



Effectiveness of Type II Fuzzy Predictive Control in Mathematical Algorithms and Modeling

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Abstract

The main objective of this research is to develop a new system resulting from combining both predictive and decision-based control methods. This system leverages the advantages of each approach: the predictive method provides accurate future sensing, while the decision-based method ensures smooth and precise sequencing of operations within the system. This system allows for the integration of mathematical objectives and their constraints through fuzzy relationships and processes, enabling the accurate and consistent achievement of all objectives. The research also compared the two types of fuzzy controllers by comparing scenarios for both types using MATLAB. The main finding of the study was that the Type II fuzzy controller demonstrated higher performance and greater effectiveness.

Keywords: Decision-based approach – Fuzzy controller – Hybrid system.

فعالية التحكم التنبؤي الضبابي من النوع الثاني في الخوارزميات والنمذجة الرياضية
الباحثة دعاء كريم عبد الأمير

ملخص

يهدف هذا البحث إلى تطوير نظام جديد يجمع بين أساليب التحكم التنبؤية وأساليب التحكم القائمة على اتخاذ القرار. يستفيد هذا النظام من مزايا كل أسلوب: إذ يوفر الأسلوب التنبؤي استشعارًا دقيقًا للمستقبل، بينما يضمن الأسلوب القائم على اتخاذ القرار تسلسلاً سلساً ودقيقاً للعمليات داخل النظام. يتيح هذا النظام دمج الأهداف الرياضية وقيودها من خلال العلاقات والعمليات الضبابية، مما يمكن من تحقيق جميع الأهداف بدقة واتساق. كما قارن البحث بين نوعي وحدات التحكم الضبابية من خلال مقارنة سيناريوهات لكليهما باستخدام برنامج MATLAB. وكانت النتيجة الرئيسية للدراسة هي أن وحدة التحكم الضبابية من النوع الثاني أظهرت أداءً أعلى وفعالية أكبر.

الكلمات المفتاحية: أسلوب قائم على اتخاذ القرار - وحدة تحكم ضبابية - نظام هجين.

Introduction

Uncertainty is a challenging and important process in practical life. Inaccuracy generally stems from the incompleteness or ambiguity of a system, as well as the inability to accurately measure its fundamental variables. This can be due to high economic volatility or complex operational conditions within the work



environment. Consequently, an inaccurate description of the system leads to an equally inaccurate model.[1] In such circumstances, fuzzy models are used to represent the system. The acquired experience and logical reasoning of the expert are fundamental in designing a role-based control system. We can say that by using human knowledge, we can control complex, nonlinear, and ambiguous systems under various operational conditions and constraints, while traditional linear controllers fail in such situations. Fuzzy control techniques are among the most prominent technologies capable of translating human experience into the field of control.[2] Fuzzy control techniques have been a focus for control researchers and are now used in almost every field, including many industrial applications. Two cement companies in Denmark developed the first general-purpose industrial controller in 1982 [3]. The Japanese then refined it and named it Fuzzy Boom [4]. It has been used in many areas of life, and its development has been further enhanced by its integration with decision-making tools and methods. It plays a significant role in addressing ambiguity in nonlinear situations [5], and it is also important in creating synergy and integration between objectives and their constraints, leading to the efficient implementation of these objectives. [6] As mentioned earlier, fuzzy logic has many applications in various places, such as power plants [7], engines [8], and many industries [9].

In the current study, its efficiency was evaluated in an air conditioning plant. We then compare the results between the first- and second-type controllers using three different floating-group integration methods in a modeling process, performing computer simulations using MATLAB and Simulink.

Research Problem

The core problem in this research lies in the difficulties arising from the lack of precision and uncertainty in nonlinear models and algorithms, due to the lack of clarity in some information. Therefore, it is necessary to create precise algorithms of high quality and efficiency that surpass traditional methods. Hence, the need arises to employ modern techniques such as fuzzy logic prediction and other intelligent methods that provide better management and control of the work in such circumstances.

Research Significance

The scientific importance of the research is highlighted through the integration and synergy between the study sample controllers and decision tools to create a system capable of achieving objectives with high efficiency by aligning objectives and constraints in nonlinear cases at the study sample air conditioning plant.



Lecture review

Several studies have addressed this topic, including the following:

The study by Zeng et al. (2025) presents two modern approaches: a fuzzy controller, as used in the current study, and a neural network approach, for managing the operation of hydroelectric power equipment and increasing its load-carrying efficiency. The study concluded that load management efficiency increased by approximately 11%, fault detection time decreased by 18.2%, operational deviations decreased by approximately 8%, and maintenance costs decreased by approximately 13%. [10].

The study (Cortese et al., 2025) The study aimed to demonstrate the importance of fuzzy logic in two experimental applications: first, through the automatic identification of common orbital systems in the three-body problem, a novel application with important implications for understanding asteroid behavior and designing interplanetary mission trajectories; and second, on a financial dataset of five assets representing different market sectors (stocks, bonds, foreign exchange, cryptocurrencies, and utilities), where the model accurately tracks both the upward and downward phases of the market. [11].

The study by Ramírez & Melin aimed to investigate the impact of certain cognitive abilities on human decision-making. The proposed approach combines neural networks and Type II fuzzy logic. It involves integrating computational models of artificial neural networks and fuzzy logic to perform clustering and prediction of time series data for populations, urban populations, particulate matter (PM_{2.5}), carbon dioxide (CO₂), and recorded cases and deaths from COVID-19 in selected countries. [12].

The study by Nishanth et al. (2024) This study aimed to identify the theoretical concept of the fuzzy logic method used in the current study, as well as to study the algorithms, relationships, and equations related to this method, the latest scientific findings in this field, and the practical applications of this method in robotics, image processing, and self-driving cars.[13]

The study by Kia et al. (2025) This study aimed to evaluate the efficiency and validity of the proposed robust SIT2FPC technique, which was applied to address the Automated Control (AGC) problem in a four-zone interconnected power grid. A 39-carrier IEEE power system was used as a case study to validate the proposed AGC method. The results of six different simulation scenarios clearly demonstrate the effectiveness of the proposed AGC method. [14]



Added Value of the Research

The added value of our study lies in creating a second-generation floating-point predictive control algorithm that utilizes both control prediction theory and decision-making theory, leading to high prediction accuracy in nonlinear systems.

Materials and Methodology:

MATLAB and Simulink software were used to create search algorithms, to illustrate the fuzzy algorithm, to create the controller for this algorithm, and to discuss the results.

Fuzzy Model:

This model is used to simulate, represent, and express non-linear or fuzzy mathematically unconventional systems or environments through equations that represent reality with its parameters according to Equation.(1)

$$\mathbf{R}_i : \text{If } \mathbf{x} \text{ is } \mathbf{A}_i, \text{ then } \mathbf{y} \text{ is } \mathbf{B}_i (i=1,2,\dots,m) \quad (1)$$

The Takagi–Sugeno (TS) model uses floating conditions similar to the Mamdani system, with these conditions being expressed by belonging functions that express both the inputs and the outputs (Equation 2).

$$\mu_{\mathbf{A}_i}(\mathbf{x}), \mu_{\mathbf{B}_i}(\mathbf{y}_j) \quad (2)$$

The current research will focus on the singleton system of Mamdani, as it guarantees a single output function according to equation (3):

$$\mathbf{R}_i : \text{If } \mathbf{x} \text{ is } \mathbf{A}_i, \text{ then } \mathbf{y}=\mathbf{c}_i \quad (3)$$

Where:

c_i is the output of each rule, and to calculate the degree of compliance with the conditions for each rule we use equation (4).

$$\alpha_i = \mu_{\mathbf{A}_i}(\mathbf{x}) \quad (4)$$

Where:

$\mu_{\mathbf{A}_i}(\mathbf{x})$ represents the membership function of the set \mathbf{A}_i at \mathbf{x} , and the float is eliminated in this model through the center of gravity (COG) or through the floating average according to equation (5).



$$y = \frac{\sum_{i=1}^m iaic}{\sum_{i=1}^m ia} \quad (5)$$

Instead of defining the floating model, a single floating model defined by sixteen rules is used with belonging functions that represent the system input, and Figure (1) shows the floating decision resulting from the intersection of the floating guide and constraint.

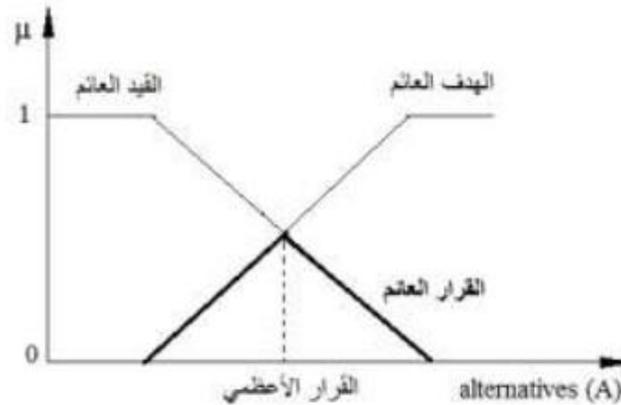


Figure (1): The fuzzy decision resulting from the intersection of the fuzzy objective and constraint.

Fuzzy Decision Making (FDM):

Optimal decision-making is achieved through a fuzzy approach, as it involves linking and intersecting the set of objectives and the set of constraints with the membership function (Equation 6).

$$\mu_D(x) = \min(\mu_F(x), \mu_C(x)) \quad (6)$$

Where:

"min" represents the minimum values.

For the optimal option to be selected, this decision must achieve the maximum value of the affiliation function according to equation (7).

$$x^* = \arg \max \mu_D(x) \quad (7)$$

The best model is the one that evaluates both constraints and objectives as equal belonging combinations in a grouping process to assess the suitability of alternatives, Figure.(2)

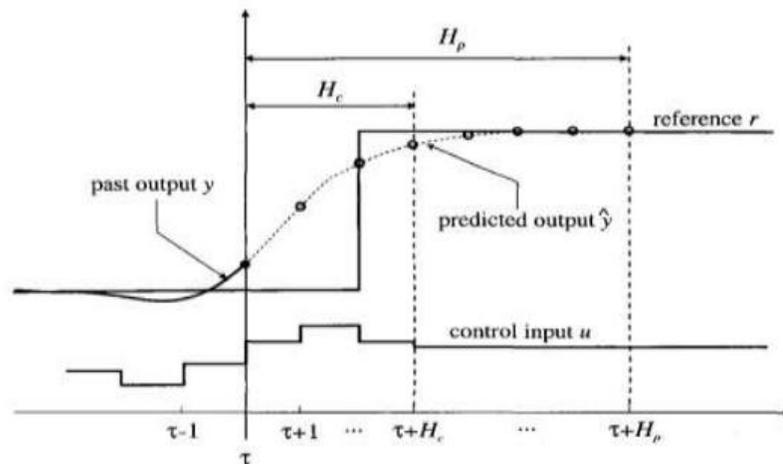


Figure (2): Predictive Control (MPC)

Multi-Attribute Decision Making (MADM)

In this theory, alternatives are chosen using floating-point belonging parameters, and the choice is made based on values with function integration via t-norm binding methods: Equations (8), (9), and (10)

$$\text{Productivity } \mu A \wedge B = \mu A \cdot \mu B \quad (8)$$

Hamacher μ link

$$\mu A \wedge B = \frac{\mu A \cdot \mu B}{B \mu A + \mu B - \mu A * \mu} \quad (9)$$

Dombi μ link

$$\mu A \wedge B = \left(\left(\left(1 - \frac{1}{B\mu} \right) + \left(1 - \frac{1}{A\mu} \right) \right)^{\frac{1}{\nu}} + 1 \right)^{-1} \quad (10)$$

Predictive Control (MPC)

This method involves choosing between commands by reducing and finding the value that minimizes the cost function, according to Equation (11) and Figure (3), which shows the prediction horizon and the control horizon:

$$\text{The value that minimizes } J = u(k) \quad (11)$$

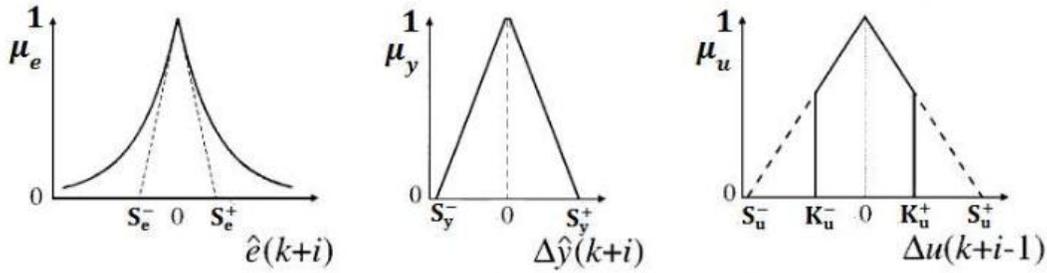


Figure (3) Prediction Horizon and Control Horizon

Floating Prediction Control Pattern 1 (T1FMPC)

This approach is a hybrid of the two previous approaches, as it expresses both the objectives and constraints as belonging functions, and then calculates the composite belonging function π from the product of future samples (Equation)

$$\pi = \prod_{t=1}^T \mathbf{Tmin} (\mu_F(x_t), \mu_C(x_t)) \quad (12)$$

The optimal sequencing is found using equation (13).

$$\pi^* = \max \pi(x) \quad (13)$$

This is a non-convex optimization problem that requires numerical methods such as dynamic programming. Figure (3) shows the functions for error parameter belonging, output variation, and control command variation.

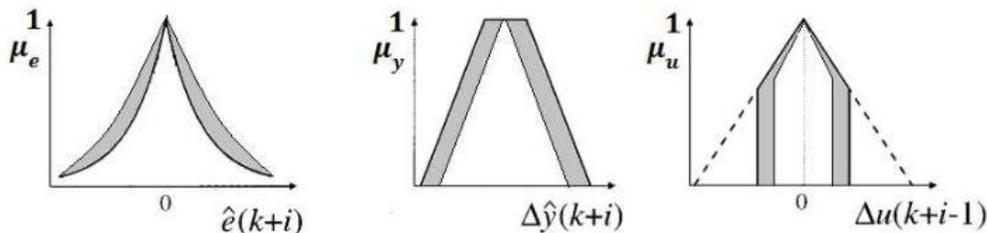


Figure (3): A membership function representing the error, the change in output, and the change in the control command.

Type 2 Floating Predictive Control (T2FMPC)

Type 2 Floating Predictive Control (T2FMPC) is an evolution of the first type, adopting a more flexible and accurate approach to handling objectives and constraints. This approach creates a balance between objectives and the constraints that hinder their achievement. It transforms both objectives and constraints into functions and employs a set of equations and calculations to determine the optimal solution that maximizes the value of the desired objective function. Consequently, this system is designed to respond flexibly to any potential changes.

From Figure (4), we observe that (a) represents the effect of uncertainty, while (b) more accurately represents ambiguity.

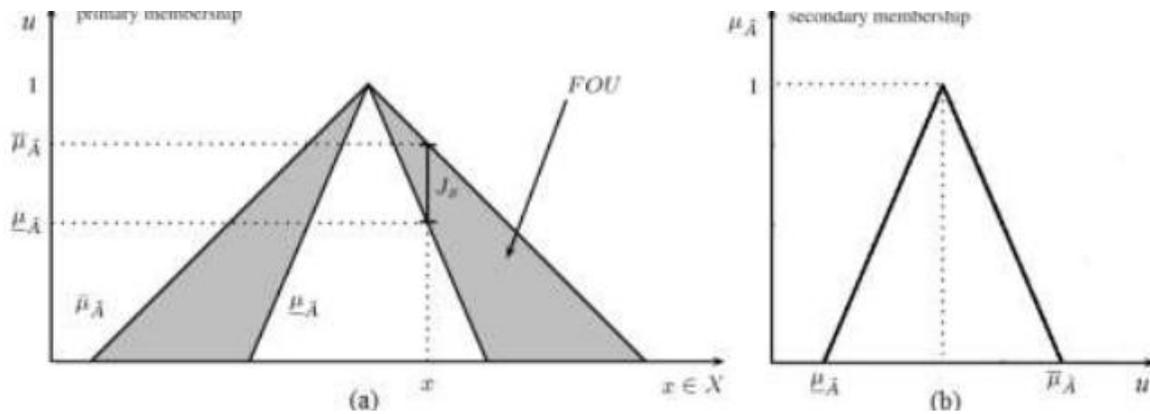


Figure (4): A second-order floating-point set: (a) Uncertainty fingerprint, (b) Representative secondary affiliation function.

Table (2): Rules of the single floating-point model.

	Temperature			
Valve opening	Small	medium	Medium – high	high
Small	30.3	43.9	52.6	56.4
Small -medium	30.0	43.8	54.2	57.6
Medium - high	32.8	47.4	55.6	59.7
high	35.5	47.3	55.1	60.3

Results and Discussion

Figure (5) illustrates the operating mechanism of the program used for the studied system, presented as a block diagram. MATLAB software implemented code for the controller within the function.

The system's response efficiency was evaluated for several time jumps under two conditions: the first using a Type 1 predictive floating-point controller (T1FMPC) and the second using a Type 2 predictive floating-point controller (T2FMPC), employing three different connection methods. It was noted that both the prediction



horizon and the control horizon were compatible for both methods.

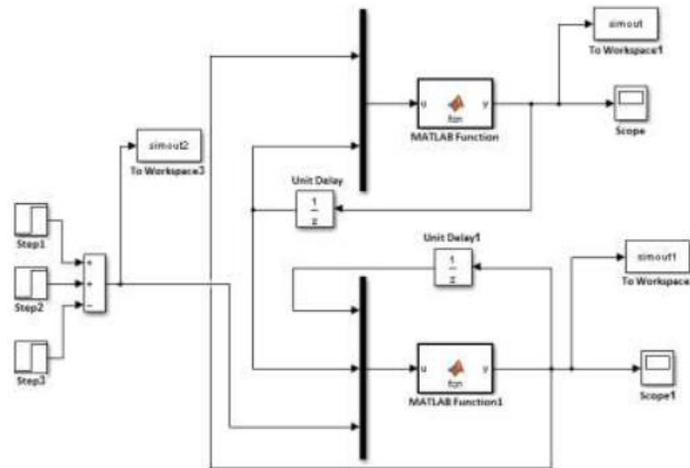


Figure (5) shows the system model using Simulink.

If we begin by discussing the first type of controller, we can observe that its error belonging function is exponential, meaning it is far from zero and does not reach it.

To ensure and guarantee the practicality of the application, input data and information were selected to verify outputs under specific conditions. The valve was also controlled, adjusted, and managed to prevent significant variations in the results.

As for the second-type controller, the same control conditions were used, but with additional components: upper (overhead) and lower (lower).

The binding mechanisms used in this type are product, Hamacher, and Dombi. Each binding mechanism demonstrated its effect on the system, whether first or second type, as shown in Figures (6), (7), and (8). Figure (6) illustrates the algorithm's response when using the first-type controller with the first binding mechanism (product operator), as well as the response of the second-type controller with the same binding mechanism. From this figure, we observe that the first-type controller did not provide the required response accurately depending on the state change, while the second-type controller was able to respond smoothly to the changes.

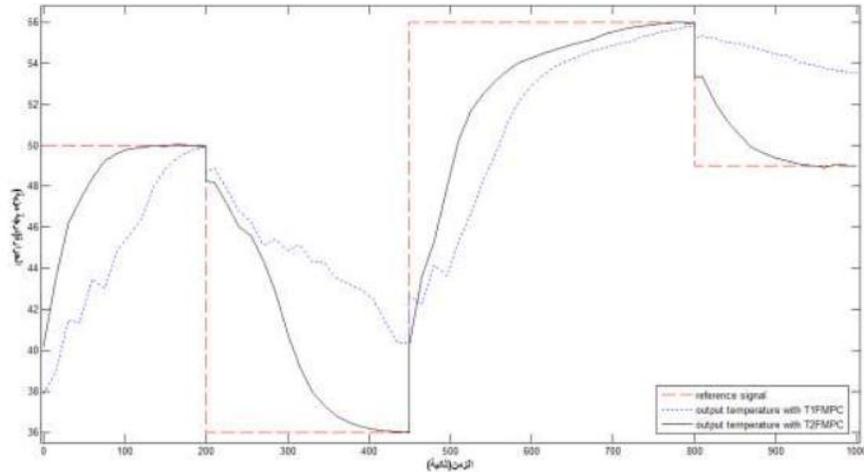


Figure (6): System response to temperature when using a first- and second-type controller with a product-type connection base.

While Figure (7), which shows the controller commands representing the valve opening for the two types of controllers, reveals that each type of controller has its own method of responding to valve opening and closing, but the second type of controller was more efficient.

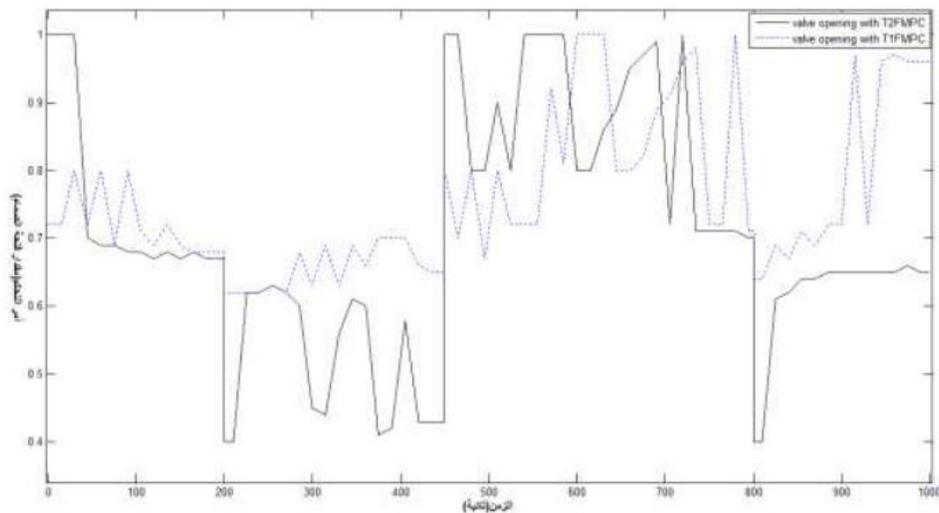


Figure (7): Controller commands or valve opening quantity when using a Type I and Type II controller with a product-type connection.

Figure (8) shows the response of the two controller types in the study sample with a Type II connection (Hamacher type).

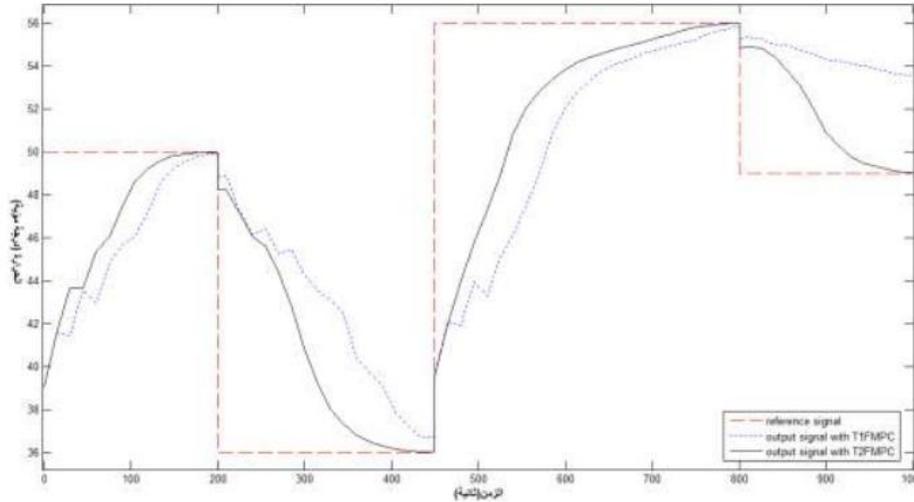


Figure (8) shows the response of the two types of controllers in the study sample using the Hamacher type of type II binding.

From the figure, we observe that the first type of controller was unable to respond as required at certain values, while the second type of controller demonstrated more accurate and smoother performance.

Similarly, Figure (9) illustrates the superiority of the second type of controller with respect to control commands (valve opening).

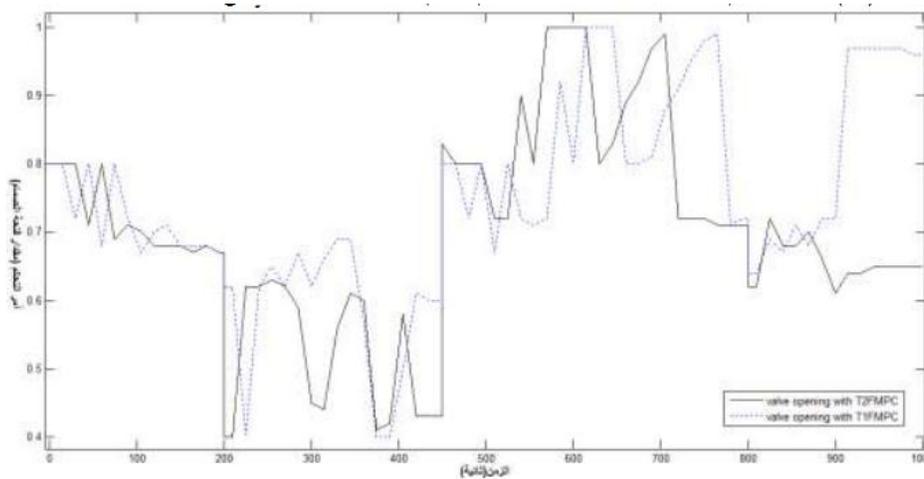


Figure (9): Controller commands or valve opening size when using a Type I and Type II controller with a Hamacher coupling.

Applying the third coupling process, Dombi, the response was also measured for both controller types. Figures (10) and (11) demonstrate the superiority of Type II controllers in both response and control commands.

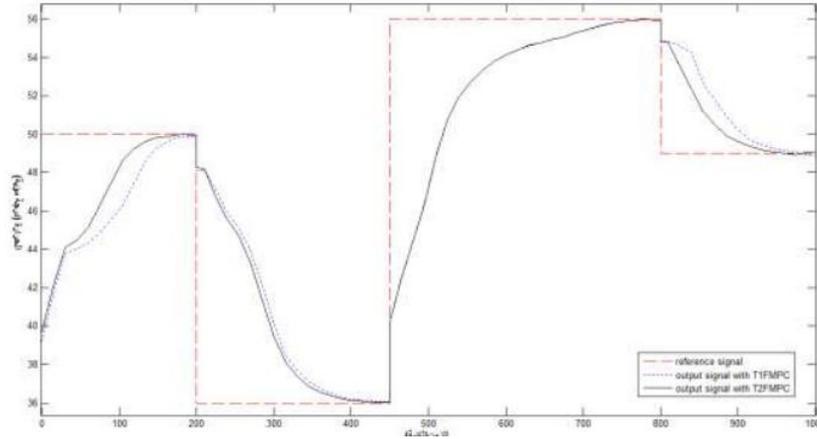


Figure (10): System response to temperature when using a first and second mode controller with a Dombi binding base.

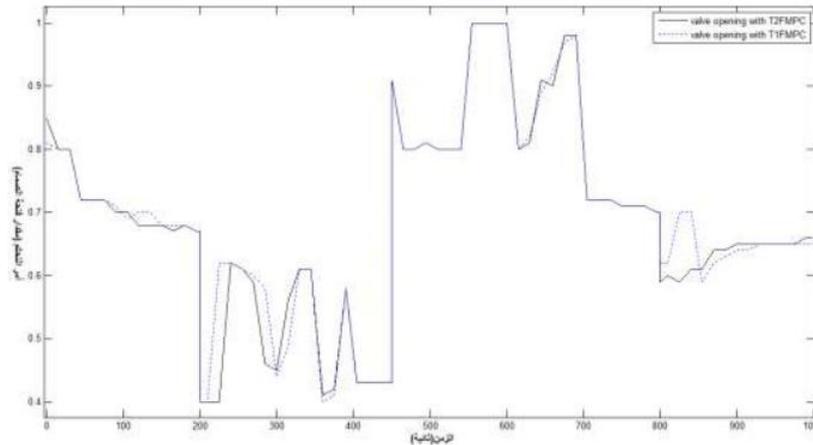


Figure (11) Using the Dompey Connection Method to Determine the Valve Opening for Two Types of Controllers

From the above, we observe that the second-type fuzzy controller provides more flexible and accurate results when compared to the first-type controller.

Conclusion and Recommendations

By using the hybrid system in the study sample, resulting from the integration of fuzzy decision and prediction methods, it was observed that the second-type controller achieved higher accuracy and performance efficiency when compared to the first-type controller, as it was able to overcome ambiguity with high skill. Furthermore, when using the three connection methods, the second-type controller showed responsiveness to change and adaptation, while the first-type controller



was unable to do so. In conclusion, this research recommends further in-depth research in the field of fuzzy logic, as this topic is of great importance and is constantly evolving.

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