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Intelligent search and location system for people trapped in landslides caused by earthquakes.

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Abstract: *Earthquakes are unpredictable natural disasters that cause buildings to collapse. This means that some people are trapped in the landslides and must be searched, located, and rescued in the shortest possible time. Today, all rescue efforts in these types of natural disasters involve other people digging through the rubble to identify potential survivors. Which is risky, compromising its integrity. Thus arises the need to apply technological tools to improve these processes. For this reason, it is proposed to design a people detection system based on biometric variables that may be present in the environment such as temperature, relative humidity, presence of carbon dioxide and the distance between nearby objects. The detection system is complemented by an intelligent system in the form of an Artificial Neural Network (ANN) that processes and determines the probability of having found a survivor and an interconnection system abroad through the Internet of Things (IoT) to send the data. The detection system was integrated into snake robots (YaMoR), with which an artificial community was made. This community is deposited in a space and they begin to explore until they find survivors, in which case they light an indicator and send data so that the rescue maneuvers can begin. The robots were controlled by an ANN that was adjusted by means of a genetic algorithm in a virtual environment of the Webots simulator.*

Key Word*: Artificial Neural Networks, Internet of things, Evolutionary Robotics.*

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I. Introduction

Earthquakes are unpredictable natural phenomena. When earthquakes of moderate or greater magnitude occur, there may be damage to buildings in the affected areas. These damages range from cracks in the walls to the collapse of buildings. Which puts building users at risk, as they can get trapped.

When there are landslides due to this type of natural phenomenon, it is important that the victims are located as soon as possible. This offers the possibility of being able to rescue them alive. Otherwise, if time elapses, victims can aggravate their conditions leading to death.

In Mexico, these types of natural disasters are common since the country is in an area of high seismicity [19]. This is because part of the country lies between two tectonic plates in the Pacific (Cocos and North America). Thus, the history of earthquakes in the country has some important antecedents such as the earthquake of September 19, 1985, with an approximate duration of four minutes and a magnitude of 8.1 in Mexico City [22]. This natural disaster claimed the lives of 40,000 people. An earthquake with a magnitude of 7.1 shook the country on September 19, 2017. This earthquake damaged countless buildings in the states of Veracruz, Guerrero, Oaxaca, Puebla, Morelos, the State of Mexico, and Mexico City. It killed 369 people and affected 12 million.

Currently, one of the searches and location mechanisms for people trapped in landslides due to earthquakes is the use of the canine binomial [9]. This system operates with a trained dog to locate survivors in the rubble through the animal's smell. For this they use a human guide who facilitates the search by moving debris, restricting the search space, or accompanying the dog into narrow spaces. Although it is a mechanism that has saved many lives, this mechanism puts the life of the binomial at risk.

Another search mechanism is operated exclusively by trained personnel. In this system, rescuers go through the rubble to locate survivors. Many times, this dangerous work requires propping up landslide areas and debris removal. So, it is a dangerous and slow method.

The use of technology in this type of natural phenomenon is becoming a safe and fast alternative. In this sense, probes can be used with video cameras [3], thermographic [7] or with some other instrument that allows identifying trapped people by means of X-rays or radars [13]. But it is important to improve the available solutions to try to save as many lives as possible in the shortest time, trying to reduce the risk for the personnel involved.

The question with which the research arises is: Is it possible to create a technological solution that allows searching and locating people trapped in landslides due to earthquakes without risking the lives of rescuers? Therefore, the objective of the research is to create a system for detecting people with Internet of Things and integrated into an autonomous robot.

This article presents six sections of information. In the first, the study problems and the research objective are presented. The second section presents the theoretical tools that allowed the solution of the problem. The third presents the solution, while the fourth shows the results. The discussion of the proposed solution is found in the fifth section and the conclusions are presented in the sixth.

II. Background

Biometric signals are those that can be measured because of the body's activity. Among them are temperature, neuronal activity, heart rate, bone density, among others. These variables have characteristics that allow us to identify human beings from other living species that can also possess them.

Being able to measure these signals using inexpensive sensors is a possible action today. This is due to advances in the field of biomedical instrumentation. The signals can be acquired and processed by computers or embedded cards.

One of the most important biometric variables is temperature. This can be measured directly using thermocouples or direct contact sensors such as the LM35. But it can also be measured by a PIR sensor. These types of sensors capture radiation from bodies and approximate the temperature. Contact with people is not necessary, as it can be done remotely. A person's temperature can determine whether they are alive. If the person is alive, the temperature usually ranges between 36 ° C and 37.5 ° C.

Another important variable for this work is carbon dioxide (CO_2). This is a gas that is produced in the respiratory system on expiration. In a first stage, the lungs are filled with oxygen (O_2), which is absorbed and mixed in the circulatory system [17] . Once this is done, the remaining oxygen is converted into carbon dioxide that leaves the body. Therefore, the variation in oxygen or carbon dioxide levels are indicative of the presence of human beings breathing.

The process of respiration and the temperature of bodies also causes changes in the levels of relative humidity in the environment [6]. Relative humidity is the relationship between ambient humidity and the amount of water vapor in each place.

Infrared sensors can be used to measure distance to objects. However, these usually present significant noise when it comes to measuring the proximity of a human being. Therefore, the use of ultrasonic sensors is recommended to determine the proximity of this type of objects.

On the other hand, the technological revolution of Industry 4.0 implies the combination of different technologies to grant autonomy to cyber-physical systems. A cyber-physical system is one that, in addition to the physical components that make it up, also has a virtual identity [8]. This means that you can connect with other devices, exchange information, receive orders or make decisions. Among the multiple branches of technological development that Industry 4.0 implies, there are two that are important for this research: Internet of Things (IoT) and Autonomous Robotics.

The Internet of Things is an architecture to provide communication and autonomy to objects [12]. It is a four-layer model: Sensing and identification, Network, Cloud Services, and Application. The sensing and identification layer involves all the sensors used and the system that acquires and processes these signals, generally in the form of an embedded card, a computer, or a mobile device. In the network layer is the communication medium used and its scope. For example, wireless local area networks. The cloud services layer oversees storing the data. As devices equipped with IoT produce large amounts of data, it is impractical to store it in the devices of the sensing and identification layer. That is why cloud services are used. Finally, the application layer is related to the actuation devices of the system, but above all with the tools that give them autonomy to generate an output. That is why Artificial Intelligence tools are usually trained to control systems. Thus, an IoT system is usually an intelligent system that exchanges data in real time for decision-making [16].

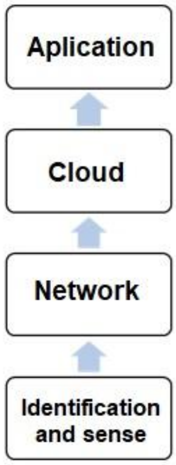

Figure 1. IoT architecture.

ER is a branch of knowledge that studies the means to empower robots [2]. There are several divisions within it, but Mobile Robotics (MR) and Evolutionary Robotics (ER) are of interest. MR studies all those robots that can move in different environments. While ER uses evolutionary computation techniques to train control systems (or morphology) of robots in the form of unsupervised learning. In other words, robots are immersed in the environment. Driver versions change and adapt to improve performance. For this reason, it is said that the environment performs a pressure mechanism to improve the control systems of robots. This is a mechanism comparable to the natural evolution process of the species, which favors the robot's experience with its environment.

As a means of controlling mobile robots in RE, it is common to use Artificial Neural Networks (ANNs). It is a computational model of natural neurons. They serve as a mechanism for classification and discrimination [21]. Each artificial neuron is made up of inputs that are weighted through synaptic weights. Both components are mixed in a Net function that multiplies each input by its weight, and sometimes adds the value of a Bias or a trigger threshold setting. To know if a neuron is active, an activation function is required that uses the value of the net function as an indicator. Finally, the output function determines the value of the network output depending on whether it is active or not. ANNs have as their main advantage their tolerance to faults and environmental noise. But also, the ability to operate with a large amount of data as presupposed using IoT technology.

When there is an interconnection unit between artificial neurons, an ANN is produced. The most popular interconnect architecture is feedforward. In it, the outputs of the lower layers are the inputs of the neurons of the next level. If the number of layers of an ANN that controls a mobile robot is related to the degree of reactivity or deliberation of the same. In other words, a neuron with two layers (input and output) discriminates less information and is considered reactive. If a set of intermediate layers is added, the discrimination process in the neural network becomes robust and the system is considered deliberative.

There are various learning mechanisms for an ANN. The classic method is supervised learning using an algorithm such as Backpropagation or error backpropagation. This requires a database that contains the exact output of the network for each possible stimulus, which implies the use of a database. The database contains measurements of the physical phenomena that you want to automate or the knowledge of a human expert through Knowledge Engineering. In the latter case, the knowledge of the human expert serves as a guide for the autonomy of the system and the learning process replicates the acquisition of information. For supervised learning there is software that allows you to create a robust network selection and tuning process. Such is the case of WEKA, which is free and open-use software for machine learning.

In ER, the ANNs are adjusted by an evolutionary computation algorithm. Only the weights or various characteristics such as architecture, type of connections, activation function, among others, can be adjusted [5]. To carry out the weight adjustment, a Generational Genetic Algorithm (GGA) can be used. For this, the weights are encoded in the form of a genotype and a chromosomal representation that can be binary, in the basic versions, or of any other numerical type in modified versions. The genotype of a controller represents the characteristics to be adjusted during the computational process.

An GGA is a bio-inspired optimization algorithm. It employs an artificial genetic combination mechanism through the selection and crossing operators. In addition to a mechanism of changes controlled by the mutation operator. An GGA begins with the random initialization of chromosomes from a population, which are then tested in each environment. The testing process is reflected by a fitness or fitness function that quantifies how good a solution is under controlled environment and conditions. Once the entire population has been evaluated, potential parents are selected through various mechanisms such as the tournament or a roulette wheel. With the parents selected, a crossover point is selected, and the parents' artificial genetic information is recombined to produce a new individual. After this, the mutation process is applied that changes in a controlled way some genes of the chromosomes of certain randomly chosen individuals. Finally, the new generation is produced by some controlled substitution mechanism and the new generation is put to the test. This process is repeated until a specified number of generations or a desired fitness value is reached.

Optimization processes can be done in environments where a single robot participates, where behaviors can emerge. These are behaviors that are the product of the robot's experience with the environment and are not sought within the approximate functioning modeled in the fitness function.

If the optimization processes are carried out by groups of robots, the emergence of behaviors and coordination mechanisms are common. This technique makes it easier to find a better solution because the environment can be explored in a better way, since there are different individuals who can take different directions.

When it comes to tasks where the environment is hostile, the choice of the robot to use is essential. In the event of a landslide, mobile robots with wheels can get caught between obstacles. But there are robots that have different movement mechanisms. One of them is the YaMoR robot. It is a robot that emulates the movement of snakes. It is built of links that allow it to crawl and climb over obstacles such as a set of debris. It is a robot designed by the EPFL and found as a computational model in the Webots simulator (free license simulator). It is a modular robot, in which each link has an independent control provided by servomotors.

III. Material and Methods

The objective of the research was to create a system for detecting people with communication that is integrated into an autonomous mobile device capable of dealing with the environment. Therefore, the proposed solution was divided into two components: the location module and the search module.

Figure 2. Solution system.

The location module was created using an Arduino ADK board and the WIFI communication module. The system was equipped with an artificial neural network that was fed with four categorized biometric variables: temperature, relative humidity, carbon dioxide and distance. A modified IoT structure was used, where the cloud layer is replaced by storage of the variables on an SD card. The system sent the warning when it has located a trapped person for rescuers to begin their work.

The search module was run by a set of four YaMoR robots equipped with infrared proximity sensors. The control system used was an ANN adjusted by means of an GGA. When the locating module identified a victim, the robot had to turn on an indicator and stay on the spot. In another case, the robot had to explore without colliding with the surrounding obstacles.

Localization module.

The location module used the IoT architecture for its operation. So, the sensing and identification occupy the first two layers. The autonomy of the system rests with an ANN and it communicates with the outside through a WIFI network.

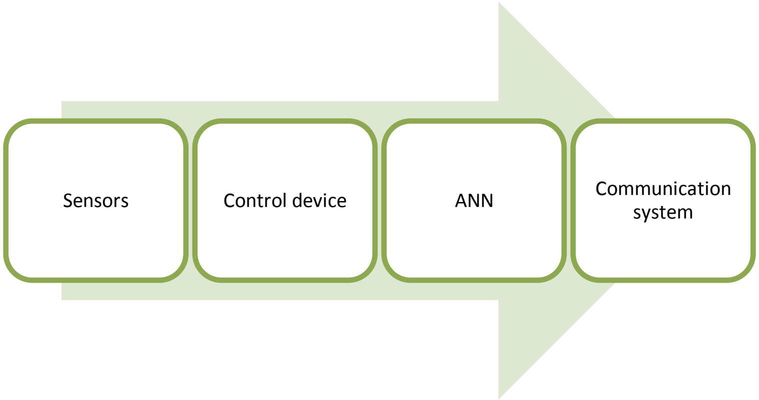

Figure 3. Localization module architecture.

For the sensing and identification layer, the measured variables were temperature, relative humidity, carbon dioxide in the air and distance of the object in front of the device. To measure the temperature, a PIR sensor was used that detects the radiation produced by the bodies. This guarantees that the data obtained is more robust and prevents the system from having to come into contact with bodies [11]. Once the temperature was measured, the signal was processed to produce three possible levels: Low, Normal, High. Low temperature was associated with values lower than 36 ° C. The normal temperature was considered between 36 ° C and 38 ° C. While the high temperature value was associated with values greater than 38 ° C.

To measure relative humidity, the SEN-09569 sensor was used, which makes the physical phenomenon to be measured linear. In this case, we sought to detect variations in the readings that could indicate the presence of people in a space. Thus, there were three levels of detectable variation: Low(less 50%), Medium (50% to 60%) and High (more 60%). The greater the variation detected, the more likely it is that a person will be breathing nearby.

The distance from the object at which the temperature is detected is an important factor. Therefore, the location used an HC-SR04 ultrasonic sensor. The sensor signal was processed and categorized into three levels: low (less 10cm), medium (10cm to 20cm) and high (more 30cm).

As for carbon dioxide, the MQ-135 sensor was used. This sensor measures the presence and quantity of particles per million (ppm) in the air of different gases. Therefore, it was essential to create a calibration system to fit the response curve to carbon dioxide. For this, the gas was created under controlled conditions and stored. The pre and post storage device was weighed to obtain the amount of stored gas. With this variable the amount of ppm present in the gas tank was approximated. Finally, the sensor was introduced, and the incorporated resistance was calibrated to obtain the desired value.

As in the case of relative humidity, the desired value in the locating module is the variation in the presence of the gas in the environment, which could indicate the presence of a person. It is important to note that a person can produce 720ppm in their breath. Thus, the variable was quantified at four levels: low (less 500 ppm), medium (650ppm to 790ppm) and high (more 790ppm). Being a high variation that associated with the presence of a person breathing.

An Arduino ADK board was used as the control or acquisition board. All the sensors were connected to it. To provide energy autonomy to the system, the card was connected to a 9V type D battery. Measurements are made every second and are stored on an SD card incorporated into the WIFI extension used for communication.

The Arduino board included the program of an ANN that emitted four output values: A, B, C and D. For A it is determined that the possibility that a person is nearby is less than 40%. B when the possibility that a person is close goes from 40% to 58%. C if the possibility that a person is close ranges from 58% to 83%. D if the possibility that a person is nearby is greater than 83%.

To train the neural network, a database of four attributes (temperature, distance, relative humidity, and carbon dioxide) was created, a class with four class values (A, B, C, D) and 81 instances. The database was filled by knowledge engineering for each of the instances. For this, a table was created that weighted each of the variables in the knowledge base (see table 1). Each variable contributed a maximum of 25% of the total decision, but if the conditions do not represent those associated with the presence of the person, the contribution of each variable was reduced.

Table 1. Weighting of each variable in the knowledge base.

Level	Humidity	CO2	Temperature	Distance	Numerical value
Low	$\frac{25}{3}\%$	$\frac{25}{3}\%$	$\frac{50}{3}\%$	25%	0
Medium	$\frac{50}{3}\%$	$\frac{50}{3}\%$	25%	$\frac{50}{3}\%$	1
High	25%	25%	$\frac{25}{3}\%$	$\frac{25}{3}\%$	2

A computational experimental procedure was created in the WEKA software by means of which the classification percentage of three ANN configurations was compared to select the one that best solved the database. The configuration of the networks increased the deliberation level of the system, increasing the number of intermediate layers and the number of neurons in the system. For all networks tested, the data was not normalized.

The first ANN had a two-layer configuration (see figure 4): entry and exit. The input layer included 10 neurons that received the four variables from the sensors as input. Four neurons whose activation represents each class value (A, B, C, D) were placed in the output layer. The neurons included the bias, and the total amount of weights was 94. He used the sigmoidal transfer function and a binary output function (0, 1). This network represented the intermediate level of deliberation or the intermediate level of reactivity since the information is discriminated in two layers.

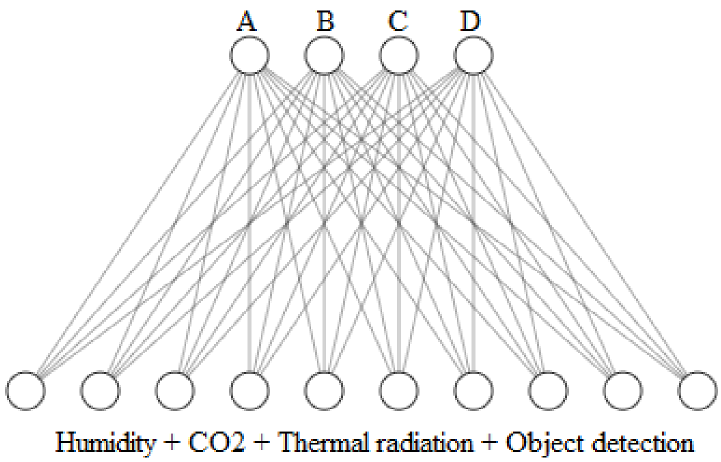

Figure 4. Two layered ANN.

The second network was made up of three layers (see figure 5): input, middle and output. The input layer included 10 neurons that received the four variables from the sensors as input. In the middle layer, 5 neurons were used. While in the output layer four neurons were placed whose activation represents each class value (A, B, C, D). All neurons included the bias, and the total amount of weights was 129. He used the sigmoidal transfer function and a binary output function (0, 1). This network represented the high level of deliberation or the low level of reactivity since the information is discriminated in three layers.

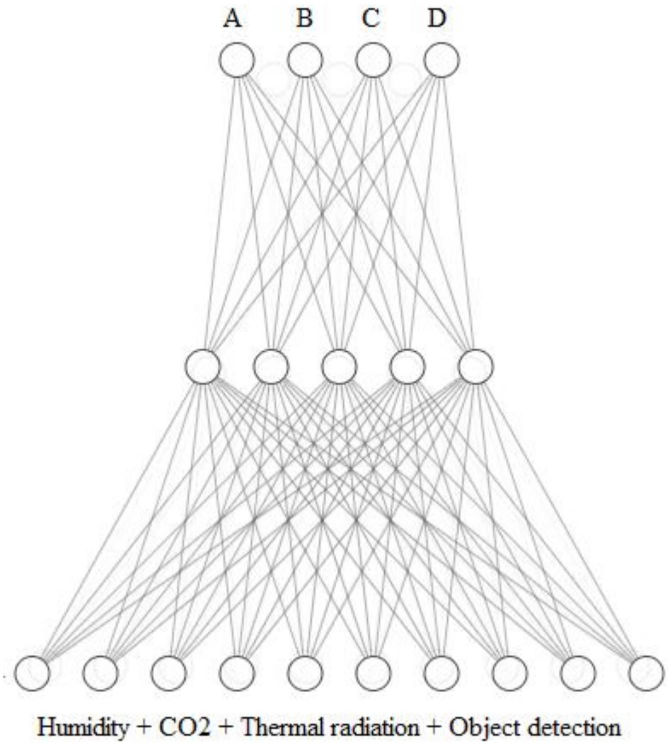

Figure 5. Three layered ANN.

Each neural network model was trained 90 times. Using the mechanism of division of the database, using 70% of the base for training and 30% for testing. Each training process generated a random database partition mechanism. Networks were compared using a one-way ANOVA applied to the percentage of correct classification ($p < 0.05$). A post-hoc Student-Newman-Keuls test was used to find significant differences ($p < 0.05$). The network that best solved the database was chosen and programmed in the control card.

Finally, the communication layer was based on the Arduino WIFI extension. Interconnectivity was chosen through a wireless local area network because in the last earthquake events, the companies that provided said service released them so that any user could use them to communicate. WIFI communication improves the interconnection characteristics that other mechanisms such as Bluetooth imply.

The data of the measurements and the outputs of the network were saved on an SD card that suppresses the Cloud component of the original IoT model. This is because, although there are connection conditions, the ideal is not to overload it. In such a way that the system operators received by WIFI and a Client - Server architecture only the situations that indicate the presence of people associated with the class D value of the ANN.

To validate the functioning of the prototype, the input variables were manipulated to check all instances of the knowledge base. The number of hits in the system was counted as a dependent variable.

Search module.

The objective with the search module was to create a controller in the form of ANN that would allow organizing a set of YaMoR robots to detect people. This part of the investigation was carried out in a simulated environment using the Webots simulator. The robot model was chosen because of its morphological and locomotion characteristics, which allow it to avoid obstacles and access tight spaces.

The test environment was a 5m x 5m size sand. The arena contained obstacles of various forms (see figure 6). To simulate the presence of people, four circular targets with random positions were included. Four eight-link robots were placed at a starting point. Their task was to find the targets while avoiding obstacles. Once the targets were found, the robots had to stay close. Two infrared sensors were included at the front of the robot and an infrared sensor at the end. Two infrared sensors were also included on the sides of the start and end links. With which a sensory system was obtained with seven total infrareds that worked in binary form, with a value of 0 if nearby obstacles and 1 with nearby obstacles. In addition, a sensor or input was included that determines how close the robot is to the area. This input simulates the output of the locate module. This input had four possible values, the value 0 corresponded to the very low possibility of finding a person nearby (class A at the output of the location module). The value 1 corresponded to the low possibility of finding a person nearby (class B at the output of the location module). The value 2 was assigned to the average possibility of finding a person nearby (class C in the output of the location module), which occurred if the robot was close to a target. The value 3 corresponds to the high possibility of finding a person nearby (class D at the output of the location module), which occurred when a robot met a target.

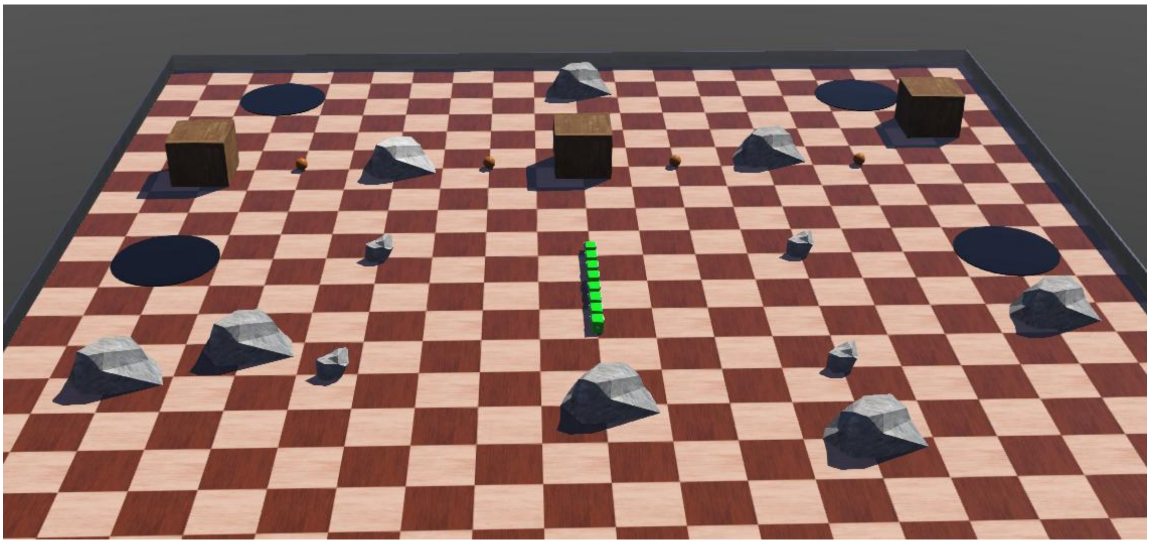

Figure 6. Test environment.

To control the robot, a three-layer ANN was designed, with feedforward architecture, bias in each neuron and a sigmoidal tangential transfer function (see figure 7). In the input layer, sixteen neurons connected to the seven infrared sensors and the value of the output of the localization module network were used. In the middle layer, twelve neurons were placed that receive connections from each neuron in the previous layer. The output layer was made up of eight neurons that directly encoded the motors of each of the robot's links. The total of weights or synaptic connections was 452.

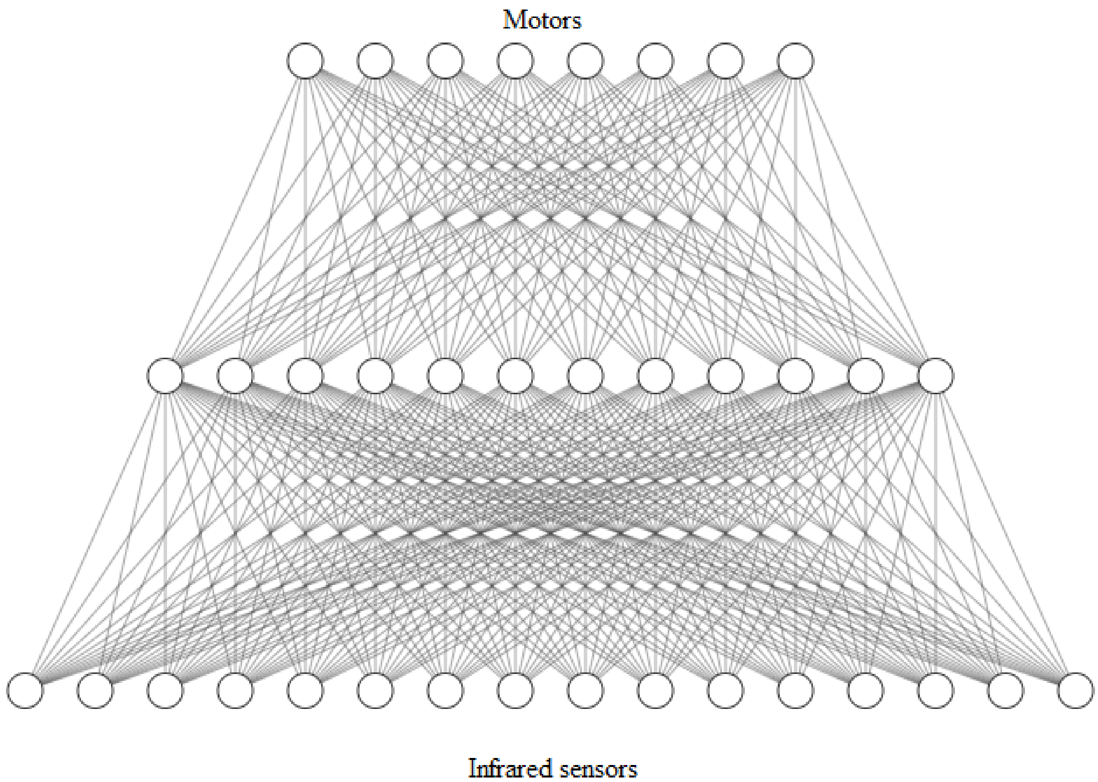

Figure 7. Robot control ANN.

Due to the complexity of the environment, the task, and the morphology of the network, it was decided to optimize only the ANN weights using an GGA. The algorithm population was 200 individuals. The binary representation was used for the chromosome of each individual, representing each weight in nine bits and a range of -5 to 5. The first bit represented the sign, while the rest represented the value of the weight. Thus, the chromosome size for each individual was 4068.

The selection operator relied on the tournament selecting two parents to apply a random crossover point in the recombination process. The replacement operator allowed the retention of up to 20% of the total number of parents in the new generation. The configured mutation percentage was 2% of the total number of individuals in the new population. The elitism operator was used to keep the best individual of each generation intact and include them in the new generation.

Four trials of 500 steps each were used to test each individual. At the beginning of each trial, the group of robots was placed together in one of the corners of the environment in a random way. To reduce simulation time, the simulation version was used without the graphical tools. This process reduces the total simulation time to a quarter. The individuals were evaluated by the following fitness.

$$fitness = \sum_{i=1}^{8}(1 - Infrared\ sensor_i) + target$$

$$Infrared = \begin{cases} 0, obstacle\ absence \\ 1, obstacle\ presence \end{cases}$$

$$target = \begin{cases} 0, on\ target \\ 1, out\ target \end{cases}$$

The evolutionary process was repeated twelve times. At the end of each process, the best individual of the last generation was preserved. The fitness of the twelve best selected individuals was compared to establish the highest fitness and select it as a test item.

IV. Results

The solution for the search and location of people trapped by landslides in earthquakes consisted of two modules: location and search. The first module oversaw identifying possible survivors, while the second oversees exploring the environment.

Localization module.

The location module was made up of the relative humidity, distance, temperature, and gas sensors. These elements were connected to the Arduino board and the readings were stored in an SD memory through the WIFI extension (see figure 8).

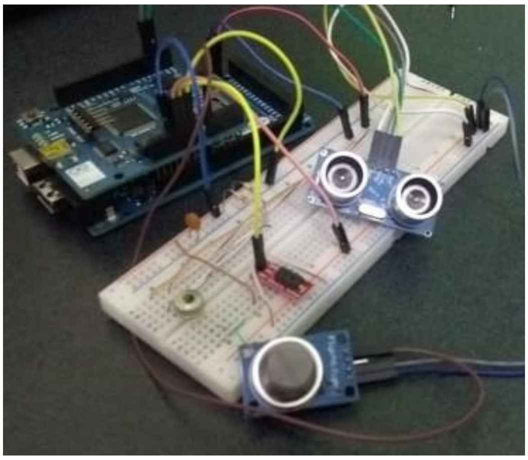

Figure 8. Localization module prototype.

The experiment to select the network that best solves the proposed database yielded the results that the neural network that represented the intermediate level of deliberation was the one with the highest percentage of correct classification (95%). The three-layer network achieved 93% correct classification (see figure 9).

The one-way ANOVA statistical test for ranges (normality not met) indicated significant differences ($p < 0.05$, 179 DF). While the post-hoc test indicated that significant differences ($p < 0.05$, 2 DF) between the performance of the two-layer AAN and the other two ANN models. For this reason, the two-layer network was selected as the module's decision-making mechanism.

The code size on the embedded card was 22,766 bytes, including ANN, communication protocol, data acquisition and processing. The connection test between the client in the form of a cell phone web browser and the server mounted on the Arduino board and its WIFI extension was carried out. The IP address was dynamic, and the connection test showed the classification performed by the neural network in real time. When testing the database in the physical prototype, a correct classification percentage of 100% was obtained by manipulating each input variable of the location module in a controlled manner.

Search module.

The search module made up of a set of four YaMoR robots was trained by an GGA in a simulated environment. The evolutionary process was repeated twelve times, obtaining good results in eight of the twelve of them (see figure 9). In three of them the fitness level was higher than in the rest.

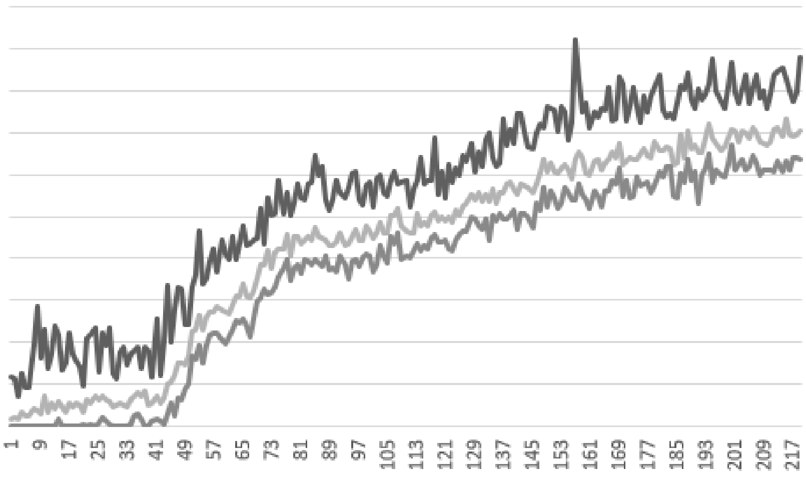

Figure 9. Fitness of the best individuals of the twelve evolutionary processes.

The GGA allowed the robots to avoid obstacles in the designed environment and to find the targets that represented the trapped people. The highest fitness value in three repetitions was due to the emergence of coordination, which allowed the robots to explore space better.

V. Discussion

The presented System is in a prototype. It is made up of two systems: location and search. Both can interact without the need for a coordination mechanism between them. They have the potential to search and locate people trapped in landslides caused by earthquakes. This is demonstrated in different investigations on robots that perform search and rescue task [18], [10], [20].

But the hallmark of this research is in the use of autonomous robots. This technology avoids the teleoperation of the systems and allows to scale the work until the collaboration between members of a team of autonomous robots This allows improving the mechanisms for the division of labor in smart communities [14]. This has been proven during the time of health contingency where autonomous robots oversee performing certain dangerous tasks for humans [15], [4]. In terms of an earthquake, it reduces the danger to which the rescuers are exposed [1].

The designed system reduces the number of variables to identify. It combines IoT technology with an intelligent detection system based on a neural network. Which is a sample of the impact that Industry 4.0 has in different fields of daily life. But it also demonstrates the importance of data management and its application to important tasks.

The location module operates through four biometric variables. The temperature makes it possible to identify if a person is in front of the device, the smaller the distance between the sensor and the person, the better the accuracy of its operation. Variations in the levels of carbon dioxide in the air can indicate the presence of a person, as can variations in the level of relative humidity. The selection of these variables privileged the detectable characteristics in a closed space. Avoid the use of cameras that require light for their operation or higher energy consumption in the general system.

The use of an ANN allows the module to be tolerant to faults and noise from the environment itself. The network was trained using supervised learning and the Backpropagation algorithm. For this, a database based on knowledge engineering was created. In it, a human expert influences the autonomy of the network through his experience. This technique is suitable when problems are solved by reasoning from the circumstances and not by numerical analysis.

The knowledge base provides a confidence estimate that allows you to establish whether a person is near the device or not. This confidence level will be maximum when the temperature is between 36 ° C and 38

°C. If the variation in the levels of relative humidity and carbon dioxide in the environment are high and the distance between the measuring device and the object sensed is low. If any of the conditions are outside the desired values, the estimation level is also reduced.

Three different types of neural networks were tested, in which the level of deliberation or reactivity was varied. The network with one layer is more reactive than the rest since the discrimination of the information is less. While the network with three layers increases the deliberation of the system since the information is discriminated in its path by each of the layers. The results of the statistical test applied to the three networks allow us to conclude that the network with intermediate deliberation capacity is the one that produces the best results in terms of the classification percentage.

This is because most networks trained with the two-layer topology have an average performance very close to 100%. The performance of the first quartile of this network architecture is close to 80%. Whereas, for the single layer network, the performance of the first quartile is less than 80%. The same case occurred with the three-layer network with a first quartile with a performance lower than 70%. All of this translates into the two-tier model producing networks that are better prepared to contend with the presented foundation.

The experimental process presented for the module aims to contribute to the standardization of neural network design procedures, trying to reduce the influence of the designer and increasing the influence of a statistical process to decide the most suitable network to solve a problem. This procedure must reach all branches of Artificial Intelligence where the process with which a specific tool is chosen for a task is based on the experience of the designer and not on the contrast of different tools, models, or versions.

When testing the prototype of the localization module, the effectiveness of the ANN in solving the problem was verified. This procedure was carried out under controlled conditions, modifying the value of each of the sensors. Although as future work the need to build scenarios similar to collapses is raised to improve the tests carried out on the prototype.

Just as variables are a hallmark of the proposed design, communication is also a fundamental element of the solution. A modified version of the IoT architecture is used to structure the prototype. The system was designed with a sensing layer and an identity layer (control card). But the cloud layer was replaced by a mechanism that saved the reading data to an SD card. The reason is that it is not necessary to continuously send the measurements obtained by the module. The fundamental performance was the value of the class, particularly when the confidence level of finding a person is high.

That is why the network layer took a WIFI network as a tool. Access to this type of network has been released by the different providers in the last natural disasters caused by earthquakes so that people can contact their families or emergency services. This feature can be used by the proposed device. In such a way that, once a person is located, personnel outside the collapse can consult the status of the measurements and the results of the exploration.

As for the exploration module, it complements the operation of the location module. Its function was to control the movement of YaMoR robots to explore an environment with obstacles while the locating module works. If the locating module identifies the conditions required to identify the presence of the person, then the robot must be kept close to the subject for rescue personnel to proceed with their work.

The choice of the YaMoR robots was based on their modular system and their locomotion. A mobile robot on wheels can get caught between obstacles, while a tracked robot can struggle in tight spaces. The YaMoR robot can crawl while avoiding obstacles, even in the smallest spaces.

The robots were equipped with infrared sensors on the start and end links to detect obstacles. They were also equipped with an input that comes from the AAN of the locating module that determines if the robot is near a trapped person or not. This is due to the type of movement made by each link. But it is possible to equip them with a greater number of sensors to improve the perception of the environment.

Three components were fundamental in the created environment. The first was the starting area, from where the robots began their journey. The second was the obstacles that were created and that put the robots' ability to do their job to the test. Finally, the four circular targets that replace people, where the robots had to stay close.

The evolutionary process occurred in a population of four robots because the necessary coordination mechanisms can emerge in a population so that the task is better solved. That in the case of the exploration of an environment is important since the population has the capacity to cover a greater space. Furthermore, in terms of the computational exploration involved in testing the various combinations of weights, exposing a controller to a greater number of conditions has positive effects.

In the case of a landslide environment, exploration through robot populations can be critical. The reason is because, with a proper coordination system, robots can cover a larger area of the collapse than if the exploration were carried out by a single robot. This increases the chances of finding survivors in a shorter time.

An GGA was used to optimize the weights of the ANN that controlled the robots. This procedure favors the experience of the robot in contact with the environment in the form of unsupervised learning. Given the characteristics of the evolutionary process, the task, and the network, it was decided to optimize only the weights. But as future work, the possibility of reducing the times of the evolutionary process and including the morphology of the network as an element to be optimized together with the weights through an GGA is proposed.

The GGA produced individuals fit to contend with the medium in 66% of the repetitions. Being 25% of them the best for the task envisioned. The three repetitions that obtained a higher fitness were related to a coordination mechanism of the robots. In these repetitions, the robots explored the environment, separating from the beginning. Whereas, in the rest of the successful cases, the robots stayed together. In other words, the main differences between the most successful repetitions were of the behavioral type and are due to the emergence of solutions.

Thus, the search module worked correctly in the simulated environment. Future work seeks to test these results in a physical model of the same robot or a similar robot. Include the locating module and evaluate it in conditions similar to those of a landslide due to an earthquake. However, it is important to note that the model presented is robust and can be used for the task envisioned. The results of the prototype stage show that the designed system can support the search and rescue of survivors trapped by landslides caused by earthquakes. It is an effort to reduce the danger that rescuers are exposed to during these types of events.

VI. Conclusion

Earthquakes are natural disasters that can cause buildings to collapse, trapping people inside. When this occurs, it is important to have search, location and rescue mechanisms that are fast, effective, and safe for the personnel involved. In this way, a design of an electronic system was presented that involves two modules to search and locate potentially trapped people.

The location module operates through biometric variables (temperature, distance, relative humidity, and carbon dioxide). In addition, it is based on the IoT model, which made it possible to send a signal to rescuers through a WIFI network when environmental conditions allowed the ANN to establish that a person may exist nearby. The ANN of this module was trained with a supervised mechanism through a database created with knowledge engineering. That is, the network has the influence of the designer since the solution of each instance is made through the perspective of a human.

The search module is an ANN that controls YaMoR robots. To optimize it, an GGA was used that operated in a simulated environment. This environment was designed with the necessary conditions to produce solutions capable of avoiding obstacles and approaching the marked areas. The use of a group of robots allowed the emergence of various solutions, and with it the emergence of coordination systems among the group's robots. This allows the exploration of the environment to cover a larger area. What in a real scenario represents increasing the chances of rescue of trapped people.

This type of system shows that technological adaptation is possible to support human beings in various tasks. Mainly with the combination of computational and electronic tools that the term Industry 4.0 presupposes. Same that has a potential beyond industrial environments, with a perspective of application to daily life.

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