Fuzzy System for Autonomous Maintenance Machine in Space

1.1- Abstract:

Due to the increasing complexity and sophistication of spacecrafts, a need for advanced control systems is arising. Traditional control systems have served its purpose in various applications, but they may not be adequate for autonomous orbital operations. These operations often involve imprecise measurements, uncertain information, and nonlinear systems, which can hinder the reliability of conventional control systems.

FLS is an exceptionally powerful tool, addresses these challenges by handling imprecise measurements, uncertain information, and modelling nonlinear systems. It can make intelligent decisions even under uncertainty, making it an invaluable asset in the realm of autonomous orbital operations.

Fuzzy logic's capabilities are exemplified in applications like trajectory control, guidance and targeting, camera tracking, and environment and life support. Its ability to significantly improve spacecraft performance and enhance resilience to the challenges of space is noteworthy.

1.2- Introduction:

The world around us is not always neatly divided into binary categories of "true" or "false." Instead, we often encounter concepts that exist on a spectrum of possibilities, ranging from "very likely" to "somewhat likely" to "not very likely." Traditional logic, with its rigid either-or approach, struggles to capture the nuances of this reality. However, fuzzy logic emerges as a powerful framework that embraces the fluidity of our world and provides a way to reason with imprecise and uncertain information.

Unlike traditional logic, which relies on crisp sets with sharp boundaries, fuzzy logic employs fuzzy sets, which allow for the representation of concepts along a continuum. This enables fuzzy logic to capture the shades of Gray between extremes, reflecting the reality that many real-world situations are not black and white. For instance, instead of simply stating that a temperature is either "hot" or "cold," fuzzy logic can represent it as "warm," "slightly warm," "neutral," "slightly cold," or "cold."

This flexibility has made fuzzy logic a valuable tool in various fields, including control systems, robotics, artificial intelligence, and aerospace engineering. In aerospace applications, where imprecise measurements and uncertain data are prevalent, fuzzy logic proves to be an invaluable asset. It enables spacecraft to navigate with precision, rendezvous with other spacecraft, and maintain a comfortable environment for the crew, even in the face of challenges posed by the cosmos.

As we venture deeper into the vast expanse of space, fuzzy logic is poised to play an increasingly important role. Its ability to handle the nuances and uncertainties of the universe will be critical in pushing the boundaries of space exploration and unravelling the mysteries of the cosmos.

Autonomous orbital operations are challenging because they often involve imprecise measurements, uncertain information, and nonlinear systems. These challenges can make it difficult for traditional control systems to operate reliably.

1.3- Role of Fuzzy Logic in Space Autonomy:

The domain of autonomous orbital operations presents a unique set of challenges, where imprecise sensory data, uncertain information, and nonlinear systems frequently pose obstacles to traditional control systems. However, fuzzy logic emerges as a powerful tool, equipped to address these complexities with exceptional proficiency.

Spacecraft are often exposed to noisy and unreliable sensor readings, leading to imprecise information about their position, orientation, and environment. This presents substantial challenges for conventional control systems, which rely on accurate and precise inputs. Fuzzy logic, on the other hand, effectively handles imprecise data by assigning membership degrees to different fuzzy sets representing the range of possible values for each sensor reading. This probabilistic approach empowers fuzzy logic to make informed decisions even in the face of uncertainty, ensuring the seamless operation of the spacecraft.

The behaviour of spacecraft in orbit is governed by intricate nonlinear systems, which are notoriously difficult to model precisely using conventional control techniques. Fuzzy logic, however, excels at modelling nonlinear systems due to its inherent ability to handle multiple inputs and outputs, as well as its aptitude to approximate complex relationships between them. This capability enables fuzzy logic to capture the dynamic nature of spacecraft motion and make appropriate control decisions in real-time.

In the dynamic and unpredictable environment of space, spacecraft often encounter situations where traditional control systems struggle to make effective decisions. Fuzzy logic, with its ability to reason with imprecise and uncertain information, emerges as a superior choice. It can weigh multiple factors, including sensor readings, mission objectives, and environmental conditions, to arrive at optimal control actions even under uncertainty.

The versatility of fuzzy logic finds applications across a broad spectrum of autonomous orbital operations, including:

- Trajectory Control: Fuzzy logic effectively guides spacecraft through complex trajectories, such as rendezvous and docking with other spacecraft, manoeuvring in confined spaces, and executing precise landing manoeuvres.
- Guidance and Targeting: Fuzzy logic assist’s the spacecraft in accurately identifying and tracking targets, such as rendezvous ports, scientific instruments, and another spacecraft. This capability is crucial for successful docking and scientific operations.
- Camera Tracking: Fuzzy logic enables precise tracking of moving objects with a camera, such as other spacecraft or debris. This capability is essential for maintaining situational awareness and avoiding collisions.

- Environment and Life Support: Fuzzy logic regulates the environmental and life support systems of spacecraft, maintaining a comfortable and habitable environment for the crew. It can control temperature, humidity, air quality, and other critical parameters.

The implementation of fuzzy logic in autonomous orbital operations has brought about significant improvements in spacecraft performance and resilience:

- Enhanced Precision and Accuracy: Fuzzy logic's ability to handle imprecise data and nonlinear systems has led to more precise and accurate control of spacecraft, enabling them to execute manoeuvres with greater accuracy.
- Improved Reliability and Robustness: Fuzzy logic's ability to make smart decisions under uncertainty has made spacecraft more reliable and robust to the challenges of space, such as sensor noise, fluctuating environmental conditions, and unforeseen events.
- Increased Autonomy: Fuzzy logic has enabled spacecraft to operate with greater autonomy, reducing the need for constant human intervention and allowing for more efficient and adaptable operations.

1.4- System FIS (V1):

Autonomous Maintenance Machine in Space:

The deployment and maintenance of autonomous machines in space require precise decision-making to ensure the success of space missions. This section introduces a Fuzzy Inference System (FIS) designed for an autonomous maintenance machine in space, focusing on its inputs, outputs, and membership functions.

Purpose of the FIS:

The purpose of the proposed FIS is to guide an autonomous maintenance machine in space through the decision-making process related to satellite detection, assessment, and potential maintenance activities. The FIS evaluates dynamic inputs such as distance to the satellite, relative velocity, altitude, and fuel levels, considering complex factors like camera status, battery levels, and the overall state of the target satellite.

Inputs/Outputs:

Within the intricate framework of System V1's fuzzy inference system (FIS), an array of meticulously crafted input variables and their associated membership functions (MFs) form the bedrock of autonomous maintenance operations in the celestial expanse. The evaluative tapestry begins with the assessment of "Distance to Satellite (M)," a pivotal metric gauging the spacecraft's proximity to the target satellite, dissected into nuanced categories such as "Very Close," "Close," "Medium," "Far," and "Very Far." This proximity metric is intricately woven with "Relative Velocity (M/s)," delving into the spacecraft's speed concerning the target satellite, navigating linguistic variables ranging from "Very Slow" to "Very Fast."

As the spacecraft traverses its orbital trajectory, the "Altitude (KM)" input variable emerges, providing insights into the spacecraft's elevation categorized by linguistic variables, namely "Low Earth Orbit," "Medium Earth Orbit," and "High Earth Orbit." Complementing this, the "Target Orbit (KM)" variable encapsulates the orbital characteristics of the target satellite, further subdivided into "Low Earth Orbit," "Medium Earth Orbit," and "High Earth Orbit." The observational prowess of the system is encapsulated in the "Camera (ON/OFF)" variable, a binary determinant of the camera's operational status marked by linguistic variables "ON" and "OFF."

Vital to the longevity of autonomous operations, the "Battery Level (%)" input variable quantifies the spacecraft's energy reservoirs with gradations spanning "Very Low" to "Very High." Simultaneously, the "Fuel Level (L)" variable navigates the spacecraft's fuel reserves, mapping linguistic variables from "Very Low" to "Very High." The efficacy of target detection is encapsulated in "Target Detection (ON/OFF)" and "Target Detected (YES/NO)," intricately weaving the activation status of the target detection system and the binary affirmation of target detection.

As the system delves deeper into intricacies, the "Target State Scan" variable scrutinizes the quality of the target scan, categorizing it into nuanced descriptors like "Very Poor," "Poor," "Average," "Good," and "Very Good." The propulsive dynamics of the spacecraft are underpinned by the binary state of "Engine (ON/OFF)," discerning the activation status of the spacecraft's engine. Concurrently, the "Robotic Arm (ON/OFF)" variable encapsulates the dexterity of the robotic arm, oscillating between the linguistic variables "ON" and "OFF." The precision of targeting hinges on the "Target Lock (ON/OFF)" variable, demarcating the locking status with "ON" and "OFF." The thermal landscape is navigated through the "Heat Sensor (°C)" variable, stratifying temperature into linguistic variables of "Low," "Medium," "High," and "Very High."

The intricacies of input variables pave the way for an array of consequential output variables, each holding sway over the system's decision-making apparatus. The "Thrust" variable delineates the propulsive force into nuanced categories of "Slow," "Medium," and "Fast," while the "Cooling System (ON/OFF)" governs the thermal equilibrium through the binary activation state. Solar dynamics come into play with the "Solar Panels (DEPLOYED/RETRACTED)" variable, dictating the status of solar panels through linguistic variables "Deployed" and "Retracted."

Navigating the terrain of decision-making, the system deliberates on whether to "Initiate Rendezvous (YES/NO)" based on the emergent circumstances, further mirrored in variables like "Initiate Repair (YES/NO)," "Initiate Capture (YES/NO)," and the decisive "Abort (YES/NO)." Each output variable reflects a crucial facet of the autonomous maintenance operation, and collectively, this comprehensive suite of input and output variables forms the algorithmic backbone of System V1, orchestrating its responses with finesse in the vast expanse of space.

FIS Rules FIS (V1):

Rule 1:

If the robot is Very_Close to the satellite, has Very_Slow Relative_Velocity, is in Low_Earth_Orbit, the Target_Orbit is Medium_Earth_Orbit, Camera is ON, Battery_Level is Very_High, Fuel_Level is Very_High, Target_Detection is ON, Target_Detected is YES, Target_State_Scan is Poor, Engine is ON, Robotic_Arm is ON, Target_Lock is ON, and Heat_Sensor is Medium, then the actions are:

- Thrust is Slow
- Solar Panels are Deployed.
- Initiate Rendezvous is YES
- Initiate Capture is YES

Rule 2:

If the robot is Very_Close to the satellite, has Very_Slow Relative_Velocity, is in Medium_Earth_Orbit, the Target_Orbit is Medium_Earth_Orbit, Camera is ON, Battery_Level is Very_High, Fuel_Level is

Very_High, Target_Detection is ON, Target_Detected is YES, Target_State_Scan is Poor, Engine is ON, Robotic_Arm is ON, Target_Lock is ON, and Heat_Sensor is Medium, then the actions are:

- Thrust is Slow
- Solar Panels are Deployed.
- Initiate Rendezvous is YES
- Initiate Repair is YES

Rule 3:

If the robot is Very_Close to the satellite, has Very_Slow Relative_Velocity, is in Low_Earth_Orbit, the Target_Orbit is Medium_Earth_Orbit, Camera is ON, Battery_Level is Medium, Fuel_Level is Medium, Target_Detection is ON, Target_Detected is YES, Target_State_Scan is Poor, Engine is ON, Robotic_Arm is ON, Target_Lock is ON, and Heat_Sensor is Medium, then the actions are:

- Thrust is Slow
- Solar Panels are Deployed.
- Initiate Rendezvous is YES
- Initiate Repair is YES

Rule 4:

If the robot is Far from the satellite, has Slow Relative_Velocity, is in Low_Earth_Orbit, the Target_Orbit is Low_Earth_Orbit, Camera is ON, Battery_Level is Medium, Fuel_Level is High, Target_Detection is ON, Target_Detected is YES, Target_State_Scan is Average, Engine is ON, Robotic_Arm is ON, Target_Lock is ON, and Heat_Sensor is Medium, then the actions are:

- Thrust is Medium
- Solar Panels are Deployed.
- Initiate Rendezvous is YES
- Initiate Repair is YES

Rule 5:

If the robot is VeryFar from the satellite, has Very_Slow Relative_Velocity, is in Low_Earth_Orbit, the Target_Orbit is Medium_Earth_Orbit, Camera is ON, Battery_Level is Low, Fuel_Level is Low, Target_Detection is ON, Target_Detected is YES, Target_State_Scan is Good, Engine is ON, Robotic_Arm is ON, Target_Lock is ON, and Heat_Sensor is High, then the actions are:

- CoolingSystem is ON
- Solar Panels are Deployed.
- Abort is YES

Rule 6:

If the robot is Close to the satellite, has Slow Relative_Velocity, is in High_Earth_Orbit, the Target_Orbit is High_Earth_Orbit, Camera is ON, Battery_Level is Medium, Fuel_Level is Medium, Target_Detection is ON, and Heat_Sensor is Low, then the action is:

- Abort is YES

System Integration FIS (V1):

The FIS integrates inputs related to the machine's surroundings, internal conditions, and dynamic factors. By employing fuzzy logic, the system copes with uncertainties and varying conditions in space, allowing the autonomous machine to adapt its actions based on a comprehensive evaluation of the environment. The three-part structure ensures that the decision-making process is well-organized, isolating structural considerations, human decision factors, and combining them for a holistic assessment of the optimal course of action in space missions.

In summary, the FIS for the autonomous maintenance machine in space is designed to enhance decision-making in satellite detection, assessment, and potential maintenance activities by considering a myriad of dynamic inputs and intricate conditions in the vastness of space.

1.5- System Test 1 FIS (V1):

During my meticulous evaluation of System V1, specifically designed for autonomous maintenance operations in space, I uncovered a significant misalignment between the anticipated and actual outcomes. This realization prompted a thorough investigation into the system's intricacies, revealing that several critical rules were not activating as intended. The failure of these rules raised serious concerns about the reliability of System V1 in its present state.

To address these issues, a comprehensive improvement initiative is underway. I am currently in the process of conducting a meticulous assessment of the system's architecture and identifying potential areas for optimization. The primary focus will be on simplifying both input and output structures. In terms of inputs, a strategic decision will be made to streamline the decision-making process by eliminating redundant variables like Distance to Satellite, Target Detection Sensor, Engine, Robotic Arm, and Target Lock. This simplification is aimed at bolstering the system's ability to efficiently process and interpret pertinent information.

Simultaneously, a pivotal change will be implemented in the output structure. Rather than maintaining separate outputs for distinct maintenance actions such as Rendezvous, Repair, Capture, and Abort, these will be consolidated into a single decision variable labelled "Decision." This consolidation aims to distil the system's responses into a concise and encompassing decision-making variable, resulting in a more straightforward and interpretable outcome.

These planned modifications, encompassing input simplification and output consolidation, signify a concerted effort to improve the reliability and interpretability of System V1. By streamlining the decision-making process and simplifying the output structure, I anticipate that the identified shortcomings will be effectively addressed, positioning System V1 as a more robust tool for autonomous maintenance in space.

Beyond the immediate performance enhancements, these planned modifications lay the foundation for future improvements and adaptability. The simplified system architecture will provide greater flexibility for incorporating new functionalities and adapting to evolving operational requirements, ensuring that System V1 remains a reliable asset for autonomous maintenance operations in space in the long term.

Note: all Figures are on the next page, Figure 1 represents the data present into the xlsx file, 14 inputs after running the system the outputted data didn't seem correct (Figure 3), so after I look at the input data as you I noticed values (2) in the Camera input and Target Detection and Target Detected, and also Robotic Arm and the value 2 should not be present and that will be addressed in Figure

2, however the output stayed the same, so I took the decision to do all what is cited above.

Distance_to_Satellite_(M)	Relative_Velocity_(M/s)	Altitude_(KM)	Target_Orbit_(KM)	Camera_(ON/OFF)	Battery_Level_(%)	Fuel_Level_(L)	Target_Detection_(ON/OFF)	Target_Detected_(YES/NO)	Target_State_Scan	Engine_(ON/OFF)	Robotic_Arm_(ON/OFF)	Target_Lock_(ON/OFF)	Heat_Sensor_(°C)
857	89	744	873	1	70	9376	1	1	81	1	1	1	120
424	46	658	781	2	81	4124	1	1	25	1	1	1	1094
712	67	162	492	1	11	5491	1	1	44	1	1	1	333
963	91	498	988	2	22	2121	1	1	64	1	1	1	534
556	35	769	697	1	94	7512	1	1	17	1	1	1	331
288	7	513	198	1	51	9874	1	1	96	1	1	1	642
654	78	315	925	1	38	2345	1	2	39	1	1	1	243
789	58	811	587	1	63	8452	1	1	75	1	2	1	477
457	19	622	341	1	84	6711	2	2	55	2	1	1	713
892	72	977	456	1	27	1234	1	2	12	1	1	1	1420
647	53	254	812	1	73	5432	1	1	87	1	2	1	1156
326	25	395	697	1	16	7890	2	2	68	1	1	1	1547
599	98	582	989	1	44	3567	1	1	33	1	1	1	1512
734	11	719	832	1	59	9870	1	1	50	1	1	1	1289

Figure 1_Fuzzy_System_Input_Data_for_Test 1

	Thrust	Cooling_System	Solar_Panels	Initiate_RendezVous	Initiate_Repair	Initiate_Capture	Abort
	50	0.5	0.5	0.5	0.5	0.5	0.5
	50	0.5	0.5	0.5	0.5	0.5	0.5
	50	0.5	0.5	0.5	0.5	0.5	0.5
	50	0.5	0.5	0.5	0.5	0.5	0.5
	50	0.5	0.5	0.5	0.5	0.5	0.5
	50	0.5	0.5	0.5	0.5	0.5	0.5
TEST 1	50	0.5	0.5	0.5	0.5	0.5	0.5
	50	0.5	0.5	0.5	0.5	0.5	0.5
	50	0.5	0.5	0.5	0.5	0.5	0.5
	50	0.5	0.5	0.5	0.5	0.5	0.5
	50	0.5	0.5	0.5	0.5	0.5	0.5
	50	0.5	0.5	0.5	0.5	0.5	0.5
	50	0.5	0.5	0.5	0.5	0.5	0.5
	50	0.5	0.5	0.5	0.5	0.5	0.5

Figure 2_Fuzzy System Output Data for Test 1

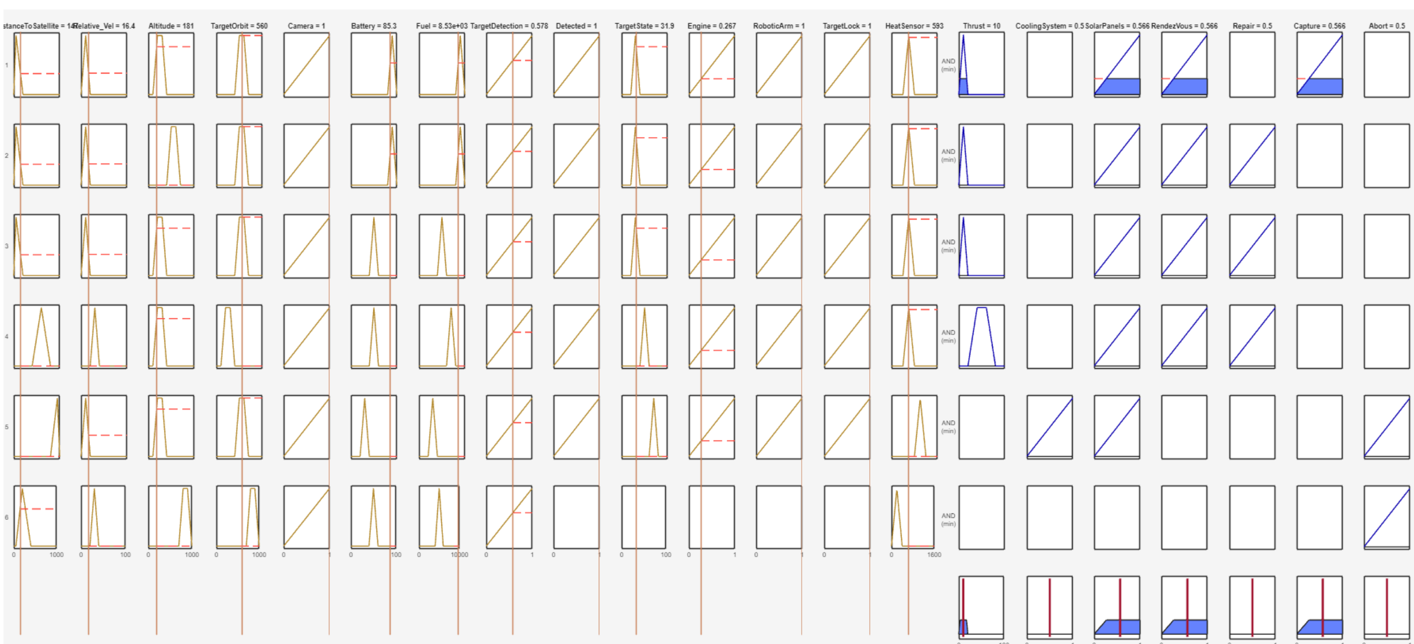
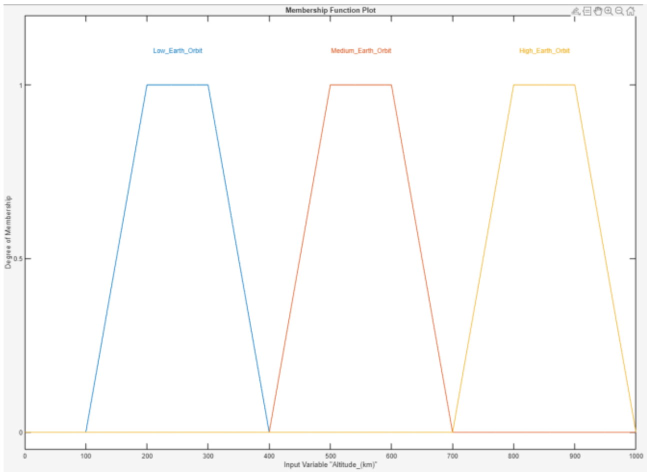
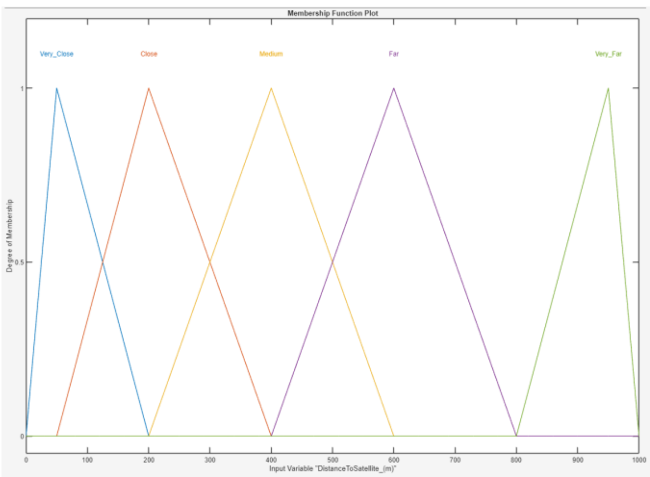
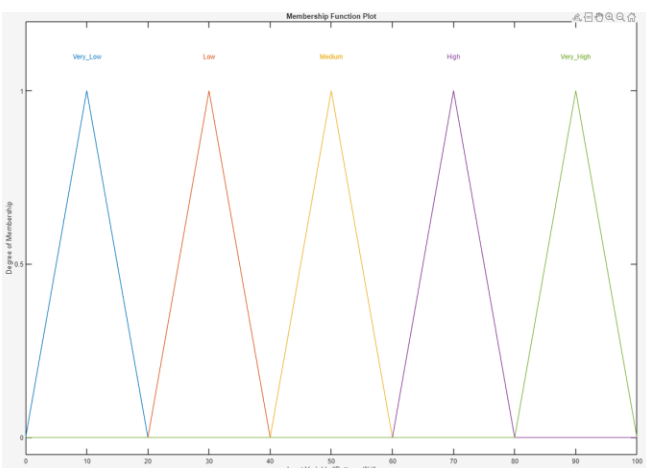


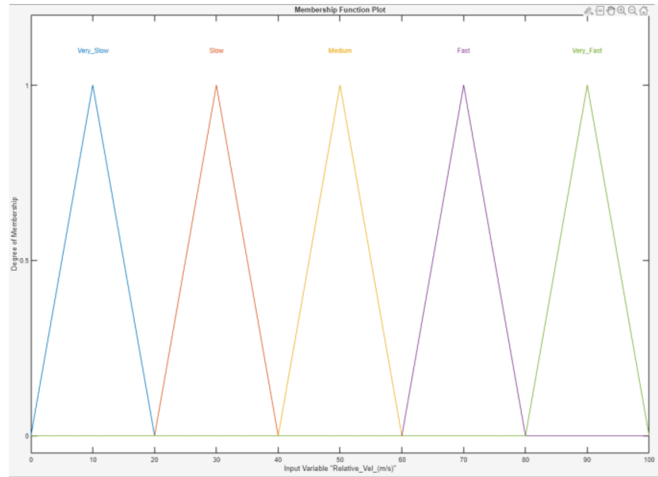
Figure 3 Fuzzy System Output Data for Test 1

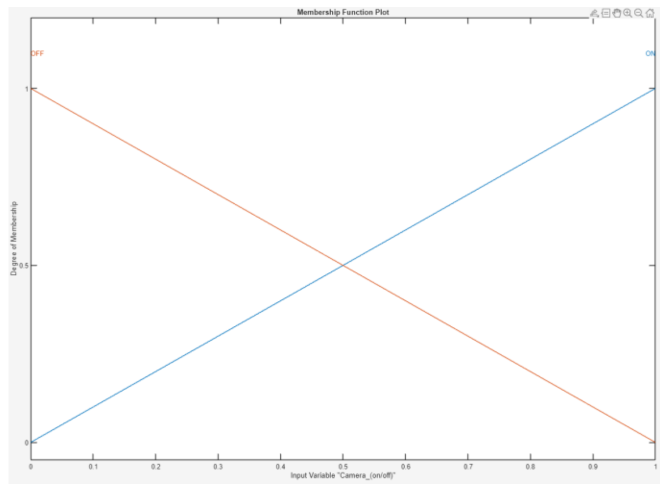
1.6- Inputs/Outputs Mf's (SystemV1):

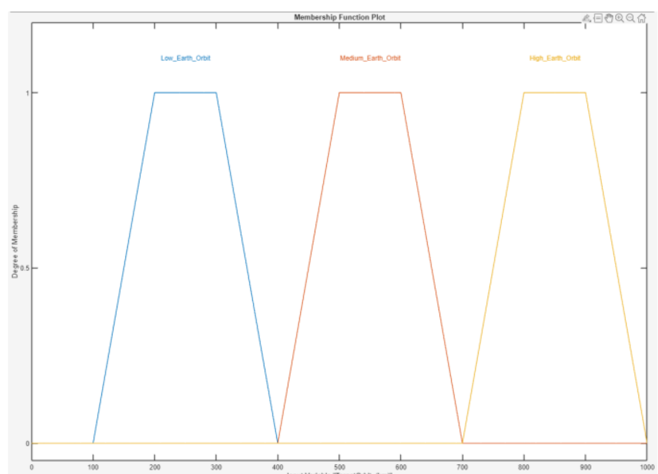


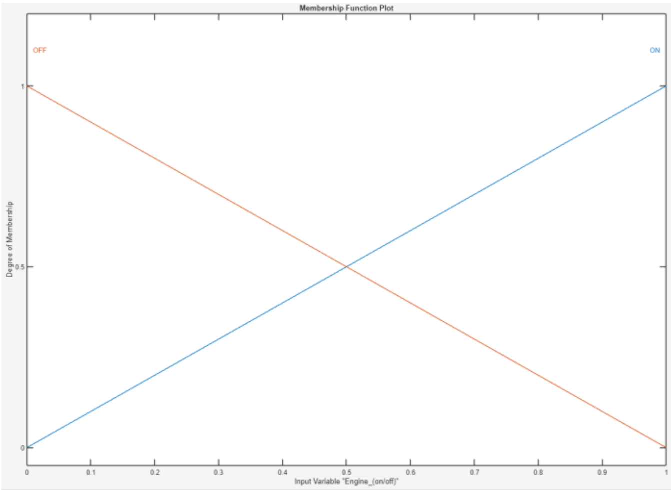


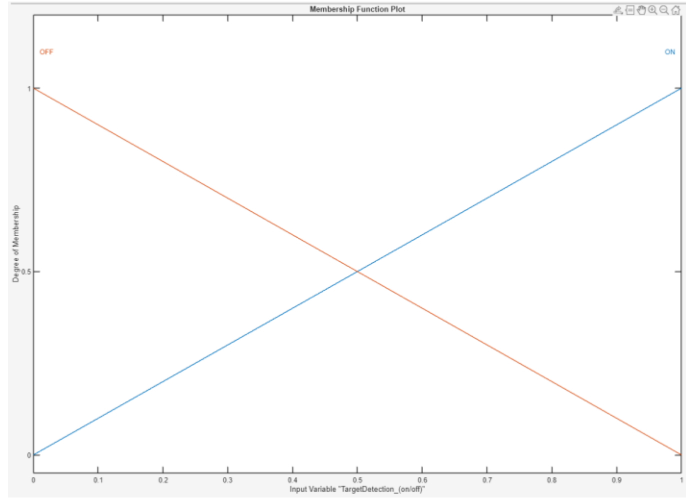


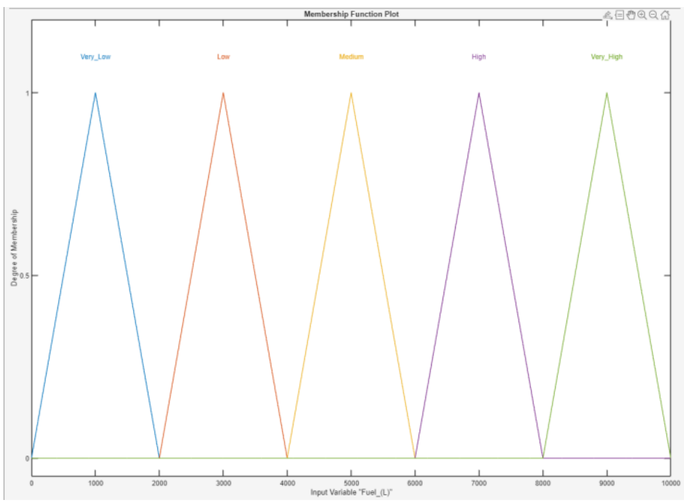


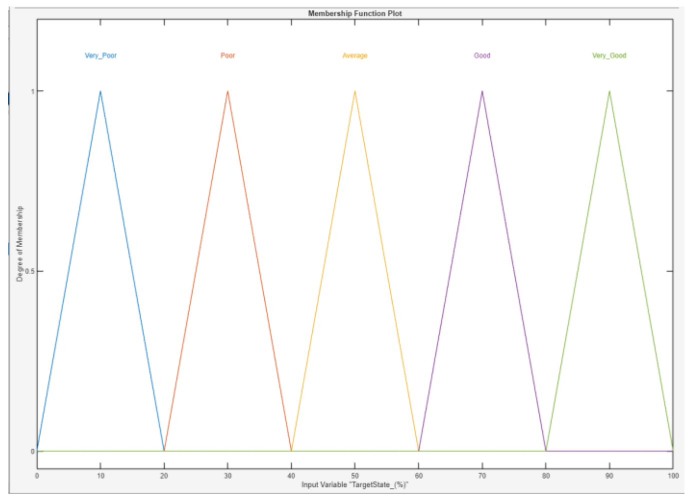


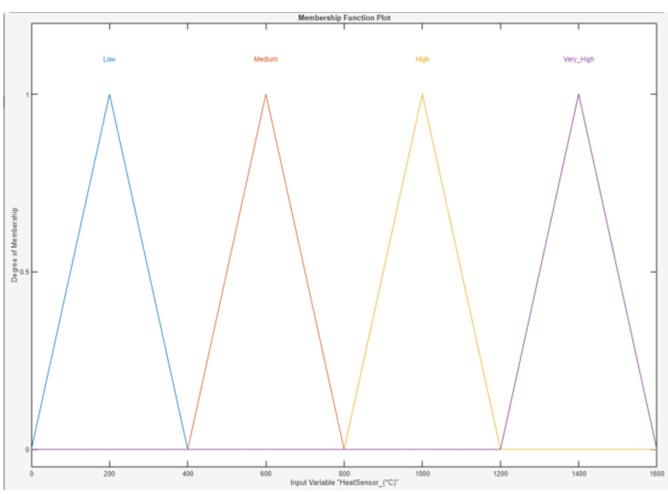


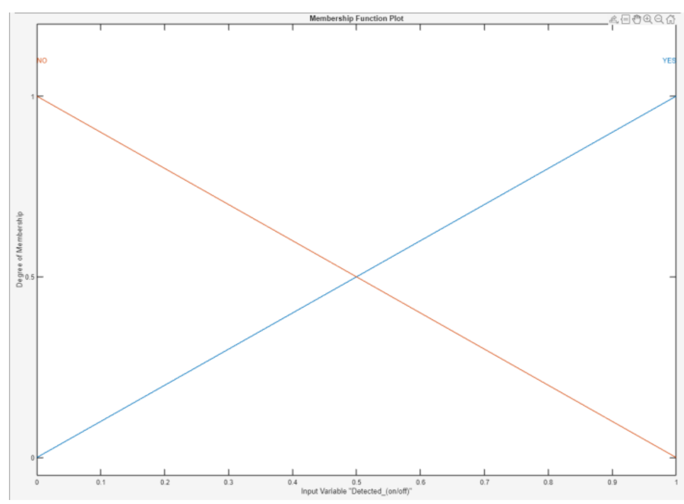

Membership Function Plot
OFF
ON
Degree of Membership
Input Variable "Engine_(on/off)"


Membership Function Plot
OFF
ON
Degree of Membership
Input Variable "TargetDetection_(on/off)"


Membership Function Plot
Very_Low
Low
Medium
High
Very_High
Degree of Membership
Input Variable "Fuel_(L)"


Membership Function Plot
Very_Poor
Poor
Average
Good
Very_Good
Degree of Membership
Input Variable "TargetState_(%)"


Membership Function Plot
Low
Medium
High
Very_High
Degree of Membership
Input Variable "HeatSensor_(°C)"


Membership Function Plot
NO
YES
Degree of Membership
Input Variable "Detected_(on/off)"

1.7- FIS System V2:

As mentioned above in this second version of the system everything was made simpler and smoother.

System Two represents a paradigm shift from the initial design, marked by a substantial reduction in both input complexity and output multiplicity. In the inaugural version, System One exhibited a staggering 14 inputs and 7 outputs, contributing to a convoluted decision-making process. This complexity posed significant challenges in terms of interpretability and computational efficiency, ultimately raising concerns about the system's practicality and reliability in real-world scenarios.

The evolution to System Two is characterized by a meticulous simplification strategy. Notably, the reduction of input variables from 14 to 6 signifies a strategic departure from unnecessary intricacies. The inclusion of only the most pertinent inputs, such as Relative Velocity, Altitude, Target Orbit, Battery Level, Fuel, and Target State, demonstrates a refined approach focused on essential parameters for autonomous maintenance operations in space. This reduction not only streamlines the decision-making process but also enhances the system's adaptability to dynamic operational conditions.

The input simplification is further augmented by the incorporation of Gaussian and Generalized Bell-shaped membership functions (gaussmf's and gbellmf's). This addition enables a more nuanced and realistic representation of linguistic variables, facilitating a smoother transition from raw data to fuzzy sets. The judicious use of these membership functions ensures a more accurate interpretation of input variables, laying the groundwork for precise and meaningful rule inference.

In tandem with input simplification, System Two introduces a discerning consolidation of output variables. From the initial set of 7 outputs, the system distils the decision-making process into 3 outputs: Thrust, Reverse Thrust, and Decision. This consolidation is not merely a reduction in quantity; rather, it represents a strategic amalgamation of related outputs, offering a more cohesive and interpretable decision variable. The Decision output encapsulates distinct maintenance actions, including Rendezvous, Repair, Capture, and Abort, providing operators with a concise and holistic understanding of the system's response.

The reduction in both input and output complexity contributes to a remarkable enhancement in system interpretability and operational efficiency. By curtailing unnecessary variables and outputs, System Two minimizes cognitive load on operators, allowing for more intuitive and efficient interaction with the autonomous maintenance system. This streamlining not only fosters quicker decision-making but also mitigates the risk of misinterpretation, crucial in the demanding and dynamic environment of space operations.

Furthermore, the utilization of Gaussian and Generalized Bell-shaped membership functions introduces a layer of linguistic sophistication previously lacking in System One. This linguistic refinement enhances the system's ability to capture and process nuanced information, providing a more nuanced and contextually aware decision-making capability. The improved linguistic representation of variables contributes to a more robust and adaptive system, well-suited for the inherent uncertainties and variations encountered in space missions.

In conclusion, the transition from System One to System Two represents a pivotal refinement in autonomous maintenance systems for space operations. The judicious simplification of inputs and outputs, coupled with the adoption of advanced membership functions, positions System Two as a more agile, interpretable, and adaptive tool. These enhancements not only address the shortcomings of the initial version but also lay the foundation for a more resilient and dependable system in the complex realm of autonomous space missions.

FIS SYSTEM V2 Inputs/Outputs:

inputs:

Relative Velocity (m/s):

- Very Slow (gbellmf, [10 1 0])
- Slow (gaussmf, [10 30])
- Medium (gaussmf, [10 50])
- Fast (gaussmf, [10 70])
- Very Fast (gbellmf, [10 1 100])

Description: Capturing the speed of relative motion, these membership functions provide a nuanced linguistic representation ranging from very slow to very fast, enabling the system to interpret the velocity of the space vehicle with precision.

Altitude (km):

- Low Earth Orbit (gaussmf, [150 0])
- Medium Earth Orbit (gaussmf, [200 500])
- High Earth Orbit (gaussmf, [150 1000])

Description: Tailored for altitude assessment, these membership functions delineate altitude into low, medium, and high Earth orbits, enabling the system to gauge the spacecraft's position relative to Earth.

Target Orbit (km):

- Low Earth Orbit (gaussmf, [150 0])
- Medium Earth Orbit (gaussmf, [200 500])
- High Earth Orbit (gaussmf, [150 1000])

Description: Like Altitude, these functions categorize the target's orbit into low, medium, and high Earth orbits, facilitating a comprehensive comparison with the spacecraft's orbit.

Battery (%):

- Very Low (gaussmf, [10 0])
- Low (gaussmf, [10 30])
- Medium (gaussmf, [10 50])
- High (gaussmf, [10 70])
- Very High (gaussmf, [10 100])

Description: Focused on the battery's charge level, these functions linguistically represent battery status, providing the system with insights into the energy resources available.

Fuel (L):

- Very Low (gaussmf, [1000 0])
- Low (gaussmf, [1000 3000])
- Medium (gaussmf, [1000 5000])
- High (gaussmf, [1000 7000])
- Very High (gaussmf, [1000 10000])

Description: Addressing the fuel quantity, these functions categorize fuel levels, offering a linguistic interpretation that aids the system in understanding the spacecraft's fuel status.

Target State (%):

- Very Poor (gaussmf, [10 0])
- Poor (gaussmf, [10 30])
- Average (gaussmf, [10 50])
- Good (gaussmf, [10 70])
- Very Good (gaussmf, [10 100])

Description: Assessing the condition of the target spacecraft, these functions capture a range from very poor to very good, allowing the system to factor in the health of the target.

Outputs:

Thrust (%):

- Slow (gbellmf, [15 2 0])
- Medium (gbellmf, [40 4 50])
- Fast (gbellmf, [15 2 100])

Description: Determining the required thrust, these functions linguistically represent the desired thrust level, aiding in the precise adjustment of propulsion systems.

Reverse Thrust (%):

- Slow Reverse (gbellmf, [15 3 0])
- Medium Reverse (gbellmf, [40 4 50])
- Full Reverse (gbellmf, [15 5 100])

Description: In scenarios requiring reverse thrust, these functions enable the system to modulate the reverse propulsion, ensuring controlled deceleration.

Decision:

- Rendezvous (pimf, [-50 0 1 40])
- Repair (pimf, [-11 29 39 80])
- Capture (pimf, [25 65 75 115])
- Abort (pimf, [60 100 100 100])

Description: The Decision output encapsulates distinct maintenance actions. Rendezvous, Repair, Capture, and Abort are linguistically represented, providing a concise and encompassing decision-making variable for operators.

In summary, the carefully crafted membership functions for each input and output parameter in System Two contribute to a sophisticated linguistic representation, enhancing the system's ability to interpret and respond to complex space maintenance scenarios with precision and adaptability.

References:

- Ousaloo, H. S. (2011) Attitude Control of a Small Satellite with Uncertainly Dynamic Model Using Fuzzy Logic Strategy.

- Lea, R. N., & Jani, Y. (1992). Fuzzy Logic in Autonomous Orbital Operations. Houston, Texas: Software Technology Branch / PT4, NASA / Johnson Space Center, Togai Infralogic, Inc.

- Navabi, M., Safaei Hashkavaei, N., & Reyhanoglu, M. (2023). "Satellite Attitude Control Using Optimal Adaptive and Fuzzy Controllers."

Appendice:

Centroid – Bisector – mom – lom - som

SYSTEM V2			SYSTEM V2			SYSTEM V2			SYSTEM V2			SYSTEM V2		
Centroid			Bisector			mom			lom			som		
Thrust_%	Reverse_Thrust_(%)	Decision	Thrust_%	Reverse_Thrust_(%)	Decision	Thrust_%	Reverse_Thrust_(%)	Decision	Thrust_%	Reverse_Thrust_(%)	Decision	Thrust_%	Reverse_Thrust_(%)	Decision
50	50	88.62195094	50	50	90	50	50	100	100	100	100	0	0	100
50	50	88.62195094	50	50	90	50	50	100	100	100	100	0	0	100
50	50	88.62195094	50	50	90	50	50	100	100	100	100	0	0	100
50	50	88.62195094	50	50	90	50	50	100	100	100	100	0	0	100
50	50	88.62195094	50	50	90	50	50	100	100	100	100	0	0	100
50	50	88.62195094	50	50	90	50	50	100	100	100	100	0	0	100
46.04853656	49.77436162	50.18533229	46	25	50	25	50	49.8	50	100	100	0	0	0
46.04853656	49.77436162	50.18533229	46	25	50	25	50	49.8	50	100	100	0	0	0
46.04853656	49.77436162	50.18533229	46	25	50	25	50	49.8	50	100	100	0	0	0
46.04853656	49.77436162	50.18533229	46	25	50	25	50	49.8	50	100	100	0	0	0
50	86.61443871	23.04642258	50	87	19	50	88	14.5	100	100	29	0	76	0
50	81.4783404	63.18410374	50	82	81	50	83.5	91.5	95	100	100	5	67	83
13.1763491	84.68983211	85.33716058	12	85	86	8	86.5	89.5	16	100	100	0	73	79
49.22917929	90.86237776	35.05761064	49	91	35	45.5	92.5	34.5	91	100	61	0	85	8
50	51.78285953	88.62194856	50	52	90	50	55	100	100	100	100	0	10	100
50	70.82842122	87.1915803	50	71	90	50	74	100	100	100	100	0	48	100
50	70.81097511	87.1915803	50	71	90	50	74	100	100	100	100	0	48	100
50	50	88.62195122	50	50	90	50	50	100	100	100	100	0	0	100
50	70.82842122	88.62130116	50	71	90	50	74	100	100	100	100	0	48	100
50	10.78796034	68.12580697	50	10	68	50	8	70	100	16	97	0	0	43
50	89.78961212	36.57355268	50	90	37	50	91	35	100	100	70	0	82	0

SYSTEM 2					
Relative_Vel_(m/s)	Altitude_(km)	Target_Orbit_(km)	Battery_(%)	Fuel_(L)	Target_State_(%)
10	300	300	30	5600	61.00
23	250	500	10	1500	33.00
44	900	200	50	3500	65.00
88	500	150	55	6100	35.00
47	950	900	20	0	0.00
0	0	0	0	1000	0.00
0	0	0	10	0	0.00
0	0	0	0	0	100.00
21	1000	110	0	4200	51.00
41	150	560	70	6400	11.00
91	920	910	52	9100	42.00