EMS512U Instrumentation and Measurements - COURSEWORK 3

Design and Construction of a Servo Drive using Electronic Components to Control the Motion of an AL5D 4DoF Robotic Arm

Student Name	Student ID
ISLAM, MOHAMMED Z	210399688
ISLAM, SYED	210932913
ISMAIL, ABDULLAHI	210181706
ISPAS, IOANA	210061590
IZZET, HALLE	210056611
JAHIR, JARINA AKTER	210460690

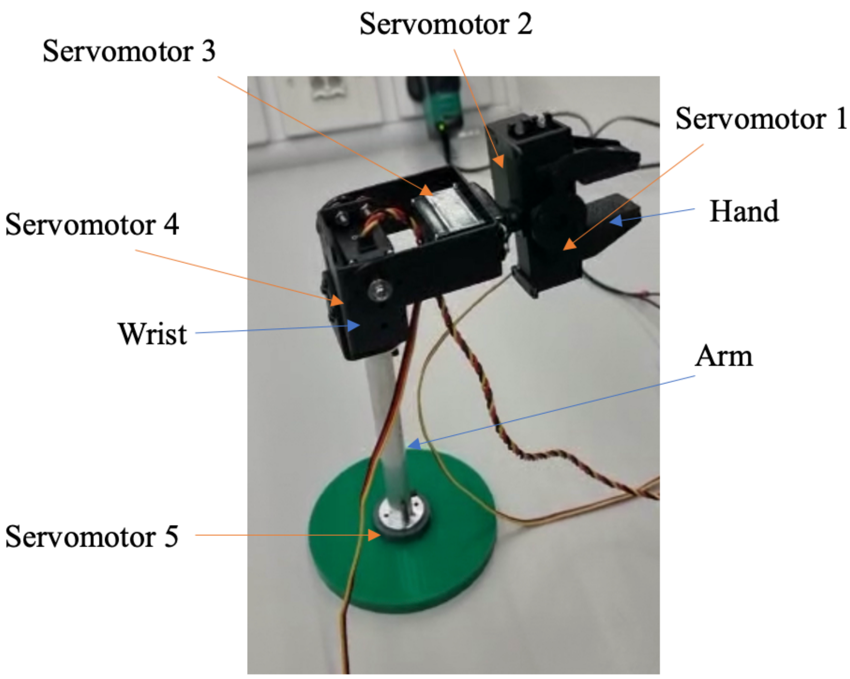
Introduction

Background:

The aim of this project was to design and build a circuit for an AL5D 4DoF Robotic Arm that would be utilised to pick up and position surgical instruments for a Surgical Robot Manufacturing Company. A servo drive circuit is desired due to the ease of use, and the prospect of an overall lower developing costs. The Robot arm consists of 5 servo motors in order to move the hand, elbow and wrist joints.

The aim of this report is to identify and describe the components utilised for the circuit interface and the design's development and construction to satisfy the company's demands. The report describes the steps necessary to create the circuit, as well as the testing and final result, followed by a discussion of the design's defects and possible adjustments, and concluding with recommendations to the company on how to improve the design.

Figure 1: Robotic Arm Diagram



To ensure that all the needs of a company are met, data acquisition methods are implemented to measure the quality of a circuit, product, or system in general. Data Acquisition (DAQ) is the process of digitizing data, to store and analyse in a computer (*A guide to DAQ Systems*). There are four methods of DAQ, which includes collecting new data, converting legacy data, sharing/exchanging data and purchasing data. Data can be collected through manual recordings or using sensors, as well as obtaining existing data from other sources (*Data Acquisition Methods*).

Data acquisition plays an important part in many fields, as well as in all aspects of engineering and in scientific studies. DAQ systems can also provide instantaneous feedback for a large array of situations, such as in vehicular performance components, which allows technicians to review issues or improve performance simply by checking the database procured (Instruments, 2018). Collecting data overall ensures that the product or system is reliable, efficient and that relevant machinery operates safely.

In the engineering industry, DAQ are prevalent due to the copious amount of safety and performance requisites that testing, and product development requires. DAQ methods are a relatively low-cost alternative to building full-scale prototypes of the final systems. This provides the opportunity to process data for small individual samples whilst providing a chance to alter and compare the performance of multiple designs at a faster pace. This can be seen in the aerospace and mechanical industries where prototypes of a vehicular body are placed within a wind tunnel to study and visualise the real time airflow around the objects. For particularly hazardous test scenarios, such as testing the performance of a rocket engine, DAQ methods allow the user to be situated in a safe location far away from the test subject while still being able to acquire the data they need (*Aerospace Data Acquisition Application Case Study*). These prototypes will have sensors protruding out of them to measure pressure, wind velocity or other topics of interest. Computing software is then used to process and compress the acquired data, to produce quantitative or qualitative results.

State of the Art Designs:

As technology rapidly develops, new methods of DAQ are required to keep up with such advancements. DAQ techniques need to be relevant to the application, whilst being able to withstand increasingly harsh testing conditions, and still provide accurate results. However, there is still the demand for Data Acquisition Units (DAUs) to be versatile enough for uses in multiple different applications. As technology develops, these DAUs need to be smaller, cheaper, and lighter (*Data Acquisition Miniature DAQ for flight testing - dtsweb.com*). An example DAU is the SLICE6 AIR by DTS which is a low energy, compact, and lightweight DAU (*Slice6 Air: Diversified Technical Systems* 2023). This state-of-the-art DAU allows measurements to be taken in harsh environments such as helicopter rotors, outside aircraft or underwater and it possesses the capability to convert an analogue signal into a digital signal. DAUs are also required to collect and process vast amounts of data to reduce noise. Advanced methods of DAQ are vital to medical applications, as there are many situations where data needs to be gathered from humanly unreachable locations. Common applications would be in the use of Magnetic Resonance Imaging (MRI), Positron Emission Tomography (PET) and Ultrasound Imaging (Sonography) (*Medical Imaging DAQ: Data Acquisition for Medical Imaging* 2019). There is a constant demand for increased bandwidth to produce higher resolution imaging, and faster processing speed.

DAQ is also significant in this PBL, since the potentiometer is the relevant DAU that monitors and regulates resistance, allowing the Robot arm to function. Without DAQ, this device's motion would not be possible, and further development would be far more challenging to accomplish.

Description of the Working Principle of the Overall System

To begin with, a breadboard was chosen to build the circuit upon as it can be utilised as a temporary circuit, which allows us to make alterations with ease when necessary. Exposed sections of the wires are placed into the holes to connect the circuit. The rows are connected together, whilst the columns are separated from each other across the board (Schousek, 2018).

Figure 2: Servo drive circuit

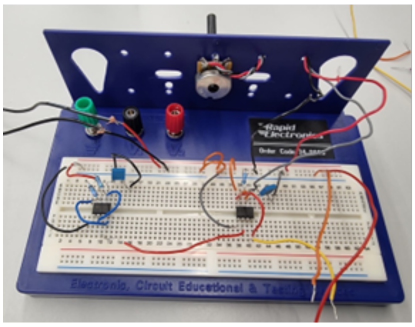
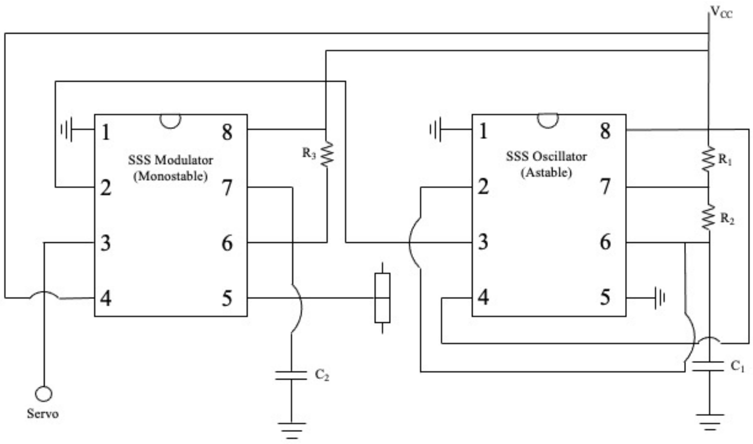


Figure 3: Circuit Diagram



The system begins with a 555 timer which has been arranged in an astable (oscillator set up). Its purpose is to produce a square wave pulse signal at pin 3, where the voltage output is either 0 or V_{max}, which is connected to pin 2 on the second 555 timer to trigger the PWM. To construct this setup, 2 resistors R_1 and R_2 were placed in series; connected to pin 7 and pin 6 respectively. This allowed the capacitor to charge through both R_1 and R_2, until the flip-flop turns on the transistor at 2/3 V_{cc}. This allows the capacitor which stores electrical charge, (Woodford, 2021) to discharge through R_2 only until 1/3 V_{cc} is reached, resulting in the desired duty cycle. The duty cycle is determined by the ratio of R_1 and R_2, the values of which were calculated using **EQ1, EQ2** and **EQ3**: (Storr, *555 oscillator tutorial - the astable multivibrator* 2022)

$$EQ1 : T_{high} = 0.693 \times R_2 \times C_1$$

$$\frac{0.3 \times 10^{-3}}{0.693 \times 0.1 \times 10^{-6}} = R_2 = 4329\Omega$$

EQ1 uses the signal "on" time to calculate R_2. Where T_{high} (Time where the signal is in the high position), is given as 0.3×10^{-3} s, and the capacitor C_1 is given as 0.1×10^{-6} F, the equation can be rearranged for R_2, resulting in $R_2 = 4329\ \Omega$. This R_2 value can then be substituted into **EQ3** to determine R_1. Before R_1 can be found, the time period T needs to be calculated for **EQ3**, where frequency has been given as 50Hz:

$$EQ2 : T = \frac{1}{f} \qquad \frac{1}{50} = T = 0.02s$$

From **EQ1** and **EQ2**, R_2 and time T = 0.02s are substituted into **EQ3** to calculate the resistance of R_1:

$$EQ3 : \frac{T}{0.693 \times C_1} - 2(R_2) = R_1$$

$$\frac{0.02}{0.693 \times 0.1 \times 10^{-6}} - 2(4329) = R_1 = 279942\Omega$$

Where the time the output voltage will remain in the "high" state, is given by **EQ4** (Storr, *555 timer tutorial - the monostable multivibrator*, 2022). The equation can be rearranged to determine the value of the resistor R_3. Where T_3 has been given as $1.5x10^{-3}$ s, and C_2 is given as $0.1x10^{-6}$ F:

$$EQ4 : \frac{T_3}{1.1 \times C_2} = R_3$$

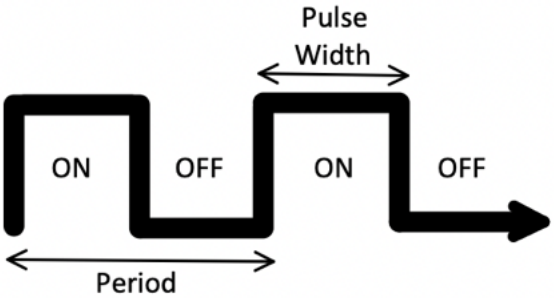
$$\frac{1.5 \times 10^{-3}}{1.1 \times 0.1 \times 10^{-6}} = R_3 = 13636\Omega$$

The second part of the system introduces the second 555 timer to the circuit. This timer has been arranged in a monostable (Modulator) format. The purpose of this setup is to make it possible to vary the width of the pulse every cycle, represented by "T_{on}" in **EQ5** (Storr, *555 timer tutorial - the monostable multivibrator*, 2022), resulting in an alternative duty cycle (Fluke, 2021).

$$EQ5 : Duty = \frac{T_{on}}{T} \times 100$$

EQ5 displays the formula for calculating the duty cycle, where "T" is the portion of the signal that is active, and where "T_{on}" is the pulse width.

Figure 4: PWM example wave



This is known as a Pulse Width Modulator (PWM). The duty cycle can be altered using a potentiometer connected to pin 5 of the monostable 555 timer.

The potentiometer is an adjustable voltage divider formed by three-terminal resistors used to control the flow of electrical current and voltage into the monostable 555 timer, which subsequently varies the output voltage of the circuit used to control the servo motor (Storr, *Potentiometers, preset potentiometers and rheostats*, 2022). A servo is an electrical component that transforms electrical energy to kinetic energy and delivers a signal to the motor for it to perform the specified motion. Initially the transistor within the 555 timer is switched on, which prevents the capacitor from charging. On a negative trigger pulse from the astable 555 timer, the comparator in the timer will flip when the pulse is below 1/3 V_{cc}; the transistor will turn off and allow the capacitor to charge through R_3 for the time T_3. Once the voltage reaches 2/3 in the capacitor, the bistable resets, and the output falls to 0 volts, allowing the capacitor to discharge through the transistor. The time "T_{on}" is determined by the time the capacitor takes to reach 2/3 V_{cc}.

Figure 5: Provided Resistors

R_1= 270kΩ R_2=4.3kΩ R_3=13kΩ

Using the resistor colour code table, the resistors' values are obtained by comparing the resistors' strips to the values in the table. After the value of each resistor was determined, they were placed in their respective locations within the circuit. Following the circuit assembly process using the circuit diagram, the Astable 555 timer was assembled and tested first, to ensure that the first stage of the circuit functioned as intended. An oscilloscope was connected to the circuit, which is a device that receives an electrical signal and visualises it on a digital display. Where the black wire was grounded, and the red wire was connected to the output pin (pin 3) of the astable 555 timer. A square wave formed upon the screen, thus confirming that the circuit works as intended. The monostable 555 timer was then assembled on the second half of the breadboard, where pin 2 of the monostable 555 timer was connected to pin 3 of the astable 555 timer, working as a trigger pulse. A potentiometer was connected to pin 5, which served as a controller for the servo motor. The circuit was tested once again where the oscillator was grounded, and the red wire was connected to pin 3 of the monostable 555 timer. A square wave appeared, where the width of the pulse varied when the potentiometer dial was spun. The time "high" signal increased and decreased relative to the potentiometer position, whilst the time period of the wave remained constant, which validated that the circuit was functioning as intended. The servo motor was then connected to the circuit. In this scenario the black wire of the servo motor was grounded, and the yellow wire was connected to the power supply whilst the red wire was connected to the output pin 3 on the monostable 555 timer, to receive the modified signal.

Results

Figure 6: Oscilloscope signal (at ~0 Ω)

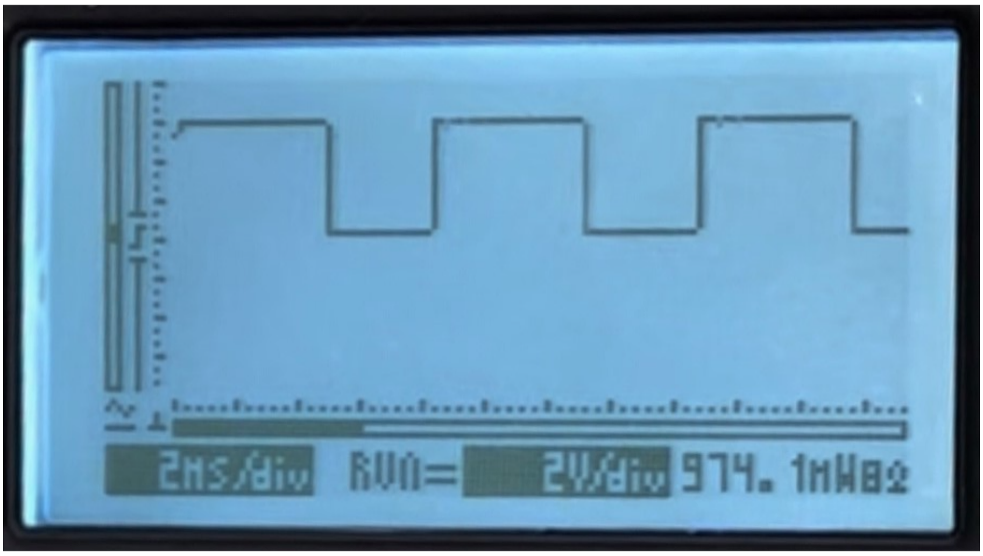
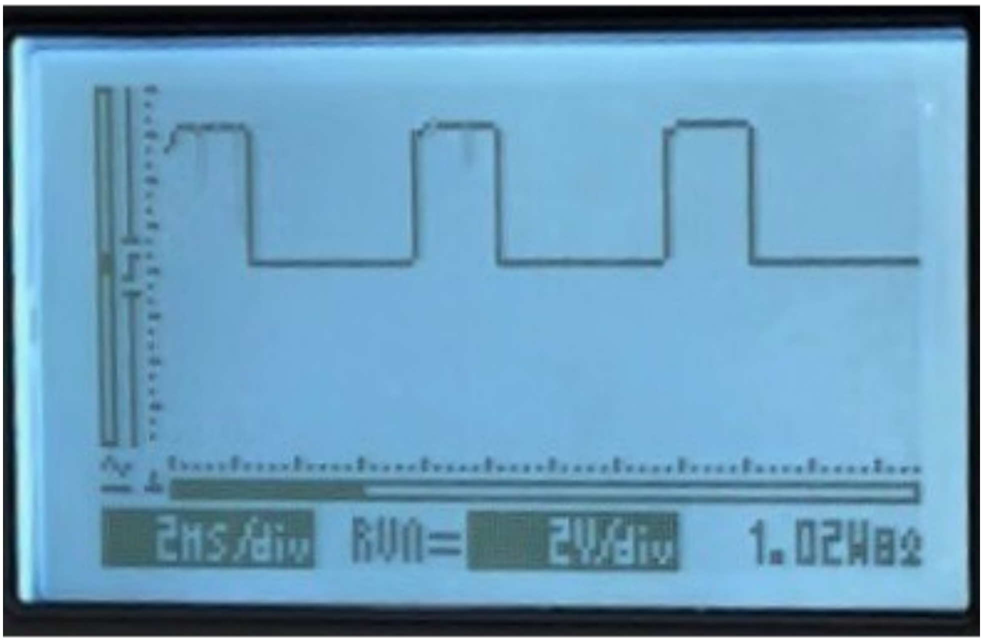


Figure 7: Oscilloscope signal (at ~10 Ω)



The circuit successfully produced a signal in the oscilloscope as shown by Figures 6 and 7.

When the circuit was connected to the servomotors, at a standard frequency of 50Hz for an RC servo and an amplitude of 5V, the Robot arm was successfully manoeuvred by turning the potentiometer contact. Additionally, it was confirmed that the Robot arm is able to hold and form a grip on small, lightweight objects, such as a pen.

Rotating the potentiometer contact alters the resistance and, therefore, the signal's duty cycle, which controls the movement of the Robot arm. Figure 6 depicts the signal when the potentiometer is adjusted at its minimum, such that the resistance is about 0 Ω, resulting in a duty cycle of ±61% for 2ms/div as computed using **EQ5**. This allowed the Robot arm's hand to open and its joints (elbow and wrist) to rotate fully in a clockwise direction, thus producing an opening motion. In comparison, when the potentiometer contact is turned toward 10 Ω (maximum), the Robot arm moves fully in an anticlockwise direction and its hand closes. This generates a signal with a ±30% duty cycle for 2ms/div, as seen in Figure 7.

Discussion

This project's purpose was to design and construct a circuit to operate the five servomotors of the AL5D 4DoF Robotic Arm used to wield surgical instruments.

The outcome of the circuit was satisfactory, with the Robot arm working effectively to grip on lightweight objects. This was accomplished via the usage of a thorough action plan and the attendance of team members during laboratory sessions, which resulted in effective and well-organized laboratory sessions and the achievement of the desired goal. The circuit was developed through researching all the individual components, then drawing a rough sketch of the design. This was then built using the provided components and wires, tested with the oscillator to ensure proper assembly, then connected to the servo motors of the Robot arm to validate the circuit's capability to move the Robot arm in the 4DoF.

Difficulties encountered:

The resources available such as necessary components were also relatively limited, which meant that if certain elements were mislocated, there were chances of the circuit being damaged or incomplete, proving to be a struggle. The wires used in the circuit design were often cut too long, which raised some confusion about their correct insertion on the breadboard. There was also an issue concerning cutting too much insulation off the wire, leaving the ends too exposed. This created points of interaction between individual wires on the breadboard, which initially distorted our results. However, after acknowledging and resolving these issues, the circuit was successful and worked accordingly.

Future Improvements:

If this experiment were to be repeated and a perfected design contrived, it would be ideal to analyse the potentiometer readings and movements of the Robot arm at each degree of motion to hone and perfect the flow of the robot’s movements, since this is a product meant for providing efficiency and precision in surgical environments. An ideal situation would be where an input from a potentiometer will result in a less than proportionate move by the surgical robot. Connecting the potentiometer to the multi-meter could be a way to implement this, so that the resistance can be analysed, and thus instruct specific motion from the resistance measured. A motion sensor implemented in the Robot arm would also be an improvement in the performance of the robot, as the movements created are more precise.

Adjusting the voltage so that the Robot arm can rotate the correct distance could also be implemented to improve the precision of its movements.

The use of software could also be useful to fine tune the circuit and certain values before assembling, in order to achieve the best results.

Another improvement would be to encase the circuit in protective casing, in case of accidents that occur which might deteriorate the condition of the circuit. Implementing a shutdown button in case the circuit does fail would also be desirable.

Conclusion

The overall experience of this PBL is a positive one. The system designed produced satisfactory results for the scenario provided, with the robot being able to move and pick up small, lightweight objects as the outcome. The PBL itself provided an enriching level of understanding regarding the use of circuit components in robotics, especially by using 555 timers to connect different aspects of the circuit together. Outside of the technical parts of this PBL, it was important to enforce communication skills to a high degree since each member had ideas to contribute, it was important to implement those ideas by listening to each member which in turn enables us to solve any critical solving problems that commenced. Teamwork was essential in this exercise, to ensure that the use of the components were researched on time and understood by each member. It was important to observe how they work and their impact on the overall effect of the entire system.

There are many elements that were improved on as a team due to this PBL, mostly regarding the improvement of core knowledge on components utilised in circuit design. The activity in which each component was researched by individual members of the team assisted in improving overall knowledge and made designing and building the circuit easier to understand and carry out. The components used in this experiment were also standard and commonplace in electrical circuits, which means that the knowledge learned in this PBL can be transferred to other concepts, making it extremely useful for future applications.
For instance, a sensor monitors when change also reads information on the surrounding environment of the robot. Servo motors are electronic devices that rotate and push parts of a machine with precision. This tells us the practicality and vital role that different types of components (electrical and electronic) have on the overall performance of a robotic arm.

The Robot itself presented a fun way to enhance circuit knowledge in the form of a more interesting challenge. The aims of the PBL were simple in theory, yet carrying the experiment out was what made the experience fun and a good exercise for improving teamwork and research methods. Overall, the experiment was a success both in terms of the aim as well as the learning capacity of the team, and the robot was able to move at a satisfactory rate.

Recommendations for the company:
In order for the company to receive the best performance out of the Robot, it is recommended to utilise a better hand shape for the Robot arm that provides more grip, as well as enforcing a non-slip material such as silicon in its' design, to prevent tools from falling. Creating a suitable sleeve for the design would also be agreeable, as the current design is quite industrial and unrefined. A sleeve would also protect the joints of the robot from damage if it falls or is covered in a substance.

References

Aerospace Data Acquisition Application Case Study (no date) *DAQ Application: Rocket Steering Motor Testing | KineticSystems*. Available at: https://www.kscorp.com/data-acquisition/aerospace/daq-rocket-steering-motor-testing.htm (Accessed: January 20, 2023).

A guide to DAQ Systems (no date) *Data Acquisition*. Available at: https://www.mccdaq.com/data-acquisition (Accessed: January 20, 2023).

Data Acquisition Methods (no date) *Data Acquisition Methods | U.S. Geological Survey*. Available at: https://www.usgs.gov/data-management/data-acquisition-methods (Accessed: January 20, 2023).

Data Acquisition Miniature DAQ for flight testing - dtsweb.com (no date). Available at: https://dtsweb.com/wp-content/uploads/2022/03/MINIATURE-DAQ-flight-testing.pdf (Accessed: January 20, 2023).

Fluke (2021) *What is duty cycle?*, *Fluke*. Available at: https://www.fluke.com/en-gb/learn/blog/electrical/what-is-duty-cycle (Accessed: January 20, 2023).

Instruments, D. (2018) *Dataq Instruments*, *Data Acquisition and Data Loggers What is Data Acquisition and Why is it Important Comments*. Publisher Name Dataq Instruments Publisher Logo. Available at: https://www.dataq.com/blog/data-acquisition/what-is-data-acquisition-and-why-is-it-important/ (Accessed: January 15, 2023).

Jin, J. *et al.* (2022) "Robotic data acquisition with deep learning enables cell image–based prediction of transcriptomic phenotypes," *Proceedings of the National Academy of Sciences*, 120(1). Available at: https://doi.org/10.1073/pnas.2210283120.

Medical Imaging DAQ: Data Acquisition for Medical Imaging (2019) *Guzik Technical Enterprises*. Available at: https://www.guzik.com/product/medical-imaging/ (Accessed: January 20, 2023).

Schousek, T. (2018) "Embedded control fundamentals," The Art of Assembly Language Programming Using PIC© Technology, pp. 73–81. Available at: https://doi.org/10.1016/b978-0-12-812617-2.00006-7.

Slice6 Air: Diversified Technical Systems (2023) *DTS*. Available at: https://dtsweb.com/slice6-air/ (Accessed: January 20, 2023).

Storr, W. (2022) *Potentiometers, preset potentiometers and rheostats*, *Basic Electronics Tutorials*. Available at: https://www.electronics-tutorials.ws/resistor/potentiometer.html (Accessed: January 20, 2023).

Storr, W. (2022) *555 oscillator tutorial - the astable multivibrator*, *Basic Electronics Tutorials*. Available at: https://www.electronics-tutorials.ws/waveforms/555_oscillator.html (Accessed: January 20, 2023).

Storr, W. (2022) *555 timer tutorial - the monostable multivibrator*, *Basic Electronics Tutorials*. Available at: https://www.electronics-tutorials.ws/waveforms/555_timer.html (Accessed: January 20, 2023).