7 (3): 324-329 (2023)

Journal of Aviation

https://dergipark.org.tr/en/pub/jav

e-ISSN 2587-1676

# PWM Controlled Servomechanism

**Mehmet Ali Soytürk** [1*]

[1*]Erciyes University, Faculty of Aeronautics and Astronautics, Kayseri, Türkiye. (soyturkm@erciyes.edu.tr)

Article Info

Received: 29 August 2023
Revised: 22 September 2023
Accepted: 04 October 2023
Published Online: 06 October 2023

Keywords:
Aviation
Servomechanism
Remote Control
PWM

Corresponding Author: *Mehmet Ali Soytürk*

RESEARCH ARTICLE

https://doi.org/10.30518/jav.1351782

## Abstract

Precise control of aircraft flight control surfaces by the pilot is critical to flight safety. The joystick and control surface positions must be detected accurately and quickly, and the motion mechanism must be operated in such a way as to ensure synchronization between them. The analogue voltage value taken from the potentiometer, which is used as a position sensor in many small aircraft, can be used directly or by converting to digital.

In this applied study, the analogue position knowledge received from the potentiometer on the joystick was converted into a PWM signal with an oscillator circuit. The PWM position signal applied to the IR (InfraRed) LED in the transmitter unit is sent as infrared light. The PWM position knowledge detected by the photodiode in the receiver unit was passed through the LPF (Low Pass Filter) and the voltage value of the joystick potentiometer was obtained again. With the mechanism controlled according to the difference between the potentiometer values of the joystick and the control surface, the synchronization between the joystick and the control surface is ensured. In this study, a wireless and stable servomechanism connection is obtained by transmitting PWM position knowledge as IR.

## 1. Introduction

The ability of an aircraft to fly safely depends on the full control of the flight control surfaces by the pilot. For full control, it is very important that the synchronization between the control handle used by the pilot and the flight control surface is uninterrupted and instantaneous. When a sudden maneuver is required during flight, an accident is inevitable if the command given by the pilot with the joystick is not completely and accurately transferred to the control surface. For this reason, a stable and correctly functioning servomechanism system is one of the most important equipment for an aircraft. In a well-functioning servomechanism, the positions of the control lever and control surface must be detected accurately and the control surface must be moved according to the control lever position.

Servomechanism can be defined as the mechanism that automatically adjusts the movement of a mechanical device according to the feedback signal from the sensor in the device. There are basically two types of servomechanisms used for position and speed control. In engine speed control, speed knowledge can be obtained analogously with a tacho generator or digitally with an incremental encoder connected to the engine shaft. This speed knowledge is compared with the reference value determined for the speed, and control signal is applied to the motor driver circuit so that the difference between the motor speed and the desired speed is minimal. Some types of speed limiting servomechanisms, called "governors", which work completely mechanically, have been used in the steam engines in the past (Wikipedia, 2023).

In the servomechanism used for position control, it is very important to correctly detect the position of both the joystick and the controlled mechanism (control surface). Position knowledge can be obtained as analog with a magnetic sensor or potentiometer, and digitally with an absolute encoder. Although the potentiometer has some disadvantages such as inaccurate value due to contamination and wear over time, it is cheap and simple to use, making it frequently preferred in many low-cost small UAV applications.

The movement of the control surface can be electrical, pneumatic or hydraulic. The servo motor used in the electrically driven unit provides motion with a gear set to produce high torque. The driver of the servo motor used is controlled by the servomechanism circuit. In the case of a pneumatic or hydraulic system, the valve that controls the fluid velocity is adjusted by a low-power electric motor controlled by a servomechanism. Hydraulic or pneumatic actuators are used, especially in large-scale aircraft that are exposed to high forces, and hydraulic or pneumatic fluid is controlled by a servomechanism.

In the literature, some examples of servomechanisms performed in many different fields and with different methods can be briefly summarized. Lang at al. proposed an electro-hydraulic servo system with pressure control valve and used two methods to compute the whole system natural frequency in frequency domain. In the study, in which the system dynamic response was increased, the natural frequency of the system was calculated by creating an electro-hydraulic actuator model. (Jang, 2009). An electronic-mechanical actuator, used IEEE-1394B bus to interact aircraft network is integrated in aircraft remote control unit. In the system where pre-distribution broadband technology is used to transmit commands, DSP + FPGA is used for decoupling control. DRV8301 was used as power conversion and motor driver for a complete protection strategy (Hu, 2021). Discrete-type position sensors for precision control at high temperature is proposed for aerospace systems by Kim at al. By using micro electro-mechanic system technology in the position sensor design, a resistive element was made with MoSi2 and multilayer metallization containing TiN, Ti, Pt was performed on the Si layer. (Kim, 2018). A microcontroller-based tester was designed for Electro-Hydraulic Actuators at fly-by-wire aircrafts. The algorithm sends a pass or fail message according to the Electro-Hydraulic Actuator pressure and position sensor signal. The Electro-Hydraulic Actuator response capability is then tested for a proper dynamic response evaluation. (Lucena, 2007). Another work is focus on Brushless Alternating Current (BLAC) motor and control algorithms, for intelligent actuators based electrical servo drivers. In the study where incremental encoder and Hall magnetic sensor were used for rotor position, the speed control algorithm and accuracy were simulated. (Toman, 2014). A stepper motor actuator is used to adjusting cabin pressure by controlling pressure valve. For correct positioning, angular displacement was achieved by controlling the number of pulses according to the stepper motor type and thus the aircraft cabin pressure was adjusted. (Zhou, 2018). A position control system using PMDC motor was designed by utilizing MATLAB based PID controller. Angular calibration data of the PMDC motor, linearity and reliability of the control system were examined. (Bandyopadhyay, 2016). In this study, a piezo actuator-based linear actuator is electrostatically controlled. The sliders in the electrostatically controlled linear actuator are driven by the electrostatic clutch mechanism and the piezo actuator, providing gradual movement of the sliders (Nguyen, 2013).

An unmanned aerial vehicle (UAV) has been produced, with the necessary designs for the transition from passive to active flight. In order to achieve maximum performance, the appropriate wing and tail structure was designed, and liquid fuel engines were used for higher power and operating times. (Coban et al. 2023). In the study, where the effects of drone use in the field of logistics on the sector were investigated for current and future situations, literature research was also conducted. When the tables created according to the research results were analyzed with the DEMATEL method, market share was the most important factor, while security problems were the least important factor. (Düzgün, 2021). In many cases, it is undesirable to notice unmanned aerial vehicles (UAVs) in the sky. In this study, a lighting system was placed on the underside of UAVs to make visual tracking difficult by the enemy. With the lighting adjusted according to the amount of light in the environment, the UAV's visibility in the sky has become difficult (Konar, 2021). Unmanned aerial vehicles (UAVs) that navigate using the global navigation satellite system (GNSS) may deviate from the target if the connection with the satellite is lost due to environmental factors. By using infrared and ultrasonic sensors data, a study was conducted to prevent the UAV from deviating from the target even in such closed environments where the connection may be lost (Y. Dalkıran, 2021). It is extremely important to know the maximum flight time and distance of an unmanned aerial vehicle (UAV) so that it can be used safely for a specific mission. In this study, the prognostic method is discussed to obtain the necessary data set to calculate flight time and distance (Erşen, 2023). The block diagram of the autopilot used in the study investigating the state space analysis and control system for the unmanned aerial vehicle (UAV) was modeled with MATLAB / Simulink. The autopilot system was later updated to minimize the cost function created by takeoff, flight time and overwork (Coban, 2018). In sport aviation, long distances can be traveled using natural air currents. One of the most important indicators for the pilot during flight is the device called variometer, which gives the vertical speed change. In the study, a low-cost Arduino-based variometer was designed and produced (Kekec, 2020). Maximum performance of an unmanned aerial vehicle depends on its aerodynamically suitable structure. In the study, four UAVs with different body structures were designed and, according to the analysis, the highest performing model was produced (Koç, 2020). There may be significant differences in the hardware of the unmanned aerial vehicle (UAV) depending on the area of use. The most important part of the UAV, which is designed according to features such as distance, carrying capacity and speed, is the engine that provides thrust power for flight. In the study, the advantages and disadvantages of different engine types used in UAVs were examined and compared (Çoban, 2018).

In the past, potentiometers were used in many analog electronic circuits to adjust quantities such as volume, light intensity and speed. In many electronic circuits today, such quantities are adjusted digitally. However, the potentiometer is still used as a position sensor because it produces an analog voltage value depending on the amount of mechanical movement. When used as a position sensor, the analog voltage value taken from the middle end of the potentiometer must be delivered to the comparison circuit without changing. Otherwise, the potentiometer will be perceived as standing in a different position. The most important factor that cause to change the analog value which express position knowledge is the cable and contact resistance, especially when it comes to long distances. The voltage drops on the resistor in the transmission line cause to change the voltage value at the end of the line. One of the most practical ways to solve this problem is to convert the analog value on the potentiometer into digital form and transmit it. Analog-digital conversion can be done using many different methods. These methods may have some advantages and disadvantages compared to each other in terms of number of bits and conversion time. In addition, converting position knowledge into digital form using an analog digital converter (ADC) causes some system complexity and extra costs.

In this study, a simple and stable servomechanism was produced. The potentiometer position knowledge on the joystick was converted into a PWM signal simply and quickly by using an oscillator instead of using an ADC. This PWM signal containing position knowledge can be transmitted to the receiver via wire or wirelessly as in this study. The PWM signal was applied to the IR LED and sent as IR light to the receiver side, then detected by the photo diode at the receiver side and converted back into an electrical signal. The electrically obtained PWM signal was passed through the LPF and converted into an analog voltage value expressing the joystick position knowledge. Then, the control surface was moved so that this value was equalized with the control surface potentiometer value.

## 2. Materials and Methods

Analog position knowledge received from the potentiometer on the joystick was converted into digital form using an oscillator instead of ADC By using the oscillator circuit, a square wave (PWM) signal whose duty-cycle ratio varies depending on the potentiometer position is obtained as seen in Figure 1. Since the duty-cycle ratio of the produced square wave signal changes proportionally to the position of the potentiometer, the position of the potentiometer can be understood by measuring this ratio. Since the position information is transmitted as a PWM signal, the analog voltage value is no longer important and the position information is not affected by the cable resistance. Additionally, when position knowledge is converted into a PWM signal, it can be easily transmitted wirelessly as RF or IR as in this study. When the position information arrives the comparator circuit as IR in the form of a PWM signal, it is converted to a small voltage level by a photo diode. The PWM signal at the millivolt level was amplified to level between zero volts and +Vcc. Since the average value of the PWM signal is proportional to the duty cycle, this PWM signal was passed through the LPF and the voltage level proportional to the potentiometer position was obtained again. Instead of using LPF, position information can be obtained digitally with a processor by measuring the "0" and "1" times of the PWM signal, but LPF was used in this study due to its simplicity. Synchronization was achieved by driving a DC motor so that the difference between the analog value obtained from the PWM signal and the analog value coming from the potentiometer on the control surface was minimal.

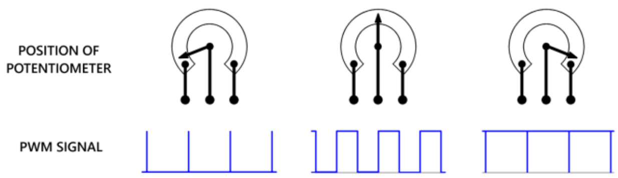


**Figure 1.** Changing the duty cycle of the PWM signal according to the potentiometer position.

In this servomechanism system, whose block diagram is given in Figure 2, the analog value in the potentiometer, whose value changes depending on the joystick position, is converted into a PWM signal. The PWM conversion is performed with a low cost and fast response 555 oscillator circuit. If the position knowledge received from the potentiometer is transmitted directly as an analog voltage, the position knowledge can be corrupted due to factors such as cable and contact resistance at the transmission line. When the position knowledge is transmitted as PWM, it is converted into a two-level (0.1) digital signal with varying duty cycle, and it can be easily used in the wired or wireless transmission environment.

In the transmitter unit, the PWM signal applied to the IR LED was sent as infrared light and after being detected by the photodiode in the receiver unit, it was passed through the LPF so that the joystick potentiometer value was obtained again. This value is compared with the analog value on the potentiometer on the mechanism and the differential voltage is applied to the motor driver. The DC motor, which run forward or backward according to this difference voltage, moves the mechanism and ensures that the control surface is in the same position as the joystick.

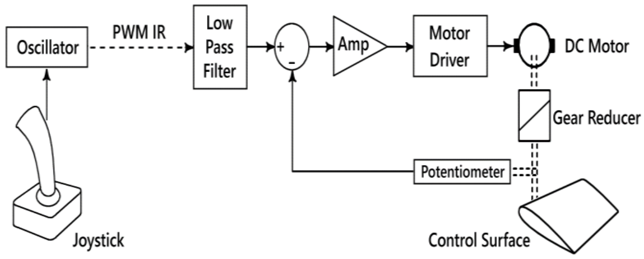


**Figure 2.** PWM controlled servo mechanism

### 2.1. Generation of Position Knowledge as PWM

The 555 integrated circuit, which can generate square wave signals in a wide frequency range, is a very stable and low-cost oscillator. The output becomes logic "1" or logic "0" according to the access time in which the capacitor voltage of C1 in Figure 3, changes between two different reference values. The lower reference voltage values are one-third of the supply voltage (Vcc/3), while the upper reference voltage values are two-thirds (2Vcc/3) of the supply voltage.

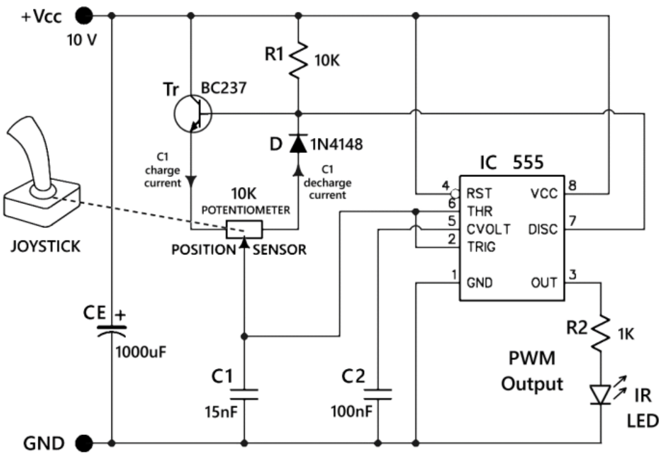


**Figure 3.** PWM IR transmitter circuit

While the capacitor is being discharged (Vo = “0”), when the voltage value of the capacitor drops below the lower reference value, the output becomes “1” and at the same time, since the open collector discharge (pin 7) pin current is cut off, the capacitor starts to charge through the resistor connected to it in series. When the voltage value of the capacitor rises above the upper reference value, the output becomes “0” again and the capacitor starts to discharge through pin 7 and the 555 continues to work as an astable multivibrator.

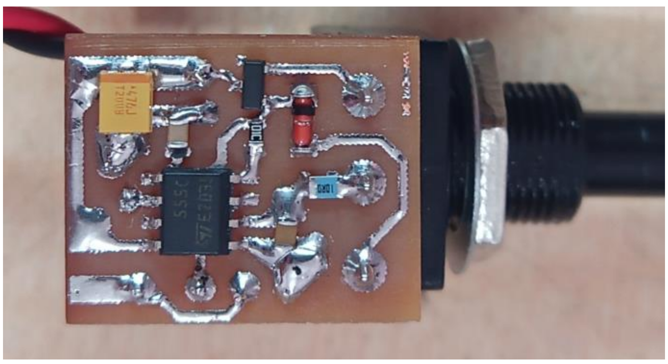

**Figure 4.** PWM IR transmitter photographic view

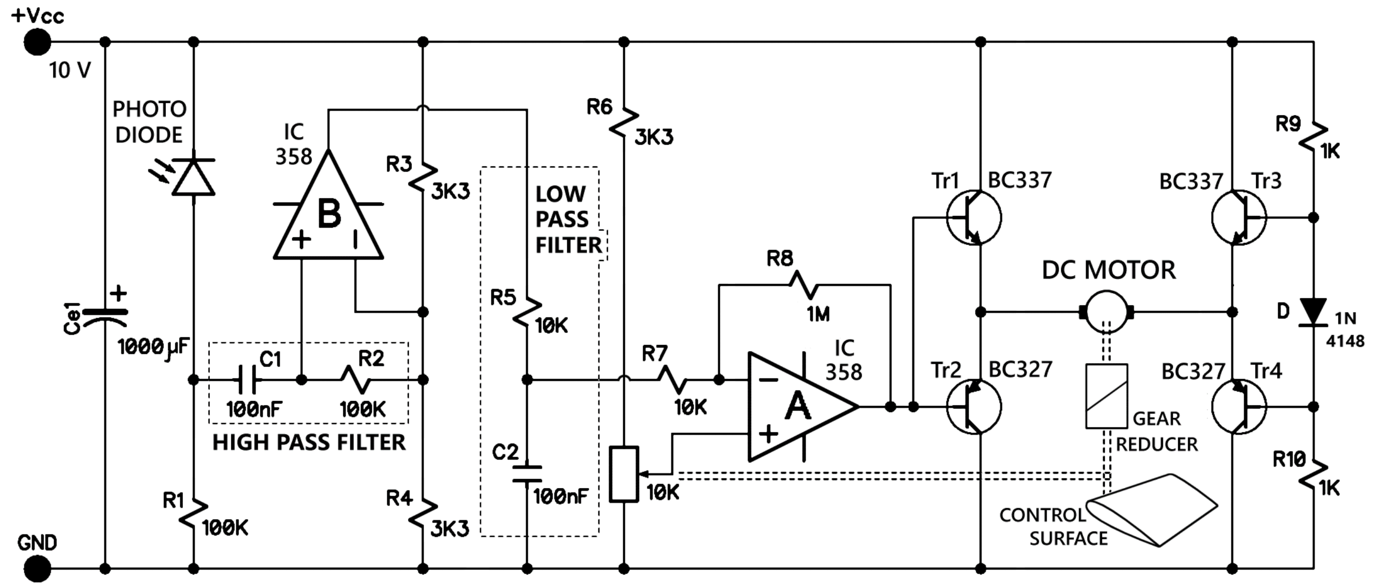


**Figure 5.** IR receiver and servo control circuit

The duty cycle of the square wave signal at the output of the 555 oscillator depends on the time it takes for the capacitor voltage to reach these two reference values during charging or discharging. This time changes with the RC time constant. The duty cycle can be changed from %0 to %100 with the transistor circuit added to the standard 555 circuit. The capacitor is charged between middle end of the potentiometer and the transistor and discharged between middle end of the potentiometer and the diode. Potentiometer wiper moving does not change the frequency of the PWM signal because the resistance of the part with the charging current increases while the resistance of the part with the discharge current decreases (or vice versa). In this application, although the frequency value is not very critical, approximately 10 KHz is used as the operating frequency. The produced transmitter circuit is seen in Figure 4.

## 2.2. Motion of Mechanism according to PWM Knowledge

When the joystick position knowledge sent in the form of IR light arrive the photo diode, it causes the diode leakage current to increase. When the PWM signal is "1", the leakage current is maximum and when it is "0", the leakage current is minimum. In this case, the voltage on the R1 resistor in Figure 5 varies according to the leakage current, that is, the PWM signal. This voltage at the millivolt level must be applied to the LPF after it is strengthened. However, the light in the environment affects the leakage current of the photodiode. Even when there is no signal, the voltage on R1 increases when the environment is bright and the voltage on R1 decreases when the environment is dark. A HPF (High Pass Filter) consisting of C1 and R2 was used to protect the PWM signal against bias voltage caused by ambient light. In this way, high-speed light changes such as the PWM signal (10 KHz) arrive Op-Amp B and are amplified.

The DC motor, which provides the movement of the mechanism (control surface), is driven by the feedback Op-Amp circuit. The feedback circuit produces output according to the difference between the signal (voltage level) coming from the potentiometer on the control surface and the PWM signal coming from the joystick. For this reason, the PWM signal must be converted to an analog value proportional to the duty cycle. This is possible with a simple LPF since the average value of the PWM signal changes proportionally with the duty cycle of the signal. As seen in Figure 5, the PWM signal was applied to the Op-Amp circuit after passing through the LPF.

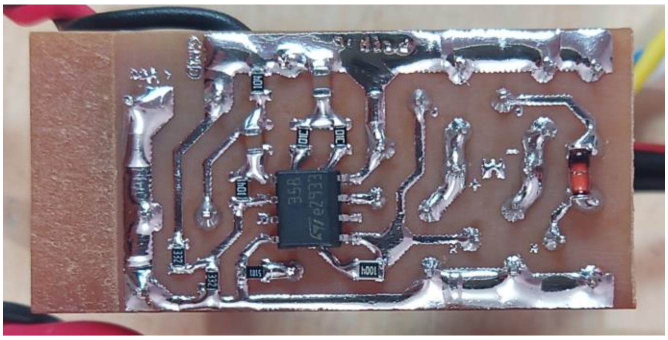

**Figure 6.** PWM IR receiver photographic view

Control surface movement is provided by DC motor connected to Op-Amp output. The torque on the shaft of the DC motor is not sufficient for the movement of the control surface. For this reason, by connecting a gear reducer to the DC motor shaft, the torque was increased and the surface movement speed was reduced to a reasonable level. In the reducer, which is a gear mechanism, the small gear connected to the motor shaft rotates a large number of times, while the large gear driven by the small gear rotates a small number of times.

The control surface position information was taken analogously with a potentiometer connected to the surface and applied directly to the comparator circuit. The difference between the voltages from the control surface and the joystick is amplified by Op Amp A and applied to the DC motor. Op Amp A output is positive or negative according to the difference between the input voltages. The DC motor drives the mechanism by rotating it forward or backward to equalize the two input voltages. This movement provides synchronization between the joystick and the control surface. The produced receiver circuit is seen in Figure 6.

**Figure 7.** Synchronization between joystick and control surface in case of minimum pulse width.

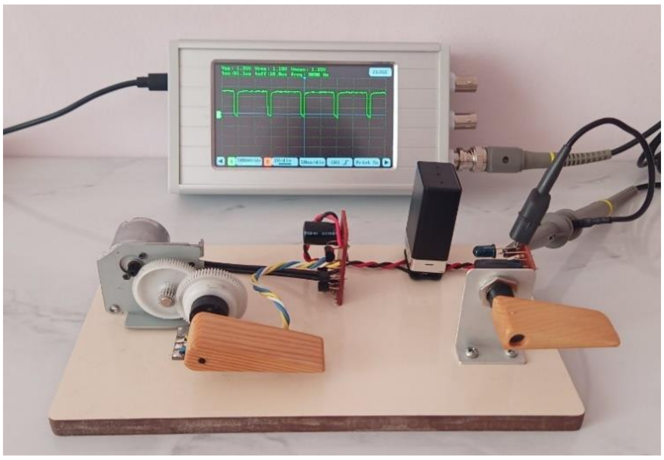

**Figure 8.** Synchronization between joystick and control surface in case of maximum pulse width.

## 3. Result and Discussion

The fact that a servomechanism system is stable and fast, as well as simple and low-cost, significantly affects its applicability. A simple and reliable servomechanism, with its uncomplicated structure, allows easier detection and repair of system malfunctions, especially in low-budget applications. In many low-budget servomechanisms, since the potentiometer used as a position sensor produces analog output, there may be some difficulties in its use depending on the cable line through which the position knowledge is sent. An impedance change in the cable line between the joystick and the control surface can easily cause the analog position knowledge to be corrupted.

The distance between the joystick and the control surface can be too large. For example, while the distance between the joystick (sidestick or yoke) in the cockpit and the control surface in a passenger aircraft can be tens of meters, it is hundreds of meters in the case of a UAV (unmanned aerial vehicle). In the aircraft, the servomechanism connection can be provided with a cable. However, in case of direct transmission of position knowledge as analog voltage in wired connection, position knowledge may change on the receiver side due to cable and contact resistance. In this case, it is not possible for the control surface to move synchronously with the joystick. If the analog position knowledge is converted to digital with ADC and transmitted, some conversion time is required and the system cost increases. In addition, a high-speed processor is required for the transmission and processing of digital angle knowledge with a certain number of bits, which increases the system cost also. This applied study can be used as an alternative method for low-cost small systems.

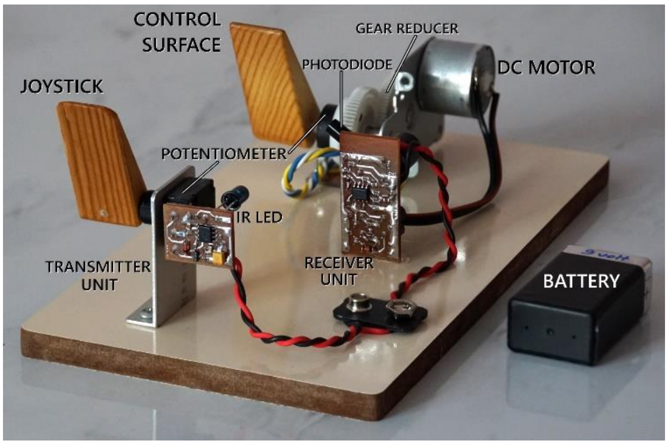


**Figure 9.** Photographic view of the PWM controlled servomechanism

The PWM signal has different pulse widths for different angles of the joystick. While Figure 7 shows the joystick position at the minimum pulse width, Figure 8 shows the joystick position at the maximum pulse width. At the joystick positions between maximum and minimum, the PWM signal pulse width also takes values between maximum and minimum. The perspective view of the entire servomechanism system is seen in Figure 9. The application video of this study can be watched from the link below.
https://youtu.be/DLkvDwn7EFA

## 4. Conclusion

In this study, analog position knowledge is transmitted by converting it to PWM signal with a simple and low-cost oscillator circuit. In this way, a simple and stable servomechanism assembly has been obtained by using the minimum number of circuit elements. This servomechanism assembly, in which the joystick position knowledge is transmitted as PWM, can be used with a wired connection between the cockpit and the flight control surface, or with a wireless connection in the UAV. In this applied study, a simple and stable servomechanism was obtained by using the PWM transmission method.

## Ethical approval

Not applicable.

## Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

## References

Bandyopadhyay, M., Mandal, N. and Chattopadhyay, S. (2016). Position Control System of A PMDC Motor. International Conference on Electrical, Electronics, and Optimization Techniques (ICEEOT). 752-754.

Çoban, S. and Oktay, T. (2023). Innovative Morphing UAV Design and Manufacture. Journal of Aviation. 7 (2), 184-189.

Çoban, S. and Oktay, T. (2018). Simultaneous Design of a Small UAV (Unmanned Aerial Vehicle) Flight Control System and Lateral State Space Model. Journal of Aviation. 2 (2), 70-76.

Çoban, S. and Oktay, T. (2018). Unmanned Aerial Vehicles (UAVs) According to Engine Type. Journal of Aviation. 2 (2), 177-184.

Düzgün, M. (2021). Investigation of the Criteria Affecting the Decision of Use of Drone Technology in the Logistics Sector by DEMATEL Method. Journal of Aviation. 5(2), 249-264.

Hu, M., Yu, E. and Yan, W. (2021). Design of Highly Deterministic and Reliable Aircraft Electronic-Mechanical Actuator Servo Control System. IEEE International Conference on Electrical Engineering and Mechatronics Technology (ICEEMT 2021). 459-463.

Kim, Y. and Choi, H.Y. (2018). Development of High-Temperature Position Sensors for Control of Actuators in Aerospace Systems. 9th International Conference on Mechanical and Aerospace Engineering. 6-10.

Kekeç, E.T., Konar, M. and Yıldırım Dalkıran, F. (2020). Realization of Low-Cost Useful Variometer Application for Sportive Aviation. Journal of Aviation. 4(1), 79-88.

Konar, M. and Bilgin, M. (2022). Investigation of Visual Disappearance by Intelligent Illumination of Exterior Surfaces of Unmanned Aerial Vehicles. Journal of Aviation. 6(1), 26-32.

Koç, E., Çalışkan, C.I., Coşkun, M. and Khan, H.M. (2020). Unmanned Aerial Vehicle Production with Additive Manufacturing. Journal of Aviation. 4(1), 22-30.

Erşen, M. and Konar, M. (2023). Obtaining Condition Monitoring Data for the Prognostics of the Flight Time of Unmanned Aerial Vehicles. Journal of Aviation. 7 (2), 209-214.

Lang, Y. and Li, Y., (2009). Concept Design and Dynamic Response Analysis of Electro-Hydraulic Compound Regulating Integrated Actuator. IEEE/ASME International Conference on Advanced Intelligent Mechatronics. 1389-1394.

Luccena, S. and Suzuki, E.Y. (2007). Electro-Hydraulic Actuator Tester for Fly-By-Wire Aircrafts. Instrumentation and Measurement Technology Conference. Poland. 1-3.

Nguyen, T.A. and Konishi, S. (2013). Position Feedback Control of Electrostatically Controlled Linear Actuator System. MHS2013. 1-5.

Toman, J., Singule, V. and Hadas, Z. (2014). Model of Aircraft Actuator with BLAC Motor. 16th International Power Electronics and Motion Control Conference and Exposition. Türkiye. 197-202.

Wikipedia. Encyclopedia. Servomechanism. (2023, March 20). https://en.wikipedia.org/wiki/Servomechanism

Yıldırım Dalkıran, F. Gençağ, M.S. (2021). Increasing the Stabilization of Unmanned Aerial Vehicle in Global Navigation Satellite System Unavailable Areas. Journal of Aviation. 5(1), 36-44.

Zhou, S. and Wang, L. (2018). Research on Modeling and Simulation of aircraft cabin pressure regulating system based on stepper motor servo system. 21st International Conference on Electrical Machines and Systems (ICEMS). Korea. 938-942.

---

**Cite this article:** Soytürk M.A. (2023). PWM Controlled Servomechanism. Journal of Aviation, 7(3), 324-329.