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Design & Development of a Prototype Intelligent Blind System Using Fuzzy Reasoning

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***Abstract*—The "everyday things" in our environment have become increasingly intelligent in recent years in the aspects of Automation of Everything (AoE). An IoT application for a smart blind system (SBS) using fuzzy logic to intelligently adjust to an optimal position based on data from local sensors, Wisdom-as-a-Service (WaaS) and Insight-as-a-Service (InaaS) from smart domains and customer preferences has been developed. Testing of this system as a proof-of-concept yields promising results, as the fuzzy logic can effectively control the blind to a position that is desirable under the given environmental conditions. Further, all the input data is utilised productively, ensuring that decisions made by the system are well-informed. Compared to competitors' offerings, the proposed system offers superior performance due to its extensive input consideration and the precise design of the fuzzy logic for automated decision-making.**

***Index Terms*—Fuzzy Logic, Smart Technology, Automation of Everything (AoE), Internet of Things (IoT), Smart City, Smart Building, Smart Blind, Automated Decision-Making, Approximate Reasoning.**

I. INTRODUCTION

"Everyday things" in our environment have become increasingly intelligent in recent years in the aspects of Automation of Everything (AoE) and Internet of Everything (IoE) [1] using geo-distributed Big Data (BD) [2] enabling them to make decisions with an increasing degree of autonomy and little to no help from humans. Integrating all mechanisms used in day-to-day life into smart domains such as smart homes and smart cities (e.g. [3], [4]) aims to continuously improve Quality of Life (QoL) by removing the human-controlled tedious or repetitive tasks that can be effectively executed using intelligent systems. Adjustment of blinds position may seem a trivial task, however, it is a tedious and repetitive task that a smart home can easily handle based on the environmental conditions (e.g. ambient light) and user preferences. Automatic blind adjustment not only saves users the effort but can also increase safety by giving the allusion of an occupied home when the user is away, helping to deter criminals. The control of this system should not be distracting or cumbersome to the user, therefore, smart applications instilled by intelligent decision-making can be employed.

Fuzzy Logic, enabling human-like decisions/reasoning with respect to uncertainty, has been successfully employed in a diverse range of industrial applications (e.g. cement kilns, subways, kitchen appliances (washing machines, microwaves, etc.), cameras, autonomous vehicles) since it was founded by Lotfi A. Zader in 1965. It is employed in modelling systems using natural language with linguistic variables (a much nicer way to categorise datasets using soft boundaries) that humans use in everyday life. The developed system (Fig. 1) in this research uses fuzzy logic – via soft computing distinctions among shades of grey – to make intelligent, human-like decisions to control the blinds based on the data provided by the environment, user and smart domains. It fuses the acquired data appropriately, sets the most desired parameters properly and adjusts the blinds accordingly in an automated manner, leading to increased quality of life (QoL) and user satisfaction.

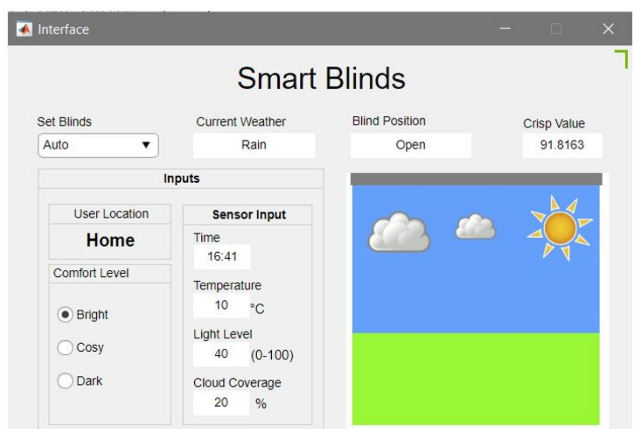

Fig. 1: User interface for smart blind system.

II. RELATED WORKS

Examining previous research and competitors' offerings is important before developing any IoT device. Doing so can inspire ideas and solutions and expose market gaps to exploit

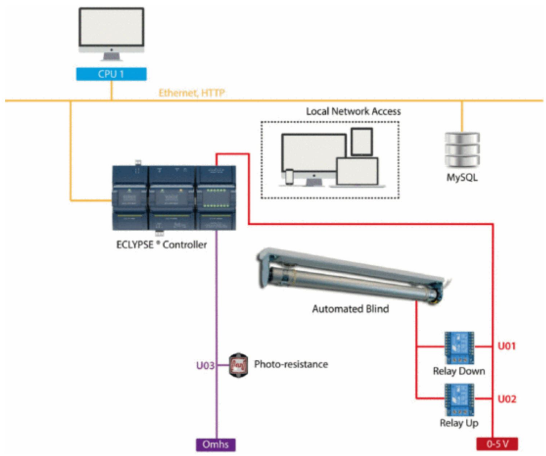

Fig. 2: This figure indicates the use of LAN and SQL databases, which would increase the sophistication of the system, however, this has not been implemented [5].

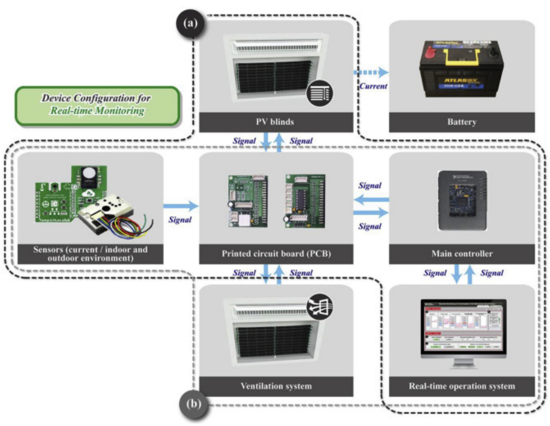

Fig. 3: This system uses real-time communication and local monitoring & control [6].

with the new product, giving a strong competitive edge. This section is split into two parts; the first will survey previous research papers on SBS, second, the features of established products will be evaluated.

A. Previous Research

An early mention of smart blinds comes from [9], in which an SBS utilising voice commands, a touch screen interface and an intelligent system for automatically adjusting the blinds based on ambient light is suggested. This is a good basic concept for its time; however, no real technological suggestions are given for the system's hardware/software (i.e. sensors or algorithms). Čongradac et al. [10] developed an algorithm for controlling the tilt angle of blinds using a genetic algorithm and fuzzy logic to reduce energy demands during summer. Čongradac et al. [10] concluded that the convenience of fuzzy logic development and similar results make it preferable over the genetic algorithm. The membership functions used are external temperature, external light, heat

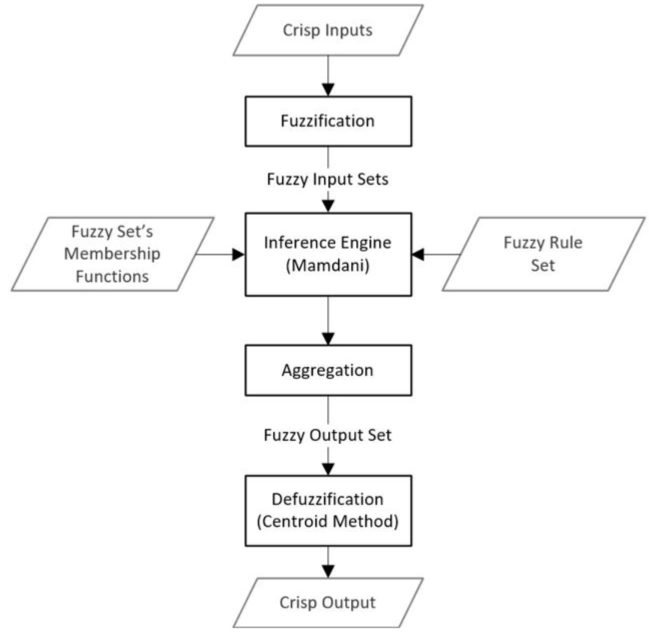

Fig. 4: Main processes of a fuzzy logic system [7], [8]. Fuzzification to determine fuzzy sets; inference engine to process the fuzzy input to the fuzzy output; defuzzification to map fuzzy sets into real-valued crisp variables.

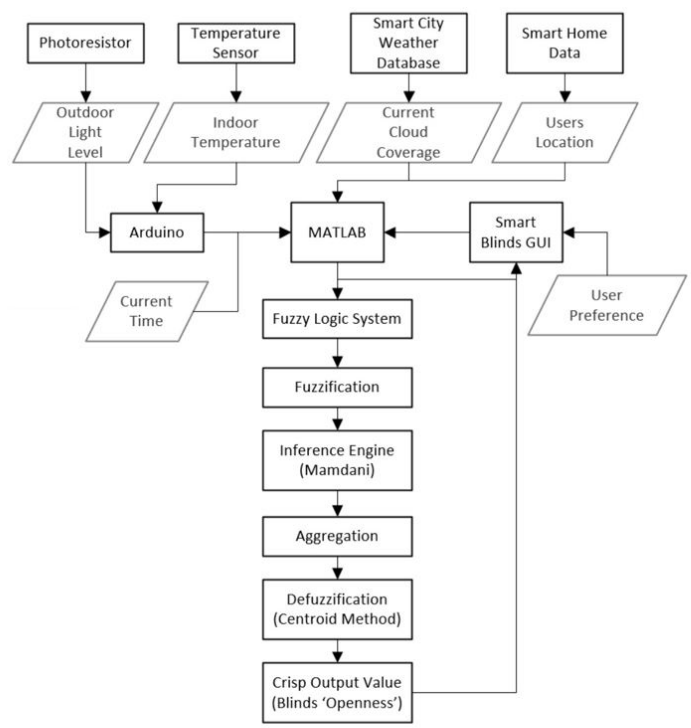

Fig. 5: Flow chart for the design of the proposed SBS. The system is fed by multiple data sources: i) Wisdom as a Service (WaaS) and Insight-as-a-Service (InaaS) from the smart domains in the cloud platform, particularly from smart city in a pay-as-you-go model, ii) data from local sensors, and iii) data from customer's preferences.

TABLE I: Fuzzification with fuzzy sets using linguistic variables: Fuzzy sets and their membership functions stored in the fuzzy knowledge base.

Fuzzy Sets	Membership Functions				
Time	Night	Morning	Midday	Evening	Late Night
Light	Very Dark	Dark	Medium	Bright	Very Bright
Temperature	Very Cold	Cold	Mild	Hot	Very Hot
User Preference	Bright	Cosy	Dark		
User Location	Home	Away			
Cloud Level	Clear	Few Clouds	Scattered Clouds	Broken Clouds	Overcast

gain and current blind position. This paper considers only the algorithmic development of a system, not any user interaction. A three-mode (manual, automatic & programmed) system was presented by [5] as illustrated in Fig. 2. The system uses a user interface for control. Users can set the open percentage of the blinds in manual mode and set a schedule via a calendar in programmed mode. Automatic mode uses a photoresistor to detect the ambient light and adjusts the blinds until the photoresistor matches a user-defined value. This system is a simple mechatronic system and can't be considered an advanced mechatronic system (AMS) due to its lack of intelligent algorithms, cloud/edge integration for Wisdom as a Service (WaaS), Insight-as-a-Service (InaaS) or location-independent monitoring and control [2], [11]. Jung et al. [6] presented a smart window system incorporating photovoltaic blinds and ventilation as depicted in Fig. 3. The system includes real-time local operation & control; however, this isn't location-independent. The system uses solar tracking as an input for both the blinds and ventilation systems, this is achieved by either monitoring the electricity generated by the blinds or monitoring location & time. A professional GUI was developed – but would not be useful to general consumers. An SBS that uses ambient and outdoor light, and a user-defined light level to automatically adjust the blinds was created by [12]. Light sensors were used to detect light, and two buttons are used to input a light level. This SBS lacks any intelligent algorithms, IoT connectivity or location-independent monitoring and control. However, consideration of outdoor/indoor light levels is certainly a must for any SBS.

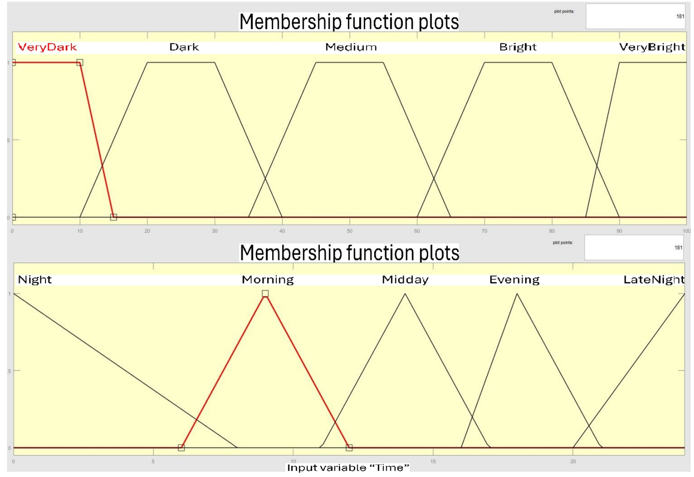

Fig. 6: Fuzzification with fuzzy sets using linguistic variables: Both triangular (for Time) and trapezoidal (for Light) membership functions are used in the fuzzy logic system.

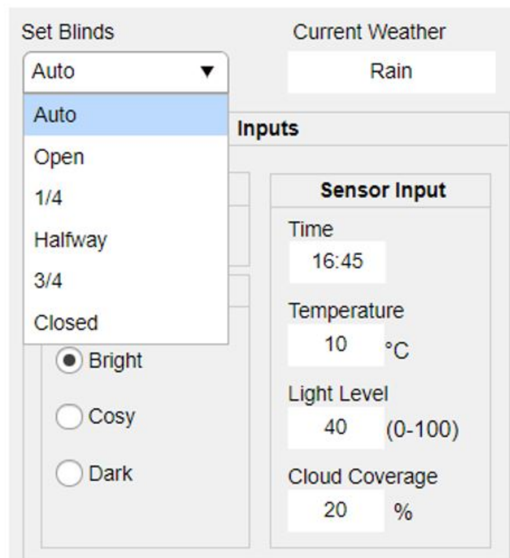

Fig. 7: User inputs for smart blind system.

B. Current Competition

The most popular currently available SBSs are presented in [13]. These blinds are powered by motors and are controlled by radio-frequency, Wi-Fi, and Bluetooth via a remote controller. Some of these systems can be integrated with their remote applications, which allows location-independent monitoring & control, scheduled positioning and geofencing via a smartphone app, as well as voice commands through smart assistants such as Amazon Alexa, Google Assistant and Siri via Apple HomeKit. Some of these systems are expensive and cannot be intelligently controlled without purchasing extra equipment. Additionally, some of them don't use sensors to monitor their environment, so they cannot make decisions other than adjusting once a user-scheduled time event arrives. Some of these systems don‘t make use of machine-to-machine (M2M) communications, cloud databases and edge environments. Some of them use a remote control for controlling position, setting schedules and setting user-favourited positions. The smart functionality of these devices can be enhanced by purchasing accessories, including a bridge device for internet connectivity, location-independent monitoring & control and geofencing. A solar sensor can be added that allows automatic adjustments based on the light intensity detected. The accompanying implementations utilise the cloud and edge environment for storing schedules and preferences. The use of a solar sensor and its use of M2M communication with IoT devices and the smart home certainly make these SBSs more sophisticated than those previously discussed. However, it still lacks intelligent decision-making based on multiple inputs and

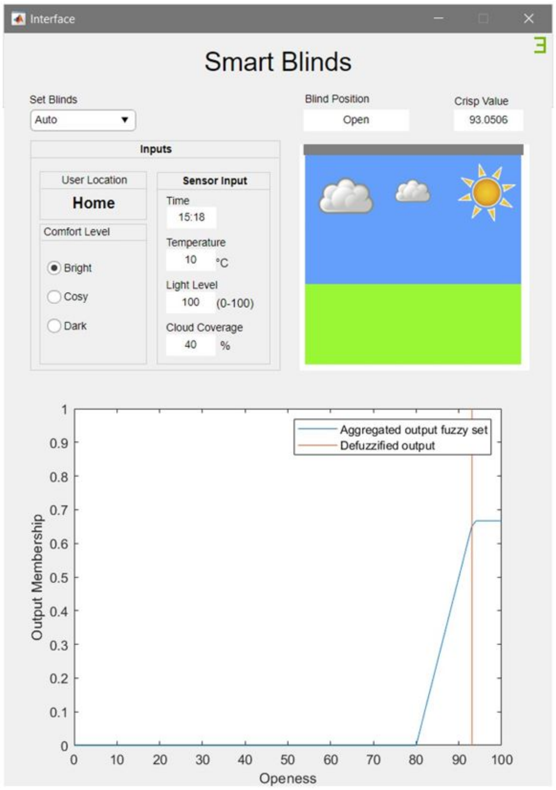

Fig. 8: Blind Position: Open - This seems suitable due to the time of day, the user preference, the light level and the user location.

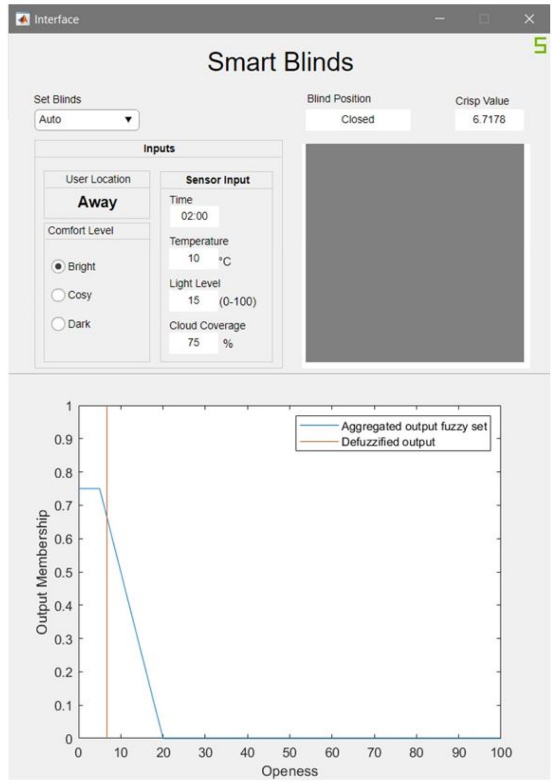

Fig. 9: Blind Position: Closed - As the user is away, it is dark outside and it is the middle of the night, it is correct for the blinds to be closed.

doesn't utilise WaaS or InaaS. Further, the sole SBS has highly restricted functionality without supplemental products.

A lot of the big players are still pretty old school in terms of the tech [13]. An SBS needs appropriate sensors (i.e., low-powered monitoring sensors [14]), WaaS, InaaS, self-learning, decision-making, and smart health monitoring, location-independent monitoring & control. Most importantly, an ideal SBS has the ability to fuse multiple data inputs including BD created by open sources for ideal decision-making. Our approach, as elaborated below, aims to incorporate all these capabilities into a system.

III. DEVELOPMENT OF BLIND INTELLIGENCE

This section explains how the machine intelligence of an SBS can be designed and developed using Fuzzy Logic. The main processes of a fuzzy logic system are outlined in Fig. 4 and the flow chart for the design of the proposed SBS is presented in Fig. 5. The phases of this chart are elaborated in the following subsections. The main user interface for the SBS is shown in Fig. 1.

A. Design

The proposed system is aimed to encompass all aspects of AoE/IoE concept including advanced mechatronics systems (AMS) i.e. sensors, processing and actuation, integration of cloud & edge computing, location-independent monitoring & control for the customer and location-independent monitoring, for the manufacturer to enable lifetime optimisation. To optimise all these components, the use of self-learning, decision-making, smart health monitoring, WaaS and InaaS are required to be implemented. Further, the use of significant data transfer using internet services necessitates the consideration of data privacy and security.

1) System Inputs: The developed system employs multiple inputs to ensure its decisions are well-informed and appropriate in any situation. Here, the inputs are detailed. 1) Light Sensors: A photoresistor is used to detect outdoor light, this will help to determine the current brightness, time of day and sunrise and sunset. Unlike other offerings, this system will not solely rely on lights sensors, as other sources of outdoor light (e.g. street lights) may trigger the sensor during the night, which may disturb the user. 2) Temperature Sensors: On hot, bright days, blinds are often used to reduce the temperature by creating shade. The temperature sensor can be integrated outdoors, to ascertain the current heat level, or indoors to ensure the room isn't too hot. 3) User Comfort Preference: The user can input their preferred environmental conditions with regards to light. The preference options include; bright (high light level), cosy (medium light level) and dark (low light level). These conditions help the system determine how much light to let in during the day. 4) Current Time: The

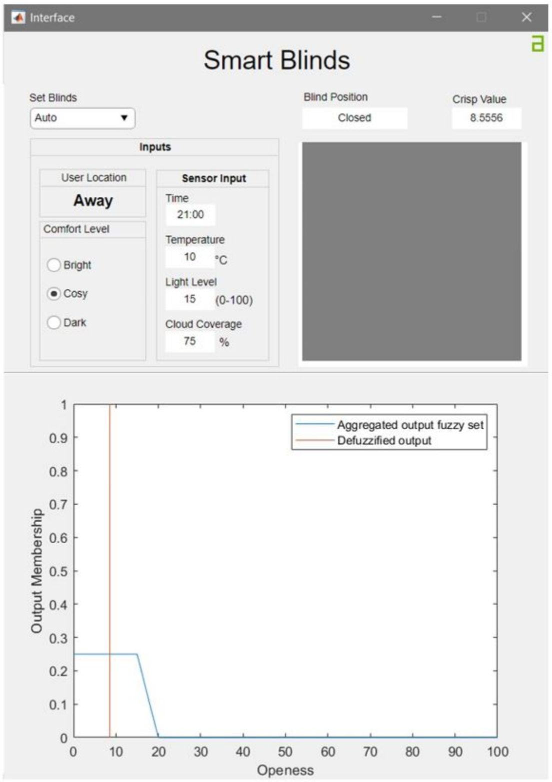

Fig. 10: Blind Position: Closed - As the user is away, the system has closed the blinds due to the low light level and the early night/late evening time period. Closing the blinds when it is dark and the user is away should increase the safety of the home.

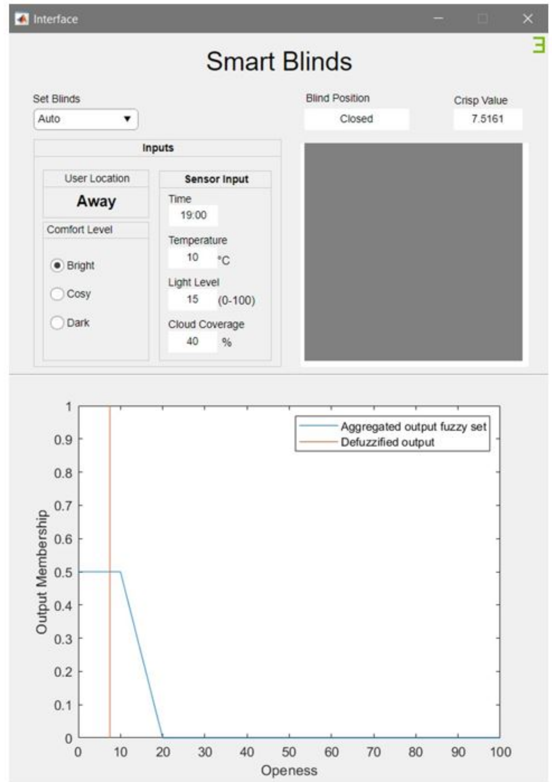

Fig. 11: Blind Position: Closed - Again, due to the time, the light level and the user's absence, the blinds are correctly set to closed.

current time in hours is used to determine what the light level should be. Using this in combination with the light sensor improves performance. For example, car lights may trigger the light sensor, mistaking it for sunlight, however, if the system knows it is 2 AM, it will not open the blinds. 5) Geofencing: Geofencing is used to determine if the user is home or away. This is important, as the decisions need not be as user-orientated if they are away. When away, the system can ensure safety by keeping the blinds closed during dark periods, but also convey the illusion that the house is occupied by adjusting throughout the day, helping to deter criminals. This information can be gathered using the IoT by detecting when the user's smartphone is locally connected to the smart home using Bluetooth or Wi-Fi. Alternatively, the smart home may use cameras or motion detectors to ascertain if the house is occupied. Using the IoT this data can be relayed to the SBS. 6) Cloud Coverage: The current cloud coverage helps to make small adjustments during the day, if it is cloudy, the user may want the blinds fully open, as the light will not be as intense, or vice versa. It serves as a supplement to the light sensor. The data for detecting the cloud coverage is acquired using InaaS and WaaS by retrieving data from Smart City domains. In this case, OpenWeatherMaps API is used for obtaining current weather data from their cloud database.

2) Fuzzy Logic Components: The inputs mentioned previously are used as the fuzzy sets in the fuzzy logic system. Each set contains several elements as shown in Table I, each of which is assigned a membership function, which maps an input value to the appropriate membership value [15]. These functions have been developed based on developer expertise and logical reasoning. Both trimf (triangular) and trapf (trapezoidal) membership functions have been used in this system as displayed in Fig. 6. These elements are given linguistic variables that relate to the given fuzzy set [16]. When a crisp value is input to the system, it is converted to a fuzzy value using its value and the membership functions of its appropriate fuzzy set. This process is known as fuzzification [15], [17].

These fuzzified inputs are processed by a widely used Mamdani inference system. Mamdani is used due to its intuitiveness, suitability with human input and popularity [18], [19]. Inside the inference system, fuzzy set operations are performed on the sets in accordance with the fuzzy rules defined by the developer. Again, these rules are developed using developer expertise and logical reasoning; they use IF-THEN techniques on the elements of each fuzzy set [20]. Three main operations of the inference engine can be mainly performed on the fuzzy set; union (OR), intersection (AND) and complement (NOT) [21].

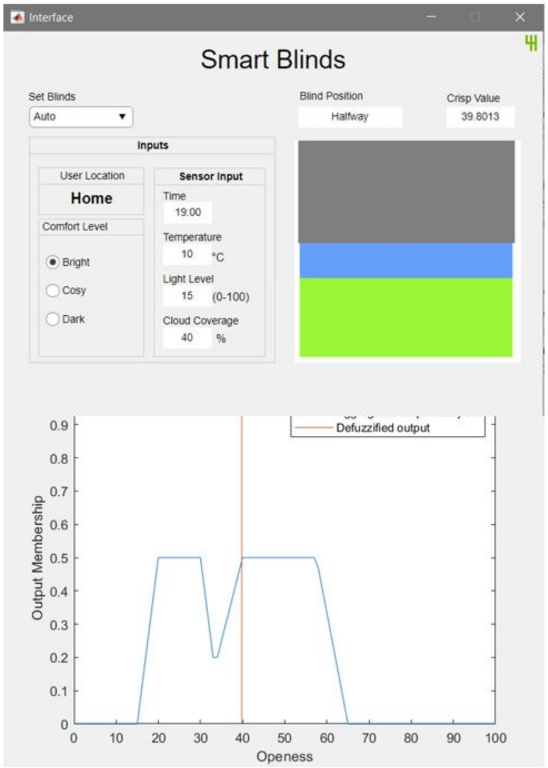

Fig. 12: Blind Position: Halfway - The user is present and has set the comfort setting to “Bright”, however, it is evening and the light level is low. To compromise, the blinds are set to halfway.

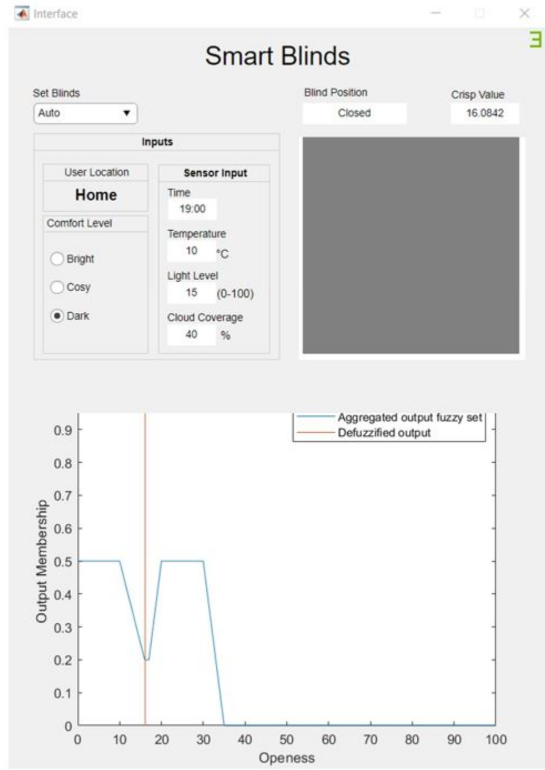

Fig. 13: Blind Position: Closed - This test used the same inputs as Fig. 12, however with the comfort level set to “Dark” instead. This caused the fuzzy logic to set the blinds to closed.

The outputs of these rules are then aggregated through the process of unification of the outputs of all rules, creating an output fuzzy set. The final step is defuzzification to acquire a crisp output value – the total degree of membership function between 0 and 1. For this system, the centroid (or centre of gravity (COG)) technique is used [22]. This method selects a point where a vertical line will slice the aggregated output into two equal masses, giving a crisp value. This value indicates the degree of membership to the elements of the output membership functions, which are; closed, quarter-open, midway, three-quarter-open and open.

3) User Interface: An interface has been developed in MATLAB as shown in Fig. 7 to allow a user to input the required values and see its output. Also, the user can manually adjust the blinds in-app or set it to automatic (Fig. 7) (which enables the fuzzy logic system).

IV. EXPERIMENTAL RESULTS

To test the efficacy of the system, it has been tested with a variety of different inputs to ensure that the outputs produced are suitable for the input conditions. From a technical standpoint, the predefined fuzzy sets are employed to obtain real-valued crisp variables using the fuzzy output of the inference engine and defuzification. The figures (Figs. 8, 9, 10, 11, 12, 13, 14, 15, 16) are a handful of test examples with an explanation of the results – approximate reasoning based on linguistic variables (Fig. 6).

V. DISCUSSION

Fuzzy Logic suits control problems that can not be easily explained by mathematical models. The founder of Fuzzy Logic, Lotfi A. Zader, envisioned a future that machines would think like humans using Fuzzy Logic-like systems by mimicking the logic of human brain with linguistic fuzzy sets. IoT application are being integrated with other domains within other larger systems such as Smart City ([23], [24], [25], [26], [27]). In the similar direction, the developed SBS in this work is integrated with other domains using BD, which reduces the cost of the system by using less number of sensors [28]. The test results show that the system can make appropriate decisions via an intelligent inference engine based on the given situation – degree of membership (truth) regarding fuzzy set (1:strong association; 0:weak association). The user is given simple control of the system and adequate on-screen information. The system will automatically update the time every second and will update the other inputs every 5 minutes.

The proposed system offers many benefits over other SBSs on the market. The use of multiple sensors for monitoring the environment, integration with the IoT and smart home for monitoring the user’s presence, incorporation of WaaS and InaaS to gain data from smart city databases using cloud

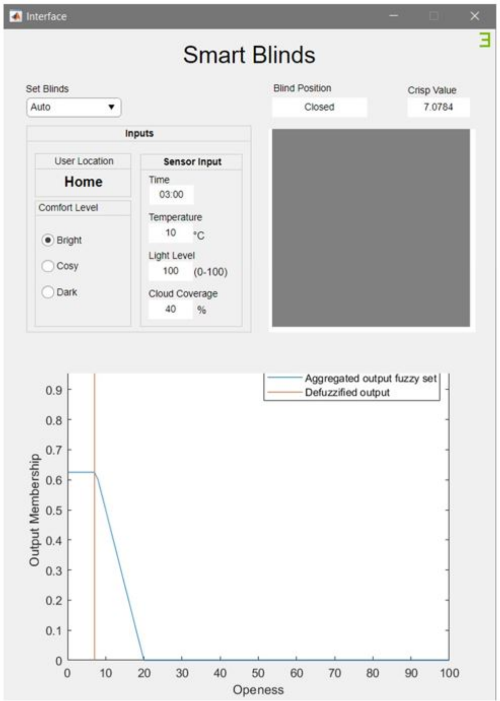

Fig. 14: Blinds Position: Closed - Despite the user settings being "Bright", the high light level and the users presence, the blinds have been set to closed. This is due to it being 2AM, which proves the system will not be triggered in the night by alternate sources of light such as street-lights.

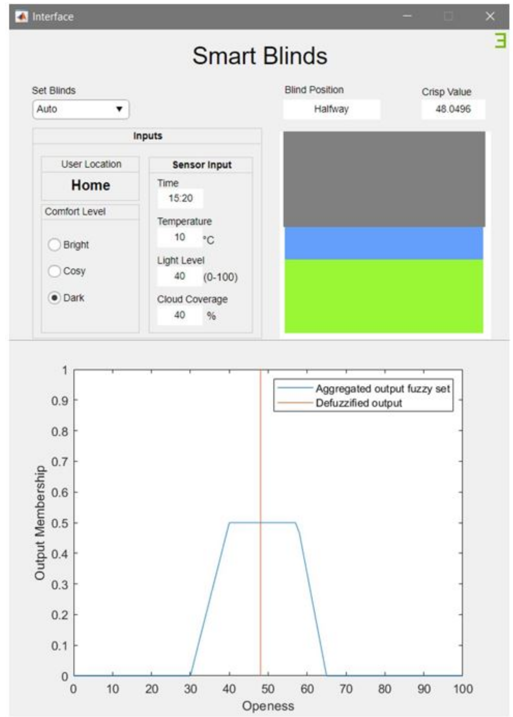

Fig. 15: Blinds Position: Halfway - The blinds are set to halfway due to the afternoon time-of-day, the medium light level and the user-defined "Dark" comfort setting.

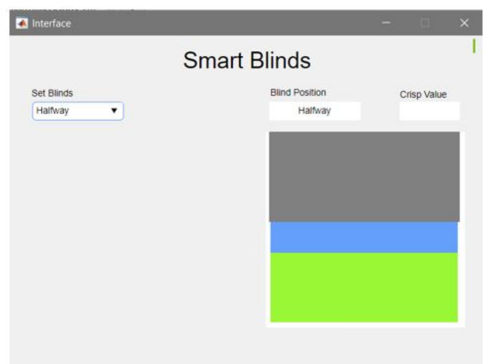

Fig. 16: Alternatively, the user can manually control the blinds with the app. This will remove any unnecessary data from the screen, but will adjust the window graphic accordingly.

computing for up-to-date weather information, consideration of user preferences and the ability to make an intelligent, logical decision based on this information ensures that the user is given the best possible experience with their system. Customisable approaches increase trust in automated systems [29] [30]. In this respect, the developed SBS incorporates user preferences into the final reasoning of the control system, leading to better decision-making. Even the most advanced competing SBSs on the market only use one sensor, and none use WaaS and InaaS. Further, intelligent algorithms do not seem particularly prevalent, instead relying on the smart aspects of other devices in the home, such as smart assistants. Additionally, in most cases, these smart components are often optional extras, increasing the overall cost of these already expensive systems.

Various communication technologies such as 6G, Millimeter Wave (MM Wave), Massive-MIMO, Non-orthogonal Multiple Access (NOMA), Visible Light Communication (VLC), and Terahertz are being developed to meet the ever-increasing needs brought about by the expansion of the IoT, cyber-physical domains and cloud & edge computing. The successful development and implementation of these communication technologies would allow for revolutionary IoT developments.

VI. CONCLUSION

An application for an SBS (Figs. 1, 7) using fuzzy logic to intelligently adjust to an optimal position based on data from local sensors, WaaS and InaasS from smart domains and customer preferences has been built. The application implements autonomous decision-making in determining the ideal blind position with membership functions using a combination of fuzzy sets (Table I, Fig. 6) and fuzzy rules through computing with words – how much the window ought to be closed/opened as an optimal output. More explicitly, an evaluation of the currently available SBS is presented, as is a comparison with the system proposed in this paper. Further, details of the fuzzy logic system and its inputs are provided, with an explanation of the workings of fuzzy logic in general. Testing has been undertaken using fuzzy logic and a user interface developed in MATLAB. Results (Figs. 8, 9, 10, 11, 12, 13, 14, 15, 16) show that the output values of the fuzzy logic (i.e. the openness of the blind) are in keeping with what would be desirable under the given conditions, and meet the intended performance. Examples of these tests are presented and reasoning, i.e., approximate reasoning, is explained. Overall, the system performs extremely well and implementation into a physical system should lead to a product of superior performance than that offered by current vendors. Additionally, the flexibility of this system should make incorporation into a real-world physical blind system a simple task as a fuzzy controller. This research can guide the research community and related industry about how human-like thinking along with instant environmental parameters can be incorporated into a fuzzy control system by developing an SBS through fuzzification (using membership functions to graphically describe a situation where real-valued variables (crisp inputs) are transformed into fuzzy sets, i.e., linguistic variables), inference engine (the process of the fuzzy input to fuzzy output) and defuzzification (obtaining the crisp or actual results) (Fig. 5).

It is imperative to look forward at what future developments should be made to further enhance the efficacy of this system. As with all smart devices and domains, communication between one another is the key to improving performance by transferring more data with; faster speeds, reduced latency, increased stability and maximum efficiency. Here, some promising forthcoming technologies are discussed, with an insight into their potential benefits to the IoT, cyber-physical domains and the automation of everything (AOE). The proposed SBS, as a future work, is aimed to be integrated into a real-world blind system using a single board computing device (SBCD) (e.g., Arduino, Raspberry Pi) and spoken term detection [31].

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