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DEVELOPMENT OF A CONTROLLED MANIPULATOR FOR REMOTE CONTROL OF AN AIRCRAFT

Shtokalo D., Pasternak I., Pasternak O. Development of a controlled manipulator for remote control of an aircraft. The goal of this work is to develop the controlling manipulator for the remote control of fixed wing aircraft. It consists of the mechanical part of manipulator, it`s electronics and software written for the microcontrollers. This paper describes the process of developing controlling manipulator using 3D printing technologies for mechanical part and creating a flexible software for microcontrollers which will be relevant and easy to maintain and recreate in the future. The technologies used in the development process, the materials and part manufacturing process, the software libraries were integrated into the project, the main approaches to software development, as well as an explanation of why this particular stack of technologies and engineering decisions were preferred for the implementation of this project have been described. To make sure that developed system meets its requirements it has been tested for its practical use cases.
Keywords: human interface device, 3D modeling, CAD software, 3D printing, microcontroller, Hall effect sensor, wireless communication, C.

Штокало Д.Ю., Пастернак І.І., Пастернак О.І. Розробка керованого маніпулятора для дистанційного керування літаком. Метою даної роботи є розробка керуючого маніпулятора для дистанційного керування літальними апаратами. Він складається з механічної частини маніпулятора, його електроніки та програмного забезпечення, написаного для мікроконтролерів. У цьому документі описано процес розробки керуючого маніпулятора з використанням технологій 3D-друку для механічної частини та створення гнучкого програмного забезпечення для мікроконтролерів, яке буде актуальним і простим в обслуговуванні та відтворенні в майбутньому. Технології, які використовуються в процесі розробки, матеріали та процес виготовлення деталей, бібліотеки програмного забезпечення були інтегровані в проект, основні підходи до розробки програмного забезпечення, а також пояснення, чому саме цьому пакету технологій та інженерних рішень було віддано перевагу для описано реалізацію цього проекту. Щоб переконатися, що розроблена система відповідає поставленим вимогам, її було протестовано для практичних випадків використання.
Ключові слова: пристрій людського інтерфейсу, 3D моделювання, програмне забезпечення САПР, 3D друк, мікроконтролер, датчик Холла, бездротовий зв'язок, С.

Introduction. Nowadays in modern battlefield a huge role is dedicated to an unmanned aircrafts. Those aircraft serve a huge role in modern combat, having mainly several roles such as reconnaissance and precise strikes. Developing and implementing such systems can save human lives, ammunitions and economical resources. Though such devices are not just aircrafts by itself. In order to be effective it has to be a whole system which consists of controlling, communication, maintenance, competent crew, optics, and weapon system if such is needed. This paper describes the control part of those systems. With a rapid development of those machines there appeared a demand to have a comfortable and precise control of such vehicles. Human interface devises can be used for multiple roles like for training crew in simulators or for controlling an aircraft directly. A controlling manipulator (joystick) can be used not just for controlling aircrafts but also for training crew. So developing such joystick can be very useful for practicing aircraft flying skills.

To be able to use joystick in flying simulators it has to be a Human Interface Device. The Human Interface Device (HID) [1] class was originally targeted at human interface devices; however, HID is very useful for any application that requires low-latency input-output operations to an external interface, and the ability for that device to describe itself. Many typical HID class devices include indicators, specialized displays, audio feedback, and force or tactile feedback. Therefore, the HID class definition includes support for various types of output directed to the end user. HID enables initialization, and control of self-describing devices.

So since it is a device that human interacts with, it has to be a physical object. Such object can be made using a 3D modeling. 3D modeling, which is the process of developing the mathematical representation of a three-dimensional object through special software [2] is widely used in the fields of cinema, advertising, medicine, industry, engineering, forensics, architecture, games, culture and education. The widespread use of 3D printer technology in industry and education settings and decreased costs of 3D printing technologies in recent years push up the interest in 3D design and modeling technologies.

To create a controler manipulator it is necessary to make a mechanical parts of a device. For designing of those parts a computer-aided (CAD) design software were used. Since for manufacturing of those parts a 3D printing technology were used it was necessary to use CAD software to create a mechanical parts. The manufactured objects that surround us in everyday life are represented programmatically in CAD software as a sequence of 2D and 3D modeling operations. Parametric CAD files contain programmatic information that is critical for documenting design intent, maintaining editablity, and compatibility with downstream simulation and manufacturing. Embedded within these designs is the knowledge of domain experts who precisely define a sequence of modeling operations to form 3D shapes. We believe having access to a real-world collection of human design sequences, and the ability to execute them, is critical for future advances in CAD that leverage learning-based approaches [3].

3D printing, commonly known as additive manufacturing technology, is a practice of making three dimensional objects through layer by layer printing. 3D printing technology is an interdisciplinary technology which includes machinery, computer technique, numerical control, material technology. Usually, the process of 3D printing contains three steps: firstly, the design of the 3D models using CAD software; secondly, the 3D model being cut into slices; finally, printing the model layer by layer. Thus, in theory, any complex three-dimensional model could be fabricated by 3D printing technique. The applications of 3D printing have expanded not only covering traditional manufacturing but also electronics, medical and other industries. 3D printer can print almost any item ranging from small thing such as jewelry, toy, gadget, teeth to large one such as engine, car, house and so on [4]. And in our case it is the only option to create a physical model for the manipulator.

In order to read the sensors data, process it and send to machine a microcontrollers were used. Microcontrollers are used in automatically controlled products and devices, since they make easier to digitally control devices and processes, reducing at the same time the cost and the size of the embedded control system as a whole. Today there exists a rapid development of such systems towards intelligent control units [5].

In order to detect rotation of axis a Hall effect sensors were used. The main principle of this sensor is that it can detect the presence and magnitude of a magnetic field. In our particular case a linear Hall effect sensor is needed since it`s output depends on polarity of magnet field which can be achieved by placing a sensor between north and south pole of two magnets and rotating it around axis.

One of the parts that can improve usability of the controller is the aspect of being wireless. Without spare cables it is more simple to setup, transport and maintain and use the device. Wireless communication will be between two microcontrollers, where one is connected to a PC and is used as HID device and another is for reading signals from sensors and buttons.

The software part of the system is written in C-like programming language that is called Arduino programming language and it is used in Arduino IDE.

Problem statement. So to have the unmanned aerial vehicle (UAV) to operate effective the operating crew should be really competent and well trained. To do their tasks effectively a crew should be able to quickly detect any problem and to solve it as quickly as possible. Since in air it is the matter of seconds between life and death. For example when you performing reconnaissance task and signal is starting to lose. First of all you as a pilot should notice that, and then make a maneuver depending on situation. And if pilot would not notice that problem then he can easily loose an expensive equipment and what is worse he would fail the task, which could lead to a devastating consequences. And there are a lot of such situation when pilot have to quickly detect problem, make a right decision and act accordingly.

But to have such skills a pilot should be training a lot. But training not just in theory but on practice. And with a lot of practise it would be much easier and effective to perform the real tasks. Though it would be too expensive for newbie pilots to train on real UAV`s, since without a lot of experience it would be much easier to damage or destroy an aircraft because of human error.

In this case to not damage expensive equipment there are special simulator software that simulates a real model and behaviour of an aircraft, where pilots can improve their flying skills. Usually such software runs on personal computers (PC). Also there is a problem that common PC does not have any input control as the aircraft does.

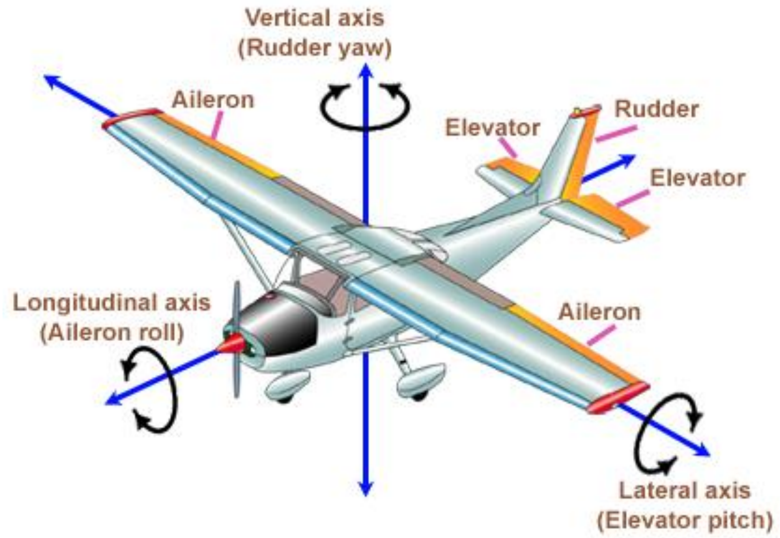

Fig. 1 – Main controls of an aircraft

So in this article a special universal input device that can be used for training and other purposes were made. Such a device should have the same control that common aircraft has. Usually common aircraft has four main controls. The elevator for controlling an elevation pitch, the ailerons for controlling an aileron roll, a rudder for controlling the rudder yaw, and the thrust lever to control the power of the motor (see Fig. 1). And for each part there is separate controll units: joystick for aileron and elevator control; a pedals for rudder control; a thrust lever for controlling the power of the motor.

Purpose of the work. The purpose of this work is to create a controller device to imitate a real aircraft controls. This device should be able to be recognized as a HID device, so it can be used in flying simulation software. The device should have three main components.

Joystick for controlling pitch and roll with additional custom programed buttons;

Pedals for controlling yaw;

Thrust lever for controlling power of the motor with additional custom programed buttons;

Those parts are used as user input and information from sensors and buttons of those parts should be sent to a microcontroller that is connected to a PC. A data from user input parts should be sent wirelessly. In this case we achieve mobility and modularity of the device which makes it easier to setup, maintain, upgrade and use.

Created device can serve a multiple roles. First of all it is made for training aircraft pilots. But since flying by itself is quite exciting and interesting the device can also serve a role for entertainment. Since there are a lot of video games that includes flying an aircraft vehicle in it`s gamepaly.

Chose of elements for implementation. To implement this controlling device it is needed to chose the components for implementation. This choice depends on availability, price, and technical parameters of each part. Basically what do we need is a main sensors to detect the position of each axis, and a microcontroller which can transmit a data from those sensors to the PC. But there is also wireless part that is need to be considered. So to make this device it is needed at least two microcontrollers: one for reading data from sensors, and another to put data into PC.

For the microcontroller for reading sensors data the Arduino Nano microcontroller board was chosen. Arduino is an open-source platform arranged in a simple microcontroller board. The Arduino is designed to be easy to use and it has its programming language called as the Arduino programming language. Arduino has the advantages of being able to connect with a computer easily through the USB port [6]. Arduino can also combine with other components such as the transceiver NRF24L01 which will be used for wireless communication between two microcontrollers. This board uses the ATMega328P microprocessor. It has 32kB of flash memory, 1kB of EEPROM and 2kB of RAM. It operates on a two stage pipeline with fetch and execution stages: the next instruction is fetched during execution of the current instruction. It`s processor runs at 4 MHz [7]. Another important point is the availability of Analog-to-digital converter (ADC). Arduino has 6 on-board ADC channels which can be used to read analog signal in the range 0-5V. It has 10-bit ADC means it will give digital value in the range of 0 – 1023 (2^10). This is called as resolution which indicates the number of discrete values it can produce over the range of analog values [8].

Second microcontroller should have a HID compatability. But it would also be quite convinient if it would have the same IDE for it`s programming. Such microcontroller have been found and it is Arduino Pro Micro wich ATMega32U4 microprocessor. It has basically the same specifications as previous ATMega328P, but it can be used as HID device.

To chose a sensor for detecting an axis position the two specification need to be considered, a precision of sensor and reliability. So there are two types to chose: a potentiometer type sensor or a Hall effect sensor. Since potentiometers are partially mechanical, and can there is higher possibility of them to malfunction, a Hall effect sensor was chosen. So AH49E linear Hall effect sensor was chosen for this part of system.

Communication between microcontrollers is provided with the help of NRF24L01 module mentioned before. It uses the 2.4 GHz band and it can operate with baud rates from 250 kbps up to 2 Mbps. If used in open space and with lower baud rate its range can reach up to 100 meters. The module can use 125 different channels which gives a possibility to have a network of 125 independently working modems in one place. Each channel can have up to 6 addresses, or each unit can communicate with up to 6 other units at the same time. The power consumption of this module is just around 12mA during transmission. The operating voltage of the module is from 1.9 to 3.6V. This system needs two modules, one for transmitter to transmit data from sensors and one as receiver to get data from transmitting module.

Development of the mechanical part. The main part of the device are it`s mechanics. As it was said before the device should imitate an aircraft controls. And there are basically three main mechanical parts to implement. And those parts are joystick, pedals, and thrust lever.

The joystick part is the most complicated one because it has to be a lever that can move on two axis. More than that this joystick should be always centered at zero position. So to model such mechanism a CAD software Fusion 360 was used. Other than just rotating around two axis the joystick rotation angle should not exceed 30 degrees. For that purpose there are special limiters in design that prevent moving the joystick to an angle of more than 30 degrees. Another thins to be considered is how to attach the Hall sensors and magnets for them. And also there should be enough space to wire everything up. To center joystick on all two axis a spring mechanism should be used. Last but not least thing to be considered that every part should be able to be printed on a 3D printer. So considering those important input parameters the needed model was designed (see Fig. 2). At the top of this model there is an adaptor to attach different handles.

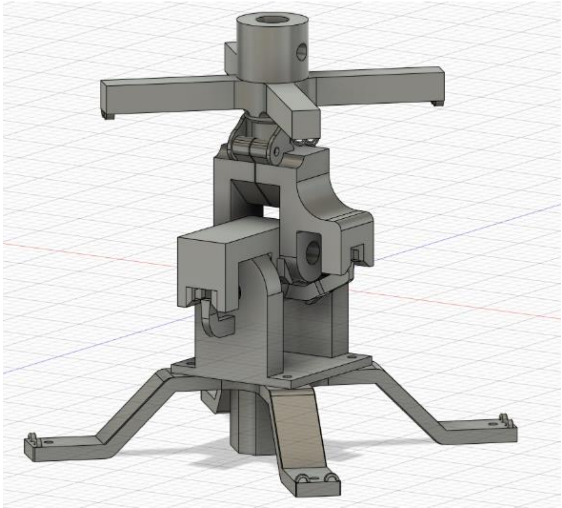

Fig. 2 – The model of joystick developed in CAD software

Making a pedals was an easier task since it has only one axis. But there also should be a limiter for axis angle. And pedals should also be returned to a zero position by itself. But apart from this there are no special requirements for pedals.

A thrust lever though was not so easy to create since there is one catch in this part. It should stay in the position that user left it in. And this task is a bit complicated mechanically since the handle there is quite big and would me moved by gravity force. So it was decided to use traction force in order to prevent lever from moving by itself. To implement this there are several plates in a rotor part that causes a traction to a mechanism (see Fig. 3).

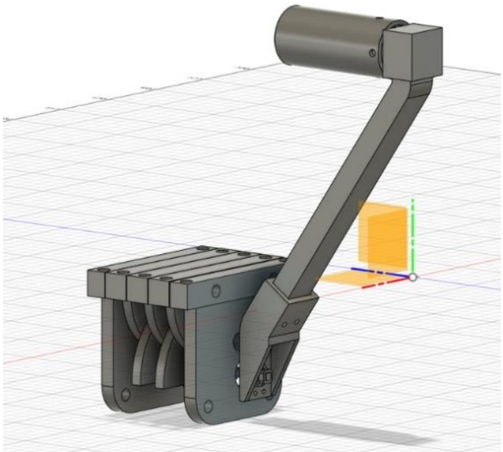

Fig. 3 – The model of thrust lever developed in CAD software

Development of the hardware part. Generally speaking to create a hardware part every electronic component has to be connected together. As it was said before there are two microcontrollers (Arduino Nano and Arduino Pro Micro), two wireless communication modules NRF24L01, four Hall effect sensors AH49E, and four buttons. The schematics of the device can be seen at Fig. 4. Also one thing that was not mentioned that is the NRF24L01 module voltage level is 3,3 volts. But the Arduino Pro Micro does not have such output. So a simple voltage step-down circuit was used. This circuit uses the LM1117 linear voltage regulator.

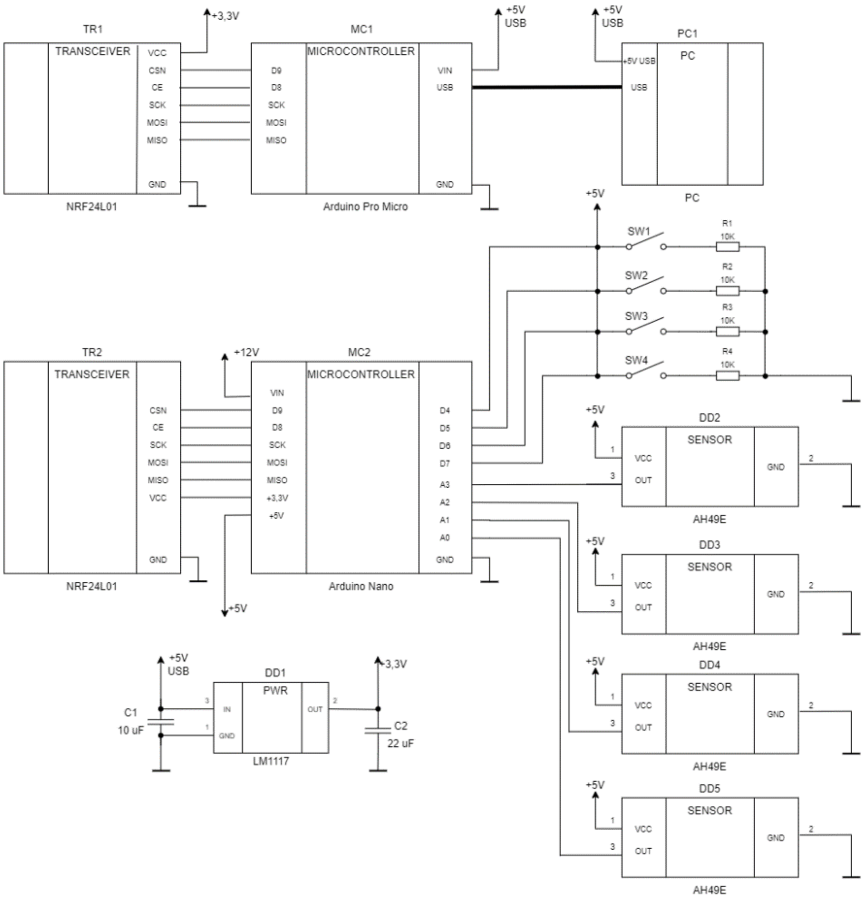

Fig. 4 – Schematics for the hardware part

Development of the software part. The software part in this system consist of two parts. First part is for the microcontroller thar reads data from sensors and buttons, and second part is for receiving those data and sending it to a PC. Communication between those two parts happens with help of module NRF24L01 which uses Serial Peripheral Interface (SPI) to communicate with the microcontroller. But in order to not invent a bicycle a few libraries for this specific module are used. Those are SPI.h, nRF24L01.h and RF24.h.

Transmitted data is formed into array of four integer values. Each integer is responsible for each axis. Since the size of integer in C language is 16 bits, they were divided in the next structure. Each of those integer consists of 2 bits for axis, 4 bits for buttons status, and last 10 bits are for axis value (see Fig. 5). First two bits are to detect for which axis the value is. Since there are only four axis, two bits would be enough to mark every axis. Next four bits are for buttons statuses. So it is logically that it is possible to have up to 16 buttons. Axis value has 10 bits because microcontrollers ADC has 10 bit resolution.

So to transmit this data it is firstly is read with analogRead() and digitalRead() method. Then received data is packed into each integer of the array. It is done using simple logical operations like AND. For example a T-axis has value 555 (0000 0010 0010 1011), and no button is pressed (0000). And also T-axis is marked as -16 384 (1100 0000 0000 0000). Then using logical AND we combine this data into one integer. And then we have our data for one axis, which is -15 829 (1100 0010 0010 1011). Using this simple actions for each axis a complete data package would be ready to be sent. The next step would be to send this data, using method send() from nRF24L01.h library.

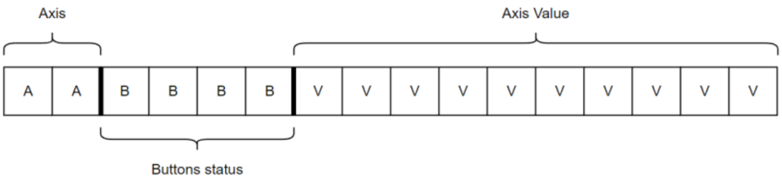

Fig. 5 – Data structure for one axis

At the other end of this system a data should be read, unpacked from integer array, and sent to a PC. To send data as from a HID device a library Joystick.h. was used. This library allows to easily set up a multiple axis and buttons, depending on user needs [9].

Testing the device. In the testing of this device there should be considered several aspects. First of all it has to flawlessly do whatever it designed to be doing. To be exactly it is a work four axis movement, correct buttons pressing, and to be recognizable in the operation system as a HID device. To test this there is a special utility in Windows 10. As we can see at the Fig. 6 the device is detected successfully, and it has all four axis and four buttons.

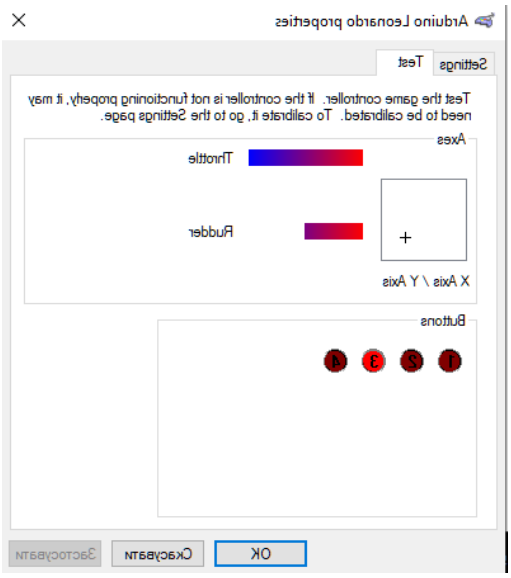

Fig. 6 – Testing the controller using Windows utilities

Another thing that has to be tested is a comfortability of usage. Having used a controller for a brief period of time, it was a pleasant experience to use it. But since this aspect is very personal to each human it is hard task to test it.

Conclusion. As a result of this work, a controlled manipulator for controlling an aircraft was created. Created manipulator can be used as a tool for a flying practice and for an entertainment. It`s main advantage is possibility to be customizable and upgradable. The elements for implementation were chosed considering a reliability, availability on current market, price, and simplicity of a development. The mechanical parts were designed considering specificality of the task, where roll, pitch and rudder axis has a 30 degrees of movement. The hardware part was made from chosen elements to satisfy the needs for wireless communication and sensors precision. The precision for each axis is 10 bit. For this hardware a software were written, using publicly available libraries. Created software can support 4 axis with 10 bit precision and support up to 16 custom programmed buttons. Everything was tested in order to check the created device. At the end device turned out to be a finished work with possibility to improve it further.

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