Design of Self-leveling Table for FFF Additive Technology

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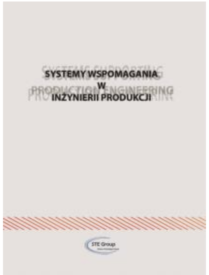

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Abstract: The presented paper describes the conceptual design of a worktable intended mainly for use in combination with FFF additive technologies, calibrated using a gyroscope and accelerometer. The proposed system is based on a programmable Arduino platform that operates with three digital servomotors and a mechanical gyroscope. In the introduction, the theoretical assumptions, and definitions of basic concepts such as a gyroscope, electric motor, and RC servomotor are described. Subsequently, the contribution is devoted to the selection of suitable components, the schematic connection, and the design itself in the Autodesk Inventor program. In the conclusion, the anticipated benefits of using the technical solution when applied in FFF additive technologies are described.

Keywords: Additive Technologies, Calibration, Arduino, Structural Design

INTRODUCTION

The content of this work is the design of a worktable, which is calibrated using a gyroscope and an accelerometer. One of the areas where this proposal would find its application is in the field of additive manufacturing. If the design is used in this area, a calibrated table would ensure an almost perfect plane, which would increase the quality of 3D printing. This proposal would play a big role, especially in the initial phase of printing, because it is important that when applying the first layers of material, there is sufficient adhesion between the printed model and the substrate of the calibrated table [1, 2]. The advantage of this designed worktable is that it eliminates the vibrations of the 3D printer, thus contributing to higher printing accuracy. The introductory chapter is devoted to the division of gyroscopes and the basic principles of operation of electric motors. The second chapter describes selected components for the proposed solution. The content of the last chapter is the actual design of the workbench solution [3, 4, 5].

Gyroscopes

Before the development of GPS, the gyroscope, together with the magnetic compass, was probably the most commonly used navigation sensor. In many cases where the magnetic field is altered by interference or is completely absent, a

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gyroscope is essential for determining the position of, for example, a vehicle or an aircraft. Currently, the use of the gyroscope is much wider than just for navigation. The gyroscope is used to stabilize various devices, in robotics, weapons, and in many other systems where it is necessary to maintain direction. Gyroscopes intended for navigation must meet certain requirements, such as good linearity, a suitable range, and high accuracy as well [6].

Among other things, the gyroscope must be able to capture different rotation rates from constant up to 100°/s. It must also meet the requirement of very good production quality. For example, a shift of 2 nm between the center of gravity and the area of buoyancy action can cause insufficient balance of the gyroscope, thus creating a deviation of 10−9°/h. The lowest possible deviation is required for gyroscopes. For example, with ships whose transportation can take several weeks, errors can accumulate, and therefore periodic correction is necessary. In comparison, for airplanes that only fly for a few hours, these accumulated errors are acceptable. In the standard case, the gyroscope has a deviation of 10−2°/h [7].

The basic principle of the gyroscope's operation is the conservation of momentum. In any system of particles, the total angular momentum of the system relative to any fixed point in space remains constant as long as no external forces act on the system. In the field of inertial navigation, we practically divide two types of gyroscopes according to the principle of angular velocity measurement, into mechanical gyroscopes and optical gyroscopes. Mechanical gyroscopes contain the so-called flywheel, while optical ones do not, and that is their fundamental difference. In more detail, we can divide gyroscopes as:

- with one degree of freedom,
- with two degrees of freedom,
- with 3 degrees of freedom,
- dynamically tuned gyroscopes,
- vibrating gyroscopes,
- MEMS gyroscopes using the Coriolis force.
- optical gyroscopes:
  - fiber optic gyroscopes,
  - ring laser gyroscopes [8, 9].

Electric Drive

An electric motor is an electrical machine that converts electrical energy into mechanical work. In the opposite case, when mechanical work is converted into electrical energy, we speak of a generator. A dynamo is a direct current generator, an alternator is an alternating current generator. These two devices tend to be very similar or even identical, except for some small design differences. Most of the electric motors used today work on the electromagnetic principle, but there are also motors based on other electromagnetic phenomena, such as the piezoelectric effect, electrostatic forces, or thermal effects of the passage of electric current. However, currently, these alternative electric motor designs are hardly used at all. The basic principle on which electromagnetic motors are built is the interaction of electromagnetic fields that are created by electric circuits through which electric current flows. In an electric rotary machine, the rotating part is mostly located inside and is called the rotor. The static, non-rotating, i.e., fixed part of the machine is called the stator. A DC electric motor can also contain a rigidly connected set of electromagnets that are usually located on the rotor. We call the frame of the electric motor an armature. The armature refers to the part of the electric motor that performs work, or the part through which the output voltage is generated. Depending on the type of motor, both the rotor and the stator can serve as an armature. The term is not very precise, and it is also outdated because, from a general point of view, the whole structure does the work and not just one part of it. [10].

In a conventional rotary motor, the position of the rotor is chosen so that the magnetic field created in the conductors and the magnetic field of the stator together develop a torque and transmit it to the rotor. This torque performs the necessary rotation of the rotating part of the motor. We can divide electric motors into the following categories:

- DC Electric Motors:
- Permanent Magnet Motors,
- Serial Motors,
- Derivative Motors,
- Compound Motors,
- Brushless Motors,
- Steppers Motors,
- Servo Motors.
- AC Electric Motors (single-phase or multi-phase):
- Synchronous Motors,
- Asynchronous motors,
- Servo Motors [11].

SELECTION OF COMPONENTS FOR THE DESIGN OF THE WORKTABLE

RC Servo motor

Electric servomotors are controlled exclusively by transistor converters with pulse-width modulation. They are mainly used for radio-controlled models such as model cars, airplanes, etc. The control method differs from ordinary and stepper electric motors because the input signal is the changing shape of the low AC voltage, which, in practice, is mostly provided by a microcontroller with a precise definition of use. For the design of the workbench, a digital servo motor from the model-making category, manufactured by Hitec, model D625 MW, shown in Figure 1 [12].

Fig. 1 Servomotor Hitec D625MW

Gyroscope with Accelerometer

The three-axis MPU-6050 type gyroscope shown in Figure 2 was chosen for the design.

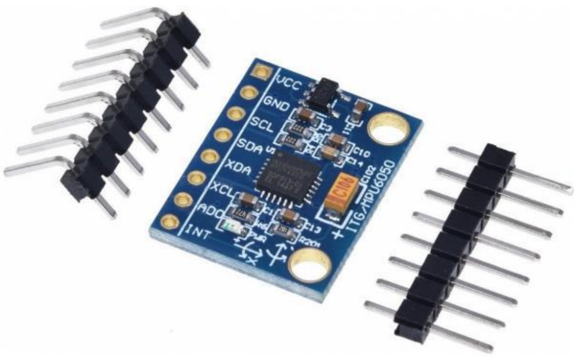

Fig. 2 Gyroscope with Accelerometer MPU-6050

Thanks to the 16-bit analog converter, it achieves high accuracy and reliability. This module scans all 3 axes simultaneously and uses a 12C interface to communicate with the microcomputer.

A DMP unit (Digital Motion Processor) is built into this module, which can also be programmed separately for calculating complex operations with measured values. Thanks to DMP, it is not necessary to load the Arduino board and calculations directly on it, but thanks to the 12C interface, it can even calculate with values from another chip. The parameters of this module are listed in Table 1 [13].

Table 1 MPU-6050 Gyroscope Specifications

Working Voltage (V)	3-5
Gyro Full-Scale Range (°/s)	±2000
Accelerometer Sensitivity (g)	±16
Gyroscope ADC Word Length (bit)	16
Gyroscope Operating Current (mA)	3.6
Length (mm)	21
Width (mm)	15
Height (mm)	1.2

Arduino UNO

Arduino is a microcontroller system built on a single circuit board. This system is based on simple hardware and user-friendly software. The platform was created in 2005 in Italy in the city of Ivrea as a program for students. Founders Massimo Banzi and David Cuartielles named this project after Arduino Ivrejski, who was one of the important historical figures of the city. It is an open-source platform, which means that anyone can create their own circuits, improve them, and that all sample programs and documentation are freely available. The project was a great success in the world. More than 120,000 units were sold in just 5 years of its existence. This success is also confirmed by the fact that various clones (imitations) are created all over the world, which are their faithful functional copies. Arduino Uno is one of the basic models of the Arduino microcomputer system. It is a very popular and often used type. The reasons for choosing this platform were its affordability, low consumption, high compatibility with other electronic components and many expansion options. The board can be powered by batteries or directly from the mains via an adapter. The Arduino Uno motherboard is shown in Figure 3.

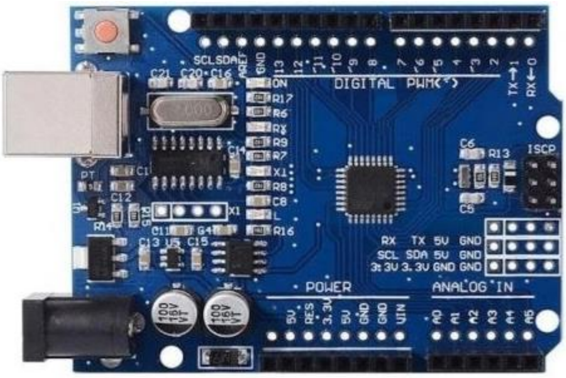

Fig. 3 Arduino Uno Board

The basic parameters of the Arduino Uno board are listed in Table 2 [14, 15].

Table 1 Technické parametre Adruino UNO

Microcontroller	Atmega328
Max I/O Voltage [V]	5
Recommended Board Power Supply [V]	7.12
Min/Max Power Suply [V]	6.20
Digital I/O pins	14
PWN Pins (8 bit)	6
Analog Pins (10 bit)	6
DC Current on I/O Pin [mA]	20
DC Current from 3.3 V Pin [mA]	50
Flash Memory [kB]	32
SRAM [kB]	2
EEPROM [kB]	1
Microprocessor Frequency [MHz]	16
LED_BUILTIN	13
Length [mm]	68.6
Width [mm]	53.4
Weight [g]	25

CONSTRUCTION DESIGN

The structural design was implemented in the Autodesk Inventor program. It consists of several parts. The first part is the lower base plate, on which three servomotors and one holder are placed with the help of screws, which holds the fourth fixed point. The servomotors are placed on the bottom plate so that the connecting rod between the base and the top plate (the table itself) is exactly in the middle of both plates. The output force is transmitted from the servomotors to the lever of the motor. This lever is attached to the connecting rod with a pin and nut. A threaded rod was chosen as a connecting element, thanks to which it is possible to slightly adjust the distance between the base plate and the table itself. The last part of the assembly is closed by a ball pin or joint that connects the threaded rod and the table itself. This pivot allows the table a sufficient range of tilt. The Arduino control unit is placed on the motherboard. The gyroscope with the accelerometer is located on the underside of the table. The assembly design is shown in Figure 4.

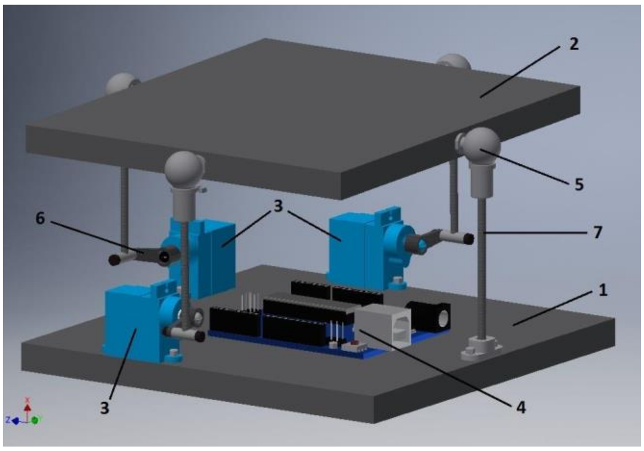

Fig. 4 Description of parts of the structural design

Assembly composition:

1. Base table with dimensions 280x280x20 mm,
2. The board of the work table itself with dimensions of 250x250x20 mm,
3. Servomotor Hitec D625 MW,
4. Arduino UNO control board,
5. Ball pin that allows movement when tilting the table,
6. Servo motor lever,
7. Connecting rod between the base plate and the table top itself.

Schematic connection of the electrical installation

Figure 5 shows the schematic connection of all the components that make up the assembly. When connecting, it is necessary to be careful not to change the polarities of the power supply of the devices. With the data pins, it is no longer so important, and everyone chooses the connection according to their discretion, which is subsequently taken into account when creating the control program. A voltage regulator and a capacitor were also added to the scheme.

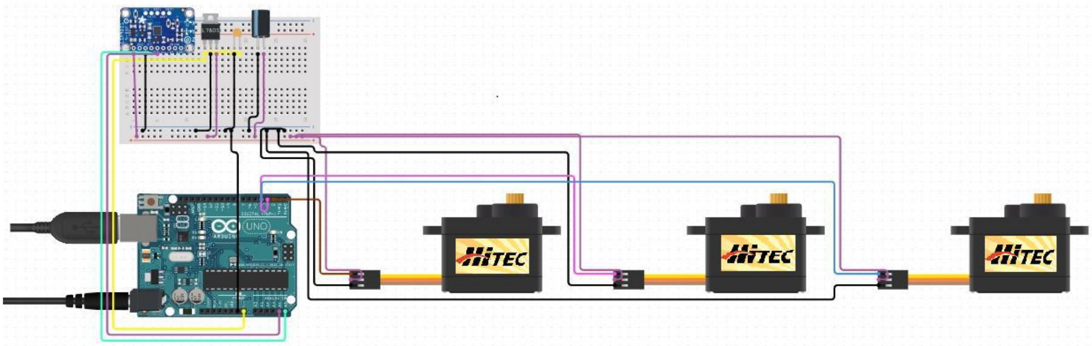

Fig. 5 Wiring diagram

The control program for Arduino can be programmed in C, C++ or there is an option offered by the manufacturer of this board itself, namely the Arduino IDE programming language. This software is available for free download. It is an add-on for C++ and is basically a simplification of the C programming language. Thanks to this, even a person with no programming experience can easily learn this language. With the help of this software, we can create programs, save them or directly upload them to the Arduino.

CONCLUSION

The main goal of the presented contribution was to design a work table that will be calibrated to the plane using a gyroscope and an accelerometer. Basic terms such as gyroscope, electric motor, RC servomotor are defined in the introduction. In the next part, the work describes the design itself and the selection of components. For the needs of the conceptual design, a suitable RC digital servo motor was chosen, while the proposed solution contains three of these motors. Subsequently, a platform was selected on which this entire proposal will work. Due to its versatility, modularity and expansion possibilities, the Arduino platform was chosen, for which a gyroscope with an MPU-6050 accelerometer was designed, which meets all the necessary requirements.

The structural design took place in the Autodesk Inventor software, where all the necessary parts of the assembly were gradually designed and then assembled into a functional assembly. The last step was to create a wiring diagram of individual components and insert the generated program into the Ardunio IDE software.

The design presented in this work was aimed primarily at use in the field of 3D printing, but it would certainly find its application in other smaller machines, which, thanks to their compact dimensions, can also be found in e.g. in the home environment. In 3D printing, this design plays its role mainly in the first phase of printing, where it is important that there is a precisely defined gap between the worktable and the printed component, which this calibrated worktable could provide at every point of the worktop.

One of the possibilities of further expansion of this proposal in the future could consist in the targeted tilting of this work table, which would create the so-called a "fourth working axis", thanks to which the printing possibilities would be increased. The mechanical part of this continuation of the design could be identical to the design of this work, but the schematic and control parts would be much more complicated. In addition to 3D printing, this design could be used e.g. in the area of small engraving CNC milling machines or in other applications where it is necessary to ensure the best flatness.

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