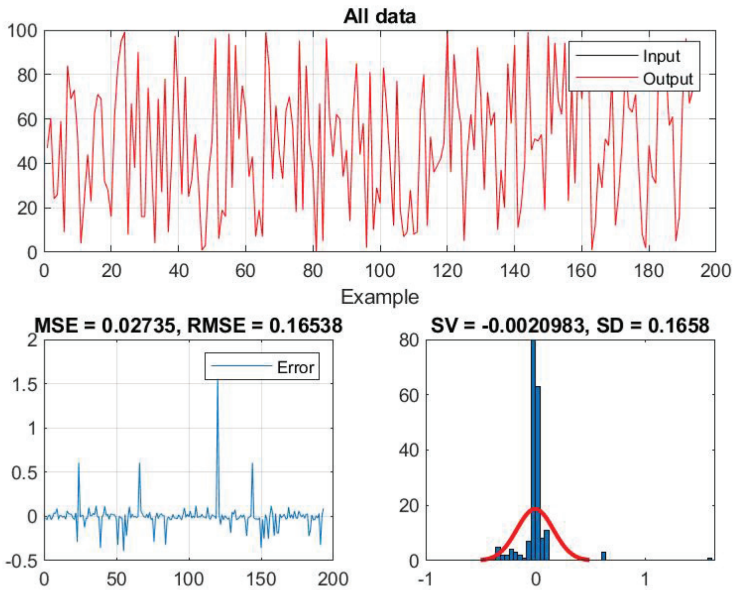

Figure 3. All ANFIS network data - one input

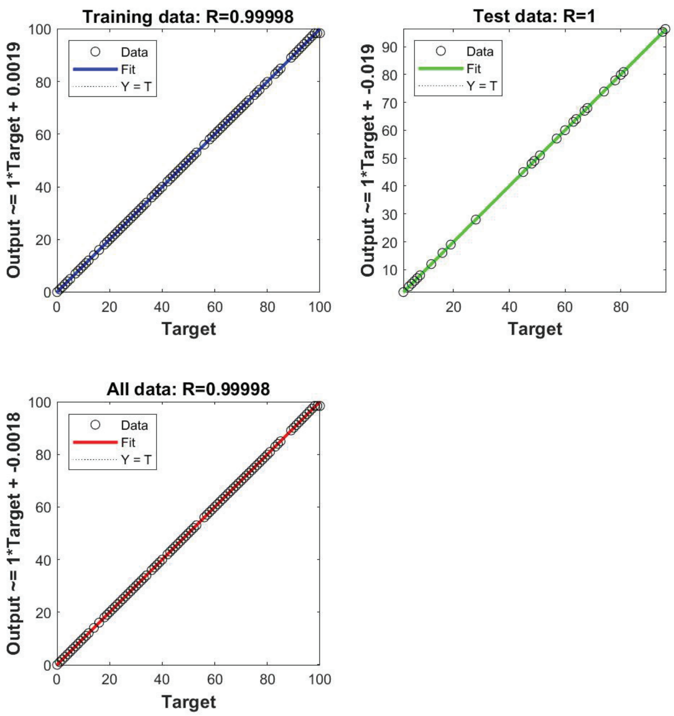

Figure 4. Regression of training, test and all data - one input - achievement

Figures 1, 2 and 3 show complete data on errors during training, test and all data obtained by applying the ANFIS methodology in the Matlab software package. Figure 4 shows the regression analysis and reliability of the model, while Figure 5 shows the graphical interpretation of the training data.

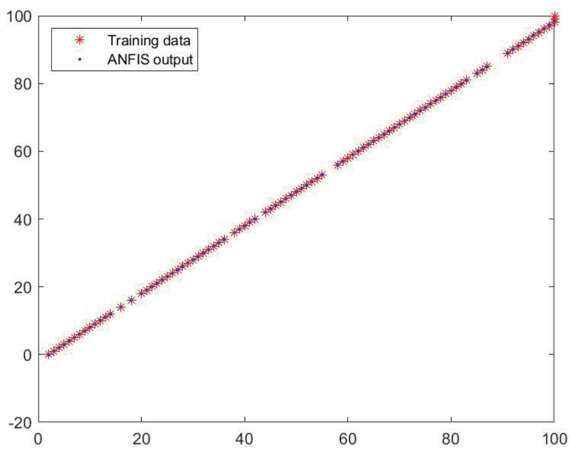

Figure 5. Graphical interpretation of training data - one input – achievements

In addition to the one input that affects the output the most, the two inputs that most affect the quality of the product were obtained, that is, the two inputs that in combination give the smallest RMSE error. Inputs 1 and 3, that is, the starting material and the operator, have the greatest influence on the quality of the product.

Table 4 shows all error values for training, testing and all data, taking into account the two most influential inputs - input 1 and input 3 - concerning the output size. Also, table 5 shows the reliability coefficient of the obtained model.

Table 4: The impact of two inputs on the output

INPUT 1 - 3
TRAINING – ERROR SV = -0.000000 SD = 0.000082 MSE= 0.000000 **RMSE**= 0.000082 TEST – ERROR SV = -0.000007 SD = 0.000070 MSE= 0.000000 **RMSE**= 0.000069 ALL DATA – ERROR SV = -0.0000146 SD = 0.000080 MSE= 0.000000 **RMSE**= 0.00008

Table 5: Reliability of the model

Reliability of the model
TRAINING DATA R=1 TEST DATA R=1 ALL DATA R=1

Figures 6, 7 and 8 show complete data on errors during training, test and all data for the influence of two combined factors. Figure 9 shows the regression analysis and reliability of the model, while Figure 10 shows the graphical interpretation of the training data.

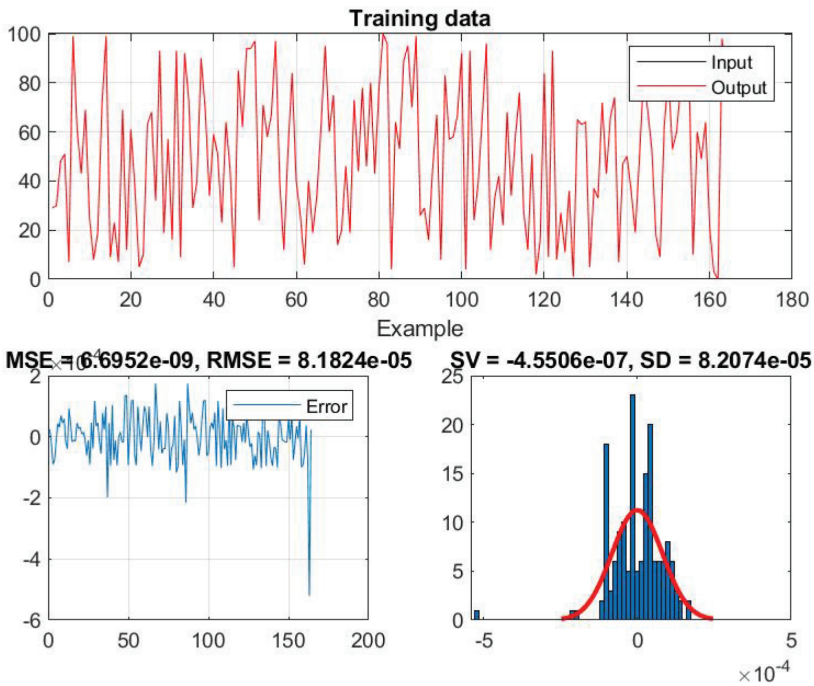

Figure 6. ANFIS network training - two inputs - achievements

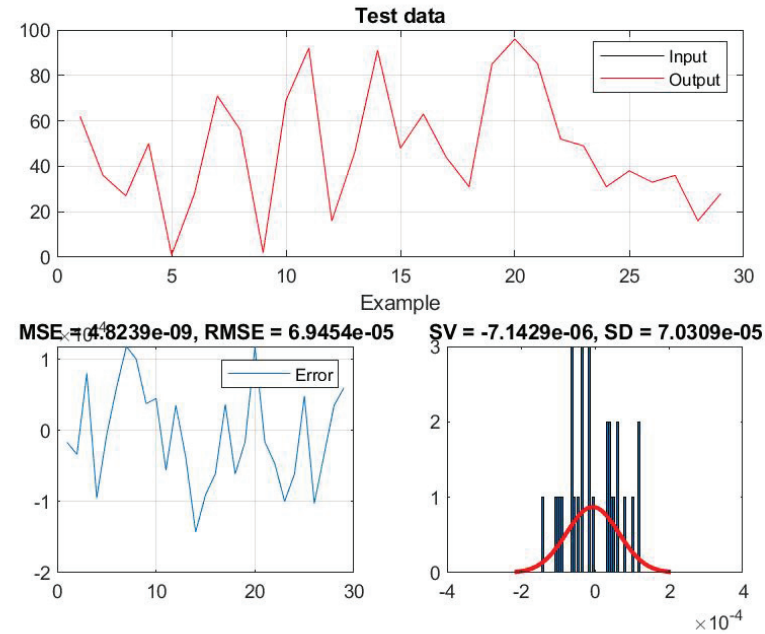

Figure 7. ANFIS network test - two inputs – outputs

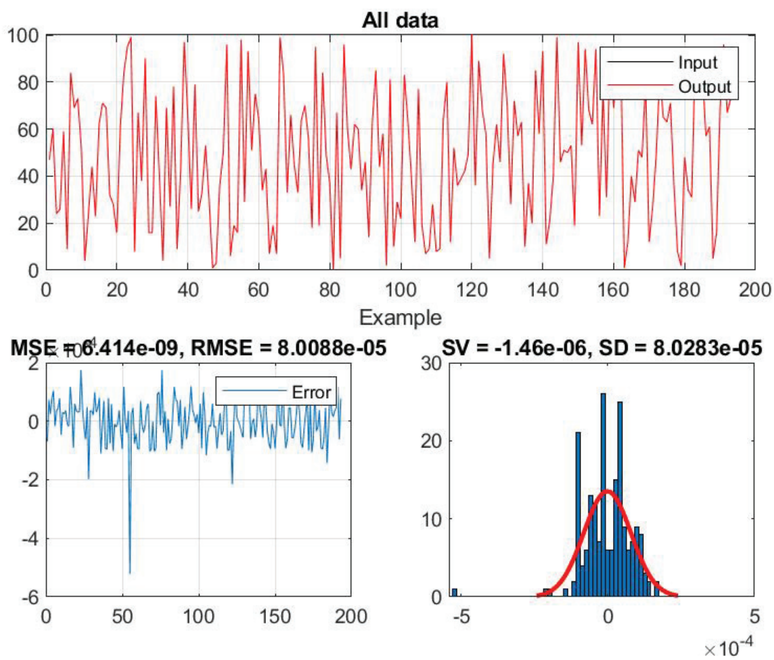

Figure 8. All ANFIS network data - one input

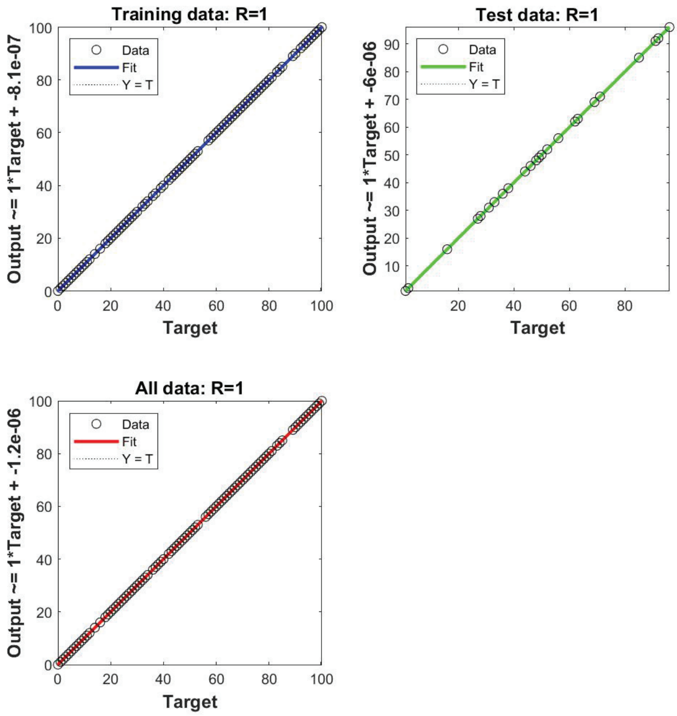

Figure 9. Regression of training, test and all data - two inputs - achievements

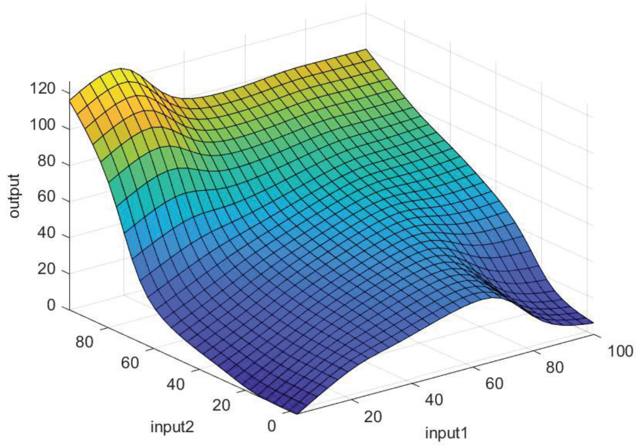

Figure 10. Graphical interpretation of training data - Matlab - two inputs – achievements

Table 6 shows the training, test, and all data for the three input factors that together have the greatest impact on product quality. In Table 7, the reliability of the model for the three combined factors is shown. The obtained research results highlight three key input factors - cutting tool, operator, and machine - as the main determinants of product quality.

The analysis showed that these factors are essential to achieve a high standard of production. The cutting tool is crucial because it directly affects the machining precision and product finish, while the skills and experience of the operator play a key role in the correct use of the tool and the optimization of the process. On the other hand, machines represent the basis of the production system, and their efficiency, precision, and reliability directly affect the quality of the final products. These three factors, when optimally coordinated and managed, provide the foundation for achieving high quality and competitiveness in the production process.

Table 6: The impact of three inputs on the output

INPUT 2 - 3 - 5
TRAINING – ERROR SV = -0.000000 SD = 0.000029 MSE= 0.000000 **RMSE**= 0.000029 TEST – ERROR SV = 0.000005 SD = 0.000024 MSE= 0.000000 **RMSE**= 0.000024 ALL DATA – ERROR SV = -0.00000382 SD = 0.000283 MSE= 0.000000 **RMSE**= 0.0000282

Table 7: Reliability of the model

Reliability of the model
TRAINING DATA R=1 TEST DATA R=1 ALL DATA R=1

Figures 11, 12, and 13 show complete data on errors during training, tests, and all data for the influence of three combined factors. Figure 14 shows the regression analysis and reliability of the model, while Figure 15 shows the graphical interpretation of the training data.

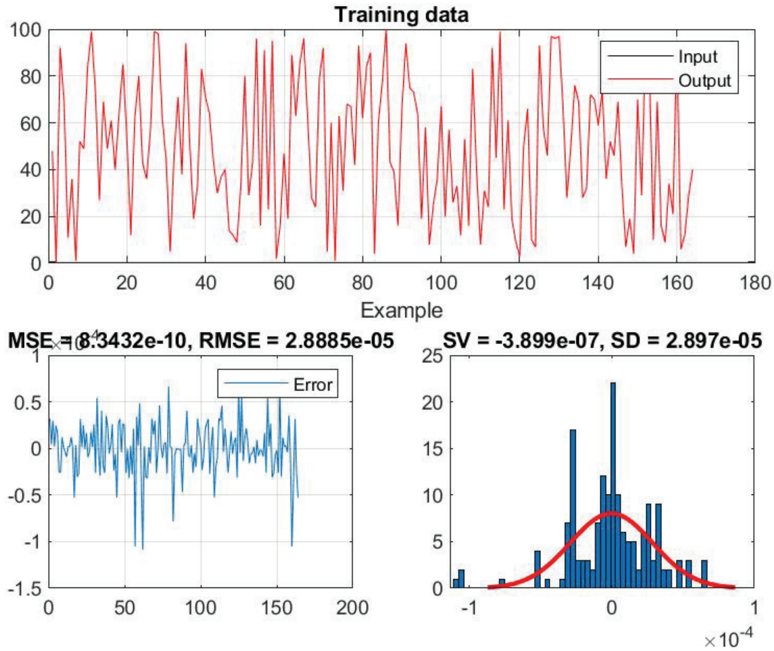

Figure 11. ANFIS network training - three inputs - achievements

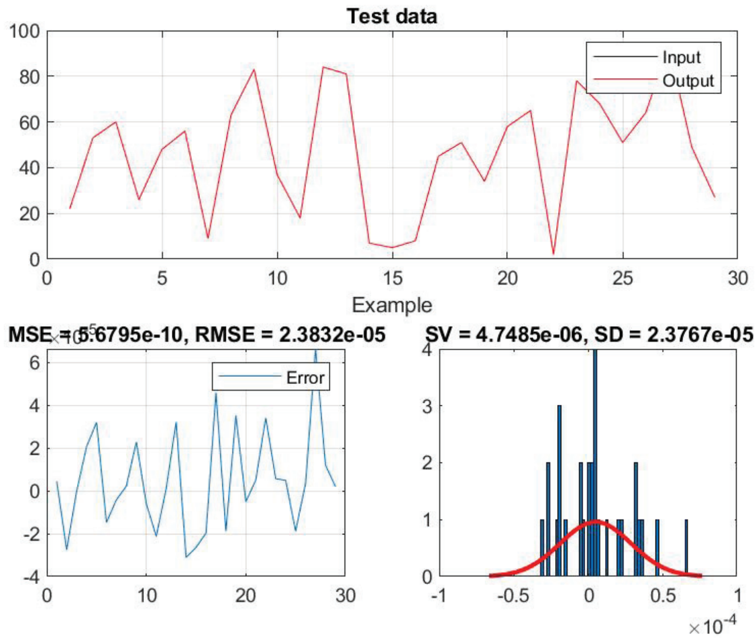

Figure 12. ANFIS network test - three inputs – achievements

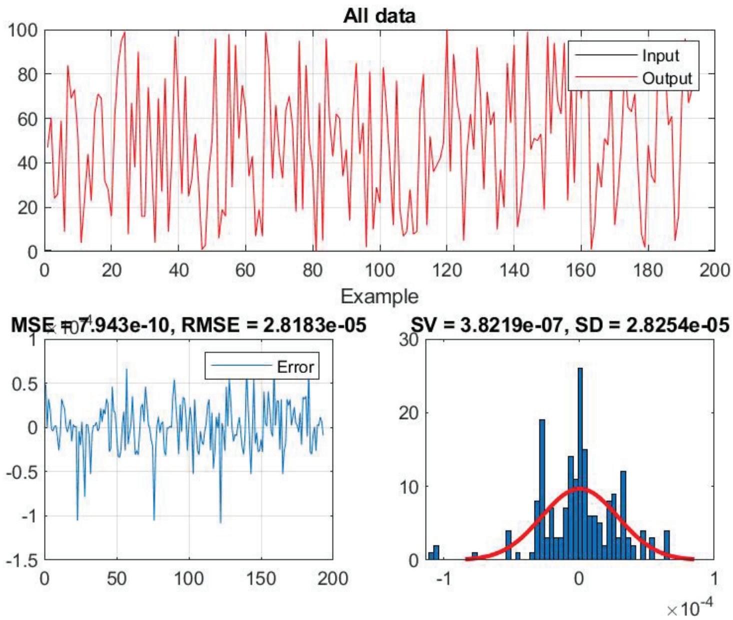

Figure 13. ANFIS network test - three inputs – achievements

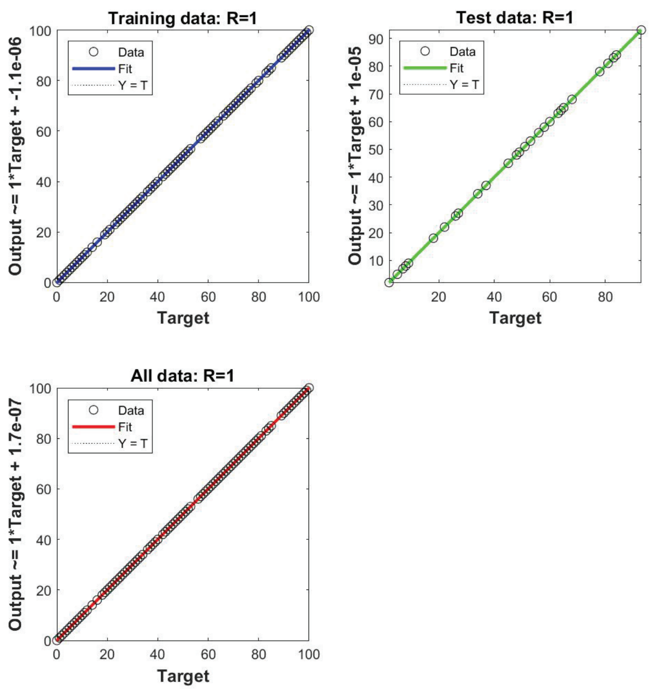

Figure 14. Regression of training, test, and all data - three inputs - achievements

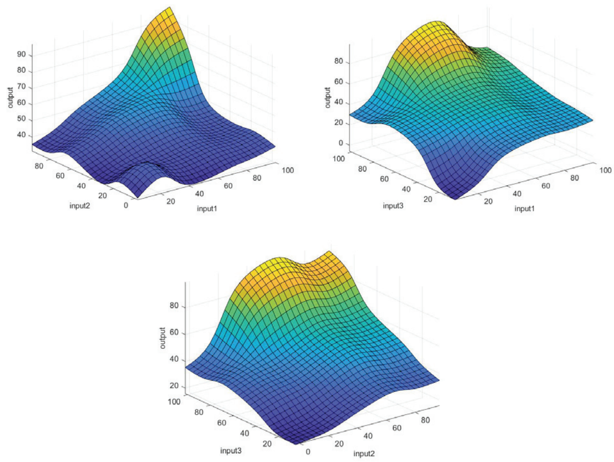

Figure 15. Graphical interpretation of training data - Matlab - three inputs – achievements

4. Conclusion

In the final consideration of the research of advanced technological methods in the optimization of product quality in the dedicated industry, the key influence of input factors on the quality of product manufacturing was highlighted. It has been shown that the starting material, the casting, has a key role in determining the quality of the product in the production process. Its chemical structure, mechanical characteristics, and surface treatment directly affect the performance and durability of the final product. In the dedicated industry, the quality and homogeneity of the metal alloys used as starting material can significantly affect the strength, corrosion resistance, and other key properties of the product.

Then, the two factors that together give the best result, i.e., the most impact on quality, were investigated, namely input 1 and input 3. In production, the combination of quality starting material and the skills of an experienced operator creates a top-quality product. That combination allows every element of the material to be used in the best possible way, providing the end product with exceptional value and impeccable quality.

After analyzing the previous factors, the focus was on the research of three basic factors whose joint influence is crucial for achieving high product quality. These factors are the cutting tool, operator skills, and machine characteristics. Establishing an optimal balance between these elements is an essential step toward improving the production process. The harmony and efficiency of this trio make it possible to achieve exceptional quality of the final product.

Potential improvements could include further refinement of techniques and technologies related to cutting tool processes to increase the accuracy and efficiency of material processing. Also, investing in operator training on the latest methods and tools could contribute to better utilization of the machines' potential. Also, the implementation of a system for monitoring and analyzing the performance of machines could enable the identification of potential problems or deficiencies in operation, which would enable faster problem-solving and optimization of the production process.

An AI-related advancement may include the application of advanced data analysis algorithms to monitor the performance of production systems. These algorithms would enable the automatic detection of patterns and trends in production data, enabling faster and more accurate decisions in process optimization. Also, the introduction of a self-learning artificial intelligence system would enable the automatic adjustment of production parameters to achieve optimal product quality with minimal human supervision.

5. References

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