ADVANCES IN CYBER-PHYSICAL SYSTEMS

Vol. 6, Num. 2, 2021

COMPUTER SYSTEM FOR CONVERTING GESTURES TO TEXT AND AUDIO MESSAGES

[1]Dmytro Borovets, [2]Tetyana Pavych, [1]Yaroslav Paramud

[1]Lviv Polytechnic National University, 12, Bandera Str, Lviv, 79013, Ukraine.
[2]MedBridge Inc, 1633 Westlake Ave, Seattle, WA, 98109, USA.
Authors' *e-mail: dmytro.borovets.mki.2020@lpnu.ua; tpavych98@gmail.com; yaroslav.s.paramud@lpnu.ua*

https://doi.org/10.23939/acps2021.__.___
Submitted on 10.10.2021
© Borovets D., Pavych T., Paramud Y., 2021

Abstract: Today, there are quite a large number of deaf-mute and hard-of-hearing people which communicate using gestures. Therefore, it is simply necessary to provide them with modern means of communication with the surrounding world. This paper creates a holistic computer system architecture for converting gestures into text and audio messages. The principles of construction and basic design solutions of a computer system based on a modern element base with increased productivity and minimization of hardware costs and energy consumption have been developed. The most popular existing solutions for gesture recognition are considered and analyzed. The operation of the main components has been described, the principle of functioning of the entire system has been analyzed, and their advantages and disadvantages have been compared. The latest structural components for building a computer system (both physical and software) have been selected and investigated. Physical features include: the state-of-the-art Arduino Nano computing platform, the HC-05 Bluetooth module, the ADXL335 accelerometer, and the latest ZD10-100 Information sensor (flexibility sensor). Software features include: firmware for the Arduino Nano hardware platform, Python-based software for splitting the flow of letters into words, displaying them, and voicing them. The methods of Google Media Translation API and Google Text-to-speech (gTTS) have been analyzed. The expediency of conducting research has improved performance through the use of a new information sensor, which is a flexibility sensor ZD10-100 500 g. The general structural scheme of all systems has been designed.

***Index Terms*: computer system, gesture, computing platform, module, serial port, firmware, sensor, thresholding**

I. INTRODUCTION

Today, there are about 1.5% of people with partial or complete hearing loss, which is about 70 million people from 123 countries. According to these statistics, every 9th person in the world suffers from this disease. There are about 40,000 of such people in Ukraine. Therefore, it is simply necessary to provide such people with equal opportunities to communicate with each other and with people around them.

The so-called "Sign Language" comes to the aid of such people. It provides an opportunity for deaf and dumb people to communicate with each other. But it does not solve the problem of communicating with people who do not speak the language [1].

From a technical point of view, the development of modern science, computerization of society, the use of multimedia and Internet technologies create sufficient conditions for the development of computer systems and programs for communication of these people in forms and images understandable to them and the world.

II. REVIEW OF LITERATURE SOURCES

In [1] presents the world and all-Ukrainian statistics of deaf-mute people. The means of communication of these people are also spilt.

In [2] shows the patent of the computer system Enable talk for converting gestures into text and audio messages, as well as describes the principle of its operation, structure and element base of the device.

In [3] describes the computer systems NuGlove, Interact, Droid Agent for converting gestures into certain symbols and commands, as well as describes the principle of their operation, the element base of the device and the structural component.

In [4] presents a computer program

and a mobile application for converting gestures into text information describes the principle of their structural and the principle of operation.

In [5] gives the meaning of the word "Gesture", its varieties and meaning.

In [6] states what "Sign Language" is, its varieties, analysis and stages of development.

In [7] describes the Arduino Nano microprocessor computing platform. The main technical characteristics are given. Its structure, structural elements and programming tools are displayed.

In [8] shows the datasheet of the analogue accelerometer ADXL335. The main technical characteristics are given. Its structure and electrical schematic are shown.

In [9] describes the Bluetooth module HC-05 for the Arduino Nano computing platform. The main technical characteristics are given. Its structure and schematic diagram are reflected.

In [10] describes the latest information sensor, which is the flexibility and pressure sensor ZD10-100 500g. The main technical characteristics are given. Its structure and electrical schematic are shown.

In [11] describes the high-level python programming language.

In [12] provides information about the Word Segment segmentation module for the Python programming language. And also the principle of its work is described.

In [13] provides information about the Google translation module, its functions, capabilities and translation techniques.

In [14] provides information about the Google Text-to-speech module for the Python programming language. And also the principle of its work is described.

In [15] provides information about the Google Media Translation API. And also the principle of its work is described.

A review of these sources allows us to conclude about the relevance of research on this topic.

III. THE PURPOSE OF THE ARTICLES

The purpose of the work is to design a computer system for converting gestures into text and audio messages at the level of structural diagrams, on a modern element base with increased productivity and minimizing hardware costs and energy consumption. Which will help people with hearing and speech impairments to communicate properly with their surroundings.

IV. REVIEW OF EXISTING METHODS FOR SOLVING THE PROBLEM

Today, there are solutions for gesture recognition and sign language in the form of Enable Talk, NuGlove, SignAll and others. These systems perform gesture transformations into ordinary spoken language.

Enable Talk - This is a pair of gloves that, using a set of sensors and software for smartphones, can change the way deaf people communicate with the world around them.

This project is a pair of gloves, which includes a microcontroller, 15 flexibility sensors, an accelerometer, gyroscope and compass to determine the position of the glove in space, a Bluetooth module for data transfer from gloves to a mobile device and a USB port for synchronization with a PC.

Enable Talk is a system that consists of two parts - hardware and software, which is designed for Windows Phone. The glove is connected to the mobile device using Bluetooth technology.

The principle of operation of the device. To begin with, you need to form a certain gesture that will affect the performance of the built-in Flex sensors and positioning sensors in the space of the accelerometer and gyroscope. Then the indicators of these sensors will be processed by a microcontroller and transmitted to a computing device (PC, tablet or smartphone) using Bluetooth technology.

On a computing device, thanks to special software, the information received from the microcontroller are interpreted into a sign system of sign language for the deaf and dumb. After interpretation, the obtained data are converted into words and sentences and displayed on the screen, as well as their sounding [2].

Enable Talk is quite an efficient gesture conversion system, but it requires a lot of computing power from the information processing device, works only on the Windows platform, and by the standards of modern technology is considered obsolete, as it is 10 years old.

NuGlove is a smart glove from AnthroTronix USA. It is a computer system with a set of gyroscope sensors, magnetometers and accelerometers for positioning the hand in space and placing the fingers relative to the palm of the same hand. Based on NuGlove, the INTERACT project is built, which provides multimodal feedback for learning environments with immersion to promote learning to acquire multimodal skills.

NuGlove provides gesture recognition and tactile feedback to the listener. Combined with the virtual learning environment, INTERACT will create a whole new exciting experience of virtual immersion with VR virtual reality glasses.

NuGlove is also used in the DROID AGENT project. This project serves to evaluate, guide and as an engineering tool to design a dynamic robot interface for the operator. The purpose of DROID AGENT is to promote the machine learning of medical procedures to support an automated system of education and training for physicians [3].

The main disadvantages include the fact that this system does not accurately determine the position of the hand in space when demonstrating gestures, wired connection to a computing device, the lack of specialized software to convert gestures into a sign language system for the deaf and dumb, and the lack of a mobile solution.

SignAll is one of the world's first programs that provides communication between deaf people and their environment through ASL translation technology. SignAll has developed technology to use artificial intelligence and computer vision that can recognize and translate sign language. SignAll uses machine translation and natural language processing. The main SignAll all technology is a visual entrance from the outside world. Visual input can be done through one or more cameras. The combined experience of developers, researchers, linguists and sign language experts has allowed SignAll to use technology to collect and analyze key elements of sign language. Capturing these components is the first step towards effective sign language translation. The conversion process is as follows:

- Capture visual data;
- Data Processing;
- Selection filtering;
- Choosing the right translation;
- Presentation of a single answer.

The disadvantage of SignAll can be considered a paid subscription to the program because it is not affordable for everyone, as well as a low accuracy of gesture recognition in poor or completely absent lighting [4].

V. THE MAIN MATERIAL OF THE STUDY

A gesture (a form of nonverbal communication) is the movement or action of a specific part of a person's body, usually a hand, that carries a well-defined context or meaning to reflect certain information or emotion. A gesture is a full-fledged sign or symbol that carries a communicative orientation and exists on a par with other means of communication.

Every gesture rarely exists in its "pure" form. Most often, the gesture is accompanied by appropriate facial expressions and posture. For the deaf and dumb, for the most part, a gesture means the letters of the alphabet and the numbers of the language they speak. Gestures allow these people to convey a variety of feelings and thoughts, from contempt and hostility to approval and affection, often with body language. The set of gestures forms the so-called sign language [5].

Sign language is a means of communication for people with partial or complete hearing loss (deafblind), which is analogous to ordinary language. Sign language is a full-fledged language where words are pronounced using so-called gestures. Everyone can understand a gesture. Many gestures are quite logical and understandable because mostly gestures duplicate the actions and phenomena described by the interlocutor.

Sign language is usually used by everyone when they do not want to speak, but it is the only means of communication for deaf people. Sign language is an equal language and has the same meaning as spoken language. This language is divided into two forms: spoken and tracing.

The conversational form is an independent kinetic system in which there are enough gestures for interpersonal, informal communication of the deaf and dumb. With the help of a conversational form, communication about everyday life and everyday topics is carried out. This form is directly related to the situation in which the conversation takes place.

A tracing form is a form of communication in which gestures duplicate the speaker's oral words. Gestures are analogous to these words. This form does not have the grammatical structure of words according to the verbal language, it only copies it.

Today, there are as many sign languages as there are ordinary languages in the world, but unfortunately, there is no universal sign language. Each sign language is formed based on the cultural traditions and history of a particular country. Therefore, even sign language has certain dialects and features of the same intensity, which are mixed. Each color has its own weight when mixing, and depending on this, the resulting image will contain more information from the channel that has the highest weight.

Thus, sign language acts as a full-fledged and independent sign system of communication for deaf people, with its own rules and features [6].

The project was based on the American Sign Language (ASL). ASL is the primary language of communication in the deaf-mute communities of the United States and the English-speaking population of Canada. In addition, ASL dialects are spoken by many countries around the world, mainly in West Africa and Southeast Asia. The American alphabet ASL is shown in Fig. 1.

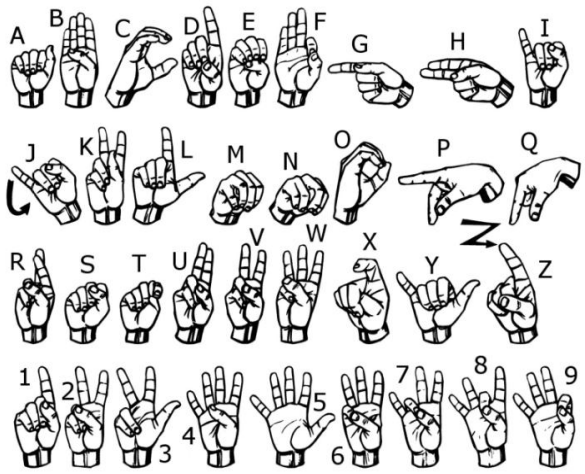

Fig. 1. American sign alphabet for the deaf and dumb

VI. SYSTEM COMPONENTS

The developed system includes the following components: hardware, which is based on the computing platform Arduino Nano, analogue accelerometer Adafruit ADXL 335, Bluetooth module HC-05 and Flex sensor (bending sensor) ZD 10-100 500g.

The software part is the firmware for the Arduino hardware computing platform. Python-based software is for expanding the flow of letters in words, their display and sound.

A. HARDWARE PART

Arduino Nano hardware computing platform;

Arduino Nano is a multifunctional device, rather small size of which is based on the microcontroller ATmega 328 in Arduino 3.0 with an operating frequency of 20 MHz. The Arduino platform is quite popular and user-friendly in today's world due to its open architecture and software code. As well as the Processing / Wiring development environment, which is a simplified version of the C / C ++ programming languages. Arduino Nano is programmable via USB without the use of a programmer. The Arduino Nano board consists of an ATmega 328 microcontroller, as well as binding elements for programming (USB programmer FT232R) and integration with other devices (I / O connectors). The block diagram of the Arduino Nano is shown in Fig. 2.

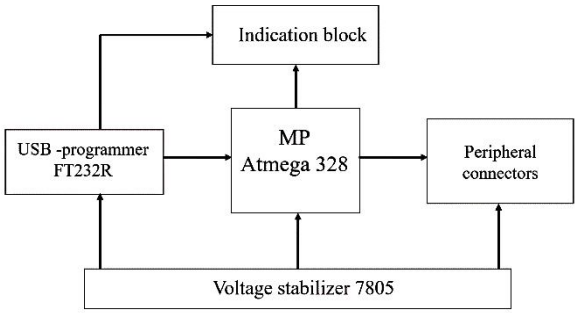

Fig. 2. Block diagram of Arduino Nano

In a computer system, the Arduino Nano hardware computing platform acts as an I / O and information processing module, a computing processor module, a memory module, and an output signal synthesis [7].

Thanks to its characteristics and functionality, the Arduino Nano fully meets the requirements of a computer system for gesture conversion.

Analogue accelerometer Adafruit ADXL335;

In this computer system, the analog accelerometer Adafruit ADXL 335 works as a high-precision positioning module for the hardware of the computer system (smart glove) and marks it in space. With such indicators, the Adafruit ADXL 335 accelerometer increases the overall accuracy of gesture recognition systems. The ADXL335 is a miniature, energy-efficient, multifunctional triaxial accelerometer with remote signals in accordance with the voltage and analog signal conversion scheme.

The ADXL335 is able to measure static acceleration, which affects gravity, determines the angle of deflection, as well as dynamic acceleration, which is associated with movement, shock or vibration. The bandwidth of the accessories can be adjusted with capacitors CX, CY and CZ, which are connected to the educators XOUT, YOUT and ZOUT. Depending on the needs of the programs, the bandwidth can be selected in the range from 0.5 Hz to 1600 Hz for the X and Y axes and from 0.5 Hz to 550 Hz for the Z axis. Features ADXL335:

- Chip: ADXL335;
- Supply voltage: 3-5V;
- Current consumption: 30 μA;
- Measurement range: -3.6 g-3.6g;
- Sensitivity: 300 mV / g;
- Operating temperature: -40 ... + 85°C;
- Dimensions: 20.3 mm x 15.7 mm;
- Weight: 5 grams.

The functional diagram of the analogue accelerometer Adafruit ADXL335 is shown in Fig. 3.

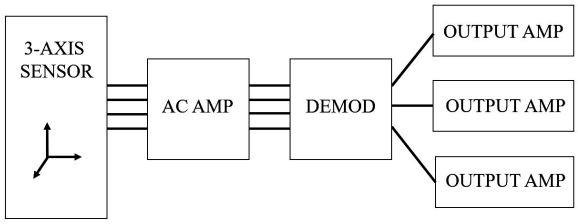

Fig. 3. Functional diagram of the Adafruit ADXL335

The ADXL335 accelerometer contains three axes (X, Y, Z), so it can determine the acceleration vector in three-dimensional space. Given that the force of gravity is a vector, the accelerometer can determine its orientation in three-dimensional space relative to the centre of the Earth. The sensor is a polysilicon structure built on top of a silicon wafer. Polysilicon springs suspend the structure above the surface of the plate and provide resistance to accelerating forces. The deflection of the structure is measured using a differential capacitor, which consists of independent fixed plates attached to the moving mass. Fixed plates are driven by non-phase square waves of 180 °. Acceleration deflects the moving mass and unbalances the differential capacitor, which leads to the output of the sensor, the amplitude of which is proportional to the acceleration. Then, phase-sensitive demodulation methods are used to determine the magnitude and direction of acceleration. The output of the demodulator is amplified and outside the chip through a resistor 32 Com. Then the bandwidth of the device signal is set, with regard to the addition of a capacitor. Filtration occurs, which improves the resolution of measurements and helps prevent smoothing [8].

Bluetooth module HC-05;

The Arduino Nano controller itself does not have a built-in wireless information transfer module. Therefore, the Bluetooth HC-05 wireless module was chosen to address this issue. This computer system will transfer information from the hardware to the software on the computer providing a fast and reliable connection.

The Bluetooth module HC-05 is a module of a wide range of applications for the connection of devices via Bluetooth connection. The Bluetooth module is controlled by UART, acts as a UART-TO - Bluetooth converter. Unlike the HC-04 module, it can operate in both Master mode and can initiate connections to detect devices, as well as in Slave - it can accept connections from other devices that initiated the connection. Bluetooth module HC-05 - is a convenient way to implement control and data transfer by microcontroller devices using a tablet, phone, laptop or computer [9].

Specifications of the Bluetooth module HC-05:

- Module type: Fully Qualified Bluetooth V2.0;
- Supported frequencies: 2.4 - 2.48 GHz;
- Sensitivity: 84 dBm;
- Transmitter power: +4 dBm;
- Operating voltage: from 3.3V-5V (usually + 3.3V);
- Operating current: 40 mA;

- Range: approximately 10 m;
- Transmission protocol: IEEE 802.15.1;
- Uses an extensive frequency hopping spectrum (FHSS);
- Operating modes: Master, Slave (Master / Slave);
- Supported data rates: 9600, 19200, 38400, 57600, 115200, 230400, 460800;
- Working temperature: -20 - +70 ° C;
- Dimensions: 26.9 mm x 13 mm x 2.2 mm.

Flex Sensor (flexibility sensor);

The main source of information for the computer system (smart glove) is the flexibility sensor ZD10-100 500g. Flex Sensor has been providing services on the market recently, for about 2 years. Due to modern production technologies, it will have high accuracy. Therefore, it was formed as a provision of information for a computer system for converting gestures. Its main work is to change the resistor, which changes its resistance relative to the angles and bends of the sensor. The Flex Sensor is also pressure-sensitive, which means that it can also change its resistance to the restored position and press on the sensor. Flexible sensor ZD10-100 500g is shown in Fig. 4.

Fig. 4. Flexible sensor ZD10-100 500g

Specifications of Flexible sensor ZD10-100 500g:

- Model: ZD10-100;
- Length: 100 mm / 3.9 inches;
- Width: 10 mm / 04 inches;
- Range: 0 ~ 500g;
- Thickness: less than 0.25 mm;
- Answer point: less than 20 g;
- Test voltage DC: 3.3V;
- Durability: more than 1 million times of bending;
- Response time: less than 10 ms;
- Recovery time: less than 15 ms;
- Operating temperature: - 20 □ ~ 60 □.

The signal from the Flex Sensor can be converted into a specific electrical signal output using a fairly simple electrical circuit shown in Fig. 5.

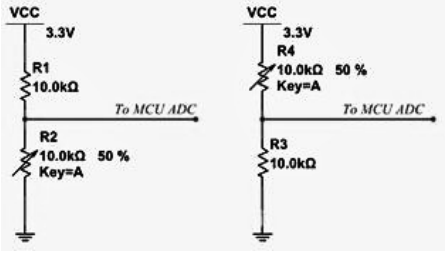

Fig. 5. The scheme of formation of an electric signal in ZD10-100 500g

The principle of operation of the sensor distributes the voltage corresponding to the latest sensor ZD10-100 500 g and an external resistor with a nominal value of 10 kOM. As the sensor changes its resistance, restoring the bending angle and external pressure on it, it changes its output voltage, which will change the output signal. Regarding this, the needed signal is being formulated.

Field of application ZD10-100 500g: smart home, medical electronics [10].

Due to the use of a modern element base, the presented computer system has the following advantages among competitors [2, 3]. In particular: increased speed of 20 MHz against 16 MHz, reduced the number of hardware components 8 against 19, reduced the total power consumption of 120 mA against 340 mA.

B. PROGRAM PART

Firmware (sketch) for Arduino Nano platforms. The role expands the backup of the computer system: initializes components, collects the received data from sensors (5 sensors with 1 and the accelerometer), turns the received data into a corner, recognizes and searches for the letter declaration where the table addresses, the received data is transmitted via Bluetooth.

The block diagram of the firmware (sketch) for our hardware is shown in Fig. 6.

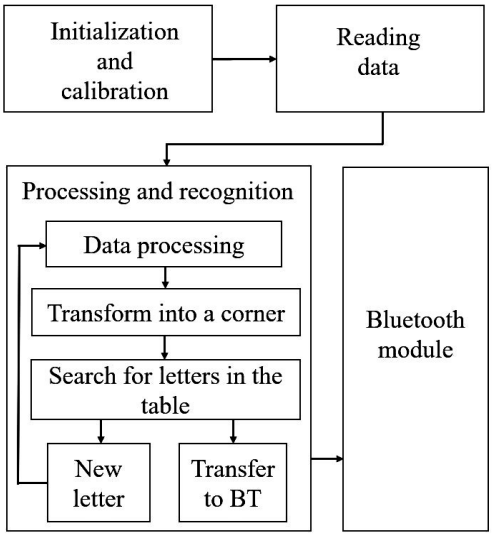

Fig. 6. Block diagram of the firmware (sketch)

Description of modules;

The initialization and calibration module initializes all hardware components of the system. Namely, it scans ports A0, A1, A2, A3, A4 - connection points of five bending sensors ZD10-100 500g, A5, A6, A7 - connection points of analogue accelerometer ADXL335, D7 - connection point of calibration button, D8, D9 – points of Bluetooth HC-05 module connection, and also calibrates the indicators if the button D7 = 1. Calibration is required to determine the maximum value (1023) and minimum value (0) of the indicators from the sensors.

The data reader module reads information from five bending sensors and the accelerometer and transmits them to the processing and recognition module.

The processing and recognition module process the obtained data by converting this data into an angle according to formula.

$$A(0 \dots 4) = \frac{Ax - Ax\ min}{Ax\ max - Ax\ min} * 90 + b(= 0), \quad (1)$$

where A (0… 4) is the name of the change (sensor port number), Ax is the value obtained from the sensor,

Axe min is the minimum value of the sensor (= 0), Ax max is the maximum value of the sensor, Ax min is the minimum value of the sensor (= 0), 90 is the constant component, b is the constant (= 0).

For example:

$$A0 = \frac{600-0}{720-0} * 90 + 0 = 0.83 * 90 + 0 = 75.$$

Calculating angles affects other sensors. After calculations, the obtained values of the base are viewed in the table according to the number of search requests. If the obtained data are similar to each other, the values of the accelerometer are taken into account. If the desired letter cannot be recognized, the cycle repeats. Thus, a significant angle is converted to a certain letter of the alphabet. After the recognition period the stream of the letter is transmitted to the Bluetooth module, which is transmitted to the investigated port, Bluetooth module that provides Python software, further expands the flow of letters on the words, display and sound.

Python-based software;

The Python programming language was chosen to implement the software component of the computer system called "Smart Glove". Based on it, we have developed our own program for dividing the flow of letters into words, their reflection and sound.

Python is a simple, high-level programming language that includes efficient data structures and is quite efficient for object-oriented programming. Python is based on an open-source license, which makes it freely usable and distributable software even for commercial use [11].

The block diagram of the developing computer program is shown in Fig. 7.

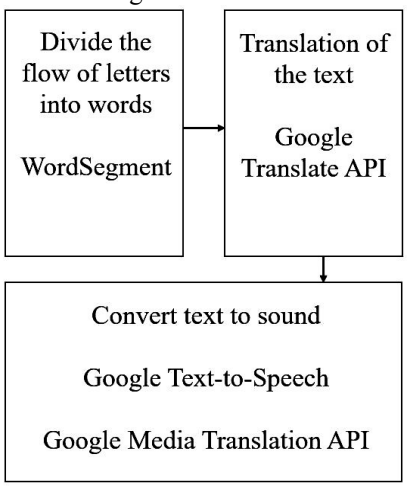

Fig. 7. Block diagram of a computer development program

Description of modules;

The flow of letters is divided into words using the Word Segment module. Word Segment is an Apache2 licensed English word segmentation module written in pure Python and based on an array of trillions of words.

Unigram data includes only the most common 333,000 words. Similarly, Bigram data includes only the most common 250,000 phrases. Each word and phrase are written in lower case and punctuation is deleted [12].

Google Translate API text translation module;

The Google Translate API was used as a module for translation text, as it is the best among competitors and provides translation into more than 109 languages.

The Google Translate API is the closure of Google's cloud translation system. It is a multilingual neural machine translation service designed to translate text, documents and websites from one language to another. The Google Translate app offers a website interface, a mobile app for Android and iOS, and an application-built interface that helps developers create extensions for browsers and apps. The Basic Translation API uses Google's neural machine translation technology for instant text translation.

Google Translator can translate a variety of text and media file formats, including text, speech, and text into still or moving images. In particular, its functions include translation: written words, translation of a web page, documents, online broadcasting, translation of mobile applications, images, handwritten translation.

Google provides translation requirements, vocabulary, and listening to distribute its features. In addition, Google Translate presents its own application Translate, with the ability to download a mobile package and provide offline translation to smartphones or tablets offline [13].

Text-to-sound module Google Text-to-speech, Google Media Translation API;

Google Text-to-speech (gTTS) is a closed Python library and CLI tool for interacting with Google's text-to-speech translation API.

For sound, it is necessary to write a voice mp3 page in a file similar to the byte string object file for further manipulations with sound or stdout, or, in advance, generate the URL of Google's TTS translator requests for future voice data submitted in an external program.

Features include the ability to adjust a certain tone for the sound of the review, which provides specific to the selected language, which allows you to read an unlimited length of text while maintaining the appropriate intonation, abbreviations, ten such fractions. Additional configuration of word processors, to ensure the correction of errors in the requirements [14].

The Media Translation API transmits real-time audio to your content, as well as applications that enhance accuracy and simplified integration. You also improve usability with low-latency streaming and fast scaling with easy internationalization [15].

Due to the use of the Python programming language and modern modules from Google, the presented computer

system has the following advantages among competitors [2, 3, 4]. In particular: increased system-wide performance thanks to optimized firmware for the Arduino Nano microcontroller, increased letter recognition accuracy thanks to Word Segment, increased translation accuracy thanks to Google Translate API, increased pronunciation accuracy thanks to Google Media Translation API.

VII. RESEARCH RESULTS

Studies on the application of the developed structure to build a computer system for converting gestures into text and audio messages have shown its effectiveness and feasibility.

First of all, it reduces hardware costs and software costs. The accuracy of the whole system increases due to the use of modern element base and the latest algorithms for information processing.

The general block diagram of the hardware components is shown in Fig. 8.

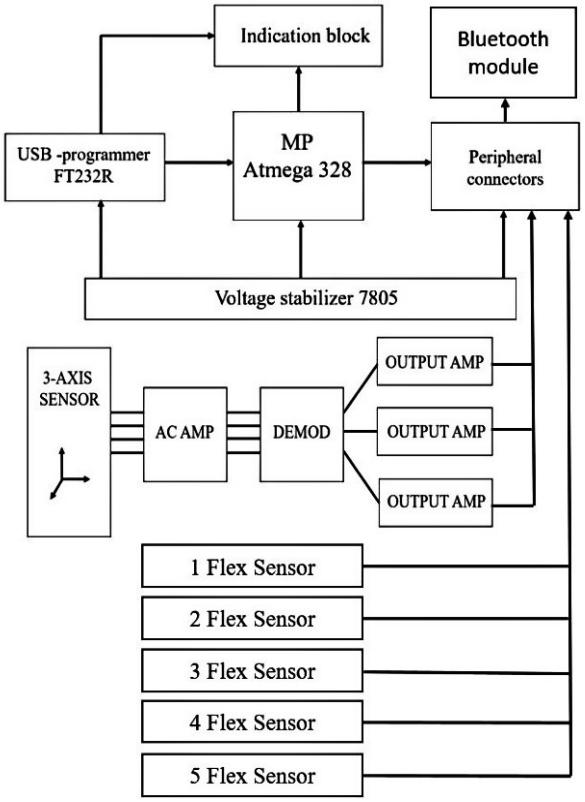

Fig. 8. General block diagram of the hardware components of the system

The general block diagram of the software component is shown in Fig. 9.

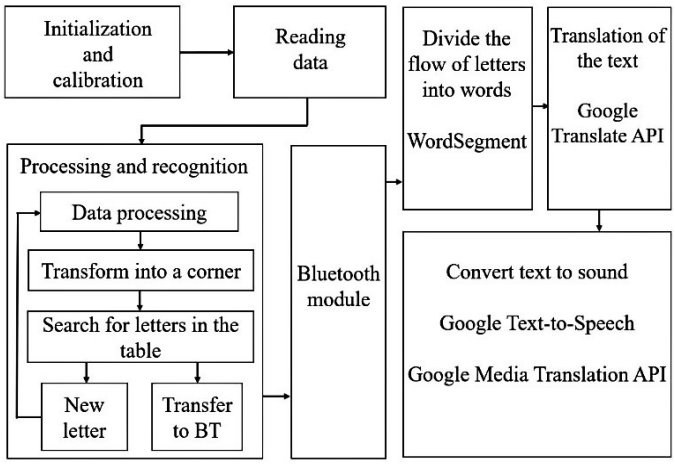

Fig. 9. General block diagram of software component modules

The given block diagrams of the hardware and software components act as a ready-made template for further implementation of a computer system for converting gestures into text and audio messages.

VIII. CONCLUSIONS

The principles of construction and basic structural solutions of a computer system for converting gestures into text and audio messages were developed in this paper.

The most popular existing solutions for gesture recognition were considered and analyzed.

The created integral architecture of the computer system for conversion of gestures into text and audio messages. The developed computer system has the following advantages:

- Improving system performance by using a modern Arduino Nano microcontroller with an operating frequency of 20MHz vs 16MHz;
- Reducing the economic costs of the final product by reducing the number of system components. The system has 8 hardware components compared to 19 competitors;
- Improving energy efficiency through the use of modern elements. Consumption of the whole system is 120 mA compared to 340 mA in analogues;
- Reduce software costs. The program is based on the Python programming language using free libraries. In turn as a product SignAll provides its services for a certain price;
- high accuracy of the whole computer system, which uses a modern elementary base and new algorithms for information processing.

The computer system consists of two parts, the hardware of which includes:

- Arduino Nano computing platform;
- Analog accelerometer Adafruit ADXL 335;
- Bluetooth module HC-05;

- Flex Sensor (flexibility sensor).

And the software part, which contains two main components:

- Firmware (sketch) for the Arduino Nano computing platform;
- Python-based program for dividing the flow of letters into words, their display and sound.

The selection of basic elements and modules – for the design of hardware and software components. The structural scheme of both parts of the system was developed, and also the principle of their functioning was described.

References

[1] Gov.ua. (2017). *World and Ukrainian statistics of the deaf and dumb, International Day of the Deaf.* [online] Available at: https://www.kmu.gov.ua/news/250293661 (Accessed: 5 October 2021)

[2] Uapatents.com. (2014). *Description Enable talk system.* [online] Available at: https://uapatents.com/9-86748-sistema-enable-talk-inejjbl-tolk.html (Accessed: 6 October 2021)

[3] Anthrotronix.com. (2018). *Description NuGlove system, Interact system, Droid Agent system.* [online] Available at: https://www.anthrotronix.com/ (Accessed: 6 October 2021)

[4] Signall.us. (2021). *SignALL translate program.* [online] Available at: https://www.signall.us/ (Accessed: 6 October 2021)

[5] D. Mheill. "Gesture and Thought", *University of Chicago Press, Degruyter,* 2005. DOI: 10.7208/9780226514642.

[6] Ap.uu.edu.ua. (2004). *The bilingual method is an indispensable condition for the learning of the deaf.* [online] Available at: http://ap.uu.edu.ua/article/404 (Accessed: 5 October 2021)

[7] Y. Badamasi. "The working principle of an Arduino", *ieeexplore, 2014.* DOI: 10.1109/ICECCO.2014.6997578.

[8] Analog.com. (2010). S*pecification analogue accelerometer ADXL335.* [online] Available at: https://www.analog.com/ru/products/adxl335.html#product-overview (Accessed: 7 October 2021)

[9] V. Sing, A. Shahy, A. Beg, B. Chay, S. Kymar. "The Specification Bluetooth HC-05 module", *ieeexplore, 2019* . DOI: 10.1109/ICACAT.2018.8933698.

[10] Desertcart.com.py. (2021). T*hin film flex and pressure sensor ZD10-100 500g* [online] Available at: https://www.desertcart.com.py/products/107132867-thin-film-pressure-sensor-flex-bend-sensor-zd-10-100-500-g-resistance-type-fsr-sensor-thin-film-pressure-sensor-force-sensing-resistor-force-sensitive-resistor (Accessed: 7 October 2021)

[11] J. Crammer. "Python -The Fastest Growing Programming Language", *International Research Journal of Engineering and Technology (IRJET),* vol. 4, iss. 12, 2017. DOI: 2395-0072/pan.2017.12.

[12] Pypi.org. (2021). *Word segmentation module v1.3.1.* [online] Available at: https://pypi.org/project/wordsegment/ (Accessed: 8 October 2021)

[13] E. Vries, M. Schoonvelde, G. Schumacher. "Google Translate Works" *Political Analysis,* vol. 26, iss. 4, 2018, pp. 417 – 430. DOI: 10.1017/pan.2018.26.

[14] Pypi.org. (2021). *Google Text-to-speech* m*odule v2.2.3.* [online] Available at: https://pypi.org/project/gTTS/ (Accessed: 8 October 2021)

[15] Cloud.google.com (2021). *Google Media Translation API.* [online] Available at: https://cloud.google.com/media-translation (Accessed: 8 October 2021).

Dmytro Borovets is a second-year Master's student of Computer Engineering in the field of computer network and systems at Lviv Polytechnic National University.

His research interests - computer systems and networks, microcontroller programmable devices, modern robotics and cyber physical systems.

Tetyana Pavych. Senior Business Analyst at MedBridge Inc. Bachelor's degree of Management Information System in 2019 at Northwood University, Midland, MI, USA. Business Career Program graduated in 2021 at Computer Systems Institute, Chicago, IL, USA. Her research is in the CRM management, business intelligence, data analysis areas.

Yaroslav Paramud Candidate of Technical Sciences, Associate Professor of the Department of Electronic Computers, Institute of Computer Technology, Automation and Metrology, Lviv Polytechnic National University.

His research interests - processing radar information, research algorithms, and structures of specialized computing devices and systems. The number of scientific publications – more than 30, has 13 Inventor's Certificates.