

# Research of Robotic System Positioning Accuracy

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**Abstract.** Robotics is one of the technologies of the fourth industrial revolution, which has a wide range of applications, from household chores to manufacturing and healthcare to entertainment and space exploration. The purpose of the study is to determine and evaluate the repeatability and positioning accuracy indicators of the robotic system when reproducing the movements of the hand repeating a human hand. The article conducts a comparative analysis of the methods and software control algorithms for creating feedback of robotic system electromechanical control gears displacement, and provides the rationale for the choice of physical equipment for the technical experiment. This article describes the plan of stages of the experimental research, the research bench, presents the systematized results of the research, conclusions and suggestions for practical application.

**Keywords:** feedback, robotic system, servo drive

## I. INTRODUCTION

Historically, early servo motors performed the basic functions of position control. Servomotors use a feedback controller to control the speed or position of the motor, or both. With the exception of constructional highlights, a DC servo motor (DSM) is basically a normal DC motor [2]. However, the increasing demand for more complex and precise movements in robotic systems has highlighted the need for improvements in servo motor technology. Over the years, advances in materials, design and control systems have significantly improved the accuracy of servo motor movements. One of the main barriers to achieving precision in servo motor motions is the provision of accurate position control: delay, mechanical effects and

non-linearity in the feedback loops can introduce an error factor and reduce the overall precision of the robotic system motions [6]. In the analysis of electric servo drive motors, the equations for the motor indicate the presence of two time constants. One is a mechanical time constant and the other is an electrical time constant. Since these two time constants are part of the motor block diagram used in a servo analysis, it is important to know the real value of the time constants under actual load conditions [5]. To overcome these problems, the development of advanced control algorithms and position feedback systems is currently receiving much attention [6]. Advanced control algorithms are essential to optimise the accuracy of servo motor motions. These algorithms take into account variables such as motor dynamics, environmental conditions and position sensor feedback. These algorithms allow precise control of the actuator movements by compensating for mechanical imperfections and adapting to changing load conditions. Servo motors often use potentiometers as the operating elements of a position feedback system. A potentiometer is a variable resistor that provides feedback to the actual position of the actuator. It measures the rotation of the motor axis and converts it into an electrical signal that is used by the control system to control the exact position of the motor. Potentiometer-based feedback systems are reliable and cost-effective solutions to ensure precise leg movements. To increase the accuracy of servo motor movements, it is necessary to integrate potentiometer feedback systems with sophisticated control algorithms.

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## II. MATERIALS AND METHODS

This section analyses research on various feedback systems, including potentiometers, encoders and inertial sensors, to clarify their advantages, disadvantages and suitability for integrated control systems. A review article by Garcia-Barragan describes an inexpensive optical encoder system for providing position feedback to amateur servo 16 motors. Optical encoders are essential components of motor control systems as they detect the rotation angle, speed and distance of a moving machine element and provide position feedback to the controller. The controller transmits electrical signals to the driver, which amplifies and interprets the signals for the servo motor. Optical encoders support high speed and high resolution, but are expensive and sensitive to contamination. This paper discusses the design and implementation of a cost-effective optical encoder system for hobbyist servo motors that improves position feedback accuracy and speed while maintaining a small footprint for a limited PCB area [3]. In a research paper by Veitschegger, the authors present a method for calibrating and compensating for kinematic errors in robotic manipulators. In this work, a method for selecting a set of independent kinematic errors is developed to model any geometric errors in the manipulator design. A calibration algorithm for calculating kinematic error values is provided for measuring the position of the end-effector. The kinematic errors of the six-joint manipulator PUMA 560 are experimentally determined and two general-purpose compensation algorithms are developed. The improvement of the Cartesian position of the end-effector is experimentally measured and the results are presented. Using a relatively simple method of measuring the Cartesian position of a tool attached to the end of the manipulator, the paper demonstrates that the positioning accuracy of a robotic manipulator can be significantly improved [8]. Aragon-Jurado's research paper analyses servo drives. The aim of this research is to understand the function of the potentiometer in a servo motor system and how it can be used to improve servo motor performance in a variety of applications, including robotics and automation systems [1]. The authors describe the design and development of a low-cost servo motor controller using pulse frequency modulation (PFM) instead of conventional pulse width modulation (PWM). This paper focuses on the development of a small printed circuit board (PCB) that replaces the original control circuitry in a commercial servo motor housing. The potentiometer is left as a feedback sensor and the motor position is controlled by a microcontroller. The authors compare a PWM-controlled and a PFM-controlled servo motor and demonstrate that the PFM-controlled motor achieves faster commutation of the motor drives and a lower drive response delay [4]. This controller can be used with neuromorphic systems in order to avoid the need for converting the events to pulse-width modulation (PWM), and is therefore an important contribution to robotics and servo motor control [4].

A review of scientific publications lacks specific information on methods for monitoring the servo drive feedback systems themselves, but Zhu et al. describe a low-cost microelectromechanical system (MEMS) inertial measurement sensor for position sensing of spherical motors. The proposed sensor combines a three-axis gyroscope and a three-axis accelerometer to acquire raw

position data from spherical motors in order to estimate the rotor position Fig. 1. The aim of this study is to improve motor performance in terms of speed feedback and control by implementing MEMS sensors in servo motor applications.

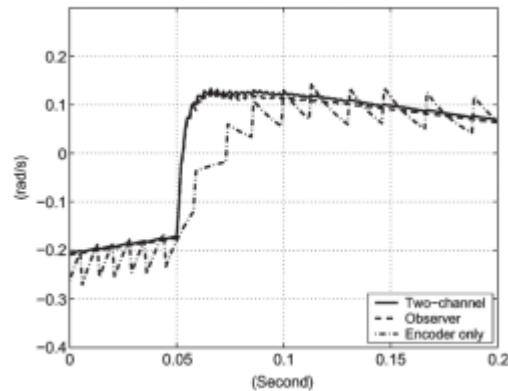


Fig 1. Comparison of the effect of gyro and accelerometer feedback systems on the steering angle of a servo drive

By using the ability of MEMS sensors to measure acceleration, yaw and vibration, the system can provide more accurate and reliable velocity feedback, thereby improving the overall performance of servo motors in a variety of applications [10]. Zhang's research work proposes an adaptive fuzzy logic-based tracking system to estimate the speed in servo motor drives based on the measured motor position. This method aims to improve the accuracy of speed estimation and reduce the noise caused by the quantization of measured positions. The system has two adaptation mechanisms, one for adjusting the fuzzy logic output and the other for determining the motor parameters. Experimental results show that the proposed system can significantly reduce the noise of the estimated speeds and provide excellent transient response at both normal and low speeds. This approach improves the overall performance of servo motors in various applications, especially in continuous speed control [9].

In this study, the analysis of the robotic system design focuses on the application of servo motors to the control system of a robotic hand finger. Three popular servo drives with closed-loop feedback, CoxA, Femur and Tibia, are used for the study. The test rig was designed to operate in the following mode Fig. 2: to control the position of the servo motor, the microcontroller generates a pulse width modulation (PWM) signal of a fixed frequency and variable duty cycle, the angle is determined by the width of the signal pulse. When connecting the microcontroller to three servo motors and an additional +6 V power supply, it is necessary to ensure that there is sufficient electrical current to power all components. On the microcontroller side, separate regulators with an isolating diode and a large capacitor shall be used to prevent voltage drops due to different operating modes of the servo drives from affecting the microcontroller. The duty cycle of the pulse-width modulated signal can be calculated according to the desired servo motor angle to control the position of the servo motors using PWM signals.

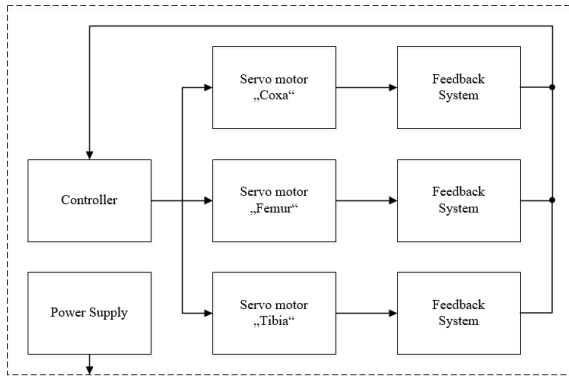


Fig 2. Schematic diagram of the test bench

Servo motor feedback is needed to transmit the current motor positions to the microcontroller. This feedback information allows the microcontroller to accurately control the position of the servo motors by adjusting the PWM signals. In the absence of feedback, the microcontroller would only be able to transmit Pulse Width Modulation (PWM) signals to the servo motors and assume that it has reached the desired position. However, due to external forces or mechanical problems, the servo motors may in practice not reach their intended position. By receiving feedback, the microcontroller can continuously monitor the position of the servo motors and, if necessary, modify the PWM signals to ensure that the target position is reached. A digital angle meter Fig. 3 is used to monitor the servo motor position. The digital angle meter is connected to the motor's rotation axis, which ensures accurate measurement of each rotation. In order to investigate the positioning of each motor, an Arduino Mega programmable logic controller and a separate power supply were used.

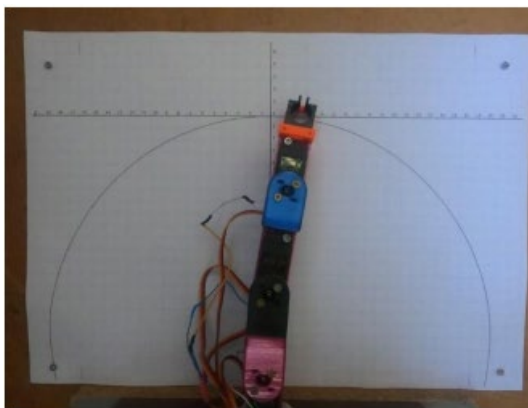


Fig 3. Test bench

By connecting a potentiometer as part of the feedback system and reading the data, this information can be used to calculate the exact angle of inclination of the servo drive, or the system it is controlling (the finger of the robotic hand). Typically, this calculation involves comparing the raw potentiometer readings with a known baseline value and using the difference to determine the system yaw angle. To ensure that the actuator moves accurately, a system is in place to detect when the potentiometer reading and the calculated position do not match. For example, if the

difference between the potentiometer reading and the calculated position is greater than two, this may indicate that the actuator is not moving accurately and the position check should be repeated. Instead of continuously reading the potentiometer feedback, it is possible to measure the exact potentiometer values at specific angles and use this information to calculate the exact tilt angle of the actuator. This method, known as calibration, provides a more accurate and efficient method of measuring the actuator position. To calibrate the potentiometer, you need to move the servo motor through several angles and record the potentiometer readings for each angle. This would allow a correlation to be made between the angle of the servo motor and the potentiometer reading. By setting a suitable value for the calibration factor, the potentiometer readings can be used to calculate the exact angle of rotation of the actuator. For example, if a certain angle is to be achieved, the potentiometer reading corresponding to this angle can be calculated and the position of the actuator can be set accordingly. This function would take the potentiometer reading as input and return the corresponding actuator angle as output Fig. 4.

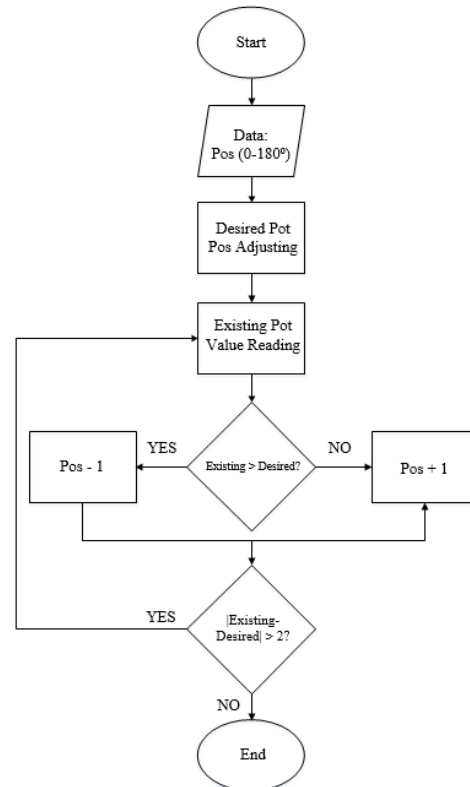


Fig 4. Algorithm for the servo drive's enhanced feedback system

### III. RESULTS AND DISCUSSION

Initial performance tests of the uncalibrated system evaluated the accuracy of three different servo drives and showed that all motors with conventional feedback and a standard control algorithm deviated on average 23.5° from the set angle during the tests, with a range of 0-180°. This indicates that the actuator movement is inaccurate and not suitable for the control of precision robotic systems Fig. 5.

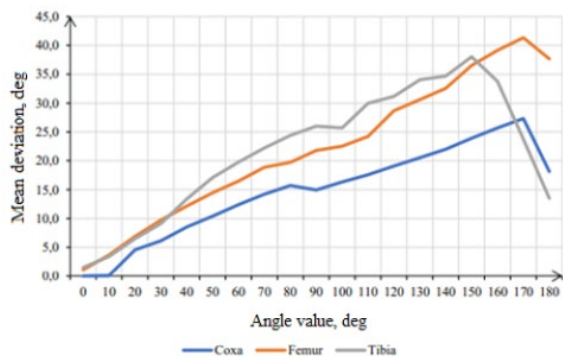


Fig 5. Plot of the specified steering angle and measured mean deviation for servo drives (without integrated enhanced feedback system)

Fig. 6 shows the aggregated test data for the same servo drives when the servo drive control integrates a feedback verification system working with a software calibration algorithm.

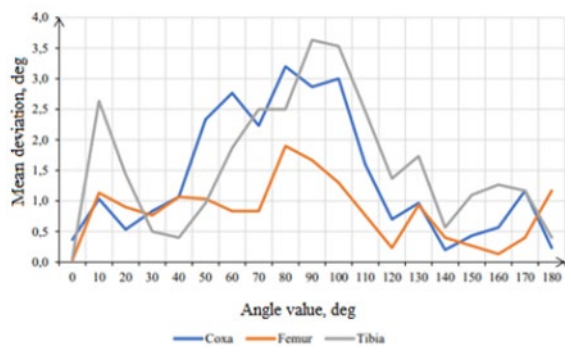


Fig 6. Plot of the specified steering angle and measured mean deviation for servo drives (with integrated enhanced feedback system)

#### IV. CONCLUSIONS AND SUGGESTIONS

The study analyses individual popular servo motors on the market with a potentiometric feedback positioning system in the absence of a feedback verification system. The average angle of rotation of the servo motors was found to be  $\sim 23,5^\circ$ . The application of a pre-calibration algorithm for the servo motor and the integration of a feedback verification system resulted in an average angle of rotation of the servo motors of  $\sim 1,4^\circ$ . Comparison of the servo motor angle accuracy with and without the potentiometer feedback verification system shows a significant increase in accuracy, i.e.  $\sim 10$  times. With the integration of the above systems, the largest deviation is observed in the servo drive operating range between  $40^\circ$  and  $110^\circ$ , due to the increased mechanical stress loads of the reduction gears in the servo drives. This would be resolved by calibrating the actuator for a segmented

operating range, rather than the full range, taking into account the dynamic loads of the system controlled by the servo actuator. During the tests, the servo drive is integrated into a six-axis robot leg with four degrees of freedom. After applying the pre-calibration system, the accuracy of the robot leg increases, the deviation of the distance from the set coordinate changes by an average of 1.1 cm. Compared to single-step with feedback or pre-calibration with foot control, feedbackless feedback shows a noticeable increase in foot position accuracy.

In order to improve the control systems, it would be appropriate to test alternative servo drive feedback systems such as optical encoders or inertial sensors in further studies.

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