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Data Glove-Based Sign Language Translation with Convolutional Neural Networks

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Data glove-based sign language translation with convolutional neural networks

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Abstract— **This research was carried out because of the communication barriers that currently exist between hearing impaired and hearing people. These barriers hinder their integration into society and affect their interpersonal relationships. The objective of the study was to propose the development of a stationary assistive robot capable of displaying sign language interpretation through the combination of data gloves and the D-CNN and LSTM algorithm to facilitate the communication of hearing-impaired children in Huancayo. The triple diamond research design was used, where the mind map and the lotus diagram were used for the delimitation and definition of the problem. In addition, the IDEF0 technique was used to obtain a structured design of the project system. A morphological matrix was also used to choose the best solution for the problem. The chosen design contemplates the use of an Arduino UNO, flex sensors, accelerometers and gyroscopes for sign detection. The main algorithm consists of the union of a deep convolutional neural network and a LSTM for a correct sign classification module. The proposed design proposes to visualize the conceptual development of the project mentioned above.**

Keywords— ***Sign Language Recognition (SLR), Data glove, Convoluting Neural Network (CNN), long short-term memory (LSTM)***

I. Introduction

Sensory disabilities are the type of disability that most affect people's interpersonal relationships. For example, it is known that 33.8% of disabled people in Peru have deafness problems [1]. One of the best means to reduce the communication barrier is sign language, which constitutes a communication bridge for this type of people [2]. However, most hearing people do not understand sign language, and it is not easy to learn it [3].

Unfortunately, in Peru there are only 23 interpreters recognized in the Association of Interpreters and Interpreter Guides of Peru (ASISEP) [4]. This situation requires greater emphasis on the development of tools that can help in the recognition and translation of sign language. In this regard, there are two methods of sign recognition. In the first, a wearable glove with sensors is used to digitize hand movements and convert them into data [5]. On the other hand, in the second, a camera is required to achieve natural interaction. This project focuses on finding a solution that combines both methods to achieve much faster and more accurate results.

Most projects use image processing techniques and algorithms, such as convolutional neural networks (CNNs). Gruber, D., et al. use this algorithm for the classification and recognition of sign language gestures. In this study, a new dataset of these gestures was created. The dataset was acquired using the Kinect v2 device and consists of recordings from 18 different individuals [6]. On the other hand, Amin, M., et al. use CNN algorithm on the extracted sequences to identify the recognized activity according to the approach. Depth images were acquired using a high-resolution Kinect camera [7]. In the present work, the CNN technique is also used for gesture recognition and identification.

Systems developed for gesture recognition usually come in two different forms. In the study of Ismail, F., et al. only computer vision methods are used for gesture recognition [8]. In the present work, the use of machine vision with CNN and sensors in a glove is proposed to achieve higher accuracy in the results. On the other hand, Ocampo, J., et al. use a wearable glove with sensors for gesture recognition [9]. This research proposes the use of a wearable glove and an auxiliary robot to interact with the user.

With all the above described, the main objective of the research is to propose the development of a stationary assistive robot with convolutional neural networks, flexural sensors, and gyroscope to interpret and facilitate the communication of hearing-impaired children in Huancayo. Section II describes the triple diamond methodology, the proposed method composed of a CNN and LSTM model, the electronic circuit of the glove for its proper development, and the flowchart of the algorithm. Section III details the results and discussion.
Finally, Section IV outlines the main conclusions of the project and areas for future application.

II. METHODOLOGY

A. Type of research

There are different types of research, in which many researchers have their point of view. Each develops its own merits and the value it holds for humanity [10]. Quantitative research focuses on numerically measurable aspects of phenomena and uses statistical tests for data analysis to explain the phenomenon through the deductive method [11] that is why mathematical, statistical and computational tools were used to develop the algorithm that recognizes sign language. This measure will be calculated based on the accuracy in the recognition of signs, and graphs will be created from which an average will be drawn for further conclusions.

B. Research design

Method standards describe how to develop something. In addition, they describe the guidelines of the development method to achieve a good overall engineering result [12]. The triple diamond framework (Figure 1) is proposed as an extension and adaptation of the double diamond proposed by the British Design Council [13], it was decided for the triple diamond design because it has more details in the design and development part. In addition, the first diamond, which is the "research" part, was already developed. On the other hand, the triple diamond design is not widely used in current research and was considered to be the best choice for our research article and our topic.

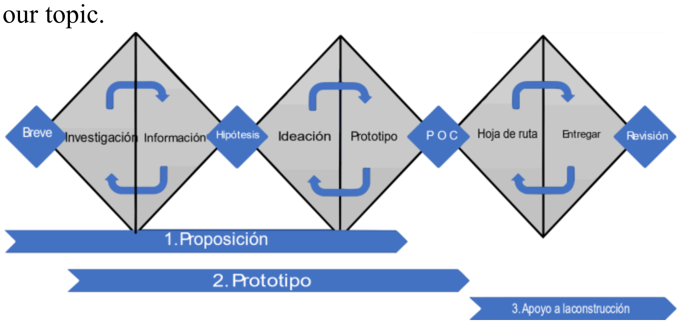

Fig. 1. Triple Diamond Design. Proposal:

This section details the activities carried out to narrow down the topic of the project. Among them are the delimitation of the topic, brainstorming, problem definition and information search for project planning.

C. Idea organizers

Idea organizers are tools that help to focus, synthesize and delimit the important information of a topic. Two types of organizers were used for this research: the mind map and the lotus diagram [14]. The mind map:

The mind map is a tool that helps to promote learning by concepts. It consists of presenting information graphically and in a structural network [14]. The central theme was assistive robotics, which was the starting point for the different topics such as artificial intelligence, target audience, fields of action, among others, as shown in Fig. 2.

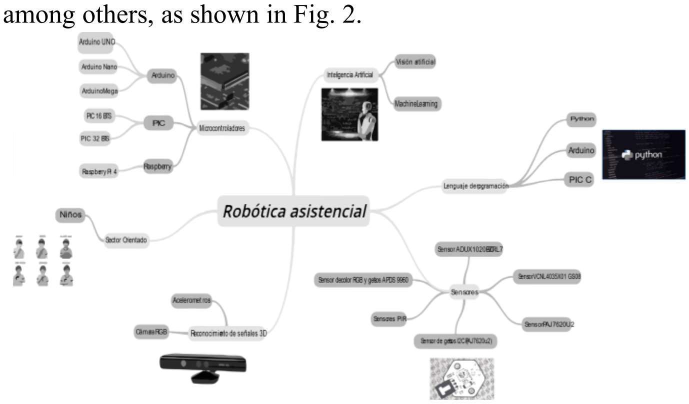

Fig. 2. The Mind Map. Lotus

diagram:

It is a cognitive-analytical tool characterized by a simple visual scenario that relates a main theme to several sub-themes and helps to define key concepts or parts of a larger picture. The center of the diagram represents the main idea, and the eight boxes surrounding it represent additional concepts [15]. Based on the above, the Lotus diagram is divided into eight main themes: digital image processing technology, microcontroller, sensors, 3D signal detection, industry-oriented, programming language, robot shape, and finally artificial intelligence, as shown in Fig. 3.

Fig. 3. Lotus Diagram.

D. Morphological analysis

Morphological analysis is a method in which an in-depth study of each specific part of the project subject is carried out. This technique is divided into three parts: analysis, morphological search and combination [16]. Analysis:

In the analysis process, the identification and characterization of the subject was performed, which was defined as "Robot oriented to sign language translation".

Morphological search:

In this process, a thorough search of 49 research articles related to the topic defined above was conducted. Then, a filter was applied to these 49 articles, from which the 25 most important ones were chosen. Finally, a second filter was applied to these 25 articles, from which the 11 most important were chosen. Combination:

In this process, three main topics were selected, which were: sensorics, microcontroller and artificial intelligence, each with their respective subtopics. From this choice, three morphological analysis tables were made, with all the possible combinations found in the search for articles.

Términos	Sensorica	Microcontrolador	Inteligencia artificial
Elementos	Sensores flex Acelerómetros Giroscopios	Arduino pro mini Arduino leonardo Arduino Mega Arduino Uno	Deep learning Algoritmo k-Nearest Neighbor Redes neuronales convolucionales Machine learning

Fig. 4. Table of morphological analysis with the studied elements and terms (1).

Análisis M.	Microcontroladores			
Sensórica	Arduino pro mini	Arduino Leonardo	Arduino Mega	Arduino UNO
Sensores flex	6,2	7,13	9,11,15,18,16, 25	10,11,18,19,22,24 , 25
Acelerómetros			11,15	10,11,24
Giroscopios	6,2	7,13	12,15,16	10,22,24

Fig. 5. Table of morphological analysis between microcontrollers and sensorics (1).

Análisis M.	Microcontroladores			
Inteligencia Artificial	Arduino pro mini	Arduino Leonardo	Arduino Mega	Arduino Uno
Deep learning	2		12,25	25
Algoritmo k-Nearest Neighbor			21,17	
Redes neuronales convolucionales			11,16	11
Machine learning	6	7,13	9,15	10,18,22

Fig. 6. Table of morphological analysis between microcontrollers and artificial intelligence (2).

Análisis M.	Inteligencia Artificial			
Sensorica	Deep learning	Algoritmo k-Nearest Neighbor	Redes neuronales convolucionales	Machine learning
Sensores flex	1,3,5,16,25	8,23,25	1,2,4,5,13	6,7,8,14,16,22
Acelerómetros	1,3,5	20,17		6,8
Giroscopios	1,16,25	20,17	1,2	6,7,14

Fig. 7. Table of morphological analysis between artificial intelligence and sensorics (3).

Subsequently, after analysis of the tables, the following possible combinations were determined:

- Flex sensors with gyroscope controlled with an Arduino Pro Mini and the use of convolutional neural networks.
- Flex sensors with gyroscope controlled with an Arduino UNO and the use of Machine Learning.
- Flex sensors with gyroscopes and accelerometers controlled with an Arduino UNO and the use of Machine learning.
- Flex sensors controlled with an Arduino UNO and the use of Deep learning.
- Flex sensors with gyroscopes controlled with an Arduino Mega and the use of Machine Learning.

Finally, the chosen combination was "Flex sensors with gyroscope controlled with an Arduino UNO and the use of convolutional neural networks".

E. IDEF0

It is a technique used for the analysis and structured design of a project system. It is used to improve productivity and as a tool to combine actions and methods that contribute to the achievement of a specific goal. Its main advantage is its structure, as it contributes to a better integration of work among multiple developers [17].

One of the main features of IDEF 0 is its decomposition possibility. That is, it allows us to create a higher-level schema to later divide it into different lower-level activities [18].

On the other hand, the IDEF0 model is composed of boxes, arrows and diagrams. These boxes represent the functions defined as activities, processes or transformations. The arrows, in turn, represent the data associated with these functions [19].

This is the method chosen for decision-making, actions and activities throughout the development of the project. It consists of a tree structure of nodes used to decompose the main theme and objectives. This decomposition includes the control of the activity (C), its inputs (I), its outputs (O) and its mechanisms (M).

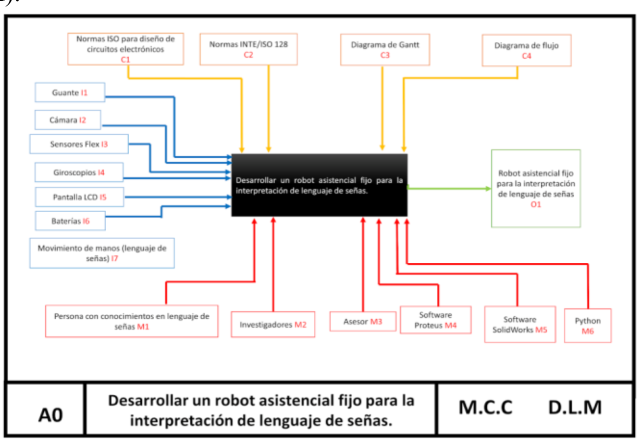

Fig. 8. IDEF 0 A0 diagram (Developing a stationary assistive robot for sign language interpretation).

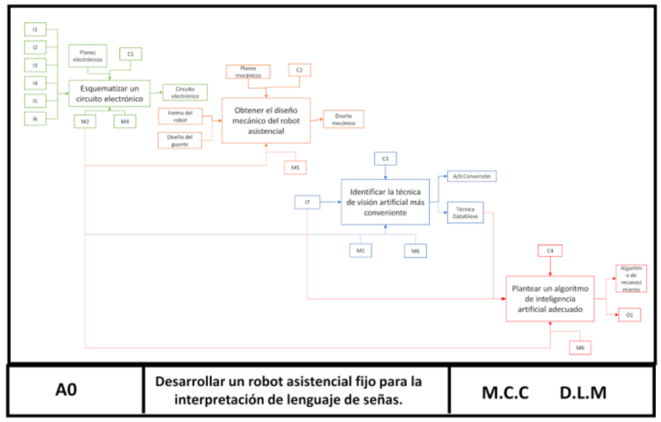

Fig. 9. IDEF 0 A0 Diagram (Specific objectives).

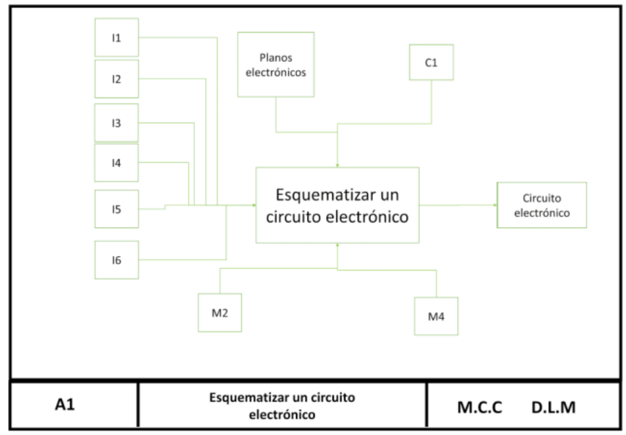

Fig. 10. Diagram IDEF0 A1 (Schematic diagram of an electronic circuit).

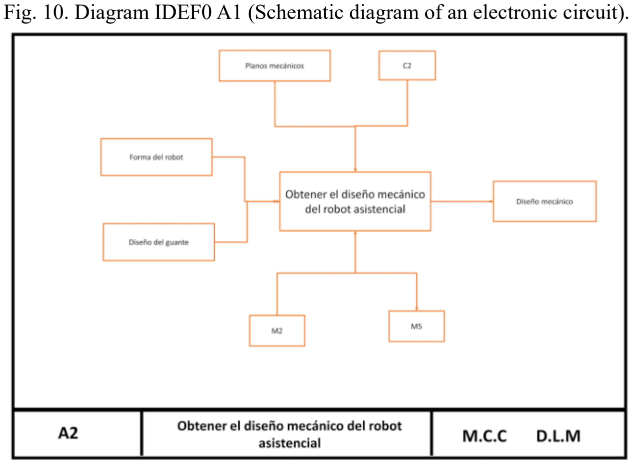

Fig. 11. IDEF 0 A2 diagram (Obtain the mechanical design of the assistive robot).

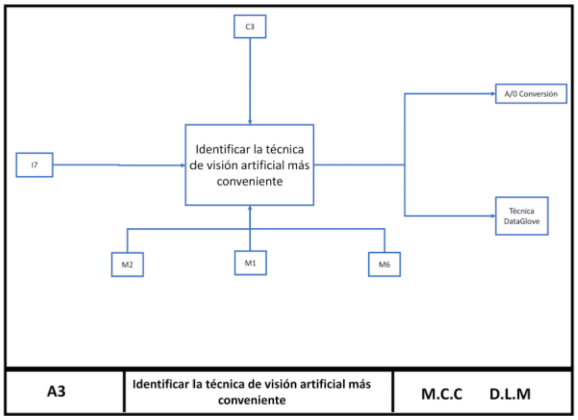

Fig. 12. Diagram IDEF0 A3 (Identify the most suitable machine vision technique).

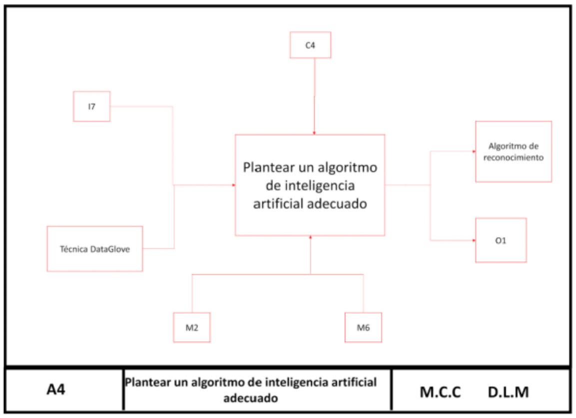

Fig. 13. Diagram IDEF0 A4 (Propose a suitable artificial intelligence algorithm).

Figure 8 shows the IDEF0 diagram A0. This is the initial diagram, which starts from the main topic of the project, defined as "Development of a fixed assistive robot for sign language interpretation". In addition, Figure 9 shows the IDEF0 A0 diagram considering the four specific objectives of the project. It can also be seen how some inputs, controls, mechanisms and outputs are related to each other. On the other hand, Figure 10 shows diagram A1 of IDEF0. This shows the first objective, which is "To schematize an electronic circuit". Figure 11 shows IDEF0 schematic A2. This shows the second objective, which is "To obtain the mechanical design of the assistive robot". Also, in Figure 12, the scheme A3 of IDEF0 is observed. This is the third objective, which is "Identify the most suitable machine vision technique". Finally, in Figure 13, IDEF0 scheme A4 is observed. These evidences the fourth objective, which is "To propose a suitable artificial intelligence algorithm".

F. Morphological matrix

The morphological matrix enables the project designer to select the best design concepts by systematically combining the possible options for each sub-theme. In addition, it is sought that each part can satisfy each partial function [20]. Although this tool does not serve as a substitute for creative thinking, it is a good structured means capable of developing different design alternatives. Moreover, it allows exploring each alternative without being limited to human short-term memory [21]. This section details the aspects considered for the choice of the best solution, from which three possible solutions are derived and one is determined as the best option.

Funcionalidades	Soluciones			
	1	2	3	4
Placa de desarrollo del tamaño adecuado y con el correcto número de pines	Arduino Uno (A.1)	Arduino Mega (A.2)	Arduino mini (A.3)	Arduino nano (A.4)
Software de diseño mecánico	SolidWorks (B.1)	Inventor(B.2)	AutoCAD (B.3)	
Software de diseño electrónico	Proteus (C.1)	Multisim (C.2)		
Lenguaje de programación	Python (D.1)	C++(D.2)	Processing (D.3)	
Sensores adecuados para obtener los datos con mayor precisión	Sensores Flex, acelerómetros y giroscopios (E.1)	Cámara(E.2)		
Comunicación y transmisión de datos rápida y eficiente	Módulo Bluetooth HC-05 (F.1)	Módulo WIFI ESP8266(F.2)	Módulo ESP32 (F.3)	
Máxima potencia y autonomía	Alimentación AC (G.1)	Batería de litio(G.2)	Batería de Níquel-Cadmio o(G.3)	
Materiales resistentes del chasis del robot	Aluminio (H.1)	ABS (impresión 3D) (H.2)	PLA (impresión 3D) (H.3)	MDF (H.4)
Interacción sencilla y agradable con el usuario	Pantalla Nextion NX1060 P101(I.1)	Display LCD en matriz de puntos(I.2)	Display OLED (I.3)	
Modelo y forma del robot fijo	Forma de perro(J.1)	Forma de gato (J.2)	Forma de caricatura (J.3)	Forma de dinosaurio (J.4)
Algoritmos de clasificación	K NN (K.1)	CNN (K.2)	D-CNN(K.3)	LSTM (K.4)

Fig. 14. Morphological Matrix

Solution 1: A.1 + B.1 + C.1 + D.1 + E.1 + E.1 + F.2 + G.1 + H.2 + I.3 + J.2 + K.3

Solution 2: A.2+ B.2+C.1+ D.3+ E1+ F.1+ G.2 + H.2+ I.2 + J.4+ K.3

Solution 3: A.3 +B.1 + C.2 + D.1 + E.2 + F.3 + G.3 + H.3 + I.1 + J.1 +K.2

Solution 4: A.4 + B.3 + C.2 + D.2 + E.2 + F.2 + F.2 + G.2 + H.4 + I.3 + J.3 + K.1

Solution 5: A.2+ B.2+ C.1+ D.1+ E.1+ F.1+ F.3+ G.1+ H.1+ I.1+ J.1+ K.4

The solution chosen was number one because it has greater feasibility in both technical and economic terms. This solution represents a combination of methods for data acquisition (sign language) and the classification algorithms used.

G. Problem situation and objective

According to the World Health Organization (WHO) [22], sensory disability refers to people who have lost the ability to see or hear and have trouble speaking or communicating. In this sense, hearing impairment in Peru is a condition that has affected many Peruvians for a long time, due to various factors such as genetic or environmental causes. This leads to the search for a way for people with this disability to communicate, either among themselves or with people who do not suffer from it, thus finding sign language, which more or less helps this sector. Although there are efforts to disseminate this language and get more people to learn it, there are few tools or means to facilitate it, and there is no barrier between people who know sign language and those who do not. Therefore, we propose the approach of a fixed assistive robot using CNN and LSTM algorithm and a glove equipped with flexible sensors to translate sign language.

H. Project overview

This section provides an overview of the process. It starts with the flexible sensors and accelerometers that collect the data to be used. The second block consists of the conversion of the data into bits, where the Arduino, together with the algorithm and the training set, performs the feature extraction and finally the classification of the gestures [23]. Finally, it can be seen that all the above processes are displayed on the LCD screen through IoT communication as shown in Figure 15.

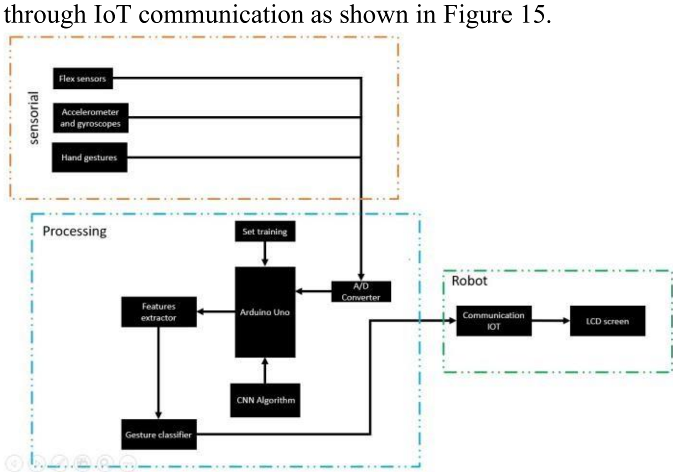

Fig. 15. Overview of sign interpretation system that consists of three modules.

I. Electronic design

This type of gloves is designed with sensors capable of detecting movements and reading sign language, to process it and convert it into text or sound to facilitate interaction and communication. In addition, algorithms can be worked with this data to make the recognition in real time and fluid [24].

Glove: Data for gesture recognition were collected with the glove device.

The glove measurement system consists of 10 sensors: ● 5 finger flexion sensors for each finger: thumb, index, middle, ring, and little finger (however, flexion of individual phalanges of a finger is not recorded),

● 3 accelerometers for each of the X, Y and Z axes, ● 2 gyroscopes: roll and pitch.

Figure 16 shows the battery-powered data glove. Data is collected on sensor arrays attached to the glove and the Arduino microcontroller. In this section, the three-dimensional finger flexion and position data are fed into a signal processing module through a CNN algorithm used to filter and analyze the motion signals. The communication module is used to exchange data and display this filter as well as the classification on the screen and display the required word.

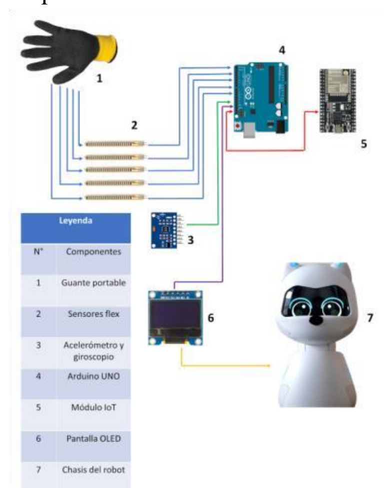

Fig. 16. Electronic design.

J. Algorithm

There are different types of classification algorithms, which can be implemented on different types of datasets. Moreover, each algorithm is specifically used to detect different objects due to its capabilities [25].

The main type of classification used in this project is the CNN algorithm. It is divided into two parts. The first part is called the future learning, where the convolution layer, the linear rectifying unit and pooling stand out. On the other hand, the second part is called the classification layer [25].

Codes were developed in Arduino and Python that transmit the prototype signals online. The acquisition web page of this data, together with the neural network, were used as input for the real-time prediction of the desired letter, which was reproduced through other codes developed in Python. The flowchart used for the operation of the prototype translator is presented in Fig. 17. Note that the training process is performed only once to obtain the parameters to work with in real time.

In the flow diagram presented in the project, the data input, which is determined by the flex sensors, accelerometers and gyroscopes, can be seen. Subsequently, the data acquisition for training and validation is performed. These data are stored in the Arduino database, so that from there the extraction of features and classification of gestures is generated.

This gesture classification is divided into training and validation. The training of the algorithm consists of a multilayer Perceptron neural network to be developed in Python, which depends on the training accuracy coefficient. On the other hand, the validation of the algorithm will also be developed in Python, from where the validation accuracy coefficient is extracted.

If any of these two coefficients is not acceptable, it will return to the multilayer Perceptron neural network process, until favorable results are obtained.

While all this is happening, real-time data acquisition is generated thanks to the communication between Arduino and Python, where the data will be online. Thanks to this, a real-time prediction can be generated, which will also be performed in Python.

Once the values of the acceptable coefficients have been obtained and the real-time prediction has been generated, the translation of the signals can be generated using an Arduinocompatible LCD.

Finally, it is evaluated if there is a new signal, to restart the whole process. If not, the system terminates.

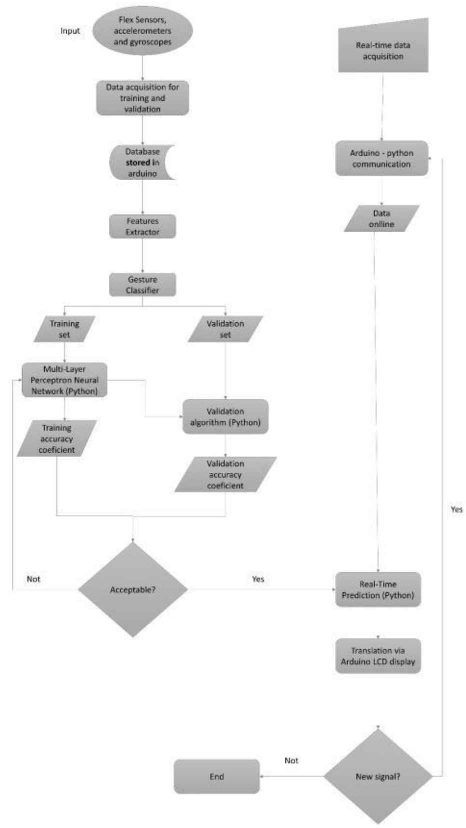

Fig. 17. Flow chart.

In this paper, a hand motion classification software is developed using a data glove. The modules of this software include: Hand gesture acquisition, data preprocessing, classification and hand gesture application. The classification module plays the main role and consists of a deep convolutional neural network and an LSTM.

The rationale for the choice of Deep Learning and LSTM is that the mechanism should be able to perform the task in the same way as the biological nervous system. The latter is defined as a cascade of multiple layers of processing units for feature extraction and information retrieval [26]. In this case, we know that each layer knows to use the output of the previous layer as input to the next layer.

III. Results and discussion

An in-depth data collection was carried out in order to find the best solution. From this study, solution 1 was chosen as the one that presented the best results. This was carried out thanks to the triple diamond methodology that, unlike its peers such as the VDI 225 or VDI 2226 methodology, the methodology proposed for this project allowed greater freedom when designing all the parts required, by this we mean the number of designs that can be made at the time of choosing one methodology or another. In addition, this methodology gave us a clear guide of the steps to follow when collecting information and designing prototypes. This led to the electronic designs and the procedural sequence that the algorithm will follow for the correct interpretation of the signs. In addition, the different criteria that were taken into account for the economic and mechanical side in search of a cost-effective and functional project.

IV. Conclusion and future work

In this paper, a new glove is designed to collect gestural data and classify them efficiently with an algorithm based on DCNN and LSTM. It thus introduces a rare way to collect data in this way. It is based on a joint work of both algorithms that allows more complex gesture recognition in different categories. The design of a deep D- CNN network helps to achieve all the requirements such as maintaining processing time and providing accuracy.

The methodology used satisfactorily fulfills the data collection and prototyping aspects for the development of the project and allows a clear and orderly development for the researcher. In addition, this methodology is an alternative with potential for future projects, since it is not so widely used. Although the conceptualization phase is finished, we consider that this whole process is necessary to start with the tests or simulations with greater reliability.

As future work we will implement the proposed algorithm to determine its effectiveness and its relationship with the glove that allows data collection. It is hoped that a future study will be conducted to test the efficacy of this prototype on multiple hearing-impaired individuals. This would provide the first results for an analysis of the integration of people with these abilities into society.

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