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Fuzzy-Based Robot Behavior with the Application of Emotional Pattern Generator

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Abstract: The article deals with the development of human–robot interaction, where the robot measures the user's emotional state as well as environmental factors by different devices, and it responds to the user with colorful patterns and controls the smart home through the guidance of the Internet of Things system. Before the design process, robots and their functions currently on the market, the role of emotions in communication, and technologies for measuring emotion (such as face recognition, measurement of heart rate, breath, and physical changes) are presented in detail. The designed robot (Em-Patty) uses a previously developed emotion-based automatic pattern generation system based on a fuzzy system, which is a suitable tool for handling emotions. A main and three fuzzy subsystems are fusioned in order to create the most efficient control system for Em-Patty. The nature-inspired design of the robot is also presented, as well as a description of its behavior with the help of a specific case study.

Keywords: human–robot interaction, social robot, fuzzy system, emotion-driven design, pattern design

1. Introduction

Until now, robots only worked behind walls, in factories, or in places where there was not so much interaction with them, but nowadays, they are becoming an integral part of our lives, and that is why the efficiency of human–robot interaction is becoming more and more important [1–3]. Among others, robots are used in the army, hospital, and transportation, and these support devices can appear in people's homes as well. What is also interesting about human–robot interaction is that the anthropomorphism – that is, people project their own inherent qualities onto other entities to make them seem more human-like [4] – is a powerful phenomenon concerning robots. There are three main reasons for this: the embodiment of robots, their ability to physical movement, and their appearance endowed with human characteristics and their social behavior [4, 5]. These reasons subconsciously force us to treat robots as alive (even if we know they are just machines) and give them social responses. Taking advantage of this will make it easier for people to engage. For instance, helping the elderly [6–8], supporting rehabilitation, educational [9, 10], and developmental processes [11, 12] are nowadays possible by robots. It turned out that children with autism develop more easily with robots than with adults [13], or robots are used in a nursing home, where they provide a nurturing sense for the elderly, which results in calmness, reducing stress, and helping in dementia therapy [14]. Figure 1 presents a few areas where the robots are contributing nowadays. Because of these facts, the development of human–robot communication is a relevant area of research.

As a concept for this research, we are about to improve the communication process. In addition to the phonetic and facial expressions, this concept incorporates the robot's cover elements into the communication by extending the display. Moreover, the goal is that the robot could understand the nonverbal signs, which makes communication more efficient, and it meets the current developing direction of emotional design. That is why, with this robot, the data gaining process would be more complex; this means that besides the content of the spoken sentences, it will gain information about the user's emotional intent by observing the facial expressions, the heart rate, the physical changes, etc.

Before describing the methods and tools for assessing emotions, it is necessary to understand what emotions we can distinguish at all, how they appear, what kind of robots exist already, and how they work.

1.1. The role of emotion

We can find different theories about the origin of emotion. For example, the 19th-century James–Lange theory states [15, 16] that after perceiving an object or event, we respond to the event behaviorally and/or vegetatively through nervous system mediation, and then the emotional experience develops during the perception of that response. Thus, the order of events is as follows: STIMULUS → INTERPRETATION → BODY RESPONSE → AFFECT [17]. (This means that people feel fear because they tremble.) One critic of the

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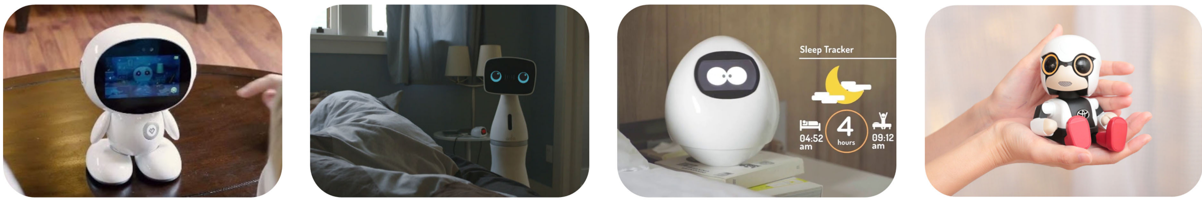
Figure 1
Contributing areas of robots

Robot tends to a COVID-19 patient | Therapeutic robot with a dementia patient | Robot helps treat autism

Figure 2
A few home robots



Honeybot | Aido | Tapia | Kirobo Mini

James–Lange theory, Walter B. Cannon, not only criticized the theory but also presented another approach that states that the activating of the thalamus causes emotion and assumed that emotional experience appears at the same time as bodily changes [18].

There are so-called basic feelings [19] (sadness, excitement, nervousness, joy, anger, and disgust) and more complex, higher-order emotions (e.g., social, moral, and aesthetic). Emotion affects the audiovisual (facial expression, voice, gesture, and posture) and the physiological (respiration, skin temperature, etc.,) states as well [20]. The basic emotions in the field of machine processing are joy, sadness, anger, fear, surprise, and disgust, which are used, for example, for facial description of virtual characters [21].

1.2. Competitors

With this research, the goal is to design a robot that can help a family's daily life, such as nursing the elderly, cleaning around the house, and babysitting. Figure 2 shows some robots used around the house. Humanoid robots are still very expensive; that is why robots with screen-based communication could be the appropriate device for an average family.

Honeybot[1] is an educational family robot, which was designed for kids. With its help, parents can guide their kids easily. The robot contains Augmented Reality (AR) technology in order to create interactive activities, for example, with picture recognition and integration, the robot could apply the children's drawing into a 3D environment. With animation, the robot can educate them; moreover, it has plenty of memorizing and learning tasks, virtual pet, and communication platform as well.

Aido[2] has three main functions, entertainment hub, personal assistant, and home automation. It can replace multiple applications and tools. The robot wakes up in a programmed way and monitors various social media. It contains cooking, mechanic, music, health, etc., applications that support family life. Toys and educational materials are also integrated; in addition to this, the lighting, heating, and security system of the house can be controlled by it as well.

Tapia[3] is helping observe the schedule; it has weather reports, sleep tracker, and Internet of Things (IoT) home control, which connect, for example, the coffee machine. It can support online shopping, it can play a required music, etc.

Kirobo Mini[4] is a miniature communication partner developed for social networking. He is able to use gestures and react to emotions, as well as remember user preferences and past events. It has a compact size (only 10 cm when seated), so it can be taken anywhere. In addition, it has information about the used vehicle and the home environment.

It can be seen that the above-presented robots help the daily life of the family similarly, and also, they are similar in appearance: they have a rounded design without sharp corners. The robot introduced in this article also follows these approaches. Moreover, with its complex fuzzy-based two-sided (environment and user) information (gathering and providing) system, the design and the behavior concept of the robot are considered novel in the market.

2. Measuring Emotions by Machines

The idea is that the robot introduced in this article would also be able to make various machine assessments of emotions besides understanding the content of the user's instructions. So it would see the body temperature, detect the user's facial expressions, and so on, from which much information can be filtered. This can be especially good during rehabilitation or various skill development when a patient, elderly, or minor cannot express themselves in

[1] https://www.indiegogo.com/projects/honeybot-educational-family-robot-for-kids-entertainment-technology/
[2] https://www.startengine.com/aido
[3] https://mjirobotics.co.jp/en/
[4] https://global.toyota/en/detail/19880995

words. This could also make the disabled everyday lives more comfortable, but even a child or elderly care would be more effective. The measuring techniques used by the robot are presented in the subsections.

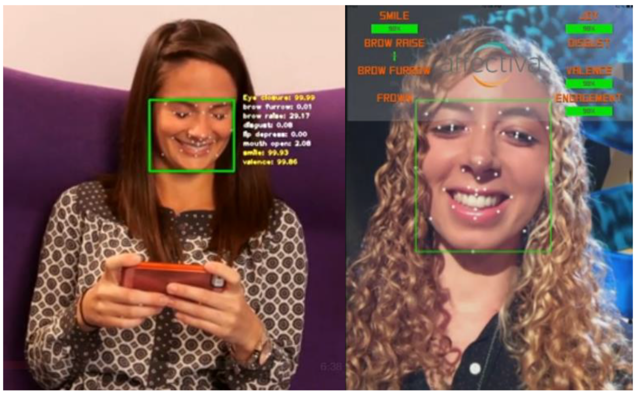
2.1. Face recognition

Measuring emotions is not an easy task. How the subject expresses a particular emotion during speech also depends on the cultural context in which it came from [22]. However, the terms mediated by the facial muscles are inherited. Charles Darwin has already stated that human facial expressions are innate, unlearned response patterns and thus not culturally defined [23]. Several studies have supported this theory. For example, researchers have investigated the emotional facial expressions of very distant groups of people (e.g., European people and isolated New Guinean tribes), and these are highly similar [24]. The same similarity can be seen between blind and healthy people [25].

In the science of emotions, facial muscle movements are called units. Movement unit 12 is, for example, pulling up the corner of the mouth, which is the main component of a smile, unit 4 is the frown, and so on. We have about 45 such units of movement, and their combination expresses more than 100 different emotions. In order for a computer to be able to distinguish these terms accurately, algorithms must provide tens of thousands of human examples of different ethnicities, ages, and genders to express the same emotion. With these, the algorithm "learns" that, for example, all smiles and grimaces have a common feature, so when it sees a new face, it can identify the facial expression based on the perceived features [26]. Machine learning techniques for emotion recognition have many applications [27].

Algorithms for assessing facial expression find the subject's face, placed in a delimiting frame, and then follow the characteristic points on the face (eyebrows, eyes, mouth, and nose) [26]. Figure 3 shows a few examples [26].

Figure 3
Face recognition based on characteristic points on the subject's face



2.2. Heart rate and breath measurement

Researchers at MIT's Computer Science and Artificial Intelligence Laboratory (CSAIL) say facial recognition software does not give reliable results [28]. (For example, a smile can mean frustration as well.) They have developed a device called EQ-Radio that uses wireless signals to detect a subject's emotions. Based on their surveys, the device can determine a person's emotion with 87% accuracy without any customized sensor.

"EQ-Radio has three components: a radio for capturing RF reflections, a heartbeat extraction algorithm, and a classification subsystem that maps the learned physiological signals to emotional states" [29] (Figure 4).

In terms of its operation, the device sends a wireless signal to the subject, from which the signal returns, which is then analyzed. It basically measures changes in breathing and heart rate. Although the device can only detect four emotions (pleasure, sadness, anger, and joy), it can be used in several areas, for example, it can provide data to filmmakers while watching a movie or give information to a smart environment [28].

2.3. Measurement of physical changes

Finnish researchers have shown [30, 31] that emotions affect our bodies in the same way. In their research, 701 participants indicated the bodily regions whose activity decreased or increased as a result of specific words, films, stories, and facial expressions. (For example, excitement often causes our palms to get cold and sweat.) A so-called body map can be used to show areas whose activation increases (red and yellow) or decreases (blue and black) due to a certain emotion as illustrated in Figure 5 [32].

It can be seen that almost every emotion changes the head's area since we smile or frown, or our temperature changes. In the case of happiness and anger, there is also an increase in the limbs, because in this case, for example, we want to hug or hit the other person. Under the influence of disgust, we feel the digestive system and the area around the throat, and so on.

Subjects from different countries made similar body maps, so we can conclude that feelings are not limited to certain language areas.

The significance of the research is that while most sensations cause only a small change in heart rate or skin temperature, the effect of mental states on the body produces strong subjective sensations. For example, when we feel envy, we will not have a red head, but we feel that.

However, since it has been shown that body temperature is affected by emotions, by measuring it, it is possible to infer the emotional state of the user.

3. Design Description and Behavior of the Robot

3.1. Design

The design of the new robot concept called Em-Patty (which refers to the background system called *EmPatGen* and to the word *Empathy*) was inspired by the form of a seahorse, as can be seen in Figure 6 [33, 34]. Seahorse has gentle curves, and it evokes joy and stability.

The main parts and diameter of the robot are presented in Figure 7. This concept is available only in the Computer-Aided Design (CAD) systems, a built-up version is not created in this research stage.

The following functions will be fulfilled by the robot:

- It can connect to WIFI, Bluetooth, and USB.
- It has microphones, cameras, sensors, projectors, and the main screen.
- It is compatible with all Android apps.
- It can detect the emotions of the users by an integrated system.
- It has communication support with side screens by patterns and colors.
- It travels with the help of a wheel.

Figure 4
EQ-Radio architecture

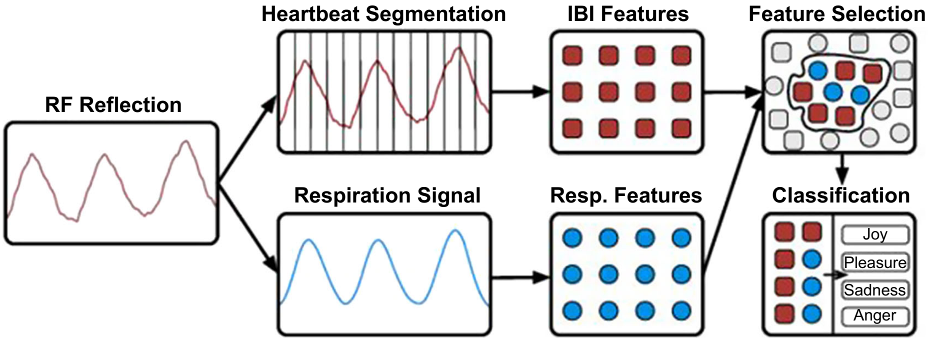


Figure 5
Bodily maps of emotions

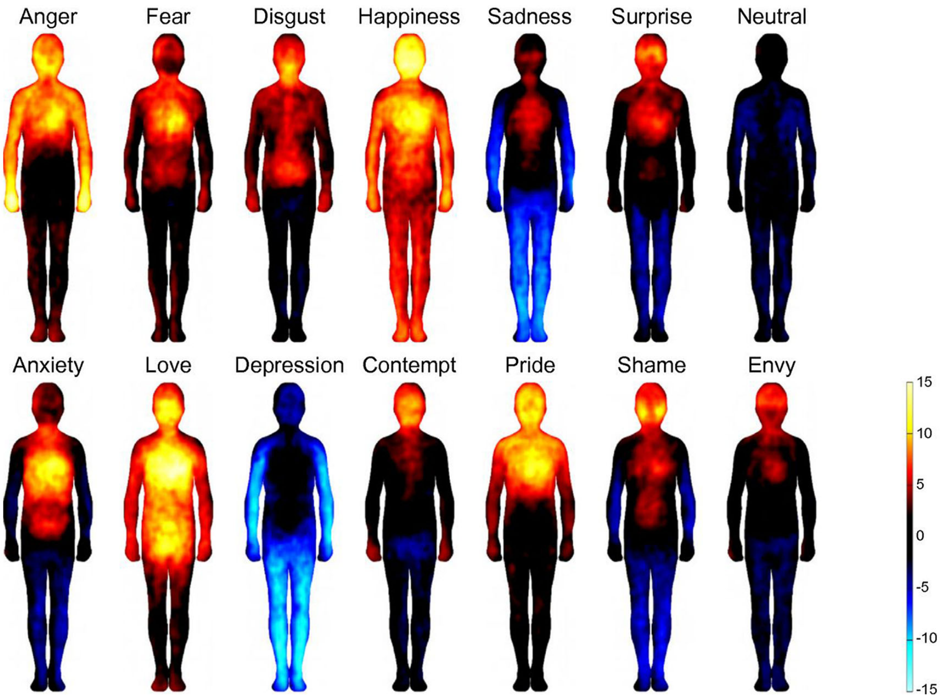
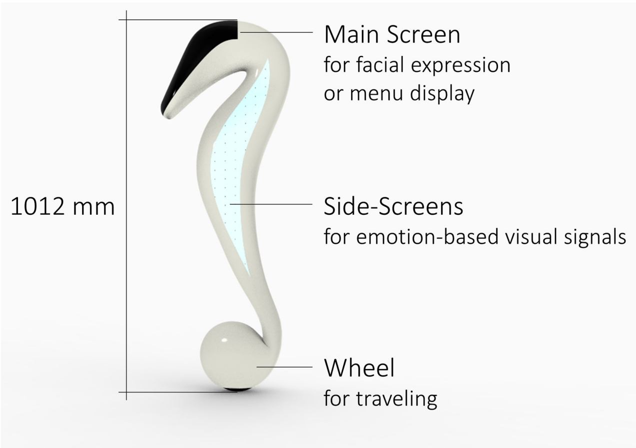


Figure 6
Inspiration for Em-Patty

Figure 7
Concept design of Em-Patty: The side screens of the robot provide emotion-based visual signals, while the menu or facial expressions can be seen on the main screen



Em-Patty helps the family's every day by the functions listed above (Figure 8).

Figure 8
Home environment with Em-Patty (created by PTC Creo Rendering)

3.2. Behavior of the robot

The concept is that the robot first analyzes the data using information gathering, from two directions: from the *user* and the *environment* side, since other research also distinguished environmental information [35]. On the user side, using the technologies presented above, face recognition, heart rate and breath measurement, body temperature measurement, and interpretation of spoken words can be listed. On the environment side, it collects information from the Internet, weather stations, IoT platforms, and home sensors. After analyzing this information, it produces information that goes in the same direction as information gathering. It gives the user an emotion-based visual signal, which is a colorful pattern on the robot's side panels, and depending on the situation, a facial expression or menu appears on the front display. The answer to the environment can be informing someone or directing members of the IoT system. Figure 9 presents the behavior of the robot.

For ease of understanding, five situations are presented where the robot operates in different ways. The home shown has an IoT system. Four people live together: Emma is a 35-year-old mother, Joe is a 38-year-old father, Noel is a 6-year-old child, and Julia is a 64-year-old grandmother.

- Noel is sleeping in his room. Once the sky starts to thunder, it looks like a big storm is coming. The child is scared. The robot conveys a calm sensation and checks that all windows are closed in the house so that rain does not fall in.
- Noel plays a developing game with the robot. When he fails to complete a task, the robot conveys a cheerful feeling.
- It is a hot summer day, and Julia is dehydrated. The robot detects this and advises her to drink fluids. Meanwhile, it indicates danger on its side.
- Emma cooks in the kitchen when the robot gives her a signal about Julia. There is a problem, and Emma should find her in her bedroom. Meanwhile, the robot indicates danger on its side.
- It is 10 o'clock in the morning, sunny weather, but the house is dark, and the shutters are lowered. Joe's calendar has a meeting written for 10:30, so the robot wakes him up.

3.3. The usage of fuzzy system

The workflow presented in Figure 9 is operated by fuzzy systems. Fuzzy logic can solve complex modeling and control problems based on linguistic rules. That attracts the interest in a wide variety of fields, from renewable energy [36] to, for example, in this case, product design.

Figure 10 shows the generic structure of a fuzzy system. Basically, it has input data, a fuzzy rule base, an inference mechanism, and output data. The fuzzification and the defuzzification actions mean the transformation of crisp to fuzzy and fuzzy to crisp data [37, 38].

The fuzzy rule base contains fuzzy rules. The general form of a fuzzy rule with one input and one output dimension is as follows:

$$R: \textbf{If } x \textit{ is } A \textbf{ then } y \textit{ is } B,$$

where $x \in X$ is the input and $y \in Y$ is the output variable, X is the universe of discourse for the input and Y is the universe of discourse for the output variable, and A and B are linguistic labels that are expressed by fuzzy sets. Fuzzy set A is the antecedent, while fuzzy set B is the consequent of rule R. The general form of a fuzzy rule with multiple inputs and one output dimension can be written in the following, so-called Mamdani form [39]:

$$R: \textbf{If } x_1 \text{ is } A_1 \textbf{ and } \dots \textbf{ and } x_n \text{ is } A_n \textbf{ then } y \text{ is } B,$$

where $x = (x_1, \dots, x_n)$ is the input vector, $x_j \in X_j$, $X = X_1 \times \dots \times X_n$ is the n-dimensional universe, $A = (A_1, \dots, A_n)$ is the antecedent vector, $y \in Y$ is the output variable, Y is the universe for the output, and B is the consequent set.

Figure 9
Behavior of the robot: The robot gains and produces information from and for the user and the environment side as well

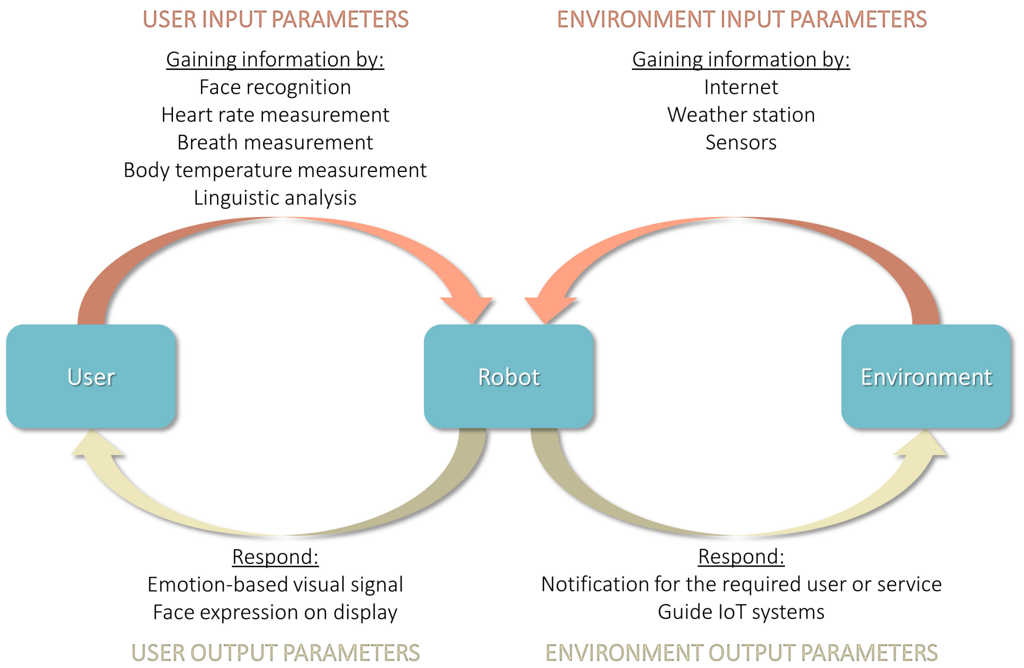
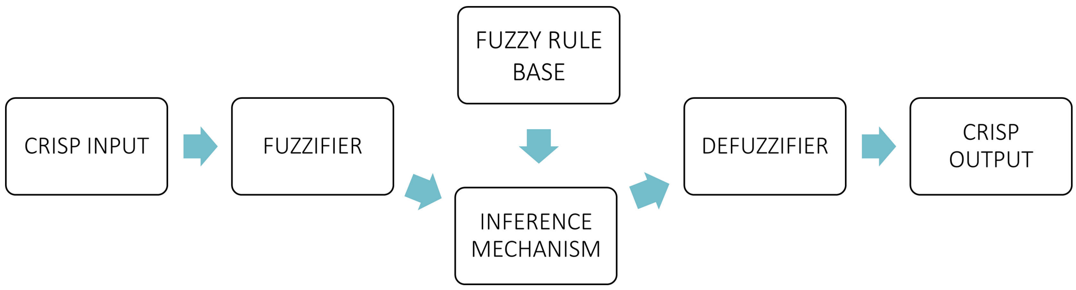


Figure 10
Generic structure of a fuzzy system



The fuzzy system works as follows. The inference mechanism compares the given observation with the antecedent parts of the fuzzy rules in the fuzzy rule base. Based on these comparisons, it will be known what the degree of matching of each rule will be for the observation. These degrees are used by the inference mechanism when taking into account the consequent parts of the fuzzy rules. In the case of Mamdani inference [39], each rule's consequent fuzzy set is cut by using the rule's degree of matching providing a sub-conclusion for the rule. The conclusion of the given observation for the whole rule base can be computed by taking the union of the previously calculated sub-conclusions. This conclusion is a fuzzy set; however, in most cases, the expected conclusion is not a fuzzy set but a crisp value. Hence, the crisp value needs to be determined, which describes the conclusion fuzzy set in the best way. This procedure is called defuzzification.

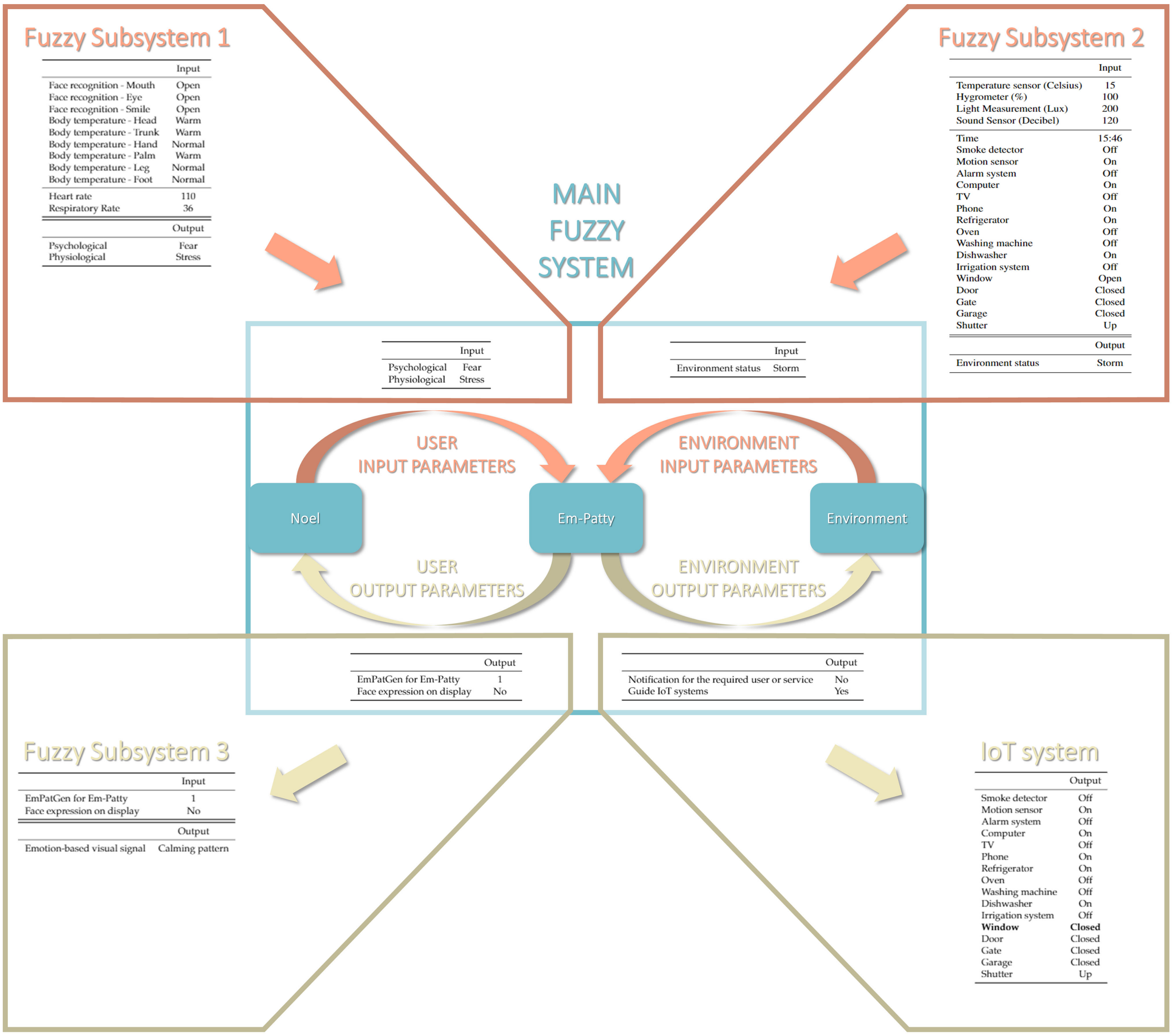
4. Case Study

The information gaining process is the collection of the input parameters (user's physical and mental states, moreover direct sensory and indirect internet data), while the responses are built up with output parameters (visual signal for the user and commands for the IoT system), which is shown in Figure 9. The mathematical system that operates this concept is based on fuzzy logic, called Main Fuzzy System. However, in order to analyze the gained numbers, fuzzy subsystems are used. In the case study, the following situation is described in detail:

> *Noel is sleeping in his room. Once the sky starts to thunder, it looks like a big storm is coming. The child is scared. The robot conveys a calm sensation and checks that all windows are closed in the house so that rain does not fall in.*

The system description for this situation can be seen in Figure 11.

Figure 11
Fuzzy system description of the situation introduced in the case study



4.1. User input parameters and Fuzzy Subsystem 1

The Fuzzy Subsystem 1 contains 11 input parameters and 2 output parameters, which are shown in Table 1.

This subsystem distinguishes five states of emotions for the psychological output: neutral, joy, anger, sadness, and fear. The facial expressions for these emotions can be seen in Figure 12 [40].

Mainly the mouth, the eye, and the smile of the person could be defined according to the different emotional states. The mouth can be closed, medium, and open; the eye can be slightly open, medium, and open; and the smile can be down, medium, and up posture. The rules develop based on these postures, for example, if the person's mouth is closed, the eyes are medium open, and the smile direction is down, it refers to sadness.

Similar to facial recognition, in this case study, body temperature perception was also determined by describing only limited states (five pieces), which are neutral, happiness, anger, sadness, and fear, as depicted in Figure 13.

Table 1
Fuzzy Subsystem 1 represents the user input parameters of the Main Fuzzy System

	Input
Face recognition – mouth	Open
Face recognition – eye	Open
Face recognition – smile	Open
Body temperature – head	Warm
Body temperature – trunk	Warm
Body temperature – hand	Normal
Body temperature – palm	Warm
Body temperature – leg	Normal
Body temperature – foot	Normal
Heart rate	110
Respiratory rate	36
	Output
Psychological	Fear
Physiological	Stress

Figure 12
Facial expressions of neutral, joy, anger, sadness, and fear faces

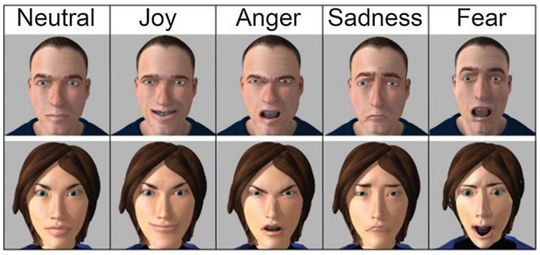
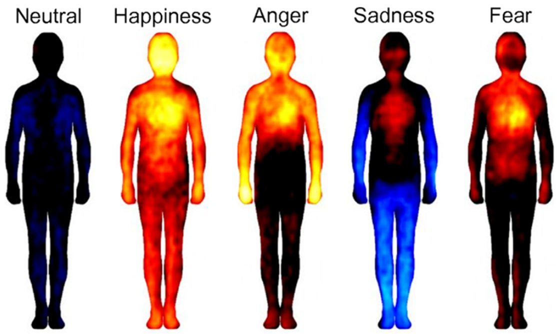


Figure 13
Body temperatures of neutral, happiness, anger, sadness, and fear sensations



The rules are the combinations of the sensation of the body parts. For example, if the user has a warm head, trunk, and palm, it indicates fear. A body part can be cold, normal, or warm in this system.

The psychological output develops by the information from face recognition and body temperature. The rules are collected in Table 2.

In this model, the physiological output is varying according to the heart rate and the respiratory rate. This outcome can be normal and stress; however, this could be expanded.

Regarding the heart rate, according to the American Heart Association (AHA) [41], the average resting heart rate is between 60 and 100 beats per minute; that is why if the rate is lower than 60, the system indicates slow, and if it is more than 100, it results in quick heart rate.

The respiratory rate is the number of breaths per minute. This is between 12 and 16 in the case of a healthy adult. From the children point of view, it varies according to their ages [42]:

- Birth to 1 year: 30–60
- 1–3 years: 24–40
- 3–6 years: 22–34
- 6–12 years: 18–30
- 12–18 years: 12–16

Below or above, this is called low or high respiratory rate.

Table 3 introduces the rules for the physiological output.

Table 3
Rules for physiological output

	Normal	Stress
Heart rate	Normal	Quick
Respiratory rate	Normal	High

Based on the Fuzzy Subsystem 1, the user input parameters for the Main Fuzzy System are presented in Table 4.

Table 4
User input parameters

	Input
Psychological	Fear
Physiological	Stress

4.2. Environment input parameters and Fuzzy Subsystem 2

From the environment point of view, in this model, in total 21 environment input parameters could be detected by sensors as presented in Table 5. There is one output, which is the status of the environment.

Table 2
Rules for psychological output

	Neutral	Joy	Anger	Sadness	Fear
Face recognition – mouth	Closed	Closed or medium	Open	Closed	Open
Face recognition – eye	Medium	Medium	Slightly open	Medium	Open
Face recognition – smile	Medium	Up	Medium	Down	Medium
Body temperature – head	Normal	Warm	Warm	Warm	Warm
Body temperature – trunk	Normal	Warm	Warm	Warm	Warm
Body temperature – hand	Normal	Warm	Warm	Cold	Normal
Body temperature – palm	Normal	Warm	Warm	Cold	Warm
Body temperature – leg	Normal	Warm	Normal	Cold	Normal
Body temperature – foot	Normal	Warm	Warm	Cold	Normal

Table 5
Fuzzy Subsystem 2

	Input
Temperature sensor (Celsius)	15
Hygrometer (%)	100
Light measurement (Lux)	200
Sound sensor (Decibel)	120
Time	15:46
Smoke detector	Off
Motion sensor	On
Alarm system	Off
Computer	On
TV	Off
Phone	On
Refrigerator	On
Oven	Off
Washing machine	Off
Dishwasher	On
Irrigation system	Off
Window	Open
Door	Closed
Gate	Closed
Garage	Closed
Shutter	Up
	Output
Environment status	Storm

The first four values can be measured outside the house and the rest inside the house. The fuzzy system presented below takes the first four values as input; thus, the input parameters include temperature, humidity, light, and sound. As an output, three states can be seen: clear weather, covered, or storm. Values can fall into three different categories. Temperature and humidity can be low, medium, and high; light can be dark, medium, and light; and sound can be low, medium, and high (Figure 14).

The first rule describes clean weather: high temperature, low humidity, bright light, and low sound. Rule two applies when the weather is somewhat cloudy (covered), so the light decreases. If the environment continues to get darker, a fully covered state is obtained according to the third rule. It indicates rain based on rule four when there is medium temperature, high humidity, reduced light, and medium sound. There is low temperature, high humidity, darkness, and high sound during a storm.

Figure 15 describes a combined event where rules three and four apply. This gives a value of 7.3, which means a mild rainy day.

In this specific example of the case study, the robot concludes that a storm is coming because of the low temperature, high humidity, and dark and loud environment (thundering). Besides that, the internet and the weather reports also confirms that; that is why the robot switches the smart home to *storm mode*. The output for the environment status is storm. The above case can be interpreted as one rule in our system. Similar to this example, the rules can be combinations of input parameters, and the system could respond according to these settings.

Figure 14
Membership functions of Fuzzy Subsystem 2. Fuzzy Subsystem 2 gives the environment input parameters for the Main Fuzzy System

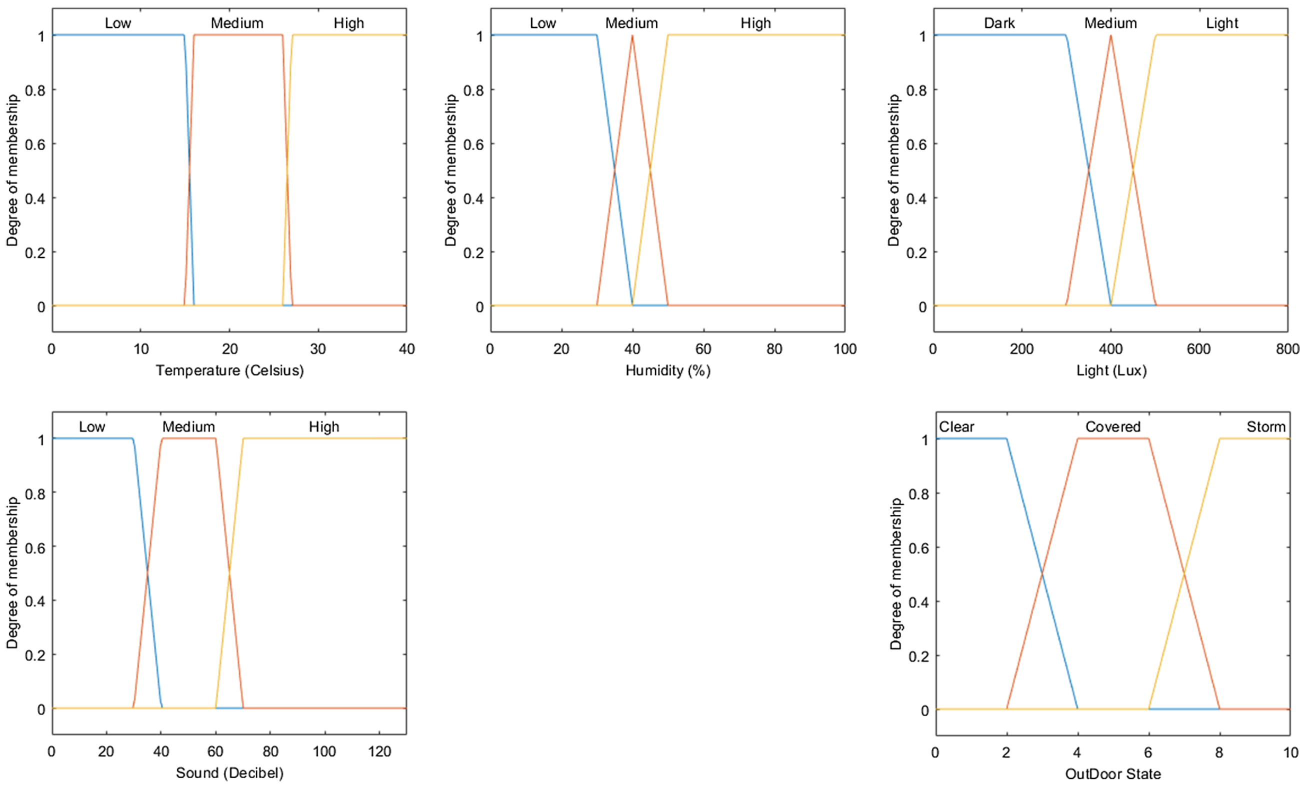
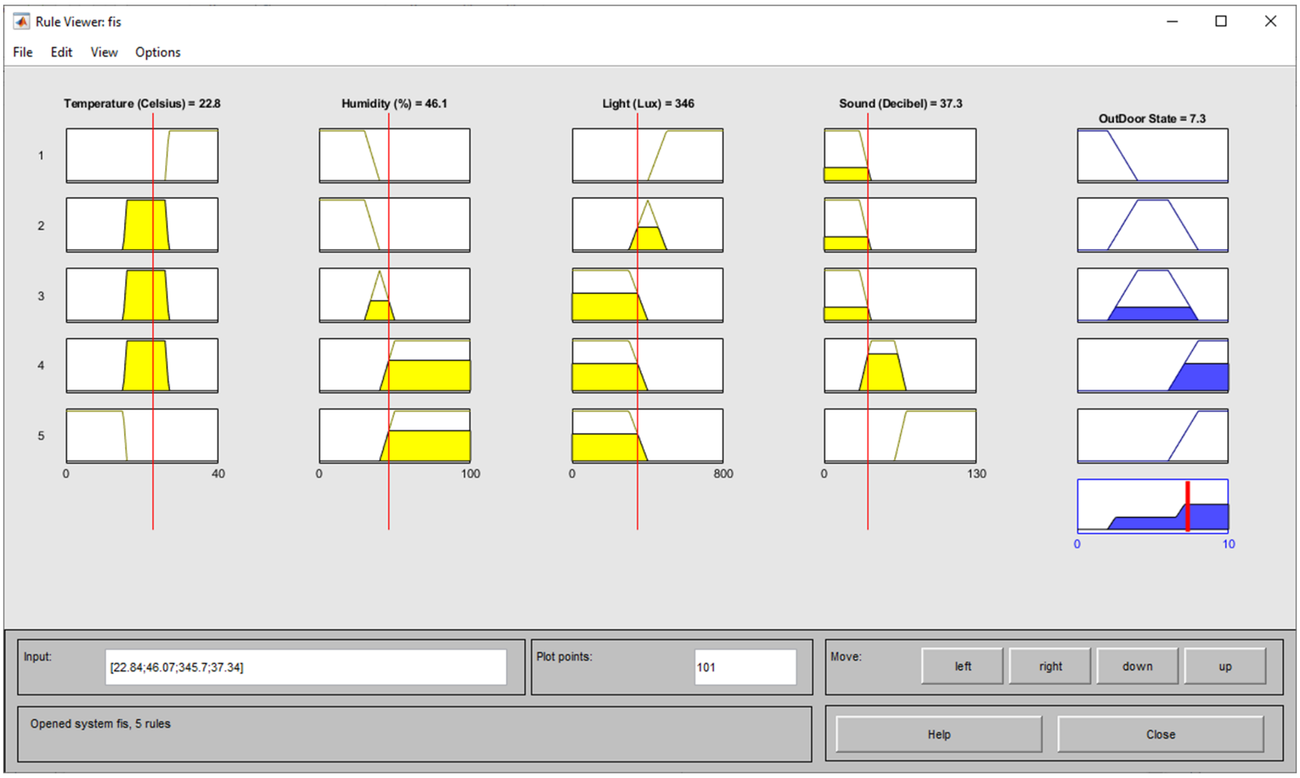


Figure 15
Fuzzy Subsystem 2 – Light rain



The environment input parameter is presented in Table 6.

Table 6
Environment input parameter

	Input
Environment status	Storm

4.3. User output parameters and Fuzzy Subsystem 3

According to the user input parameters, the output for the robot cover element (EmPatGen for Em-Patty) will be 1 (Table 7). In this situation, there is no face expression on the main screen. The information presented in Table 7 is what the Fuzzy Subsystem 3 will get. Fuzzy Subsystem 3 uses the EmPatGen system.

EmPatGen means Emotional Pattern Generator that creates connections between emotions and geometries, which was developed in previous studies [43]. It is an automated pattern development method where the consumers can give emotions and feelings as input parameters, and it generates 2D pattern outputs as images. In addition to this, the pattern can be saved with a file extension that supports industrial processing (or required for the manufacturing process), for example, in Drawing Interchange Format or Drawing Exchange Format. Figure 16 shows the concept of EmPatGen: basically, if the consumer changes the rate of the slider appearing on the program interface, the software automatically generates a 2D pattern. The inputs are emotions and moods, and the output is a pattern based on the settings of the consumer. These are also indicated in Figure 16 [44].

Table 7
User output parameters

	Output
EmPatGen for Em-Patty	1
Face expression on display	No

This tool was created on the basis of a literature study about geometries and lines (which was used as a spreading direction and movement of the pattern). With this help, it is possible to reach a better aesthetically pleasing pattern based on a consumer's preferences. This tool could help the product designer's jobs in many fields where patterns are used as decoration elements; however, this study focused on car interior trim panels, where the software-provided pattern would be placed on these elements with the purpose of unique car interior design.

We could apply this system during human–robot interaction by displaying colorful patterns on the robot's communication panels that affect the user. These patterns would vary depending on the input signals. So the order would be as follows: detecting emotions (e.g., sadness) → emitting a colorful pattern (e.g., cheerful effect).

Table 8 summarizes the short definition of the parameters used during the development of EmPatGen. These parameters and their applications were explained more in the other article connected to this research [44]. Previous studies [45] have shown that not only does the Basic Geometry (circle, triangle, etc.,) of the pattern have an impact on people but also the way the pattern spreads, called Pattern Space. That is why the attributions are connected to these two main categories.

Figure 16
Concept of EmPatGen

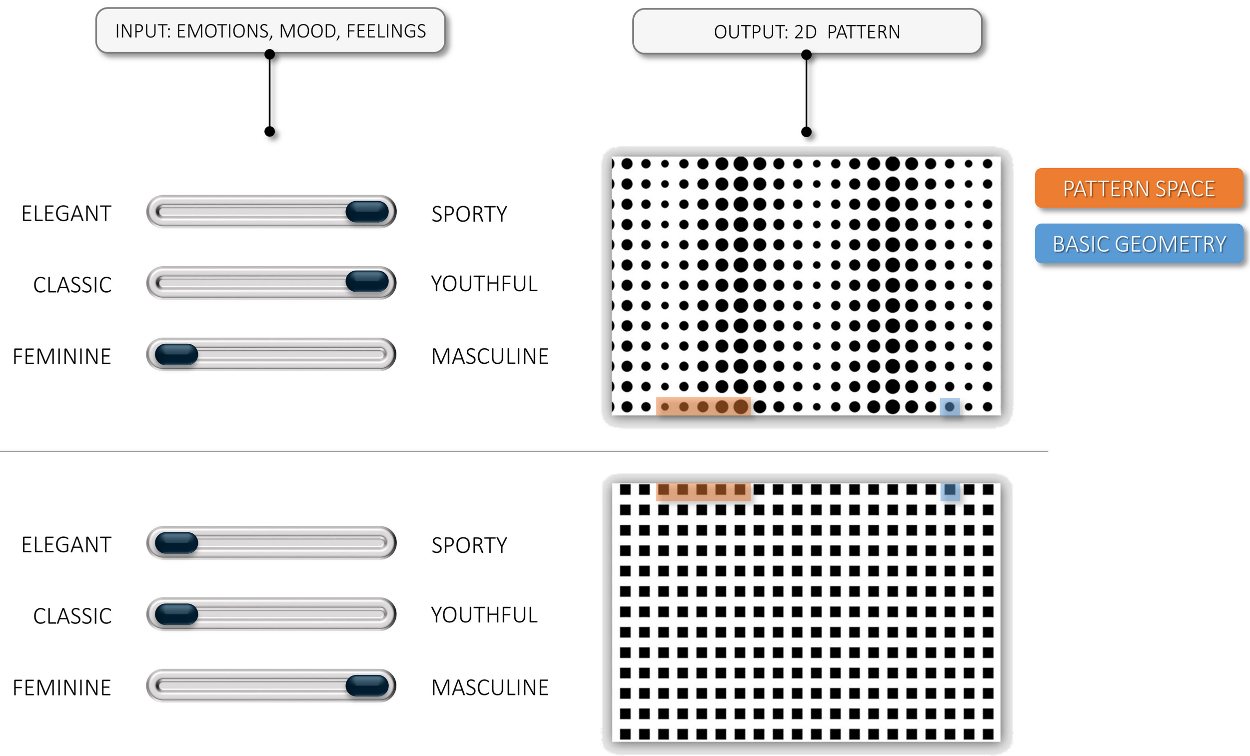


Table 8
Attributions of EmPatGen and their definitions

Related to	Name	Definition
Basic Geom.	r	Uniform scale: scale all sides of the geometry equally
	e	Non-uniform scale: scale sides of the geometry
	n	Side: number of sides of the geometry
	rot	Rotation: rotate the geometry
Pattern space	VStS	Row distance: distance of the rows of the pattern
	A	Amplitude: the height of periodic waves in a row
	dRng	Dynamic range: the number of varying pattern members
	dSft	Dyn. shift: the distance between of same pattern members in neighboring rows
	dScU	Dyn. uniform scale: the number of varying uniform-scaled pattern members
	dSnU	Dyn. Non-uniform scale: the number of varying non-unif.-scaled pattern members
	dRot	Dyn. rotation: the number of rotated pattern members

In the human–robot interaction, in this first concept *Calm*, *Cheerful*, and *Dangerous* senses will develop, which are in connection with *Calmness*; *Dynamic, Exciting*; and *Aggressive, Active* emotions, moods, and feelings.

In Figure 17, the connections of the attributes and emotions can be −1, 0, or 1. These numbers show the direction of the correlation. In the case of 0 correlation, there is no significant connections between the parameter and the emotion.

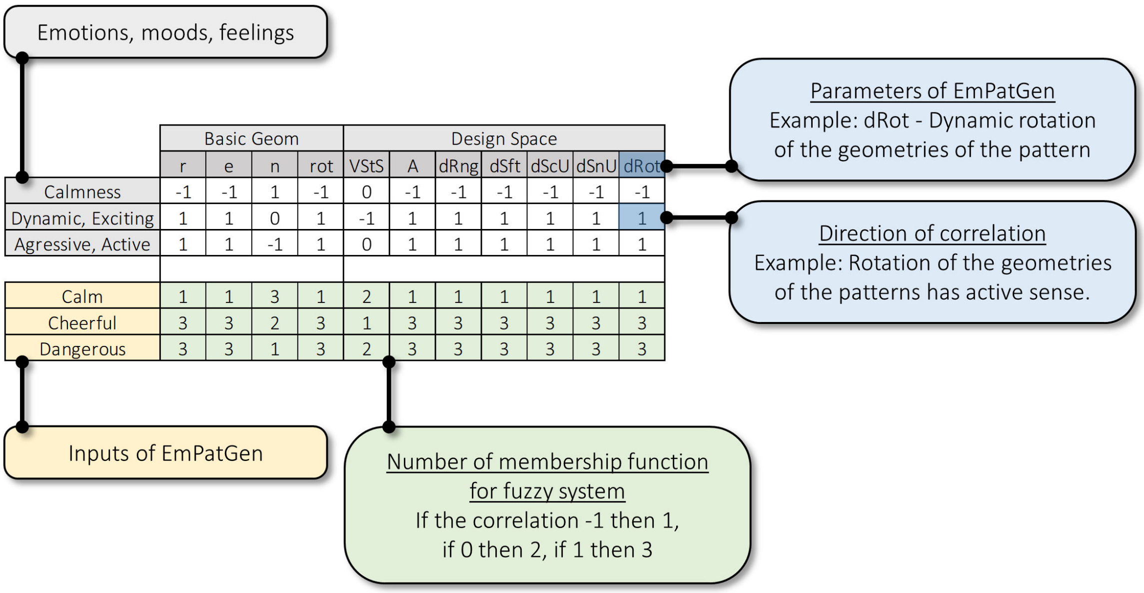
The definition of the attributions (Table 8) shows a few similarities in the Basic Geometry and the Pattern Space-related parameters. There are pairs that similarly modify the pattern; however, one of them changes the Basic Geometry, and the other one defines the Pattern Space. Because of that, the correlation will be the same in these columns. The pairs are the following:

- r – dScU
- e – dSnU
- rot – dRot

In order to better understand these correlations, a short literature review is introduced at the top of Figure 17. According to studies [46, 47], *Aggressive*, *Active* emotions are in connection with the triangle. In the "*n*" column, in this case, the correlation is −1, since, regarding the number of sides of the geometry, the goal is to reach a lower number of sides. For *Calmness* sense, the usage of round shapes is necessary.

A figure by Simonds and Starke [48] has shown that while *Calmness* sense is in connection with horizontal and vertical lines, *Dynamic*, *Exciting* link to waves, which has an impact on the "A"

Figure 17
Application of EmPatGen in human–robot interaction



column that creates waves. If "A" is 0 in the model, the rows of the pattern are horizontal.

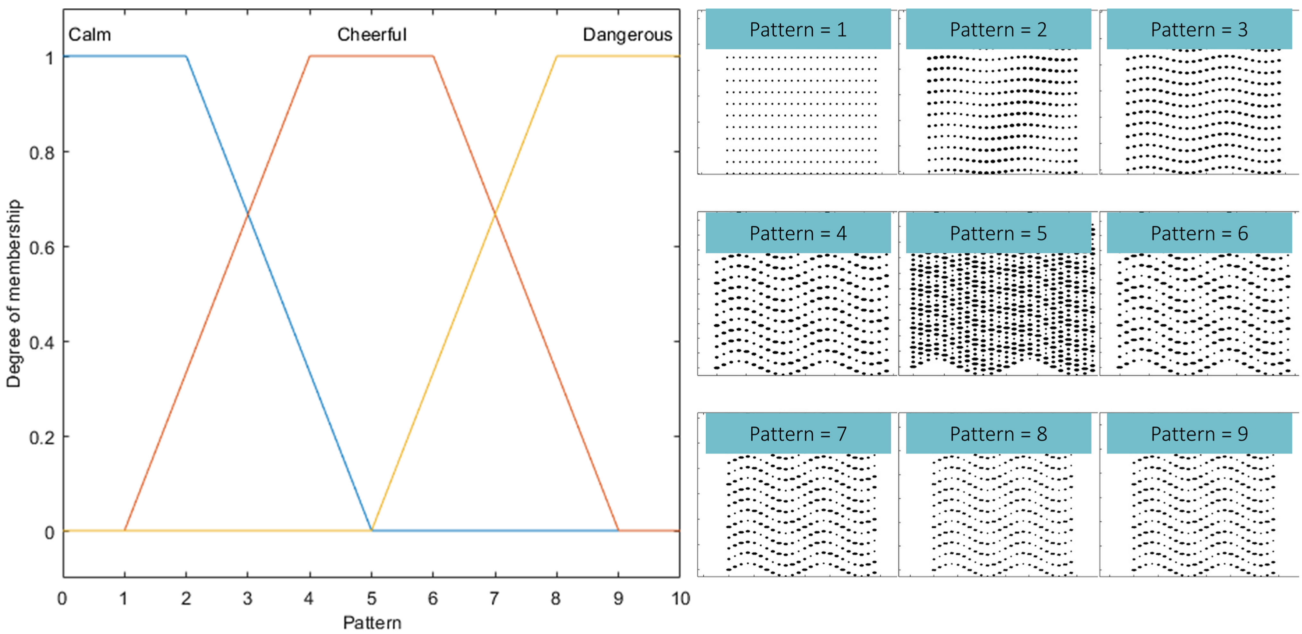
In addition to this, own studies [49] also provided information, for instance, it turned out that if the distance of the rows of the pattern is smaller (VStS), then people feel the pattern more *Dynamic*.

Besides the results mentioned above, other facts were also collected in Figure 17. It contains strong assumptions as well, according to literature reviews in many forums.

The EmPatGen system uses fuzzy logic. Human reasoning and some other phenomena cannot be accurately described by two-valued logic. This idea led L. A. Zadeh to the creation of fuzzy logic [50]. In the fuzzy set theory, an element can belong to a fuzzy set by a membership value. The green area in Figure 17 shows which membership function will belong to the given input emotion in relation to the parameters in the fuzzy system. −1 correlation will belong to the "low" (1) function, 0 to the "medium" (2) function, and 1 to the "high" (3) function. (In this model, three triangle-based functions were used.)

The membership functions of the input parameters and a few pattern outputs can be seen in Figure 18. The inputs (from 0 to 10) will depend on the detected environmental and user factors.

Figure 18
Input membership functions and pattern outputs with the usage of EmPatGen. The inputs (from 0 to 10) will depend on the detected environmental and user factors



According to the input parameter, the output of the Fuzzy Subsystem 3 will be *Calm* sensation (Table 9).

Table 9
Fuzzy Subsystem 3

	Input
EmPatGen for Em-Patty	1
Face expression on display	No
	Output
Emotion-based visual signal	Calming pattern

This pattern can be seen in Figure 19, with blue color that evokes calmness [51]. Currently, the robot is transmitting between three sensations (calm, cheerful, and dangerous) using the side panels (These can be expanded later).

The rules for this specific example can be seen in Figure 20: the system has 1 input, 3 rules, and 11 outputs. There are additional rules as well: if "dRng" takes on a value greater than 9, the dynamic factors should not appear in the pattern, and "*n*," which indicates the number of sides of the polygon, should be rounded to an integer.

In order to demonstrate the differences between the values based on the changes in the patterns, Table 10 is introduced.

Figure 19
Calm pattern

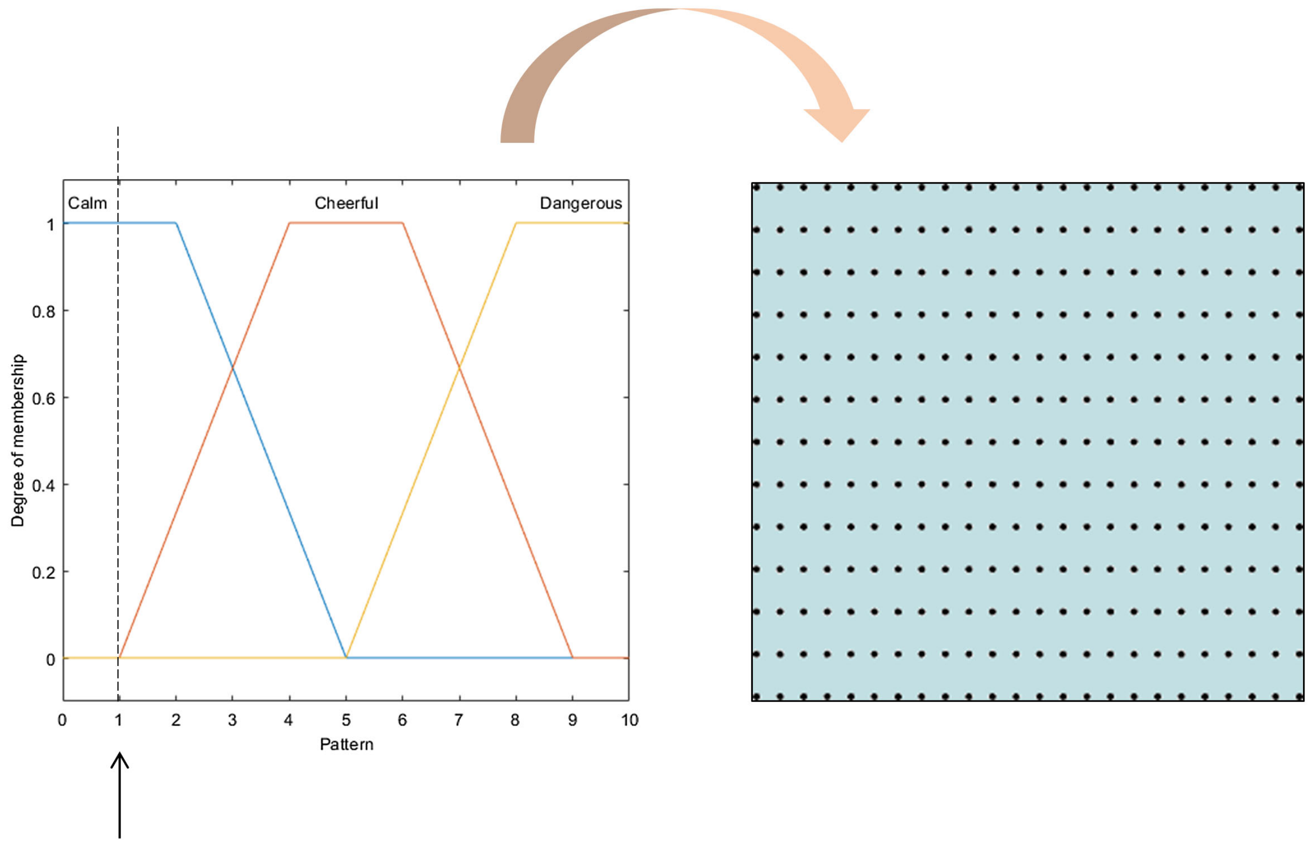


Figure 20
Rules for the pattern input for this specific example: The system has 1 input, 3 rules, and 11 outputs

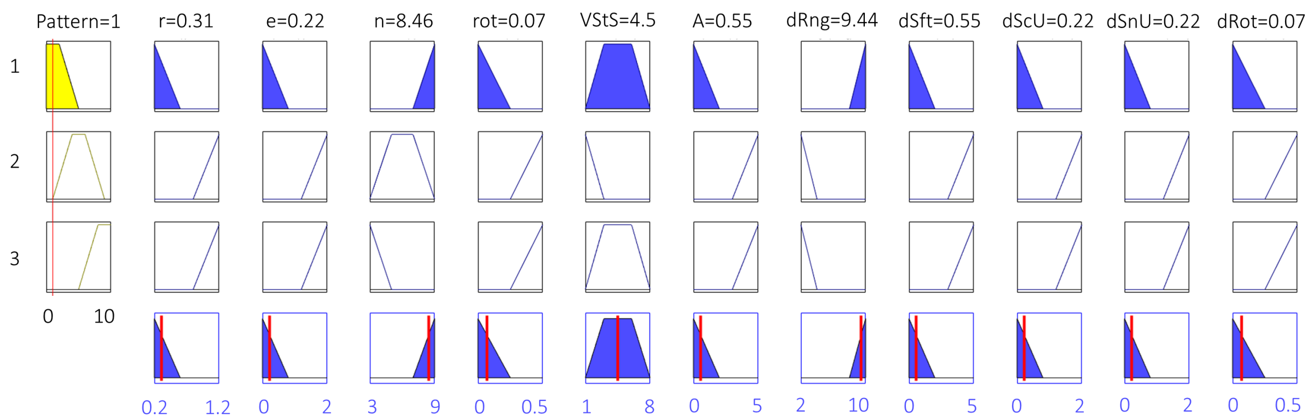


Table 10
Changes in the rules in the cases of patterns 1, 5, and 9

Pattern Style	1 Calm	5 Cheerful	9 Dangerous
r	0.31	1.09	1.09
e	0.22	1.78	1.78
n	8.46	6.00	3.54
rot	0.07	0.43	0.43
VStS	4.50	1.56	4.50
A	0.55	4.45	4.45
dRng	9.44	2.56	2.56
dSft	0.55	4.45	4.45
dScU	0.22	1.78	1.78
dSnU	0.22	1.78	1.78
dRot	0.07	0.43	0.43

4.4. Environment output parameters and IoT system

The environment output parameters are shown in Table 11. According to the environment input parameters, there is no need to notify someone; however, the storm mode of the house requires the guidance of the IoT systems.

Table 11
Environment output parameters

	Output
Notification for the required user or service	No
Guide IoT systems	Yes

The storm mode means close the windows, doors, gate, and garage and turn off the irrigation system. From these, only the windows are open; therefore, the robot is closing those.

The guidance of the IoT system is presented in Table 12.

Table 12
The output parameters of the environment side of the Main Fuzzy System are collected in this IoT system

	Output
Smoke detector	Off
Motion sensor	On
Alarm system	Off
Computer	On
TV	Off
Phone	On
Refrigerator	On
Oven	Off
Washing machine	Off
Dishwasher	On
Irrigation system	Off
Window	Closed
Door	Closed
Gate	Closed
Garage	Closed
Shutter	Up

5. Conclusions and Future Plan

Nowadays, the research about emotions and human–robot interaction is a highly studied area [52]. In this specific research, the goal was to develop human–robot communication by creating a complex fuzzy-based system that deals with the user and the environment sides and integrates the EmPatGen system.

The main results of this research in the field of robot design are as follows:

- Em-Patty is detecting emotion by machines.
- Em-Patty controls the smart home through the guidance of the IoT system.
- An emotion-based visual signal has been created for the Em-Patty cover element.
- Em-Patty has a nature-inspired design concept.
- Two-sided (environment and user) information (gathering and providing) systems are combined as Em-Patty's background operations.
- The mathematical system that operates this concept is based on fuzzy logic.
- A main and three fuzzy subsystems are fusioned in order to create the most efficient control system for Em-Patty.
- Emotional Pattern Generator has been integrated in order to increase communication during the human–robot interaction.

From the surveyed research, it can be concluded that no solution could handle qualitative and quantitative data uniformly, which is why the fuzzy system presented in the article was developed, representing a new answer in this field.

In conclusion, the previously developed EmPatGen system can be easily adapted to another industry. In this case, it could be a part of the human–robot interaction. The fuzzy system can be used well to deal with emotions, which is the basis for user decisions and reactions. The system described in the article is a rudimentary concept that can be extended. One side of expansion can be technological.

In order to develop the system, eye-tracking technology could be involved, since human emotions can also be measured by analyzing the properties of the eye. Many methods (for instance, in the research of Kołodziej et al. [53]) and software have recently been developed to track the eye movement provided for visual stimuli. Among other things, the *Emotion Tool*^{TM} software is suitable for this purpose, which uses statistical data to determine the excitement and its level, as well as the pleasant or unpleasant nature of the given emotion. An emotional reaction can be obtained from psychophysiological changes (blinking, pupil changes, etc.,) in the subject's eyes [54] (For example, pupil dilation can be linked to activation of the sympathetic nervous system [55]).

While this software is a great help to psychologists and emotion researchers, they are not the only ones using them. Marketers and product developers from different companies alike use eye tracking, for example, when testing user interfaces [56].

In addition to studies, the method also has new application areas. For example, Pizza Hut restaurants have introduced eye-tracking tablets that can be used to ask for an order without the customer speaking out [57]. The reason for that was that research has shown that the menu choice is only sometimes logical. The subconscious plays an essential role in our decisions about a meal. The technology that was developed for this project assessed in 2.5 s the ingredients that the diners gazed at for the longest. After that, a mathematical algorithm could identify their preferred pizza (from 4896 possible ingredient combinations). Social sentiment has increased by

35% in 2 m in the UK[5]. Or in the electronics industry, a software update has also been introduced for mobile phones, which allows devices to detect when, for example, the people reach the bottom of a web page and then the phone scroll itself down to the next paragraph [58].

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Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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