

A Two Link Manipulator End Effector Control

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Abstract The goal of the paper is to present a regulation and control model of a two link manipulator end effector position. Attention is paid to kinematic and dynamic analysis of the manipulator. Then the simulation model with a control algorithm of its end effector position is proposed. MSC Adams Control Toolkit is used for computer simulation. Finally the results of the simulation are presented in graphical form.

Keywords: two link manipulator, controller, links, end-effector, simulation, modeling

Cite This Article: Hroncová Darina, and Bakši Jaroslav, “A Two Link Manipulator End Effector Control.” *American Journal of Mechanical Engineering*, vol. 5, no. 6 (2017): 239-242. doi: 10.12691/ajme-5-6-1.

1. Introduction

Connecting interactive simulation and visualization allows a very comfortable process of working with the model, its modification and visualization of the simulation results. Dynamic outputs in independent windows give the user the ability to watch the actual values of the variables of interest in real time along with ongoing simulation and visualization.

2. Model of the Manipulator

An example of a two link manipulator model is shown in the picture (Figure 1). From the kinematic point of view it presents an open kinematic chain.

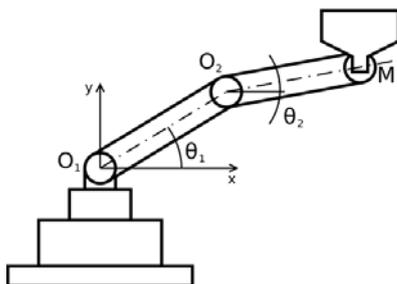


Figure 1. Model of the manipulator

The moving arms are mounted on the base ensuring the stability in the operation. The end effector, in our case a bucket, is connected to the second arm. The manipulator performs the required operation with the bucket. We can describe this motion and make its kinematic analysis [1,2].

The two link manipulator model in Figure 2, compiled in the MSC Adams software is composed of two members with lengths l_1 and l_2 [3,4,5,6,7]. We consider two degrees of freedom of movement for a plane manipulator with the masses of the manipulator arms being m_1 and m_2 respectively. The arms are connected by a rotational kinematic pair to

the frame. They are also connected to each other by a second rotational kinematic pair. There are drives providing the motion placed into the kinematic pairs. The angle of rotation of a kinematic pair is indicated by the angles Θ_1 and Θ_2 respectively. The kinematic equations describing the position of the end point M of the manipulator end effector (Figure 2) can be expressed in the form depending on the angles of rotation Θ_1 and Θ_2 [2-7]:

$$x_M = l_1 \cos \Theta_1 + l_2 \cos(\Theta_1 + \Theta_2) \quad (1)$$

$$y_M = l_1 \sin \Theta_1 + l_2 \sin(\Theta_1 + \Theta_2) \quad (2)$$

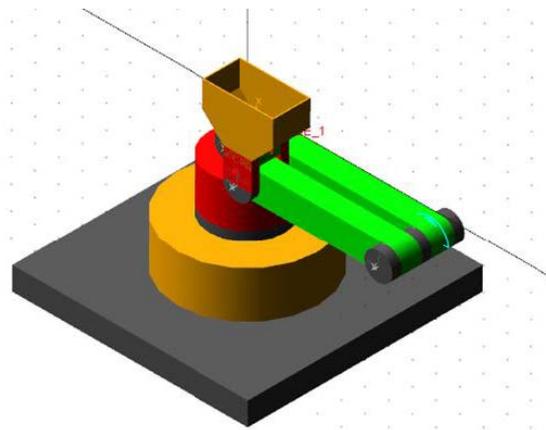


Figure 2. The two link manipulator model in MSC Adams

The driving moments M_1 and M_2 are generally obtained from servomotors in individual kinematic pairs. They ensure the movement of the manipulator arms. The dynamic equations of motion of the manipulator (Figure 1) can be written according to [4]:

$$M(\theta) \ddot{\theta} + V(\theta, \dot{\theta}) + G(\theta) = \tau \quad (3)$$

where τ is the vector of actuator torques, $M(\Theta)$ the inertia matrix, $V(\Theta, \dot{\Theta})$ the Coriolis-centripetal vector and $G(\Theta)$ the gravity vector.

Equation (3) represents a system of differential equations of the 2nd order. This equation of motion does not consider the inaccuracy and frictional effects in individual kinematic pairs, neither the elastic deformations of manipulator arms.

3. Computer Simulation

We created a 3D model of the manipulator using modeling elements and procedures for creating body, geometric and kinematic links in the MSC Adams/View environment and verified its functionality [7,8,9]. As a result, the assembled model of the manipulator and its different views are shown Figure 3.

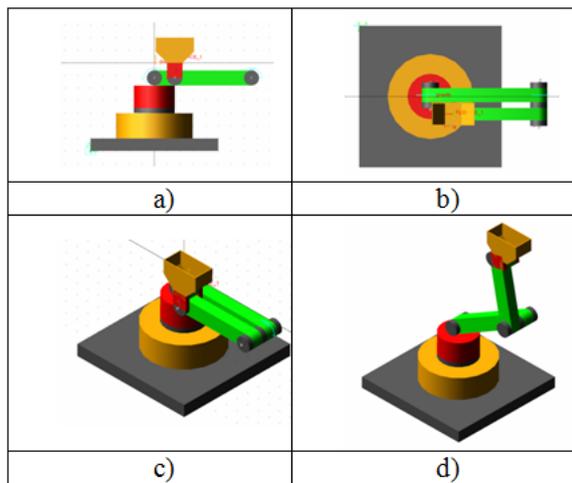


Figure 3. Different views of the manipulator model

Further attention is paid to the control. We control the position of the end effector, which in our case is a bucket attached to the two link manipulator second arm. The problem of control with regard to the proposed two link manipulator lies in the control of the horizontal position of the bucket, which is used for moving objects, whether solid, loose or liquid. The requirement is to ensure the equilibrium of the bucket during the motion.

End effector control is simulated in MSC Adams, which offers the ability to build a control system by using regulators. In our case we used a proportional regulator.

The stability of the bucket is determined by the regulating circuit by means of a compensation torque which allows the bucket to stabilize during movement. For the control system a feedback control circuit is proposed, i.e., a balancing regulator for holding the bucket in a horizontal position during arm rotation.

The proposed schematic diagram of a closed regulator system with the proportional feedback is shown in Figure 4.

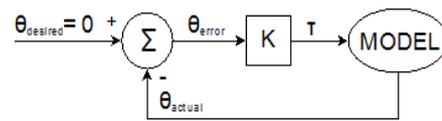


Figure 4. Schematic diagram of proportional regulator system

Using the previous feedback regulator scheme a control system is schematically assembled (Figure 5). The control system will ensure that the balancing torque maintains the end effector in horizontal position when the manipulator configuration changes thus preventing the loss of stability during the manipulator operation.

The mechanical system i.e. a two link manipulator is controlled using the following control variable:

$$u = K_p \cdot e \tag{4}$$

where:

- x - the desired value (theta_desired = 0),
- y - the actual value (theta_actual),
- e - difference (the error) in the summing block: theta_error = theta_desired - theta_actual,
- u - an action control variable which represents the gain (torque_gain) of the equalizing moment (SFORCE_1).

After creating the block diagram of the two link manipulator control system, it is necessary to define the following elements in MSC Adams:

1. Design Variable
2. State Variable
3. Measure

The proposed control system is implemented in MSC Adams using the Control Toolkit shown in Figure 6 [15,20].

The control circuit of the system is created using the logic shown in Figure 4 and Figure 5.

The input signal to the mechanical system of the manipulator is the desired and actual values of the rotation of the bucket during the operation of the manipulator over the prescribed trajectory. The first input signal entering the summing block is the desired zero value of the angle of the x-axis of the bucket with the x-axis of the global coordinate system connected to the frame.

The regulatory difference is created in the summing block as the difference between the desired and the current rotation of the bucket. This difference is then placed into the Database Navigator as theta_error.

The gain block provides an amplification of the u-signal needed to determine the equalizing torque of the bucket position regulation. The input for the gain block is the theta_error created in the previous step. After setting the gain an element called "torque_gain" is added to the Database Navigator.

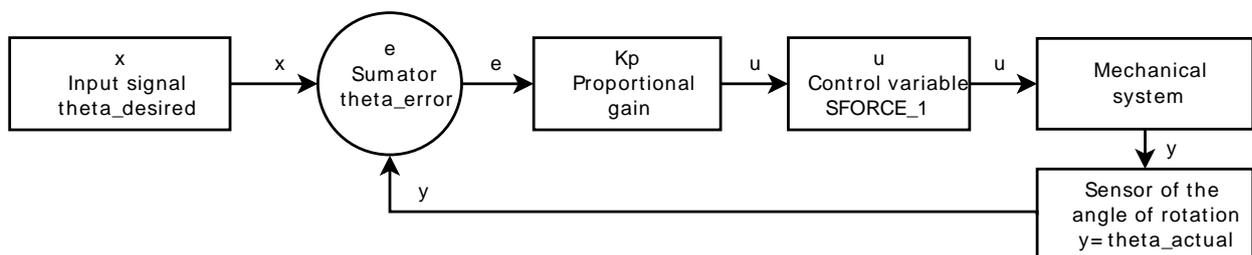


Figure 5. Control system with a proportional regulator

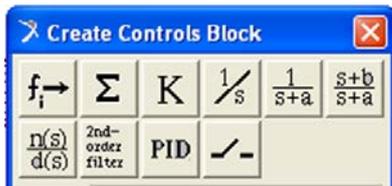


Figure 6. Control Toolkit menu

After assigning the created function, variables are added and displayed in Database Navigator. Its content is in Figure 7.

```

+ theta_actual      controls_input
+ theta_desired    controls_input
+ theta_error      controls_sum
+ torque_gain      controls_gain
    
```

Figure 7. Database Navigator content

The regulator torque (Figure 8) is required to control the bucket position, i.e. its current position with respect to the desired horizontal position during the manipulator operation. This torque (SFORCE_1) is the force that keeps the bucket in the horizontal position.

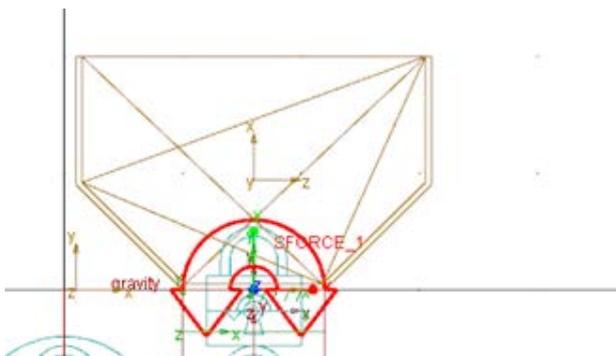


Figure 8. Regulator torque SFORCE_1

Interactive simulation and visualization allows a very comfortable connection between the process of computer model simulation its modification and visualization of the results. Dynamic graphs give the user the ability to check the actual values of inspected variables in real-time with ongoing simulation and visualization (Figure 9).

Postprocessor is an integral part of the computer prototype modeling process as well as a presentation tool [19]. An extremely comfortable tool for creating, processing, modifying and presenting simulation results in graphical form [10,11,12] has been incorporated into MSC Adams. The model current state can also be displayed in the graph generator (Figure 9).

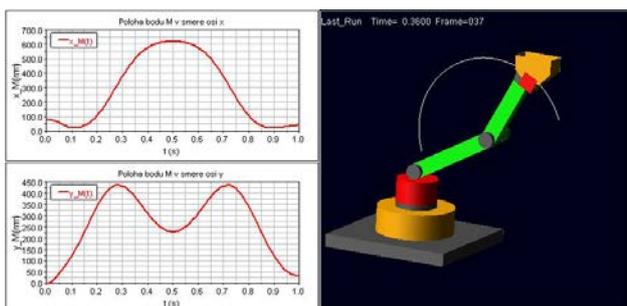


Figure 9. MSC Adams postprocessor

There is also the possibility to present the simulation process in AVI video format.

4. Simulation Results

The values of inspected variables in graphic form are displayed in following pictures.

Torque values in rotational kinematic pairs at arm weights $m_1=9.9779\text{kg}$, $m_2=7.1330\text{kg}$ and the bucket weight $m_b=0.9348\text{kg}$ are in the pictures Figure 10 to Figure 13 [20].

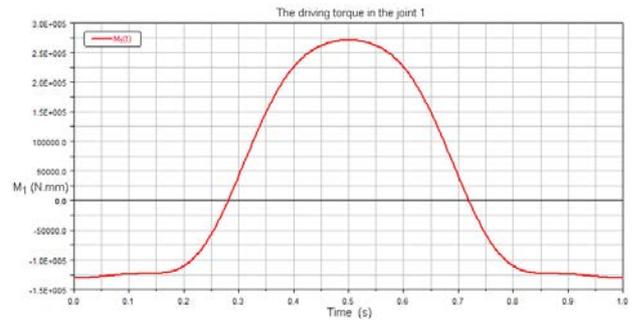


Figure 10. The driving torque in the joint 1

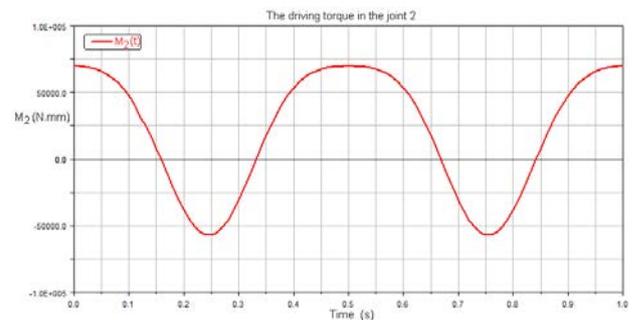


Figure 11. The driving torque in the joint 2

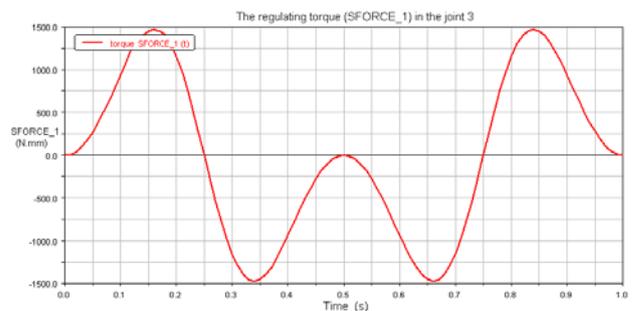


Figure 12. The regulating torque (SFORCE_1) in the joint 3

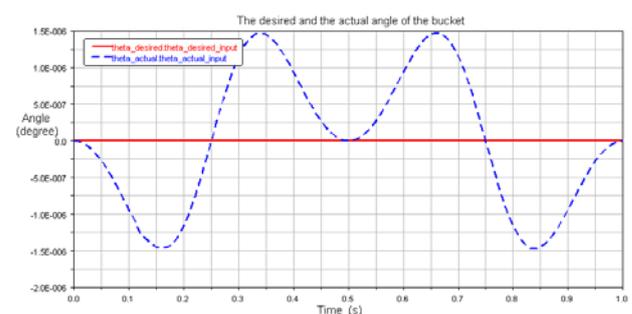


Figure 13. The desired and the actual angle of the bucket

The goal was also to obtain results from the manipulator end effector control to prove the capability and functionality of the proposed regulator for the regulating moment [20]. The obtained values of the current and the desired tilt of the bucket during the operation is shown in Figure 13.

5. Conclusion

MSC Adams works with a 3D model [21]. The advantage of this software is the possibility of simulation of motion after the model and its control has been set up in the program environment thus verifying the functionality and mobility in form of a 3D view. Based on the results obtained from simulation it is possible to build a real model and design the servo-drives. When designing the drives for a mechanical system, it is necessary to pay attention to the maximum load during the operation to dimension and design the drives with optimal parameters for the specific manipulator use.

The proposed control of the end-effector stability by selecting and adjusting the control system is an important aspect for maintaining stability and managing the working cycle. The control system and the controller used in the simulation is functional and maintained the stability during the manipulator operation.

Acknowledgements

This work was supported by grant projects VEGA 1/0872/16 Research of synthetic and biological inspired locomotion of mechatronic systems in rugged terrain and grant project KEGA 049TUKE-4/2017.

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