Fuzzy Controller for Automatic Microphone Gain Control in an Autonomous Support System for Elderly

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***Abstract*— A fuzzy controller to support older adults should be robust and respond effectively to real-life situations such as illumination changes, ambient noise, and decision-making in critical situations. Following this approach, this paper presents the general design of "SA^{3}M", an autonomous support system for older adults that implements facial recognition, voice response and the use of various sensors to prevent or alert dangerous situations (gas leaks, fires, etc.). Furthermore, this paper addresses the problem of automatic microphone sensitivity control (Automatic Gain Control) in the processing of voice commands. To validate the proposed approach, the fuzzy controller was tested with a wide range of ambient noise levels and produced promising results.**

Keywords—assistive technology; older adults; fuzzy logic; automatic gain control.

I. Introduction

The aging world population is an inevitable phenomenon that is occurring at an accelerated rate. In the last 50 years, worldwide social and economic improvement, coupled with better nutrition, better health care, and an overall increase in the quality of life, have all led to a decrease in mortality rates and an increase in life expectancy. Accompanied by this is a decrease in birth rates [1] [2] [4], and as a result, is bringing about changes to many aspects of society. This phenomenon is creating both challenges and opportunities in the scientific community, whose objective is the production of tools and technologies designed to maintain the health of older adults, and to improve their quality of life [1].

Worldwide, it is estimated that there are 605 million people over age 60, and this number is expected to increase over the coming decades. It is estimated that by the year 2025, there will be 1.2 billion older adults worldwide, with two out of three living in developing countries [3]. By the year 2050, the number of people age 60 and over, as a proportion of the global population, will have doubled, from 11% to 22%. When this number is reached, for the first time in humankind's history, there will be more older adults than children in the population [3] [5] [6].

On those grounds, it is important to note that older adults will play a more relevant role than the one that they currently play in the global community; therefore, societies must generate new tools to facilitate and enhance their living environment. Therefore, this work seeks to develop an autonomous and inexpensive tool to support the following activities that are fundamental to the elderly:

- Reminders for the schedule of prescription medications that must be taken.
- User identification via facial recognition.
- Reading and sending emails and text messages, and making and receiving phone calls using voice commands.
- Automatic risk detection and warning (gas leaks, CO2 saturation levels, moisture levels, etc.).
- Access and query information on the Internet.

Similarly, it is fundamental that those tools are able to cope with complex situations in real-life environments such as background noise, drastic illumination changes, and problems related to intelligibility of voice commands, among others.

In this paper, a method is presented that allows for the automatic adjustment of microphone gain, from a fuzzy logic based approach. Therefore, the stage is set to perform the following tasks:

- Capture sound signals in a way that the person's voice is not attenuated by ambient noise.
- Provide a methodology that allows for the simple adjustment of the microphone gain through fuzzy rules.
- Deliver a scalable solution that can be installed on processors ranging from microcomputers to mobile devices.

This paper is organized as follows: In Section 2, assistive robots and similar projects that address the automatic adjustment of microphone gain are reviewed; in Section 3, the overall design of the robot and the proposed fuzzy system are reviewed; in Section 4, the results of the pilot testing plan are analyzed; and in Section 5, the conclusion and future work are presented.

II. Related Projects: A Brief Overview

A. Assistive Robots

Currently, various robots have been developed for the purpose of assisting people, and many of those robots provide multiple functions such as delivering different forms of nutritional support, personal care, companionship, etc. [9] [10]. RIBA is a robot that focuses on the transportation of immobile patients, such as lifting a bedridden person and carrying him or her to a chair or a different location within the home [7]. This prototype differentiates itself from other robots such as RI_MAN [8] for its ability to lift weight with precise and delicate movements thanks to the tactile sensors incorporated into the design of its arms, which are similar to human arms.

In addition, there are robots dedicated to mental health care and psychological study. These robots evaluate a person's mood by looking for pathologies of depression or anxiety disorders in older adults [9], and attempt to improve older adult's communication. The robot "Paro" [9] resembles a baby seal, and its design is based on the fact that interaction with animals provides great emotional benefits to people, and it is intended for the rehabilitation and mental study of patients.

Robots such as FRIEND [11] are designed to help people with disabilities. The objective of the robot is to assist elderly and persons with disabilities in their daily and professional life activities.

Other robots have been built to help with household or office chores [17]. An example is the robot presented by the University of Tokyo; it performs daily tasks such as washing dishes, cleaning the house, picking up clothing, and carrying drinks without spilling them [18]. There are also robots designed to search for specific objects, retrieve those objects, and then bring them to the end user [17] [19], and robots such as the "PR2" developed by Willow Garage [14] [15] are capable of manipulating objects with high precision.

The list of these types of robots could be extended much further, but they all share the primary purpose of helping humans with their everyday tasks to make their lives easier.

B. Related Approaches to Automatic Gain Control

At present, several approaches have been developed in the area of Automatic Gain Control (AGC) for speech signals. In this field of research, [22] presents an approach to detect voice activity using an intelligent control based on BELBIC (Brain Emotional Learning Based Intelligent Controller). With voice activity detection, this approach attempts to reduce noise amplification from a perspective of intelligent algorithms. A distance-based AGC with a continuous proximity-effect compensation approach is presented in [24]. This proposal uses a distance sensor to determine distance between the microphone and a sound source, and uses this value to derive the gain.

In the same way, a solution to perform AGC in wireless sensors with low processing capacity is presented in [25]. This solution uses two algorithms to deal with the problem of automatically determining the volume level due to the unknown locations of the wireless sensors. The algorithms use energy level comparisons and phoneme classification to achieve improvements in the quality of the speech recognition.

Other research focuses on the scope of noise reduction on speech signals, as proposed in [23]. This research uses a BELBIC based model to reduce noise. Additionally, [26] presents an approach for Active Noise Control (ANC) based on two approaches for the attenuation of impulsive noise. The first approach is based on the on-line estimation of an SαS model of the noise probabilistic description, while the second relies on an on-line recursive procedure that reliably estimates amplitude thresholds for outlier detection.

III. SA^{3}M: An Autonomous Support System for Older Adults

A. General Design and Functionalities of the SA^{3}M Robot

SA^{3}M (autonomous support system for older adults, from the Spanish, Sistema Autónomo de Apoyo al Adulto Mayor), is a tool designed for the aid and assistance of older adults, with the primary objective of improving their quality of life. This tool consists of a static robotic structure formed by a torso, arms and head, which were constructed using a 3D printer. Similarly, its programming logic and functioning are based on a scalable and adjustable modular scheme, as shown as in Figure 1. Each module performs a specific task, supporting SA^{3}M's autonomy and interactive functioning. Below, the system's main modules are briefly described:

- Sound Source Localization Module: Determines the location of a sound near SA^{3}M. This process utilizes the interaural time difference and is able to locate sound sources in space.
- Face Detection and Facial Recognition Module: Identifies a person using face detection (Haar Wavelets) and facial recognition (Fisherfaces). With this module, the history of the older adult can be uploaded, providing support for the supply of medicines, medical appointments, etc.
- Environmental Status Sensing Module: Captures and identifies various signals from the environment in which SA^{3}M is located. This process allows for interaction between SA^{3}M and the end user and utilizes the following sensors: two distance sensors, one sonar sensor, one CO2 sensor, and one gas sensor.
- Actuator and User Communication Module: Communicates between SA^{3}M and the end user. Requested information is displayed visually using an LCD monitor and delivered audibly using a TTS (Text to Speech) system. Additionally, this module defines how SA^{3}M performs movements controlled by voice command.

- Central Processing and Control Module: Coordinates the various processes of communication and interaction with the other modules. This module is the brain of SA^{3}M and is based on one minicomputer and two Arduino cards.

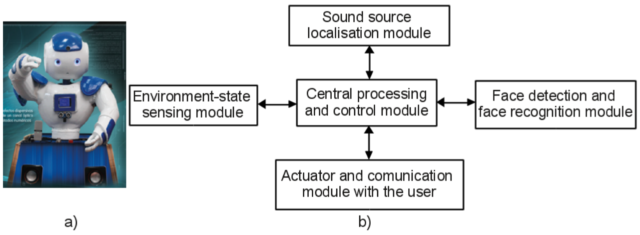

Figure 1 a) Images of SA^{3}M , b) Module Structure of SA^{3}M

B. A Fuzzy Logic Approach to Automatic Gain Control

To perform automatic gain control based on the conditions of the environment in which SA^{3}M is operating, a fuzzy logic control system is proposed. This system must control two main elements: the automatic contrast adjustment of the camera according to the level of illumination and the AGC of the microphone. In this paper, both the AGC and general controller design are explained.

The functionality of the fuzzy controller used to adjust the gain of the microphone is illustrated in Figure 2. When the ambient noise level is high, the fuzzy controller automatically reduces the gain of the microphone, and conversely, when the ambient noise level is low, the fuzzy controller automatically increases the gain of the microphone. The objective of the fuzzy controller is to provide a good quality audio capture for the posterior process of speech recognition. In the same way, the fuzzy controller adjusts the contrast level of the camera to perform better face detection and facial recognition.

Below are the hardware elements used to develop the AGC fuzzy controller:

- Samson USB microphone (frequency response from 18Hz to 18 KHz).
- SM20-A sound level meter to measure ambient noise.

The logical elements of the AGC fuzzy controller, consisting of fuzzy rules, input and output variables as well as membership functions are described below.

Fuzzy Input

Depending upon the environment where SA^{3}M is operating from, noise levels may range from silence to loud noise. It is important to note that noise or sound intensity is measured in decibels (dB), which is a logarithmic unit in which the level of sound pressure is expressed. This value is captured by the system to automatically adjust the gain of the microphone.

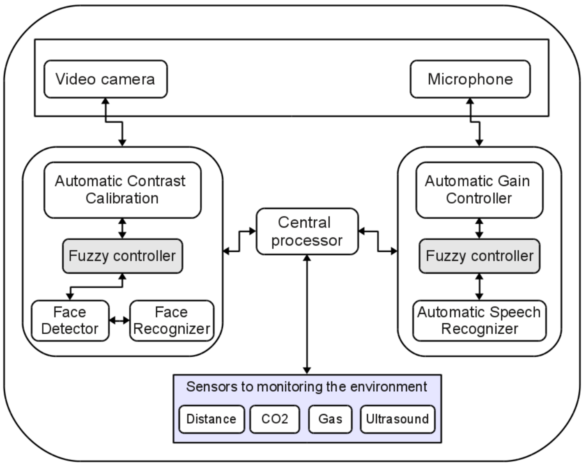

Figure 2. The interaction's schema of the fuzzy controller for AGC and automatic contrast adjustment.

In order to characterize the different dB levels in the environment, the following membership functions have been defined (Fig. 3): Very Low (0 to 30 db), Low (20 to 50 db), Moderate (40 to 65 db), High (60 to 105 db), and Very High (from 92 to 135 dB). The range of the above membership functions has been established based on those reported by [21].

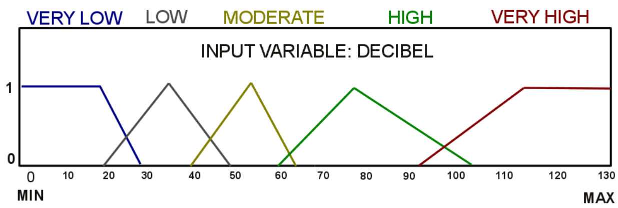

Figure 3. Membership functions for the input

Fuzzy Output

The output of the fuzzy system represents the gain of the microphone (Fig. 4), and is defined using the following membership functions: Very low (0 to 20%), Low (15 to 40%), Moderate (35 to 60%), High (55 to 90%), and Very High (85-100%).

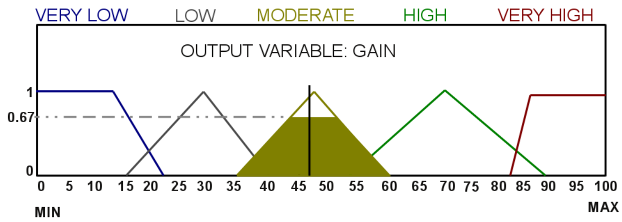

Figure 4. Example of output membership functions for an input of 51 dB.

Fuzzy Rules

To define the rules of the controller, an entry-exit relationship must be established in order to adjust the microphone gain, as shown in Table 1. Thus, it can be observed that when the ambient noise level is higher, the gain should be lower.

TABLE I. RULES OF INFERENCE

Level of Noise (input)	Very low	Low	Moderate	High	Very High
Microphone sensitivity (output)	**Very High**	**High**	**Moderate**	**Low**	**Very Low**

It is also important to note that for the modeling of the controller, fuzzy rules have been constructed using the FCL (Fuzzy Control Language) standard, which serve to define the rules that the system will implement.

Example:

RULE 0: IF (DECIBEL IS Very_High) THEN (GAIN IS Very_Low)

For example, as shown in Figure 4, when there is an input of 51 dB, the system automatically adjusts the microphone gain to 48.23%. In the Eq. (1) is depicted the formula to defuzzify the value obtained by inference process. The method used is the Center of Gravity:

$$G = \frac{\int_a^b \mu_M(x)xdx}{\int_a^b \mu_M(x)dx}$$

$$G = \frac{\int_{35}^{47.2}\frac{x-35}{47.2-35}xdx+\int_{47.2}^{52.5}0.67xdx+\int_{52.5}^{60}\frac{60-x}{60-52.5}xdx}{\int_{35}^{47.2}\frac{x-35}{47.2-35}dx+\int_{47.2}^{52.5}0.67dx+\int_{52.5}^{60}\frac{60-x}{60-52.5}dx} = 48.2 \quad (1)$$

Where:

- ***G*** represents the microphone gain (real value).
- ***$\mu_M(x)$*** is the membership function "Moderate" after accumulation.
- ***x*** represents the fuzzy output variable.
- ***a*** and ***b*** are the lower and upper defuzzification indices. For the given example, the defuzzification process goes from 35 to 60 (area defined by membership function).

To verify that the proposed system operated satisfactorily, a simulation was performed where the controller was fed various types of signals. Matlab Simulink® was used. The simulation model that was constructed is shown in Figure 5, in which the Fuzzy Logic Controller block contains the rules and the logic mentioned above. As seen, the proposed system is an open loop fuzzy controller where the input to the system is the decibel level and the output of the system is the gain of the microphone.

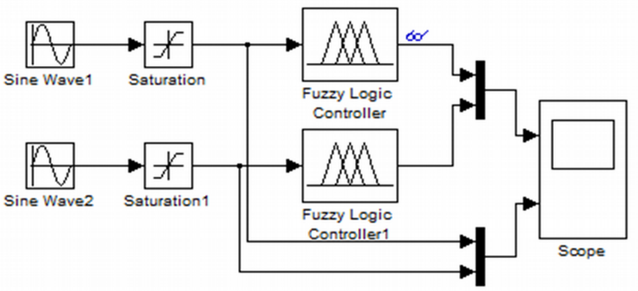

Figure 5. The proposed Fuzzy Controller Model.

In Figure 6 we can see an example with two of the signals with which the simulation model was fed. Both signals have the same frequency, but its amplitude is different. In doing so, it seeks to simulate a voice command that is fed to the robot.

The output obtained shows that the controller has the expected behavior, for example, the system automatically calibrates the microphone gain function of the amplitude of decibels entering it in order to have adequate gain to recognize more voice commands.

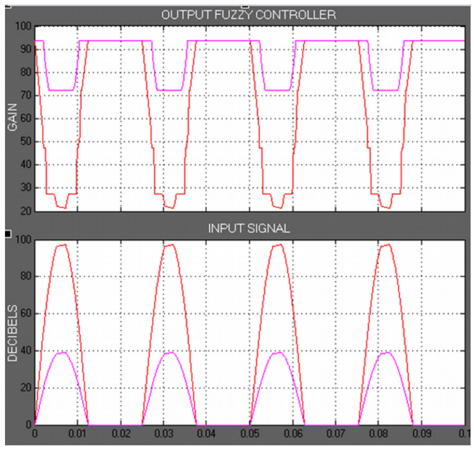

Figure 6. Response of the fuzzy controller using two signals of different amplitude.

IV. PRELIMINARY RESULTS

To determine the accuracy of the fuzzy controller, a pilot experiment was carried out in order to calculate the number of commands that were recognized under different noise environments. The test consisted of dictating 10 different voice commands to SA^3M and to vary the ambient noise level from 50 to 100 dB, in increments of 5 dB (14 in total). It is important to mention that the noise generated by a vacuum cleaner reaches approximately 70 dB, while an electric jackhammer reaches 100 dB. By using the proposed system, more voice commands were recognized despite the different levels of noise, as shown in Figure 7.

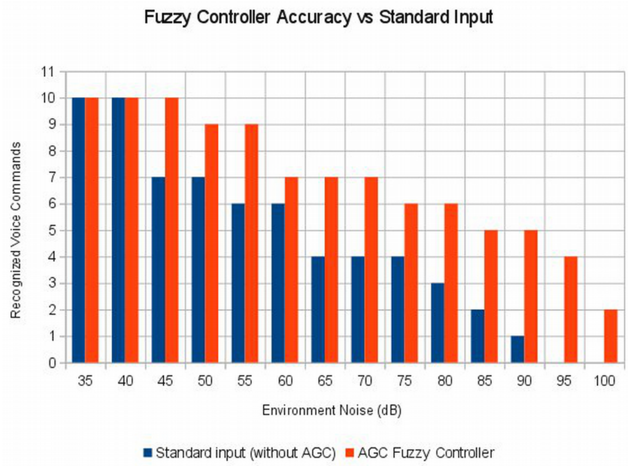

Figure 7. Recognized Voice Commands

V. Conclusions

Improvements made after the implementation of the fuzzy system were promising (more than 20 percentage points), particularly in noisy environments where the decibel level averaged a value greater than 70. The proposed system is based on a simple principle that is easy to adjust and modify. For example, if additional variables need to be added to determine the gain of the microphone, then more inputs and rules can be added to the fuzzy system. Additionally, this same principle can be utilized to address the challenge faced by users with low speech volumes.

When the ambient noise level exceeded 105 dBs, no voice commands could be recognized. This same principle of self-calibration based on fuzzy logic can be used in various sensors and applications, such as automatically calibrating the contrast of the image taken by SA^{3}M's vision module, using ambient light intensity as an input for the fuzzy controller.

As future work the following lines of research are proposed:

- Incorporate a method of active voice detection to better establish the gain of the user's voice against ambient noise.
- Analyze the possibility of using microphone arrays to increase the quality of the captured speech signal.

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