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EXPERIMENTAL SYSTEM AND SOFTWARE: TWO-DIMENSIONAL RETURN OF THE PLATFORM TO THE SOUND SOURCE

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***Abstract*: We created a system, debugged it, and conducted experimental studies of the two-dimensional rotation of the supporting platform (with a camera, and a light source.) on the source of sound waves. The system was assembled based on two SYNCO Mic-M3 cardioid condenser microphones and an Alesis IO-4 sound card. We wrote original software for analyzing and transmitting the result of processing harmonic acoustic signals for the response of the Arduino Uno control board. The rotation of the 2D platform is caused by two MG995 servos controlled by this microcontroller. We used a model of a serial COM port, which allows to send data received from the platform in the form of packets for processing by a portable personal computer. Based on the results of the experimental test and the basis of the literature data, a model of control of the two-dimensional platform of returning to the source of sound has been offered.**

***Index Terms*: two-dimensional rotation platform, software, servomotor, microcontroller, microphone**

I. INTRODUCTION

In the literature known to us, there is no description of the processes of pointing the two-dimensional rotation platform at the detected sound source for further tracking with the help of a photo capture device, illumination, etc. In previous works [1], the processes of detection and measurement of flight parameters of unmanned aerial vehicles were studied using ground installations with sound and photo receivers. A stationary photo recognition and photo capture system created for the first time using a Cannon-7D camera and proprietary software made it possible to measure the coordinates of a Phantom-3 quadcopter at distances of the order of 1 km. In addition, with the help of an experimental unmanned aircraft complex, flights of the UAV according to the coordinates of an unauthorized object previously measured by a stationary photosystem and its photo capture were investigated [2]. However, this system made it possible to detect the UAV in the direction of the installed camera, but without the ability to direct the tripod with the fixed camera to the source of sound signals.

The Internet article [3] describes a similar system for detecting sound waves and determining their direction, and where they come from. This is the "Boomerang 3" system - a shot locator created by DARPA and BBN Technologies for use mainly against snipers. Boomerang is mounted on vehicles such as Humvee, Stryker, and MRAP combat vehicles. The system consists of many microphones directed in different directions. As soon as the system detects a sound signal higher than the background sound signals, then it determines from which microphone the higher signal level came.

The article [4] proposes a mathematical model of multi-agent wireless Cyber-Physical Systems (CFS) consisting of moving objects. The model describes the interaction of cyber-physical components, which can be combined into a monitoring network, delivery network, or network of other destinations.

The authors conducted experiments that confirmed the significant difference between the theoretical performance of Wi-Fi equipment regarding data rate and communication range from the real values when CFS operates in a noisy radio environment within a city or settlement. Such a system can theoretically be used for our experimental system, but modern radar systems make it possible to detect the location of almost any radio wave source.

To prevent the detection of our system, we analyzed the principle of operation of the radio radar. These radars pick up all radio signals in the working radius and determine from which direction they come. Modern radars can determine the exact coordinates of the sound source, so wired interfaces were chosen for switching system elements.

In scientific sources [5] available methods of determination of the source coordinates of the acoustic signal were analyzed, including passive and active methods, which can be applied in different fields of science and technology. However, in recent times there has been a tendency to use artificial neural networks to solve various tasks and apply them in different spheres. This article compared the method of determining the source coordinates of the acoustic signal using an artificial neural network with already existing methods. This was determined by the presence of the signal at the receiving points, which were placed by different spatial points with known coordinates, and then the difference in the time of the signal propagation from the source to the receiving points was determined. Using this method, you can determine the source coordinate of the acoustic signal without preliminary information about the source distance and any other characteristics of the object. In addition, this method simplifies the process of measuring time intervals and calculating coordinates.

A lot of work is focused on the development of acoustic direction for the creation of means of detection of unmanned aircraft (UAVs) [6]. Noise-bearing principles, such as acoustic field characteristics such as sound intensity, frequency spectrum, and spatial spectrum, are used to develop such tools. The UAV detection device architecture complies with the algorithms of reproduction in the individual paths of the device of the registration and dynamics control ideology of changing the acoustic field characteristic, which determines the detection. Implementation of the proposed devices consists of the creation of a filter path with the use of filters of different octave widths and a detection path by power. To improve and increase the reliability of the detection, a mutual detection path and a path of the correction method of a bearing are used.

Publication [7] describes a method for determining the direction of a sound source using a mathematical apparatus that can be implemented on minimum power hardware such as Arduino microprocessors. The method allows you to determine the direction of the sound source, considering sound parameters such as basic frequencies and sound duration, as well as environmental parameters such as sound speed, which may depend on weather conditions. This publication describes the key elements of the method and the terms of use that affect the results. Furthermore, recommendations on equipment installation for UAVs and methods for achieving the best results in determining directions on a sound source were made. The formula for determining the direction of the sound source is shown, considering the movement of the platform, as well as an estimation of the angle error in degrees, depending on the angle to the direction of movement and the base between microphones. Also, the prototype of software tools is described, and the graphical interface of the program realization method is presented. Modeling of the system operation under different circumstances and the threshold value for the key criterion based on the signal-to-noise ratio is determined.

Assessing the distance to the sound source [8] is an important task in many areas, including acoustic monitoring, detection, and localization of objects in the control space. The problem of determining the exact distance to the sound source is that it is unknown. The authors of the article offered solutions to this problem based on sound power estimation and change in the frequency of sounding at a distance. A group of four connected microphones allows you to get a sound signal from different points of space and use it to determine the direction and distance of the sound source. The author's algorithm uses sound power estimation and changes in frequency at a distance to assess the distance to the source of the sound.

The acoustic wave is a sequential transmission of compressed and dissolved [9] from one part of the environment to another, and this wave is characterized by excessive pressure, which depends on the density of the environment. Sound propagation speed is entirely dependent on environmental parameters such as atmospheric pressure, air temperature, humidity, and impurities. The distribution of sound speed in the ground layers of the atmosphere determines the spread of acoustic waves and their distortion, which is called refraction. Also, the article mentions the range of acoustic signals detection considering the factor of the air environment anomaly. This range is defined as the value of the energy range of the detection on the value of the environmental impact factor in the ground layers of the atmosphere.

The authors of the article [10] explained that the servo drive is a drive with control due to negative feedback, which allows precise control of the motion parameters. It was also explained that the servo drive is an "automatic accurate performer", which maintains the necessary parameters on the sensor according to the external value. A code has been developed to control the servo via the Arduino platform, which allows setting the servo rotation angle. One of the main components of the project – the SG90 servo drive, was described as an excellent servo drive, which has the optimum torque and is not large enough. This information is important for those who plan to use this drive in their projects.

One of the scientific papers [11] presents a comparative study of three methods of control of DC servo with feedback on position with Arduino. The author emphasizes the importance of using position feedback in closed-loop systems to achieve precise control of the motor angle position. The built-in potentiometer provides accurate voltage feedback to indicate the actual position of the engine. The study uses three methods: Arduino IDE, Support target for Simulink (Support Package), and Arduino IO package. The author compares these methods in terms of their suitability and performance to manage more complex closed systems in the future. After comparison, the author concludes that the Arduino IO package method is the most suitable for the application mentioned above. The author explains that although the hardware performance of all three methods is almost the same, the Arduino IO method is the easiest and fastest for integration. The method allows the user to control and modify the program parameters in real time while executing all algorithms (the management approach) on the computer, not on Arduino.

The purpose of the work is to create an experimental system and software for research and optimization of the processes of turning and pointing a two-dimensional platform to a moving object in space based on its detected sound.

II. OBJECTIVES

Until now, the possibility of creating a complex automated system for the passive detection of unprotected objects (UAVs), their photo capture, pursuit, and neutralization with the help of UAVs has been considered. The processes of detection and measurement of GPS coordinates of moving objects by stationary sound and photo means were studied. At the same time, the issue of creating an experimental guidance system (cameras, light sources, etc.) of a two-dimensional return platform to the source of sound waves was not considered.

It is necessary to improve the existing systems of photo fixation, illumination, etc., using the method of acoustic detection of objects in space, focusing on the source of their sound. We have proposed an automated system for guiding the two-dimensional return platform to the sound source.

The need for such a system arises from the growing use of drones in both civilian and military applications, and the potential security risks associated with their unauthorized use. A complex automated system for the passive detection of unprotected objects (UAVs) would be able to detect drones and neutralize them if they pose a threat.

The first step in creating such a system is the detection of drones. This can be done using a combination of stationary sound and photo means. Sound sensors can detect the noise produced by drones, while cameras can capture images of the drones as they move through the air.

However, to effectively pursue and neutralize a drone, the pursuing drone needs to be able to return to its source of sound waves accurately. This requires the creation of an experimental guidance system, which can guide the pursuing drone back to the source of the sound waves. This system would need to include cameras, light sources, and other guidance systems to ensure that the pursuing drone can accurately locate and return to the source of the sound waves.

After analyzing our needs, we compiled the minimum required characteristics of the control board. The main requirements are the ability to switch the board with a computer, the ability to control a servo-type stepper motor, the ability to work for a long time without interruption, and low power consumption to ensure the autonomy of the node. Most boards of the Arduino platform are suitable for our tasks, so we used the Arduino Uno board for our experiment. Data transfer between the computer and the Arduino Uno board took place via the USB interface. Software transfer of data between devices was implemented as a virtual serial COM port. This implementation of communication between the computer and the microcontroller board is used by the standard Arduino IDE development code environment. In particular, the method of transmitting information using an individual program for processing the captured sound written in C++ for the Arduino Uno type microcontroller control board is not covered. The experimental system uses the original software created in the previous works of Audio Detect. In addition to this software, an extension for switching with a microcontroller is implemented. To rotate the platform, two stepper rotation motors, the so-called servo drive, type MG995 were used. To study the operation of the system, sound signals were fed to microphones, where a smartphone was used as the sound source, which reproduced a sinusoidal analog signal using a signal generator application.

The primary objective is to create a complex automated system for detection and fixation, highlighting, photofinishing of a moving object in space by visible sound waves that expand this object, namely:

Develop a platform of two-dimensional return to the sound source, which will return in the horizontal direction to an angle of at least 90 degrees and in the vertical direction to an angle of at least 70 degrees from a load in the form of a Cannon 7-D photo camera with a mass of the order of 1 kg 200 g.

III. SYSTEM COMPONENTS

A. EXPERIMENTAL SETUP

A schematic diagram of a complex system of detection and tracking of a flying object is shown in Fig. 1. The developed complex consists of three systems. Under the number 1, a sound detector is marked, which will catch sound waves emitted by aircraft. Structurally, this system consists of a special hub and the microphone itself. In our solution, we used two hubs with microphones. Number 2 indicates a two-dimensional turning platform, which consists of a specialized tripod or theodolite, a camera, and a turning mechanism. To control all systems, a ground computer system number 3 was used. The system was designed in such a way that it would allow for easy modernization and scaling of the complex.

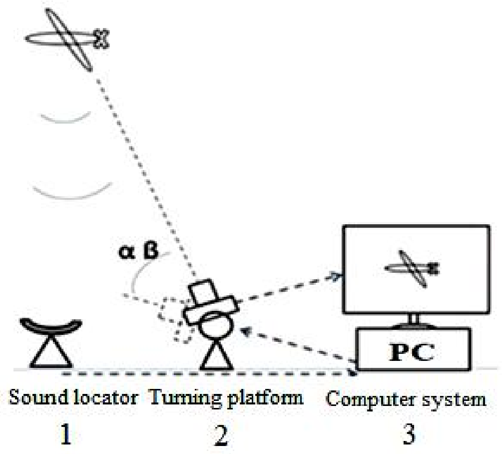

Fig. 1. Schematic representation of a complex system of turning and tracking flying objects

The experimental set includes the following components: turning platform, Cannon-7D camera, Arduino Uno board, MG995 servo, USB cable, ASUS TS-10 computer, Synco Mic-M3 microphones, headphone and microphone splitter, Micro-USB power input. This layout of the system was chosen to reduce the size of the experimental system itself. This made it possible to collect all components in a compact case. The main criterion when choosing electrical components is power consumption. Components are selected in such a way as to obtain good autonomy.

The system uses a Cannon-7D camera. A self-made tripod is made for attaching the camera to the servo drive, this frame is attached to the shaft of the servo motor. The weight of the camera with the lens is about 1.5 kg, so MG995 was chosen as the servo motor, as it can rotate the shaft 360 degrees with a maximum force of 9 kg. The MG995 power supply voltage is from 4.2 to 7.2, this allows you to connect this servomotor to a standard USB – 5 V power supply. All elements of the system are powered by a voltage of 5 V, so a portable battery (PowerBank) can be used as a power source.

A servo motor is a type of rotary actuator that is capable of precise and controlled angular rotation. It consists of several components that work together to achieve this motion. The servomotor closed-loop diagram is described in Fig. 2.

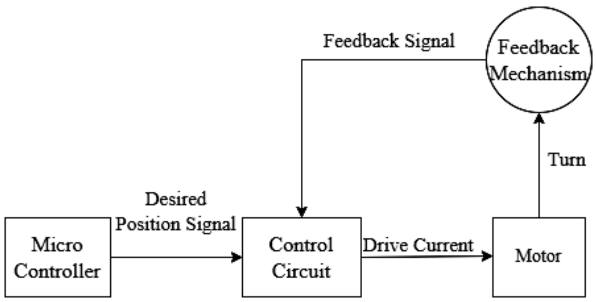

Fig. 2. Servomotor closed-loop diagram.

The controller sends a signal to the control circuit indicating the desired position or speed of the motor. The controller can be a microcontroller, a computer, or any other device that can generate a control signal.

The control circuit receives the desired signal from the controller and compares it with the feedback signal from the feedback mechanism. It then generates an error signal based on the difference between the two signals. The control circuit uses the error signal to adjust the motor's position or speed by sending an appropriate voltage to the motor.

The motor is the component that converts the electrical energy from the control circuit into mechanical motion. It can be a DC motor or a stepper motor. The motor's speed and torque depend on the voltage and current applied to it by the control circuit.

The feedback mechanism provides information on the motor's current position and speed to the control circuit. It typically consists of a potentiometer or an encoder. The potentiometer is a variable resistor that changes its resistance as the motor rotates, while the encoder provides digital signals that correspond to the motor's position and speed. The feedback signal is sent back to the control circuit, where it is compared to the desired signal, and the error signal is generated.

The closed-loop diagram represents a feedback control system, where the feedback signal is used to continuously adjust the motor's position or speed until it matches the desired signal. The closed-loop system ensures that the motor's position or speed is accurate and precise, making servo motors ideal for applications that require high levels of precision, such as robotics and automation.

The Arduino microcontroller platform was chosen to control the servo motor. After analyzing the tasks, we found out that most of the microcontroller models of this platform are suitable for us, and we chose the Arduino Uno type. This board contains an ATmega328 microcontroller that can operate at a maximum frequency of 20 MHz, a flash memory of 32 kb, for loading the control program, an SRAM memory, and an EEPROM memory of 2 kb and 1 kb, respectively.

Switching between the board and the computer was carried out using a USB cable. The software connection was implemented as a virtual COM port, which made it possible to simplify the process of sending data packets and their structure.

The general scheme of connection of Arduino Uno and servo drives is shown in Fig. 3.

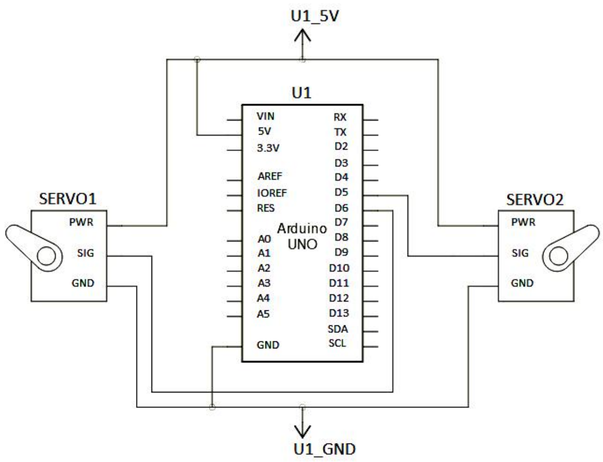

Fig. 3. Connection diagram of Arduino Uno microcontroller SERVO1 – servomotor for horizontal platform rotation servo drive, SERVO2 – servomotor vertical platform rotation servo drive, Arduino Uno – control board

In this diagram, the servomotors are connected to two of the Arduino Uno's PWM (Pulse Width Modulation) pins: pin 6 for Servomotor 1 and pin 5 for Servomotor 2. The PWM pins are used to send signals to the servomotors that control their position.

The servomotors also need to be connected to the Arduino Uno's power and ground pins, which provide the necessary voltage and current for the motors to operate.

The USB port is used to connect the Arduino Uno to a computer, which can be used to upload programs and control the servomotors.

This setup can be used to create a simple robotic arm or other types of robotic projects that require precise motor control.

B. SOFTWARE OF THE RETURN SYSTEM OF THE TWO-DIMENSIONAL PLATFORM

The Audio Detect sound processing program is designed to process the sound of a system with two microphones. The logic of the program (Fig. 4) is based on the definition of differences between sound signals received from microphones. The sound signal from rotating bodies, in our case the propeller of an aircraft, is a sinusoidal, harmonic motion, the oscillations of which are periodic. To distinguish this signal from the sound signals of objects that are not of interest to us (birds, insects, gusts, wind), the necessary frequencies are selected and the received signals are divided into Fourier series. In the future, the program searches for periodic peaks of the signal by frequency. Having determined such periodicity in the received signals, the program calculates the intensity of these signals from the first and second microphones, intensity and intensity2, respectively. After detecting the signal from the rotating object, the program calls the developed extension function void SendRotateCommand (double intensity, double intensity2) and passes the calculated intensity value (1-2).

To avoid incorrect operation of the system, we implemented a comparison of the obtained values with the intensity of the background noise. To reduce the consumption of computer resources, the value of the background noise intensity was determined experimentally and set as a constant. In the case of lower input values than the constant, the function will stop working (3).

At the next stage, the function calculates the coefficient of the ratio of the intensity of signals intensity to intensity2(4). The algorithm with the calculation of the coefficient made it possible to simplify the comparison logic and reduce the volume of the code.

Relative to the coefficient, the direction from which the stronger sound signal arrives is determined (5). When the value of the coefficient is lower than 0.5 and higher than 2, it was decided to rotate the photo frame to the right and the left, respectively. The value of the coefficient in the interval [0.5;2] was experimentally determined to be insignificant, with such a value the difference in signal intensity is small. During the tests, it was understood that in this case, the platform does not need to be returned (5).

To simplify sending data to the microcontroller and their further processing, the simplest data package was chosen, which consists only of a message without additional keys. Such a choice of package structure was obtained from the analysis of the data to be transmitted. Only the direction number needs to be sent to the microcontroller. In our case, using only 2 microphones, one symbol (index) (6) is enough.

At the end of the operation, the function of sending a message with the value of the variable through the serial COM port to which the microcontroller is connected (7).

The microcontroller is responsible for controlling the platform rotation servo motor. The Arduino Uno board is physically connected to the computer with a USB cable (USB-B to USB-C). The serial COM port model is used programmatically, so data between devices is sent in the form of packets. Our package consists only of data about the direction of platform scrolling. The algorithm of the microcontroller control program is shown in Fig. 5.

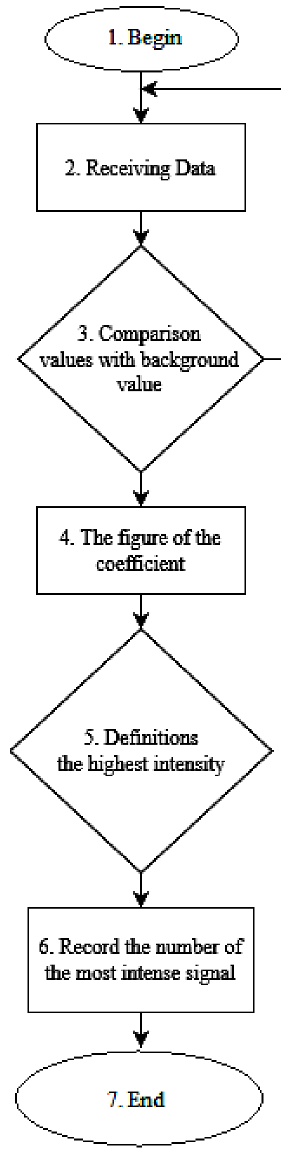

Fig. 4. Block diagram of the Audio Detect program's operation algorithm

The received data from the computer program is written to the clipboard on the microcontroller (2). All data that comes from the computer is written into this buffer, including incorrect data. The clipboard contains data presented as a sequence of bits, so the control program performs certain transformations of this data (3). In the first stage, the sequence of bits is divided into separate messages (packets). Each packet is a sequence of bits that carry certain information, but using a sequence of bits as a data type in a control program complicates the programmer's work. To simplify programming, the packet undergoes parsing, which is a procedure for converting a sequence of bits into a certain type of data. After the conversion, we get the message represented as an integer with a fixed size of unit16_t.

To avoid incorrect operation of the system, the received data is checked for accuracy (4). At the next stage, the servo motor is rotated. It is controlled using pulse width modulation. The control program, knowing the correct direction of rotation, calculates the duration of the PWM signal to rotate the servo motor (5).

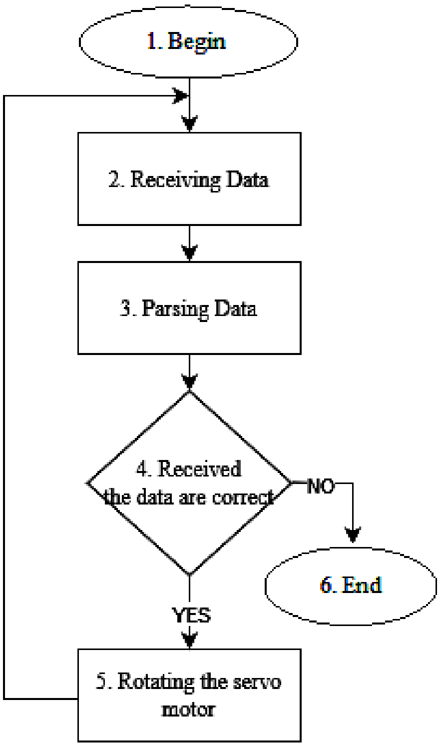

Fig. 5. Block diagram of the algorithm of the microcontroller control program

IV. RESULTS OF EXPERIMENTAL RESEARCH AND ANALYSIS

As a result of the work, an experimental installation of a two-dimensional turning platform was created, which is shown in Fig. 6, which made it possible to increase the efficiency of the photo capture system.

The developed system made it possible to combine two important systems and their software part for detecting objects. Namely, the sound wave analysis system and the photo capture system. These systems are the result of experimental research by one of the co-authors.

We have developed an extension for the software part of the sound system. On the very front of the expansion, it was possible to determine from which channel the more intense signal comes. This allowed us to determine the direction from which the sound signal propagates. We tested it experimentally bringing the sound source to the microphones in turn.

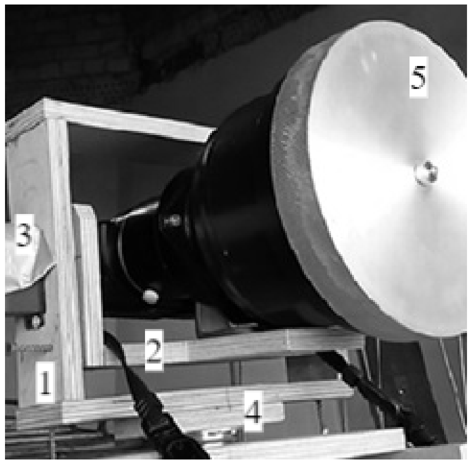

Fig. 6. Two-measuring platform of rotation: 1 – horizontal turning frame, 2 – vertical rotation frame, 3 – servo drive for horizontal rotation, 4 – vertical rotation servo drive, 5 – the locking device

A mechanism of communication with the Arduino Uno Microcontroller board has been added. The selected USB interface, for connecting a computer and a microcontroller, made our system invisible to radar detection. This allowed the establishment of an experimental facility for testing near residential buildings, without putting residents at risk.

The developed control program of the microcontroller allowed the realization of communication of the board with the computer program Audio detects. After analysis of the obtained results and obtained values, one can conclude the detection and reasons for possible signal errors, suggestions on their elimination, optimization of the use of sound characteristics of the signal for more detailed analysis, and optimization of the system.

As a result of the system test, it was found that a platform loaded with a photo system with a Canon-7D camera with a mass of about 1 kg 200 g is turned in the horizontal direction to the source of the loudest sound by an angle of 120 degrees in a time of the order of 0.7 seconds, and in the vertical direction by an angle 90 degrees in a time of the order of 0.4 seconds.

V. CONCLUSIONS

The experimental system and software for the two-way rotation of the platform to the source of sound were created. To study the system's performance, an experimental installation was created based on a portable personal computer with Windows operating system, Synco Mic-M3 type microphones and an Alesis IO-4 sound card, a platform with two MG995 servo drives, Arduino Uno microcontroller, and a Cannon-7D camera.

The original Program was written in C++ to process the information from the sound card. The Arduino Uno microcontroller board was configured to operate the returning servo drives.

Based on the results of the experimental test and the basis of the literature data, a model of control of the two-dimensional platform of returning to the source of sound was offered. As a result of the system test, it was found that a platform loaded with a photo system of a Canon-7D camera with a mass of about 1 kg 200 g was turned in the horizontal direction to the source of the loudest sound by an angle of 120 degrees in a time of the order of 0.7 seconds, and in the vertical direction by an angle of 90 degrees in a time of the order of 0.4 seconds. This indicated a high speed.

The installation together with the software can be used to introduce into practice the placement of the platform with arbitrary means of fixing, highlighting, photofinishing, etc. on different aircraft objects according to parameters.

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