SIMULATION BASED DESIGN OF ROBOTIC ARM WITH MODELICA

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ABSTRACT

This paper presents a numerical model of a robotic arm, using standard servomotors HSR-8498HB. The model was created with Modelica [3], the architecture grants the user the ability to easily change dimensions of the arm and the servomotor components. The aim of this model is to quickly analyse the operating range and compare it with the mission profile. It is also possible to define the mission profile and check if the component is well sized, and see how it reacts.

Keywords: Robotic arm, servomotor HSR-8498HB, sizing, model based design, electromechanical actuator.

1 Context

Our activity lead us to use Hitec HSR-8498HB servomotors, but the datasheet of this component give only little information about its operating range: maximum torque and speed. A major challenge for the Robotic teams which participate to the Eurobot contest is to use these servomotors (or equivalent) and with the little information given try to design systems. But servomotors are often used under or over their performance level, generally leading to failure. However, when we design a robotic arm, it is important to know how it will react according to the mission profile, to avoid physical interference with other parts of the robot or the environment. This Dymola [3] model will help for robotic arm design.
**Figure 1:** Theoretical and real trajectories of a robotic arm. Modelica [3] model.

Different characteristics during a mission profile can be plotted like current, torque or speed. Those data are useful to design the arm. For example the torque profile (Figure 2) can give the information if mechanical margin is sufficient when a shock occurs. If not it can destroy gears.

![Figure 2: Torque response (blue, N.m) for a step command (red, rad)](image)

The Figure 2 shows the torque response (in blue) for one servomotor of the arm. The step command position is plot in red. The strength limit of the gears is 1 Nm. We have a 0.45 Nm margin. It can resist a shock.
2 Design and sizing method

The design method we propose can be synthesised like the logigram following. It is quite different from standard methods because it starts with a defined actuator (here, servomotors described after) and the mission profile. Then, a compromise has to be made between lengths, speed, trajectory and mass. The Modelica [3] model described in this paper makes making this compromise easy.

![Logigram of the design method](image)

*Figure 3: Design method of a robotic arm using standard servomotors*

In our case, it is difficult to change the servomotor type, due to dimensions and because the control cards have been built for this type. Then, the modifiable parameters are the arm dimensions (1) and if there is no solution, change the servomotor (2).
3 Arm description and parameters

Based on the mission profile, arm dimensions have to be determined. The following example describes a two liberty degrees arm, mounted on an existing robot. The mission profile is to pick an object placed on the ground and place it on the top of the robot. The position and dimensions of the object on the ground are not defined.

![Image](image_url)

*Figure 4: Example of the work surface of the arm*

This mission profile imposes two dimensions, the lengths of the two parts of the arm L1 and L2, which will be used in the Modelica model.

![Image](image_url)

*Figure 5: CATIA [5] model of a robotic arm using HSR-8498HB servomotors*
4 Dynamic model

![General model diagram](image)

**Figure 6: General model**

4.1 Servomotor architecture

With the little information about the components of the servomotor there is in the datasheets, the model was created.

![Servomotor architecture diagram](image)

**Figure 7: general bloc diagram of the servomotor**

![Dymola model diagram](image)

**Figure 8: Dymola model of the HSR-8498HB servomotor**
The current limiter is not detailed in the datasheet, so we decided to use a current generator which counters the over limit current. This may not reproduce the reality but will truly reproduce the maximum torque of the servomotor.

4.2 Parameter analysis

Using Dymola[3] model of the servomotor (fig 8),

\[ U = R \times i + L \frac{di}{dt} + E \quad (1) \]

\[ \int \frac{d\Omega}{dt} = k \times i \quad (2) \]

Transfer function in open loop can be identified as

\[ \frac{\Omega}{U} = \frac{1/k \times \text{ratio}}{p(1 + \frac{R}{k} \times p)} \quad (3) \]

This is a first order function

![Figure 9: First order function response on Simulink [4]](image-url)
4.3 Corrector settings

Without any correction, the model shows a high steady-state error. Using a high proportional gain will reduce the influence of the perturbation (due to a resistive torque). A Proportional Derivative has to be applied to stabilise the response.

Figure 10: Bode diagram of the transfer function on Simulink [4]

Blue curve represents the transfer function in open-loop with low proportional gain without the derivative term.

Green curve represents the transfer function in open-loop with low proportional gain and a derivative term which produces a margin of 45°. With this result it is possible to deduce maximum proportional gain.

Yellow curve represents the transfer function in open-loop with high proportional gain without derivative term (same phase as blue curve). It is used to calculate margin correction at high proportional gain.

Violet curve represents the transfer function in open-loop with high proportional gain and a derivative term which produce a margin of 45°.
4.4 Mechanical model

The arm mechanism has to be modelled on Dymola [3]. It represents the architecture of the mechanism and has to be easily adapted to the needs. We chose a two axis arm to study and define material to use. Structure will be in composite carbon fibre. A CAD model gives us weight of the structure (depending on length of arm). A gripper is placed at the extremity of the arm to catch objects.

Figure 11: Mechanical model on Dymola [3]

4.5 Complete arm model

Once servomotor and mechanical model completed arm can be created. Two arms are created, one using an ideal actuator with an ideal response and the other using HSR-8498HB servomotor model. Those two arms driven in parallels permit a simple visualisation of the responses and a detection of oscillations. Servomotors are driven in position. A simple pulse source is used for the model.

Figure 11: Mechanical model on Dymola [3]
5 Results

Weight and displacements are the parameters studied for this analysis.
Plot 4 represents the step command (green and pink) and the response (blue and red)
Plot 3 represents the current given to the motor (red), and the current limitation (blue)
Plot 5 represents the output torque of the first axis servomotor.
Animation window shows the final position of the two arms (ideal actuator and servomotor)

5.1 Without weight charge

Figure 12: Dymola case without weight charge, and low displacement
Figure 13: Dymola case without weight charge, and medium displacement

Figure 14: Dymola case without weight charge, and high displacement
5.2 With 250g charge

Figure 15: Dymola case without 250g charge, and low displacement

Figure 16: Dymola case without 250g charge, and medium displacement
Figure 17: Dymola case without 250g charge, and high displacement
5.3 With 500g charge

Figure 18: Dymola case without 500g charge, and low displacement

Figure 19: Dymola case without 500g charge, and medium displacement
6 Analysis

Model seems to fit with the reality but there is an overshoot on medium and high displacements. Experiments have to be made on real servomotors to confirm this behaviour and by the way confirm the use of a Proportional Derivative.

For 500g charge torque created by the charge is high and Proportional gain is not sufficient to reduce steady-state error.

7 Improvement ways

This work is the first approach: it has to be improved to determine parameters more precisely and to make the model more representative of the real components.

7.1 Servomotor parameters

- To determine the corrector type of the servomotor, tests have to be made. The first point is measuring steady-state error for different weight charges. This test would determine if the corrector is driven with an integrator.

- The second test is to determine the bandwidth. This analysis consists in commanding the servomotor with a sinusoidal signal, and plotting the response.

- In this model, the motor parameter k was set by identification with another standard motor. It has to be determined more precisely. This determination can be made by measuring the voltage of the motor when the output is set at a constant speed that is to say use the motor as generator.

- Like the parameter k, the inductance L was identified with a similar motor, but for more precision it has to be measured directly.
The resistance is given in the servomotor datasheet, but it can be easily measured too.

### 7.2 To make the determination of the arm dimension easier

The design method proposed (Figure 3) imposes to determine the arm dimensions according to the mission profile. For this task, a method can be prepared: there are relations between torques, lengths and speed. For example, the two lengths of the arm affect the torque of the first servomotor, and the length of the second part of the arm affects only the second actuator.

It can be useful to determine the law between lengths and torque, and plot the necessary torque of the servomotors for different lengths. With the obtained graph, it can be easy to optimize the torque repartition of the two servomotors. It would also be easy to design a system to discharge one of the servomotors for example with spring.

### 7.3 Model

For now, the model is direct (the trajectory is calculated using the input command), and it would be interesting to create an inversed-model (the input is calculated using the needed trajectory). This improvement will make easier the command or the arm, particularly if there is more than two liberty degrees (DOF). One of the problems with the inversed-model is the non-bijection: for one position of the arm end, there are multiple solutions.

**ACKNOWLEDGEMENTS**

We would like to thanks Marc Budinger for his help on this work. The Modelica model was created for the members of INSA Toulouse Robotics Club, and may help other teams in robotic design and sizing.

**REFERENCES**

**Papers**


**Software tools**

