Automated Measurement Platform for R/C Servo Motors

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Abstract **— R/C servos are very popular as actuators in many mechatronic tasks today. In this paper an automated test platform is presented. Its purpose is to automatically measure the parameters of R/C servos like rotational range and response velocity. First, a short analysis of the operation of such servos is given followed by details about the measurement platform and the parameter extraction method. Finally, as an illustration, results obtained from a low-cost digital R/C servo are presented.**

Keywords - R/C servo, test platform

I. INTRODUCTION

R/C servos were originally developed to provide steering abilities for various remote-controlled vehicle models. Nowadays, they also provide a simple, versatile and cheap solution for a wide variety of robotic and mechatronic tasks [1, 2]. R/C servos find their application not only in robotic systems but also as actuators in various measurement systems where their integrated positional servo is supervised by an additional control loop [3].

Although in many areas of their application their performance is not crucial for the proper functioning of the system they are used in. On the other hand, there may be systems which can be influenced by the performance of the R/C servos used to a great extent. For such systems some means of modeling is necessary. A promising attempt can be found in [4].

In this paper, an automated measurement system is presented which enables the extraction of some basic parameters of a typical R/C servo motor. These parameters can be later used in the design process of the automatic control system which incorporates the servo or in the programming of the embedded system which issues the positioning commands to the servo.

II. THE R/C SERVO OPERATION PRINCIPLE

There are many different R/C servos on the market today. They differ in size, mounting type, speed, torque, maximum load, etc. Common to all of them is that they are all equipped with a combination of a small DC motor and a suitable gearing depending on the intended use. Besides that, a positional controller is integrated within the same housing. What is needed for its use is a power source and an external analog or digital system which issues the positioning commands.

The servo requires a DC voltage source from where it takes the required power. In most cases the voltage is in the range from 3 V to 6 V, and usually a battery pack is used for this purpose.

The required position command is transferred to the servo as a series of square voltage pulses as depicted in Fig. 1. The rising edges of the pulses are what activates the servo. A new rising edge is required after every time interval of T_P, where T_P is typically *20 ms* for most servos. If the pulses stop arriving to the servo, its control system shuts down until the pulses reappear again. The commanded angular position is determined from the width of the pulse itself. The pulse-width ($T_W = T_{W0} + T_{WD}$) of $T_W = T_{W0} = 1.5\ ms$ has the effect of commanding the servo to its center position. The usual range which servos support is $T_{WD} = \pm 0.5\ ms$ above and below T_{W0}, but most of them is capable of operating in an even wider range.

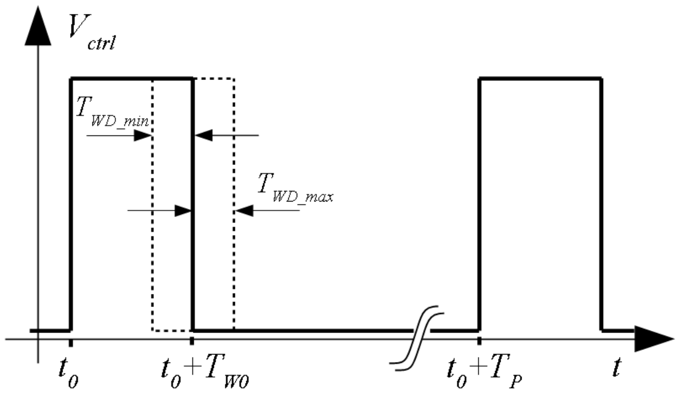

Figure 1. Explanation of the pulses required to command a typical R/C servo to the required angular position

The model of the actuator (mechanical) part of a typical servo is shown in Fig. 2. The transfer function of this system will be derived here based on this model.

The following equation governs the motion of the rotor's moment of inertia J_r and the externally attached object described by the moment of inertia J_x:

$$M = K_m i_r = B\omega_r + \tau_r + \tau_x \qquad (1)$$

where B is the coefficient of viscous friction, τ_r and τ_x are the inertial torques from the rotating masses J_r and J_x respectively. The inertial torque is always proportional to the angular acceleration and the moment of inertia, i.e. $\tau_r = J_r \dot{\omega}_r$. The external load is at the other end of the gear train with the ratio of $N = \omega_r / \omega_r'$, therefore its contribution is $\tau_r = \frac{1}{N^2} J_x \dot{\omega}_r$. By introducing these inertial torques into equation (1) and replacing the differentiation operator with s (according to the Lapalace transformation) the following is obtained:

$$M = K_m I_r = \Omega_r B + s(J_r + J_x / N^2) \qquad (2)$$

where i_r and ω_r have been changed to their complex domain equivalents.

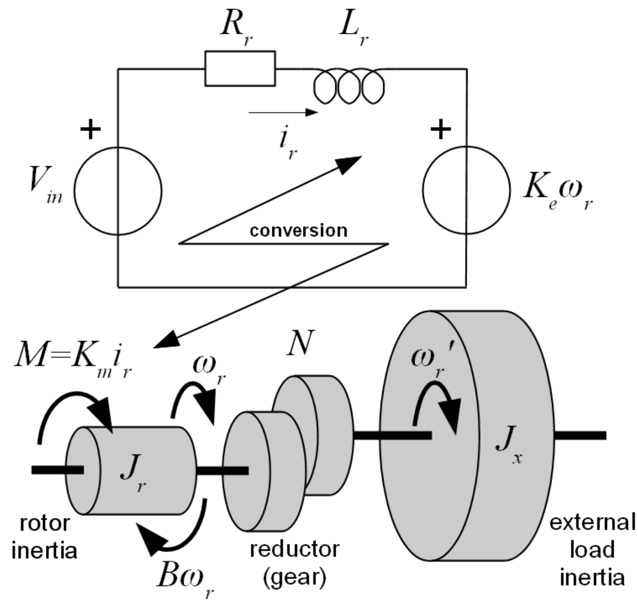

Figure 2. Basic electro-mechanical model of a typical R/C servo.

The upper part of Fig. 2 represents the electrical part of the DC motor model. The following equation can be written in time-domain:

$$V_{in} = R_r i_r + L_r \frac{di_r}{dt} + K_v \omega_r \, . \qquad (3)$$

Replacing the differentiation operator with s, and expressing the rotor current yields:

$$I_r = \frac{V_{in} - K_v \Omega_r}{R_r + sL_r} \, . \qquad (4)$$

By combining (2) and (4) and solving for Ω_r, taking into account the influence of the gear the transfer function of the geared DC motor can be obtained:

$$\Omega_r' = T(s) V_{in} = \frac{K_m / N}{(B + sJ_e)(R_r + sL_r) + K_m K_v} V_{in} , \qquad (5)$$

where $J_e = J_r + J_x / N^2$. From the last equation, an important conclusion follows. Applying the final value theorem [5] to it when the input voltage is a step function of an amplitude of V_{max} gives

$$\lim_{t\to\infty} \omega_r = \lim_{s\to 0} sT(s) \frac{V_{\max}}{s} = \frac{K_m V_{\max}}{N(BR_r + K_m K_v)} \, . \qquad (5)$$

From equation (5) it is clear that by applying a limited voltage to DC motor, its angular velocity is also limited and it is determined by the physical parameters of the motor and the applied voltage (usually the maximum voltage applicable in the given system).

One possible and probably the simplest control loop, is shown in Fig. 3. The two-sided limiter appears because of the limited voltage the (here proportional) regulator is able to apply to the DC motor. As a direct result of this limiting, the maximum angular velocity in reaching the commanded (reference) position will be limited. As a result of this limiting, it is clear that any linear model derived for this control system will be of limited value. It can be used only for small reference changes where the limiting velocity is not reached. For this reason, the parameters extracted by the automated platform presented in this paper will be confined to determining only the maximum angular velocity during transitions.

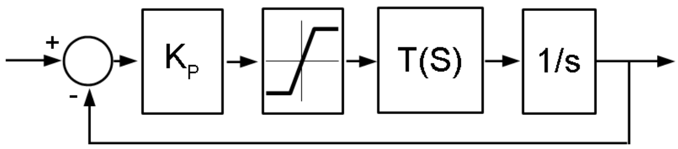

Figure 3. Diagram of the servo control loop

In Fig. 4 a captured response of a digital servo motor (Modelcraft VSD-18MBWG, large-scale digital servo) used in the experiments for this paper is presented. Quick position changes are commanded with a period of *2 s* with an amplitude sufficient for the abovementioned velocity limit to be reached. From this figure, it can be clearly seen that for most of the transition interval the DC motor is driving its output at the maximum angular velocity available at the available power-supply voltage. A small overshoot is also visible at the end of the transition interval.

III. The Automated Testing Platform

Based on the previous discussion, the following parameters were chosen for automatic measurement by the automated testing platform:

- minimum and maximum angular deflection from the center position corresponding to the *1.5 ms* pulses,
- pulse widths which correspond to the above minimum and maximum angular positions,
- maximum angular velocity achieved by the output.

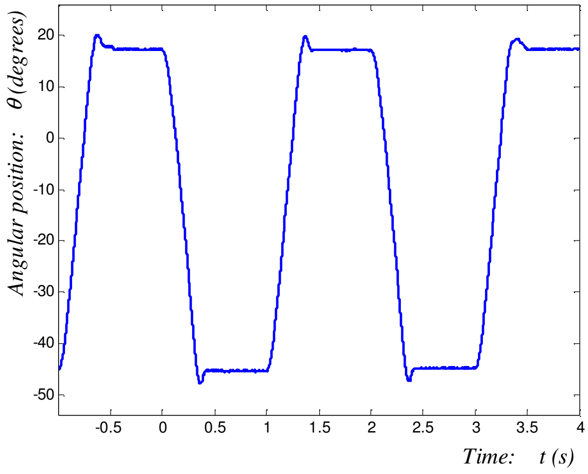

Figure 4. Typical response of an R/C servo to a step-input of a sufficiently large amplitude – captured by a Picosope 3000 USB oscilloscope. The change of the angular position in time is presented here. The linear, constant-slope parts indicate that the DC motor's velocity limit has been reached during each transition

A. Test Platform Hardware

An embedded system has been designed to carry out the planned measurements. The block diagram of the system is shown in Fig. 5. The embedded system is accompanied by a mechanical platform which makes the accurate real-time measurement of the servo's output shaft possible. Its main part is a potentiometer directly coupled to the servo. By sampling the voltage at the potentiometer's sliding-contact terminal the exact position of the servo output shaft is determined. To eliminate the need for a battery, a power supply with a regulated output voltage is also added to the system.

The central part of the embedded system is an LPC2148 microcontroller with an ARM7TMDI core. Its purpose is to generate the proper pulses needed to give out commands (set the reference position) to the servo with a precise timing. At the same time, it collects the measured data from the position-sensing potentiometer synchronized with the output (command) pulses. This enables the collection of accurate information about the servo's dynamic behavior. The collected data is sent via a serial link to a PC computer where a software especially written for this purpose evaluates the results and presents them to the user.

B. Test Algorithms

In order to conduct the servo tests, the commands to the servo should be given in a certain order and the readings from the potentiometer should be carefully processed to produce the most accurate results.

First the servo is commanded to its center position with a pulse width of T_{W0}, i.e. *1.5 ms*. Then the width of the pulses is reduced by *50 μs* and the output is monitored. If there is a change in the asymptotic values (values far enough in time from the instant where the transition command is issued), the pulse-width is further decreased. The last pulse-width value where no change in the output position is detected is considered the lower end of the output range. The same procedure is conducted for the high end of the output range in the opposite direction. From this procedure, the lowest and the highest applicable pulse-width is determined.

Since the angular range of the potentiometer is known in advance, the angular range of the servo can be determined from the analog input values obtained in the aforementioned procedure. This way the maximum and minimum angular positions (which correspond to the maximal and minimal pulse-widths) relative to the center position are determined.

In Fig. 6 a photograph of the mechanical parts of the measurement platform is given.

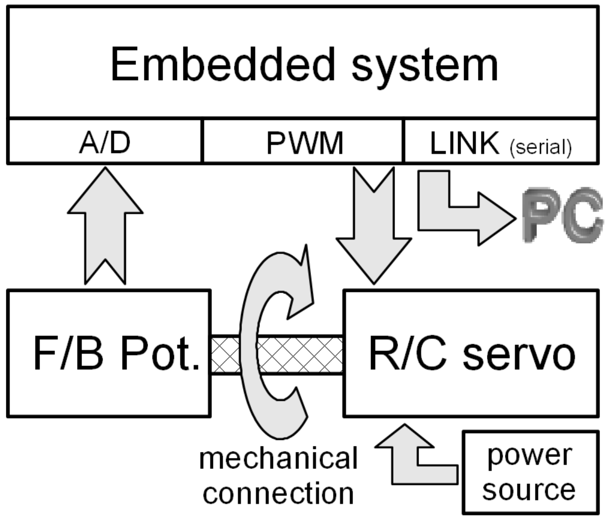

Figure 5. Block diagram of the automated R/C servo testing platform

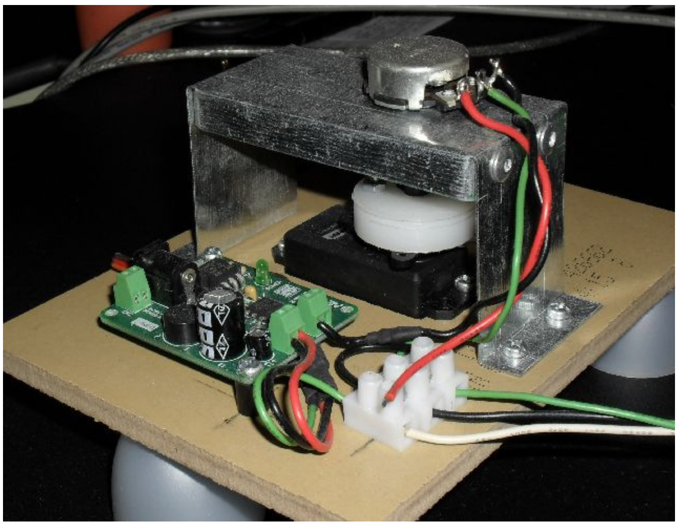

Figure 6. Photograph of the mechanical parts of the R/C servo testing platform. The power source, the feedback potentiometer and the R/C servo itself connected to it via a plastic disc can be seen in the picture.

The last piece of data the system measures is the maximum output angular velocity. For this, the servo is first commanded to a position at 20% of the measured full range and then commanded to 80% of the full range. The complete transition is recorded as an array of samples. Since the time distance between samples is known, it is easy to calculate the slope of the obtained curve at each sample position as $sl_i = \frac{\theta_{i+1} - \theta_i}{\Delta t}$. The calculated output angular positions are taken as individual sample values. In order to exclude the errors caused by noise, the mean value of the ten largest slope values (sl_i) is taken as the final value.

IV. MEASUREMENT RESULTS

Fig. 7 shows the control application running on a PC computer. The status bar shows the message "Connected" letting the user know that a connection is established with the embedded platform. When the user clicks the "START TEST" button, the status bar changes to "Busy" and the test is started. The test usually lasts for about a minute mostly due to the range test. When the status bar changes back to the "Connected" message, the finished results appear in their respective text-boxes.

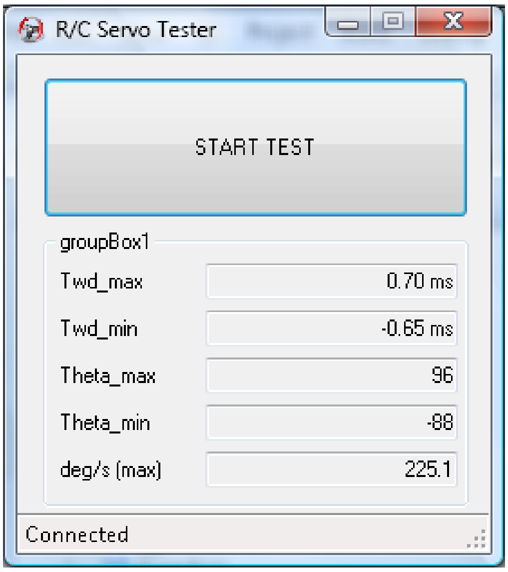

Figure 7. Screen-capture of the control application showing the test results

The results obtained for the servo under test are displayed within the application window given in Fig. 7. `Theta_max` and `Theta_min` are the maximum and minimum angular positions which can be commanded to the servo. The position acquired by the *1.5 ms* pulse is regarded as the zero position, the maximum and minimum angular positions are relative to the zero position. This way the minimum position is always negative. `Twd_max` and `Twd_min` are the pulse-widths which correspond to the maximum and minimum angular positions respectively. Again, the pulse-width of *1.5 ms* is taken as the reference value, so e.g. the real pulse-width which produces `Theta_min` is equal to *1.5 ms* + `Twd_min` = *0.743 ms*. Note that `Twd_min` is again negative.

The last measured parameter (`deg/s (max)`) is the maximum angular velocity achieved during the transition between two distant angular positions.

V. CONCLUSION

An automated test platform for determining some of the important parameters of an arbitrary integrated R/C servo motor has been successfully designed and tested. The results show that the system is functional and gives the results which coincide with the manually measured values.

Further development could include new algorithms for determining more concealed parameters of the integrated servo system. The mechanical platform could also be improved in a way to be able to accommodate a wider range of motor mountings and sizes.

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