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MODULE 6

Sensors and Electronics

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1.The Importance of Electronics and Sensors in Industrial Design

Industry 4.0, through the integration of smart sensors and IoT technology, serves as a bridge between the physical and digital realms.

In smart manufacturing facilities, the utilization of smart sensors presents opportunities for failure prediction, efficiency enhancement, and real-time monitoring, all contributing to the development of intelligent factories. Sensors play a major role in automating factory operations, rendering the system more sophisticated. Various types of sensors are accessible, tailored to specific applications, with many being mass-produced and affordable. Common sensor types include position sensors, pressure sensors, flow sensors, temperature sensors, and force sensors. They find applications across diverse sectors such as motorsport, healthcare, industry, aerospace, agriculture, and everyday life [1-50].

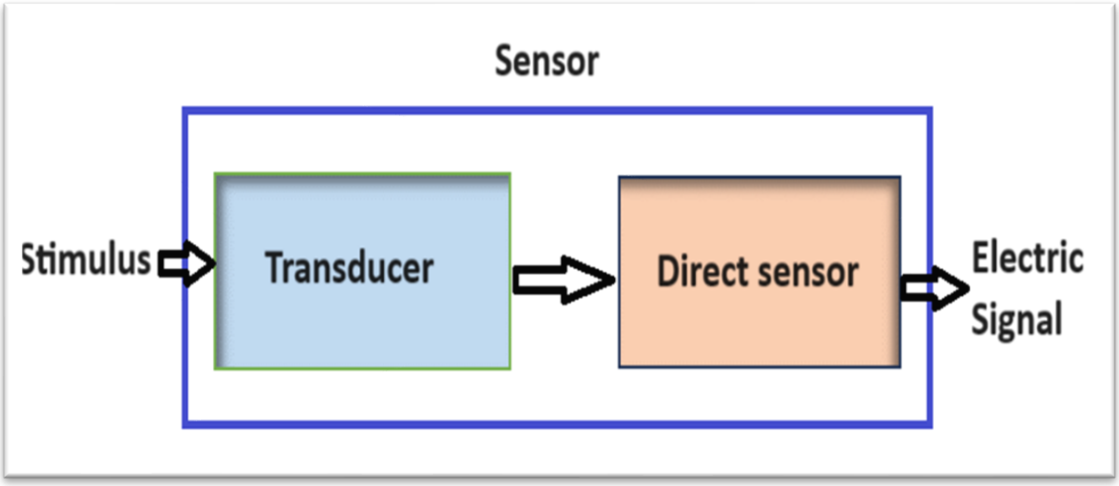

Fig.1. Schematic diagram of a sensor with input & output signal

The objective of Industry 4.0 is to increase efficiency through automation. Sensors are vital components of Industry 4.0, allowing several transitions such as changes in positions, length, height, external and dislocations in industrial production facilities to be detected, measured, analysed, and processed. Smart factories will also enhance sustainability by tracking

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real-time output, and automated control systems will minimise potential factory maintenance costs. It can also be seen that digitalisation can improve production mobility, which gives advanced manufacturing firms a competitive advantage. This chapter presents sensors and their various types, along with significant capabilities for manufacturing. The step-by-step working Blocks and Quality Services of Sensors during implementation in Industry 4.0 are elaborated diagrammatically. Finally, we identified thirteen significant applications of sensors for Industry 4.0. Industry 4.0 provides an excellent opportunity for the development of the sensor market across the globe. In Industry 4.0, sensors will enjoy higher acceptance rates and benefit from a fully enabled connecting and data exchange and logistics integration. In the coming years, sensor installations may grow in process management, automated production lines, and digital supply chains [1-50].

2. Types of sensors and their applications in Industries/manufacturing

All sensor types can be categorized into analogue and digital variants. However, within electronic applications, certain sensors are particularly prevalent. These include pressure sensors, touch sensors, IR sensors (infrared sensors), ultrasonic sensors, temperature sensors, proximity sensors, and others.

Light Sensors

The light sensor functions to detect light and typically produces a voltage difference. In robotics, light sensors come in two main types: photovoltaic cells and photoresistors. Photovoltaic cells are employed to convert solar radiation energy into electrical energy, making them ideal for use in solar-powered robots. Conversely, photoresistors adjust their resistance based on light intensity; as light increases, resistance decreases. These light sensors are generally cost-effective, making them widely utilized in robotics.

Sound Sensor

A sound sensor detects a sound and converts it into an electrical signal. By applying this type of sensor, robots can navigate through sound, even to the point of creating a sound-controlled robot that recognizes and responds to specific sounds or series of sounds, to carry out certain tasks.

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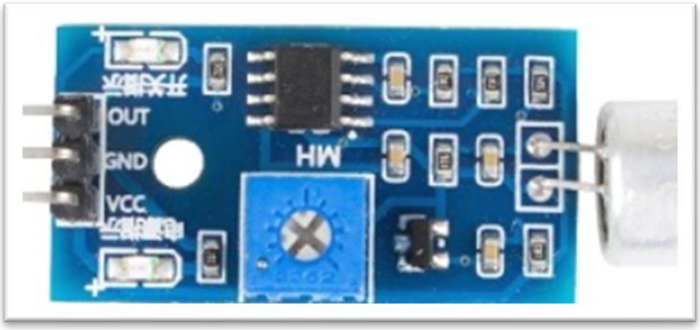

Fig.2. Sound sensor [5]

Temperature Sensor

A temperature sensor is employed to detect fluctuations in environmental temperature. It operates primarily on the principle of voltage difference to measure temperature changes and derive the corresponding temperature values of the surroundings. Various types of temperature sensor integrated circuits (ICs) are available for temperature detection, such as LM34, TMP37, TMP35, TMP36, LM35, and others. These sensors are essential for robots operating in diverse and extreme weather conditions, ranging from icy glaciers to scorching deserts [1-50].

Fig.3. Thermistor [3]

Contact Sensor

Contact sensors, commonly referred to as touch sensors, are primarily designed to detect changes in velocity, position, acceleration, torque, or force at the joints of a manipulator and its end-effector in robots. Physical contact is required for these sensors to efficiently direct the

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robot to act accordingly. The sensor is executed in different switches such as a limit switch, button switch, and tactile bumper switch.

Contact sensors are frequently utilized in obstacle avoidance robots. When these sensors detect an obstacle, they transmit a signal to the robot, prompting it to execute various actions such as reversing, turning, or halting altogether [1-50].

Proximity Sensor

In robotics, a proximity sensor is used to detect objects that are close to a robot and measure the distance between a robot and particular objects without making physical contact. This is possible because the sensors use magnetic fields to sense the objects in question. Proximity sensors are typed into photoresistors, infrared transceivers, and ultrasonic sensors.

Infrared (IR) Transceivers

An infrared (IR) transceiver or sensor is designed to measure and detect infrared radiation present in its surroundings. These sensors can be categorized as either active or passive. Active infrared sensors function by both emitting and detecting infrared radiation, typically comprising a light-emitting diode (LED) and a receiver. These active transceivers are commonly utilized as proximity sensors, often found in robotic obstacle detection systems.

On the other hand, passive infrared (PIR) sensors solely detect infrared radiation without emitting it from the LED. These passive sensors are primarily employed in motion-based detection systems.

Ultrasonic Sensor

An ultrasonic sensor is a device that measures the distance of a specific object by emitting ultrasonic sound waves and converts the reflected sound into an electrical signal. Ultrasonic sensors radiate sound waves toward an object and determine its distance by detecting reflected waves. This is why they are mainly used as proximity sensors, applied in robotic obstacle detection systems and anti-collision safety systems.

Photoresistor

Photoresistors, also known as light-dependent resistors (LDR), are devices that alter their resistance based on the intensity of light incident upon them. Because of their sensitivity to light, they are commonly utilized to detect the presence or absence of light and to measure light intensity. In photoresistors, increased light results in decreased resistance [1-50].

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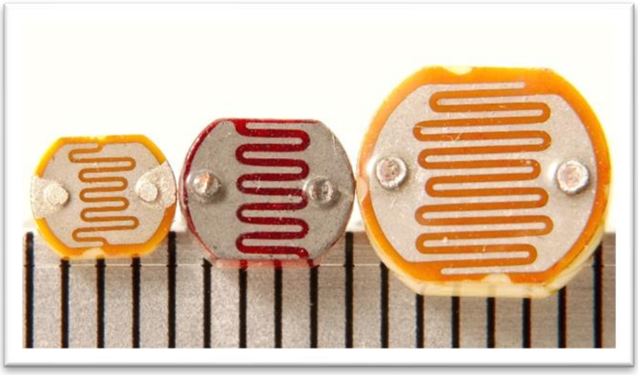

Fig.4. Photoresistors [4]

Distance Sensor

Distance sensors are employed to determine the distance between objects without requiring physical contact. These sensors operate by emitting a signal and measuring the time it takes for the signal to return. The emitted signal can be infrared, LED, or ultrasonic waves, leading to the common association of distance sensors with ultrasonic technology.

Ultrasonic Distance Sensors

An ultrasonic distance sensor is a device that gauges the distance to an object by utilizing high-frequency sound waves. These sensors emit sound waves at frequencies higher than those audible to humans and subsequently wait for the waves to be reflected. By measuring the time elapsed between sending and receiving the ultrasonic wave and factoring in the speed of sound, the sensor calculates the distance to the target object [1-50].

3. Actuators used in Industries/manufacturing

An actuator is a component of a machine that produces force, torque, or displacement, usually in a controlled way, when an electrical, pneumatic or hydraulic input is supplied to it in a system (called an actuating system). An actuator converts such an input signal into the required form of mechanical energy. It is a type of transducer. In simple terms, it is a "mover". An actuator requires a control device (controlled by control signal) and a source of energy. The control signal is relatively low energy and may be electric voltage or current, pneumatic,

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or hydraulic fluid pressure, or even human power. In the *electric*, *hydraulic*, and *pneumatic* sense, it is a form of automation or automatic control.

The displacement achieved is commonly linear or rotational, as exemplified by linear motors and rotary motors, respectively. Rotary motion is more natural for small machines making large displacements. By means of a leadscrew, rotary motion can be adapted to function as a linear actuator (a linear motion, but not a linear motor) [1-50].

Types of actuators are:

- Soft actuator
- Hydraulic actuator
- Pneumatic actuator
- Electric actuator
- Electromechanical actuator (EMA)
- Electrohydraulic actuator
- Linear motor
- Rotary motor
- Thermal or magnetic actuators
- Mechanical actuator
- 3D printed soft actuators.

3D printed soft actuators

Many soft actuators are currently manufactured using multistep processes such as micro-molding, solid freeform fabrication, and mask lithography. However, these methods often involve manual fabrication, post-processing, and lengthy iterations to achieve fabrication maturity. To address these challenges, researchers are exploring more efficient manufacturing approaches for soft actuators.

One promising approach involves utilizing rapid prototyping methods, such as 3D printing, to fabricate soft actuators in a single step. By doing so, researchers aim to streamline the fabrication process, making it faster, more cost-effective, and simpler. Additionally, these methods enable the integration of all actuator components into a single structure, eliminating the need for external joints, adhesives, and fasteners.

Shape memory polymers represent a fascinating field of polymer innovation. Essentially, these materials have the ability to 'remember' their original shape and return to it when triggered by certain stimuli, such as heat or light. These materials possess a unique ability to 'remember' their original shape and return to it after being deformed. This phenomenon, known as the shape memory effect (SME), is observed in shape memory alloys (SMAs), shape memory polymers (SMPs), and shape memory hybrids (SMHs).

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Shape memory materials are categorized under “smart materials” or “intelligent materials”, which are responsive to external stimuli. The shape memory effect can be triggered by various stimuli such as heat, light, stress, moisture, electric or magnetic fields, pH, or chemical compounds. When exposed to these stimuli, these materials undergo controlled changes in their properties, particularly their shape, demonstrating their unique adaptive capabilities.

Shape memory polymer (SMP) actuators are the most similar to our muscles, providing a response to a range of stimuli such as light, electrical, magnetic, heat, pH, and moisture changes. They have some deficiencies including fatigue and high response time that have been improved through the introduction of smart materials and combination of different materials by means of advanced fabrication technology. The advent of 3D printers has made a new pathway for fabricating low-cost and fast response SMP actuators. The process of receiving external stimuli like heat, moisture, electrical input, light, or magnetic field by SMP is referred to as shape memory effect (SME). SMP exhibits some rewarding features such a low density, high strain recovery, biocompatibility, and biodegradability. Various 3D printing technologies have been employed for this purpose, including fused filament fabrication (FDM), direct ink writing (DIW), PolyJet, and vat polymerization methods such as stereolithography (SLA) and digital light processing (DLP).

Smart materials like photoresponsive polymers and composites exhibit the remarkable ability to undergo shape changes when exposed to light. These light-induced shape-changing polymer materials can be categorized into various types, including liquid crystal elastomers (LCE), hydrogels, light-activated shape memory polymers, and composites.

Photopolymers or light activated polymers (LAP) are another type of SMP that are activated by light stimuli. The LAP actuators can be controlled remotely with instant response and, without any physical contact, only with the variation of light frequency or intensity.

A need for soft, lightweight and biocompatible soft actuators in soft robotics has influenced researchers for devising pneumatic soft actuators because of their intrinsic compliance nature and ability to produce muscle tension.

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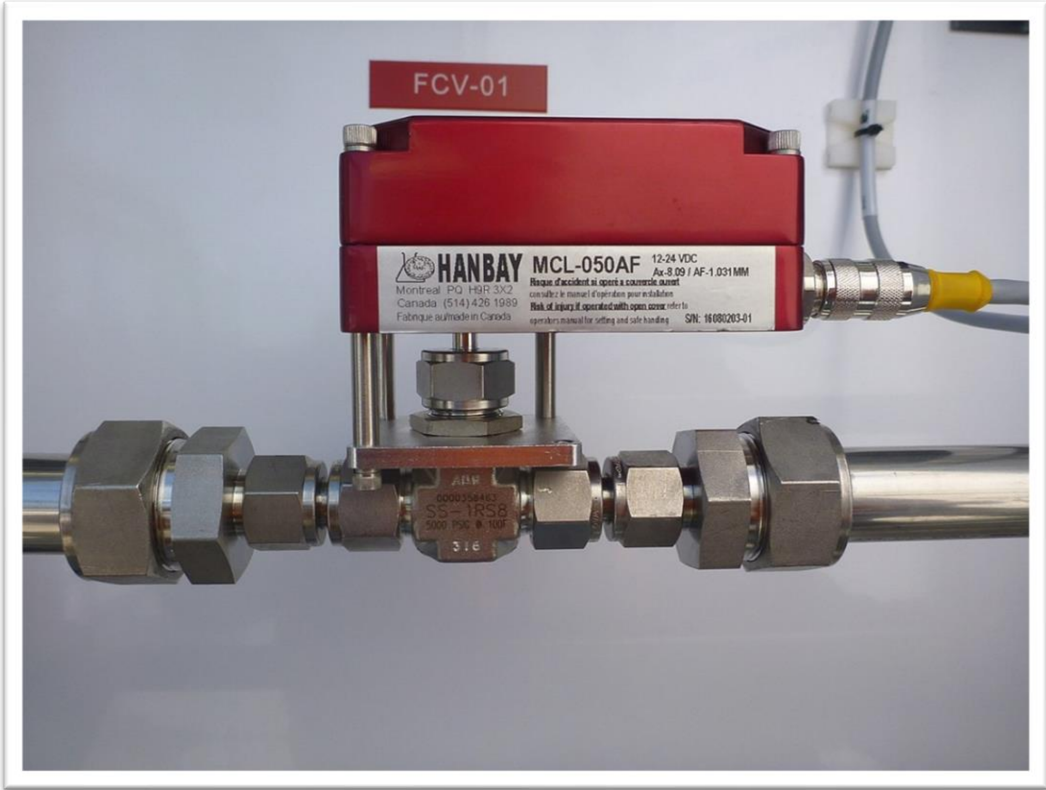

Fig.5. Electric valve actuator controlling a ½ needle valve [6]

Polymers such as dielectric elastomers (DE), ionic polymer–metal composites (IPMC), ionic electroactive polymers, polyelectrolyte gels, and gel-metal composites are common materials to form 3D layered structures that can be tailored to work as soft actuators. EAP actuators are categorized as 3D printed soft actuators that respond to electrical excitation as deformation in their shape.

The actuators are frequently used as mechanisms to introduce motion in industry, or to clamp an object to prevent motion. In electronic, actuators are a subdivision of transducers. They are devices which transform an input signal (mainly an electrical signal) into some form of motion [1-50].

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4. *Electronic components used for the manufacture of 3D hybrid printer, type DIY (do it yourself)*

In the last decade, additive manufacturing has greatly developed, and the manufacture of cheaper 3D hybrid (multitool) printers has increased. Hybrid 3D printers are equipped with interchangeable heads for manufacture and permit multiple types of processing such as 3D printing, CNC cutting, laser engraving or deposition of pasty materials. The objective of this paper was to manufacture a hybrid 3D printer prototype, type DIY (do it yourself) and was equipped with g-code software necessary for 3D printing process and for CNC cutting. The materials used for construction for this hybrid 3D printer are cheap and accessible and some of electronic components are reused and recovered from old equipment and the functional 3D hybrid printer obtained can be a model for sustainability of products.

The purpose of this research was to create a hybrid 3D printer prototype, recycling, and recovery of old electronic components, such as were used stepper motors from some old Xerox equipment, enabling sustainable development of the product. Hybrid 3D printers are multifunction printers that will replace traditional 3D printers in the future or min-CNC and will be finding in most households, because of their varied functionality. A hybrid 3D printer ZMorph is shown in figure 6 [1-50].

Hybrid 3D printers are equipped with several interchangeable heads: as simple 3D print head, 3D dual head, CNC head, laser engraving head and ceramic material deposition head.
Fused Deposition Modeling technology (FDM) uses a variety of filament-like materials of PLA, ABS, nylon, PVA, PET, PETG etc. [2]. The mechanical strength of the manufactured parts is very good, often existing 3D printers that are sold with 3D printed components in their composition [3]. Hybrid 3D printers used this technology for printing 3D parts.

The mechanical strength of the 3D printed parts is very good, often existing 3D printers that are sold with 3D printed components in their composition.

The hybrid prototype 3D printer made in this research also has in its composition, 3D printed parts, 3D printed directly on itself, like the red brackets of the printed table and the head CNC components.

FDM technology operates by building a CAD-designed product layer by layer. The object is first saved in an STL file format, which is then used by the 3D printer software to guide the printing process. This technology allows for the creation of supports, which are necessary for the fabrication of complex 3D printed parts.

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Prototypes produced using FDM technology typically do not require additional post-processing treatments and can be utilized immediately, featuring high-quality surface finishes.

The Additive Manufacturing technology helps identify any problems that may arise in the design and conception. [1-50]

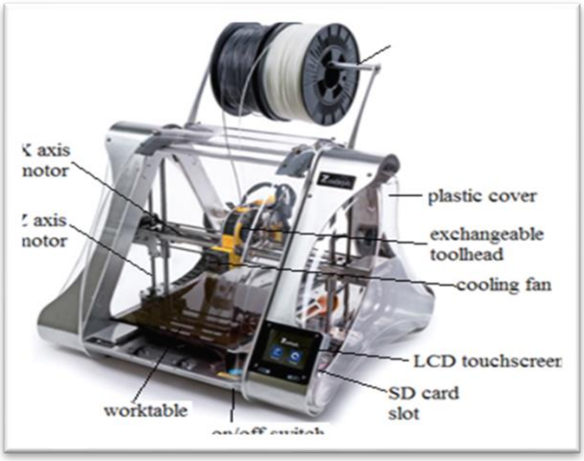

Fig.6. Commercial 3D hybrid printer ZMorph [7]

ZMorph printer can print layers up to 50 microns. ZMorph 3D hybrid printer is equipped with five interchangeable heads allowing printing, milling, drilling and engraving materials widely. The manufacturing dimensions of ZMorph printer are 300x235x165 mm. The manufactured materials of this printer are very different from PLA, ABS, special filaments wood, etc. The software used of this printer is Voxelizer. The cost of hybrid 3D printers can be relatively high, typically around 4000 euros. This research aims to develop a low-cost alternative, priced at approximately 500 euros, to be used for educational and research experiments [1-50].

4.1.Experimental research

The experimental research involves constructing a hybrid 3D printer using do-it-yourself (DIY) methods, utilizing low-cost materials and tools readily available in the market.

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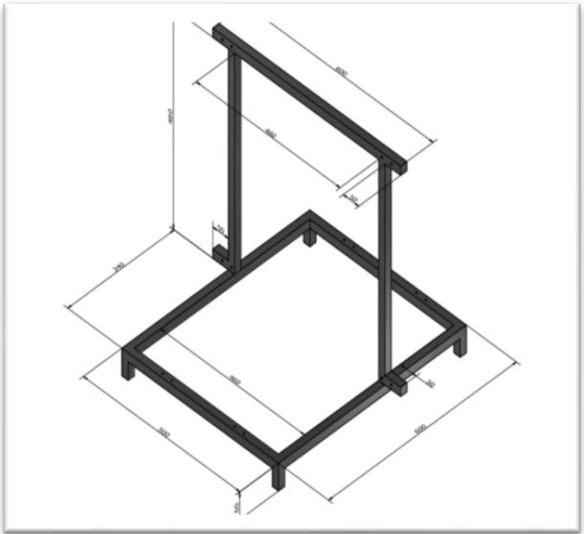

Fig.7. Structure design of 3D printer

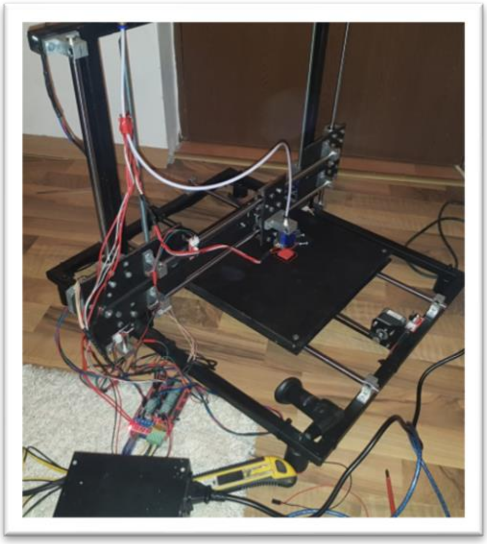

Fig.8. Assembly and welding of 3D printer parts

During the design stage, careful consideration was given to sizing the structural elements based on the dimensions of standard components used, such as clamps for SK10 and SK16, bearings for SC10UU, Ø10 linear guides, and NEMA17 motors. The 3D printer structure will be constructed using welded rectangular profiles measuring 20x20 mm, as illustrated in Figure 7 below.

In Figure 8, the cutting and drilling of PTFE material plates for the printing table were carried out. These plates will serve as the printing surface. Additionally, brackets and linear guides were attached to the fixed table, and bed springs and adjustable thumbscrews were disconnected to facilitate leveling. Linear bearings were installed on the cutting boards, and NEMA17 motors were attached to complete the construction process.

Regarding the electrical connections, various connections were established between the controller and stepper motors. To establish the electrical control network, the following components were used: an Arduino MEGA 2560 development board, a 1.4 Ramps SHIELD module, and 5 drivers 4988, as shown in Figure 9.

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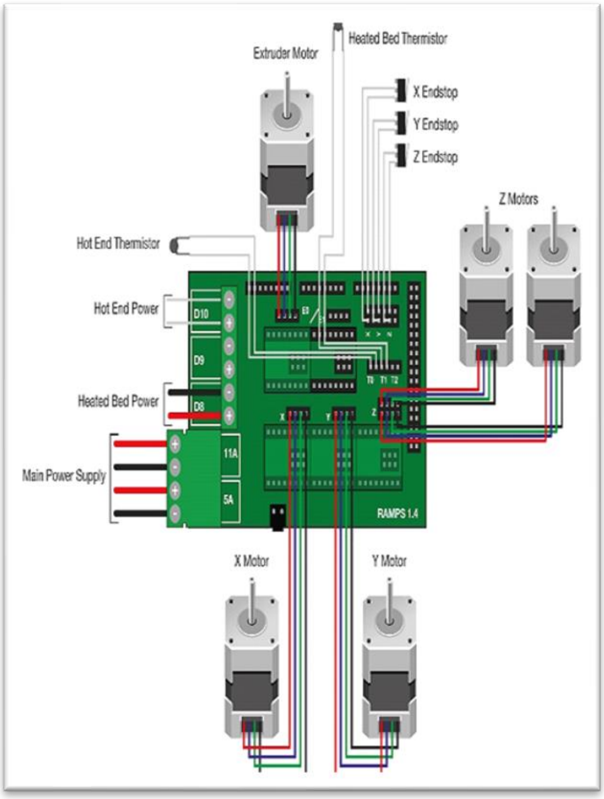

Fig.9. Arduino MEGA 2560 board **Fig.10. Electrical installation scheme**

Figure 10 illustrates the electrical installation scheme, which incorporates a PC PSU 12V 14.6 power supply. Additionally, an endstop with a mechanical feeler, depicted in Figures 11 and 12, was utilized.

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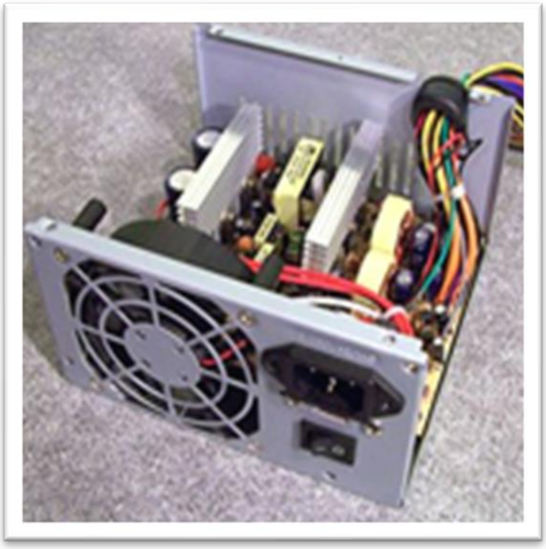

Fig. 11. Power supply PC PSU 12V 14.6

Fig. 12. Endstop with mechanical feeler

The single-pole stepping motors with 4 phases were converted into 2 phases by removing the "mid-point" of the coils A and B (MA:MB), as depicted in Figure 13.

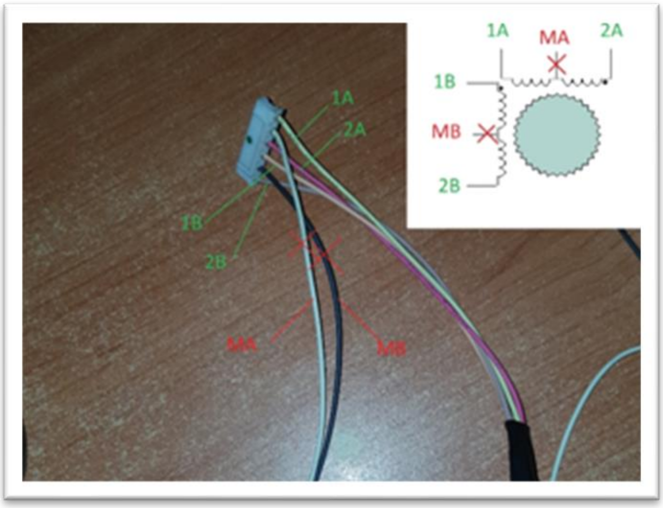

Fig. 13. Stepping motors

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The operation of the 3D printer involved scheduling and optimization using software. The implementation of the printer's physical parameters was achieved through the Marlin 1.1 code, as shown in Figure 14, which was uploaded to the Arduino MEGA 2560 development board [1-50].

```
/**
 * Default Axis Steps Per Unit (steps/mm)
 * Override with M92
 *                                      X, Y, Z, E0 [, E1[, E2[, E3[, E4]]]]
 */
#define DEFAULT_AXIS_STEPS_PER_UNIT   { 80, 100, 1600, 94.3 }
                                   Fulie z20  Fulie z16  Surub P2  Extruder MK8
/**
 * Default Max Feed Rate (mm/s)
 * Override with M203
 *                                      X, Y, Z, E0 [, E1[, E2[, E3[, E4]]]]
 */
#define DEFAULT_MAX_FEEDRATE          { 300, 300, 5, 25 }

/**
 * Default Max Acceleration (change/s) change = mm/s
 * (Maximum start speed for accelerated moves)
 * Override with M201
 *                                      X, Y, Z, E0 [, E1[, E2[, E3[, E4]]]]
 */
#define DEFAULT_MAX_ACCELERATION      { 2500, 2500, 2500, 10000 }

/**
 * Default Acceleration (change/s) change = mm/s
 * Override with M204
```

Fig.14. Marlin1.1 code used for 3D hybrid printer prototype

```
#define TEMP_SENSOR_0 1
#define TEMP_SENSOR_1 0
#define TEMP_SENSOR_2 0
#define TEMP_SENSOR_3 0
#define TEMP_SENSOR_4 0
#define TEMP_SENSOR_BED 1
#define TEMP_SENSOR_CHAMBER 0
```

Fig. 15. Thermistor type used (100K)

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With its aid were set issues, like in figure 15:
- Port for the connection;
- Extruders number;
- Existence heated bed;
-Thermistor type used (100K);
-Maximum axes travel;
-Required number of steps per mm (the pitch of the threads);
-Point0 (homing point);
-Size table printed, as in figure 16;
-Maximum acceleration, as in figure 17;
-Maximum voltage motors.

```
#define X_HOME_DIR -1
#define Y_HOME_DIR -1
#define Z_HOME_DIR -1

// @section machine

// The size of the print bed
#define X_BED_SIZE 260
#define Y_BED_SIZE 260
// Travel limits (mm) after homing, corresponding to endstop positions.
#define X_MIN_POS 0
#define Y_MIN_POS 0
#define Z_MIN_POS 0
#define X_MAX_POS 260
#define Y_MAX_POS 260
#define Z_MAX_POS 280
```

Fig. 16. Size table printed programming

```
#define DEFAULT_ACCELERATION          2500    // X, Y, Z and E acceleration for printing moves
#define DEFAULT_RETRACT_ACCELERATION  3000    // E acceleration for retracts
#define DEFAULT_TRAVEL_ACCELERATION   2500    // X, Y, Z acceleration for travel (non printing) moves
```

Fig 17. Maximum acceleration programming.

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G-code can be generated using various programs, including Slic3r with its extension Pronterface or Simplify3D. These programs utilize models in "STL" format and offer calibration of printing parameters such as printing speed, infill density, wall thickness, layer height, filament width, and temperature settings, as depicted in Figure 18. Figure 19 showcases the physical 3D parts obtained by printing using the prototype of the hybrid 3D printer.

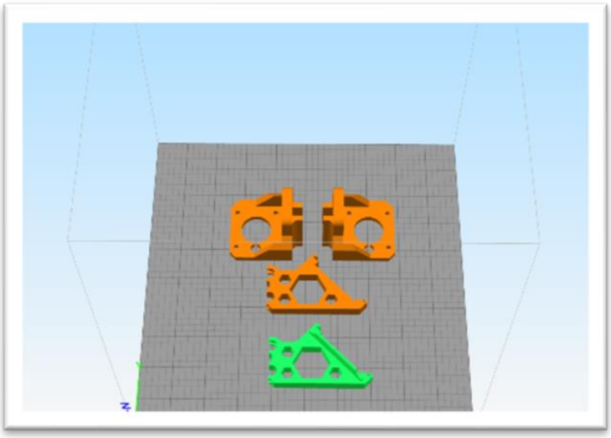

Fig.18. Simplify 3D program used to create G-code

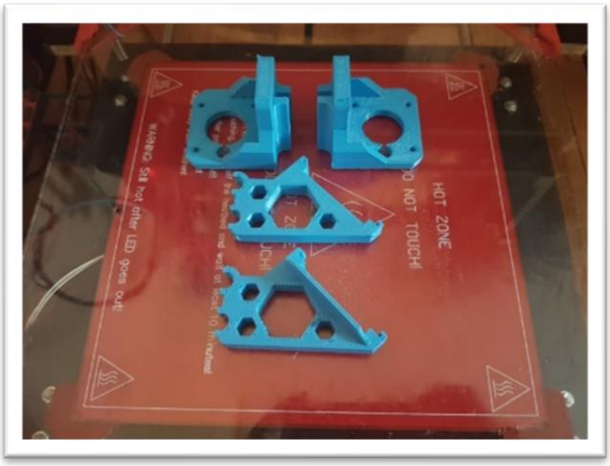

Fig. 19. Physical 3D printed parts

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Figure 20 displays the components of the hybrid 3D printer, while Figure 21 showcases the interchangeable CNC tool head, with some components manufactured using 3D printing technology. Figure 22 illustrates the CNC drilling process performed on the 3D hybrid printer, utilizing the CNC head [1-50].

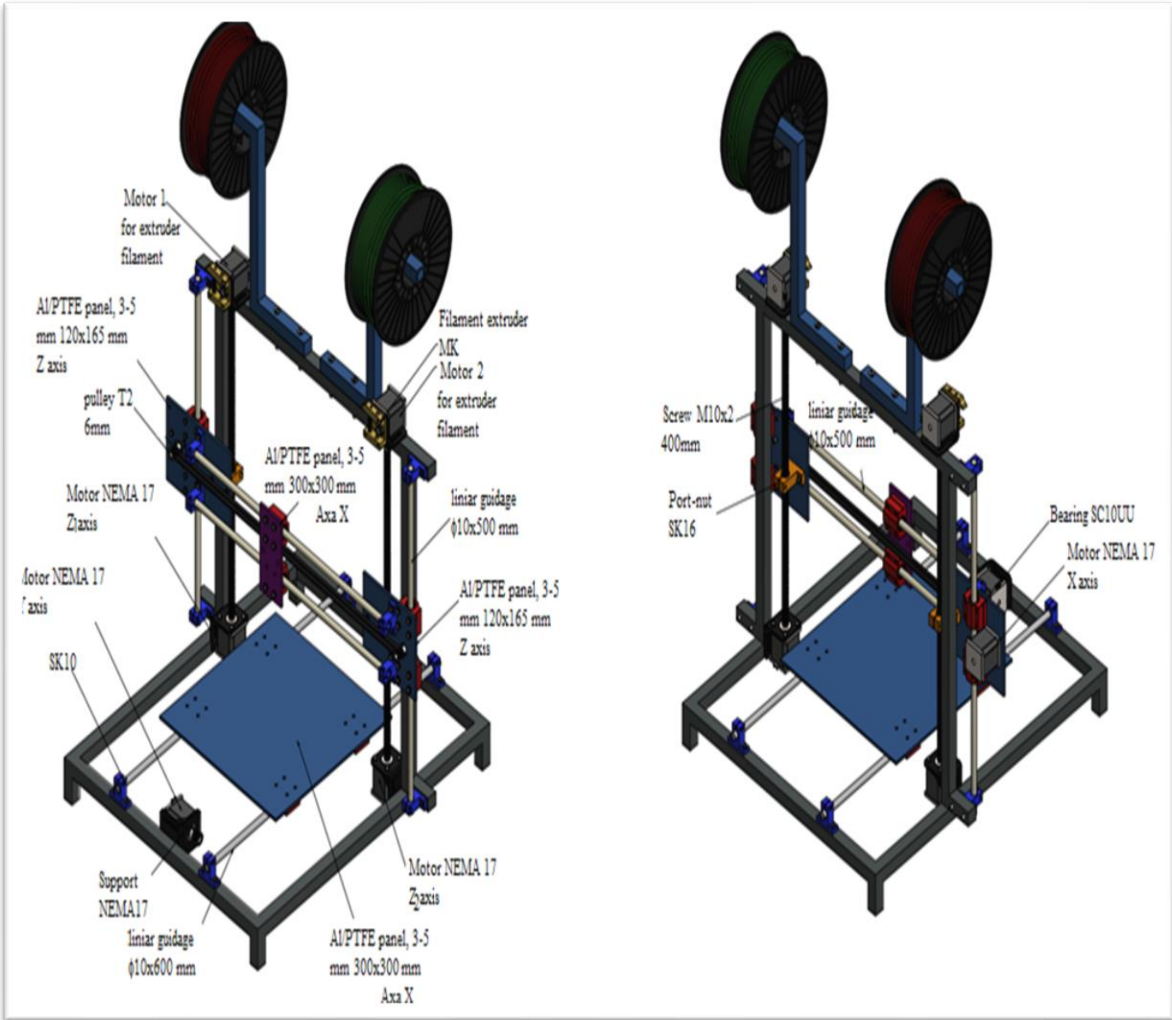

Fig.20. Components of hybrid 3D printer

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Fig.21. CNC head of 3D hybrid printer

Fig.22. CNC drilling on the 3D hybrid printer

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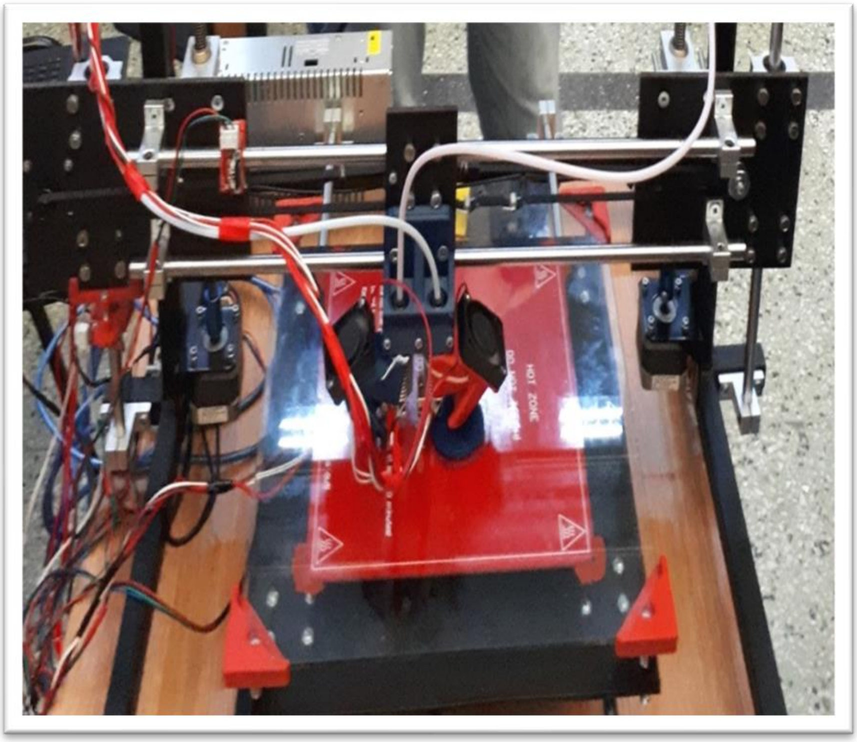

Fig.23. FDM extruder on the 3D hybrid printer

The research presented the practical implementation of a do-it-yourself (DIY) hybrid 3D printer using readily available tools and affordable materials found in most households. Additionally, some components utilized in the hybrid 3D printer were recycled from old electronic equipment, highlighting the potential for sustainable development in the production process.

The hybrid prototype 3D printer developed in this research was constructed on a limited budget and features a simple 3D print head (depicted in Figure 23) along with a CNC head. Simplify3D software was utilized for generating the G-code. Noteworthy aspects of this research include the innovative electronics, programming, and optimization software employed. The printer can produce components with dimensions of up to 300x300x200 mm, demonstrating a high precision of 0.2 mm.

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