

A Co-simulation Approach Based on ADAMS-MATLAB for Development of an Industrial Manipulator



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ABSTRACT

This paper presents a methodology using co-simulation to study the dynamic performance analysis of an industrial manipulator. The real time industrial manipulator "Stäubli TX40" is undertaken as an example with all physical data about the links. The joints are designed to have respective input from the control system simulated in MATLAB. The industrial manipulator is configured to feed back the position signal to MATLAB based controller. The effect of mechanical parameters like weight of link and electrical parameters like VI characteristics are seen to be performing in simulation. Thus the manipulator design, is possible to be tested for the performance before it is actually manufactured and/or any electrical/electronic component, sub-control system is tested for desired performance while placed in the application before it is procured. This simulation also enables to analyze and optimize the performance under various control philosophies. The kinematic analysis of the industrial manipulator "Stäubli TX40" is demonstrated in ADAMS in which the position and orientation of the each link is established with the help of joints. This co-simulation methodology allows simulation, development and validation of control strategy for robotic manipulator model. The cycle time and positional accuracy are the main performance indicators.

Keywords— Co-Simulation, Control Strategy, Kinematic Analysis, Manipulator, Simulation

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I. INTRODUCTION

Industries these days rely heavily on computer simulation to study the general trends before investing on actual experimental testing. Testing typically requires multiple hardware parts of manipulator which are very expensive instrumentation. To obtain the indicative data on all the relevant parameters, and after all this there is still a possibility that the acquired results are not found as the desired results; thus making the whole experiment is waste of resources. To minimize the expenses associated, a model is first created and simulations are run on it, to make sure that the trend shows improvement and that one may certainly go ahead and invest in the experimentation [1-5].

In this paper a co-simulation methodology is presented. It is a powerful technique for quick implementation of virtual prototype of a robotic arm system as well as the design of a control system; it also solves the effective trajectory tracking control and kinematics analysis of an industrial manipulator. A co-simulation approach is introduced with the help of the ADAMS (Automatic Dynamic Analysis of Mechanical System) multi-body dynamic software, developed by Mechanical Dynamics Inc. [6]. To validate the model in Adams, it is integrated with MATLAB/Simulink control model [7]. A co-simulation technique improves the development cycle of a robotic system, where physical or mathematical model and the model of control systems are designed.

II. LITERATURE REVIEW

The objective is to use the co-simulation approach between ADAMS and MATLAB/Simulink, thereby creating the virtual prototype of real-time system. Guet *et al.*, 2005 [1] suggested the implementation of virtual prototype model of robotic arm before building the real model. The parallel robot (2008) [5] has 3-TPT mechanism; it has been constructed in SolidWorks, The interaction between the subsystems is accurately expressed by virtual prototyping model of the physical system.

Soon and Slotine, (2009), describes the design of a coordinate system [3] for 2 DOF robot arm. The dynamic model is implemented with the coordinate system of robot arm and its defined parameters. The author describes and constructed the joint angle control of two and three DOF robot arm for the control method of co-simulation. An autonomous single wheel robot (2009) [4] is designed and simulated for a control of gyroscopically stabilized operation. The mechanical structure is imported in ADAMS. The 3D simulator is used to design and simulate

III. MODELLING

The design of an industrial manipulator “Stäubli TX40” is acquired as an example, for building multi body dynamics model in Adams/view. In modelling using CATIA and SolidWorks software, the parts of the manipulator are designed separately. The drawings are obtained from Manufacturer Company [8]. Afterwards parts are reproduced in assembly environment with specific constraints. Base part is fixed to the ground by applying fix joints, then according to design each part is imported in the Adams/view separately. Their orientation and position is specified by using rigid body properties of solid parts. The markers and physical points are created at precise location. Material has been set by default as “steel” and dc motors are assembled at each joint separately. The “motion” command is used to attach motion at revolute joints.

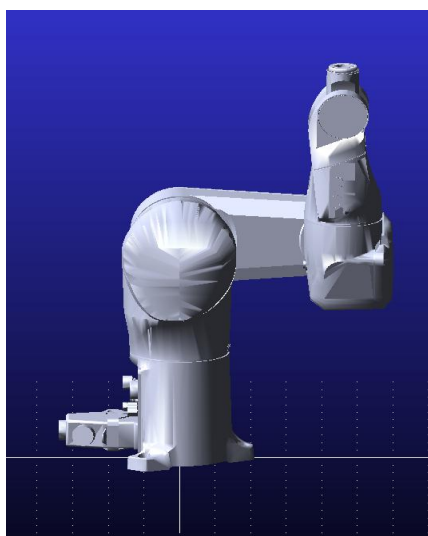


Fig. 1 Model in Adams/view

In Fig 1. Shows the model in Adams/view at its “zero” state, i.e. initial position. The manipulator contains rigid body in Adams and it has 6 dof. The links are assembled through rotational shafts and driven by motors. At each

the controller of the gyrobot. The active vibration isolation system (2010) [3] consists of a mechanical and electrical subsystem. It achieves the ultra-precision machining, testing or positioning to effectively improve the effectiveness of its isolation. The existed coupling relationship between its mechanical structure and controller is minimized by co-simulation. For control system design of a robotic arm, Xing (2012) suggested the Simulink section of MATLAB; it is interfaced with ADAMS for accurately studying the parameters of robotic manipulator. In 2013, author describes the modified D-H method [6] for representation of manipulator kinematics.

Authors FazadCheraghpooret *al.* [9] suggested dynamic modeling and simulation of the industrial robot Stäubli TX40. The dynamic identification methods are used for linear modelling [10]. The authors M. Gautier *et al.* [11] identify a method based on the inverse dynamic identification model. The least-squares (IDIMLS) technique is used to identify inertial and friction parameters of several robotic prototypes and industrial robots.

joint assembly produces rotational motions through which we get angular velocity, displacement and acceleration with respect to time. According to the links inertial properties the load torque has been measured.

The robot kinematics deals with the position of links which are connected with the help of joints, which gives the position and orientation of every link present in the robot manipulator to place the end-effector to the required target. The mechanical structure contains rigid body links, revolute joints, dc motor, motions and gravitational forces. DC motors can be chosen as externally controlled, analytical or curve based.

TABLE I
INERTIAL PARAMETERS FOR STÄUBLI TX40

Link	Mass [kg]	Inertia [kg.m ²]		
		I _{xx}	I _{yy}	I _{zz}
Base	4.14580	1.906593 2004E-002	1.640995 7016E-002	1.360754556 8E-002
1	6.27605	3.570892 077E-002	3.171595 6735E-002	2.248414401 4E-002
2	4.85567	2.230456 1004E-002	1.970394 7024E-002	1.430045781 E-002
3	2.39432	6.378908 9859E-003	6.162851 1862E-003	4.704746081 4E-003
4	1.87779	7.067140 8449E-003	6.273673 7102E-003	2.890272054 2E-003
5	0.15118	9.399325 1329E-005	8.387855 6581E-005	3.866482340 7E-005
6	1.242980 1983E-002	2.979862 8784E-006	1.580388 7901E-006	1.535241236 4E-006

After creating a model, we calculated the inertial parameters of the parts such as density, these are detailed in software database. The solid parts which are imported in Adams are without mass and inertia in default. Thus the Adams software is able to calculate the mass and moments of inertia of each part automatically. The values are illustrated in Table 1 by applying material as “steel”. The computed parameters are verified by making comparison between the total weights of simulated model with the data given in corresponding catalogue [6].

A. Kinematic Analysis

The model in Adams is transformed into MATLAB software, before that forward kinematics equations are considered. Also the joint parameters of 6 dof are specified with Modified Denavit-Hartenberg (MDH) parameter method.

TABLE III
INERTIAL PARAMETERS FOR STÄUBLI TX40

Joint	Θ_i	α_i	a_i	d_i
1	Θ_1	0	0	0
2	Θ_2	30	0	0
3	Θ_3	-10	342.068	55.57
4	Θ_4	40	0	146.067
5	Θ_5	40	0	0
6	Θ_6	-25	0	76.464

Where,

Θ_i : A rotation about the z-axis.

d_i : The distance on the z-axis.

a_i : The length of each common normal (Joint offset)

α_i : The angle between two successive z-axes (Joint twist)

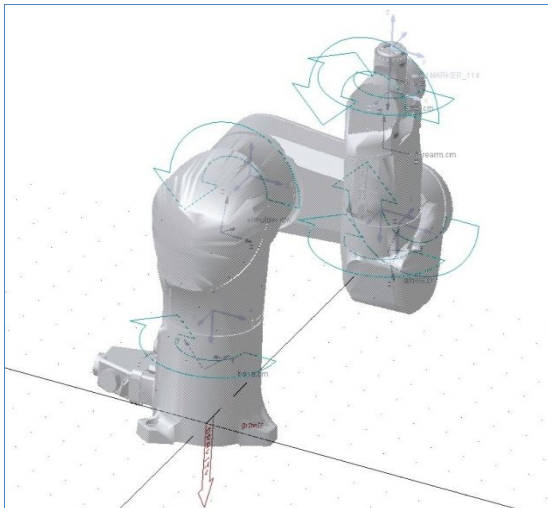


Fig. 2 the attached coordinates of robot joints

Fig. 2 shows the attached coordinates to each joint. The Homogeneous Transformation Matrices are given below, through which robot forward kinematics equations are formed.

$${}^0_1T = \begin{bmatrix} \cos \Theta_1 & -\sin \Theta_1 & 0 \\ \sin \Theta_1 & 0 \cos \Theta_1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \end{bmatrix} \quad (1)$$

$${}^1_2T = \begin{bmatrix} \cos \Theta_2 & -\sin \Theta_2 & 0 \\ 0 & 0 & 1 \\ -\sin \Theta_2 & 0 & -\cos \Theta_2 \\ 0 & 0 & 0 \end{bmatrix} \quad (2)$$

$${}^2_3T = \begin{bmatrix} \cos \Theta_1 & -\sin \Theta_1 & 0 & 342.068 \\ \sin \Theta_1 & \cos \Theta_1 & 0 & 0 \\ 0 & 0 & 1 & 55.57 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3)$$

$${}^3_4T = \begin{bmatrix} \cos \Theta_1 & 0 & -\sin \Theta_1 & 0 \\ 0 & 0 & 1 & -146.06 \\ \sin \Theta_1 & 0 & \cos \Theta_1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (4)$$

$${}^4_5T = \begin{bmatrix} \cos \Theta_1 & 0 & -\sin \Theta_1 \\ 0 & 0 & 1 \\ -\sin \Theta_1 & 0 & -\cos \Theta_1 \\ 0 & 0 & 0 \end{bmatrix} \quad (5)$$

$${}^5_6T = \begin{bmatrix} \cos \Theta_1 & -\sin \Theta_1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ \sin \Theta_1 & \cos \Theta_1 & -1 & -76.46 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (6)$$

The following relation shows the end effectors position and orientation.

$${}^0_6T = {}^0_1T {}^1_2T {}^2_3T {}^3_4T {}^4_5T {}^5_6T \quad (7)$$

B. Adams/MATLAB Co-simulation

The procedure used during this dissertation is useful for a similar model verification methodology and analysis can be done when working with co-simulations. It is highly recommended to decrease the time spent on troubleshooting. Therefore to verify the available data and use it to isolate and analyse models included in the co-simulation by close loop simulations. It is also important to stay on the troubleshooting method when realistic results are delivered using co-simulation. Depending on the initiation sequence was performed; further improvement of the results can be retained.

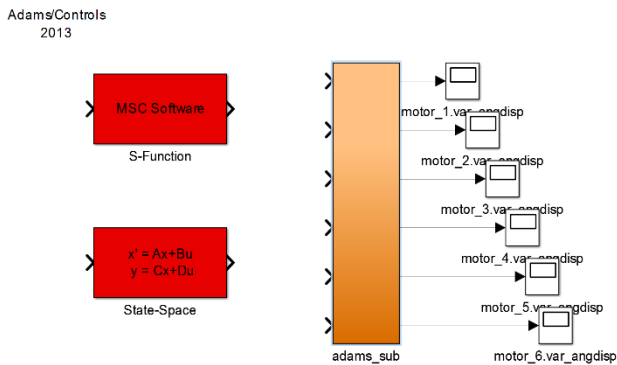


Fig. 6 shows the Adams subsystem block with respect to State-Space model and system functions.

In MATLAB software by importing “Controls_Plant” of Adams system, we get Simulink model. As shows below in Fig. The controls_plant of Adams model is exported by “Adams/control”, in the “plug_in” manager. In that, the controls plant model name and input/output variables are defined by selecting systems “pin” and “pout” variables. The target software selected as MATLAB and solver selected C++.

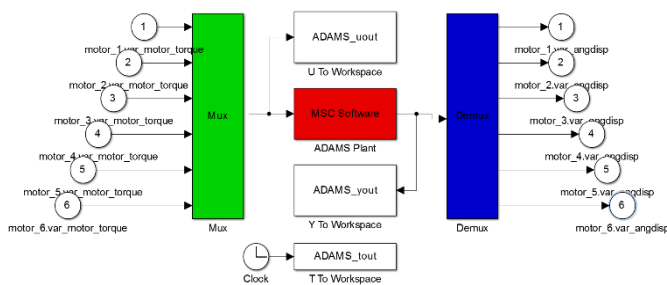


Fig. 7 shows the input/output of model in Adams with respect to 6 joints of manipulator

The required MATLAB commands are shown below.

```
>> Controls_Plant_1
```

```
%%% INFO : ADAMS plant actuators names :
```

- 1 motor_1.var_motor_torque
- 2 motor_2.var_motor_torque
- 3 motor_3.var_motor_torque
- 4 motor_4.var_motor_torque
- 5 motor_5.var_motor_torque
- 6 motor_6.var_motor_torque

```
%%% INFO : ADAMS plant sensors names :
```

- 1 motor_1.var_angdisp
- 2 motor_2.var_angdisp
- 3 motor_3.var_angdisp
- 4 motor_4.var_angdisp
- 5 motor_5.var_angdisp
- 6 motor_6.var_angdisp

By this MATLAB initializes Adams input/output variables in MATLAB environment.

```
>>adams_sys
```

This command used to explore the model of Adams in MATLAB/Simulink with block representation. As shown in Fig. 6. The input/output signals are shown in “adams_sub” block, as shown in fig. 7.

C. Results in Adams/postprocessor

The Adams/postprocessor provides the results of the simulation process in graphical and tabular form. It shows the behaviour of model created in Adams/view with respect to time and the properties provided to the dynamic model. The angular position and angular velocity with respect to time can easily observed of the manipulators joints at different system states. The control system designed in MATLAB/Simulink drives the motions with respect to torque required for each joint to acquire given trajectory. Cycle time and link position accuracy for different conditions such as with and without load on the manipulator has been observed.

Following figures shows that the torque calculation on the basis of defined mass with respect to geometry and material. Fig. 3 shows the calculated torque for 6 joints using material “glass_fiber_plastic” and comparatively Fig. 4 shows the calculated torque for “steel” material. The comparison between two figures shows that the higher density material required large torque with respect to simulation time, to drive manipulator links. Table III shows the values of compared torque between two results with respect to time and geometrical points in simulation.

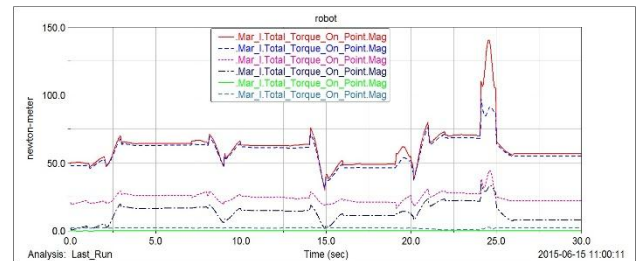


Fig. 3 Calculated torque using material “glass_fiber_plastic”

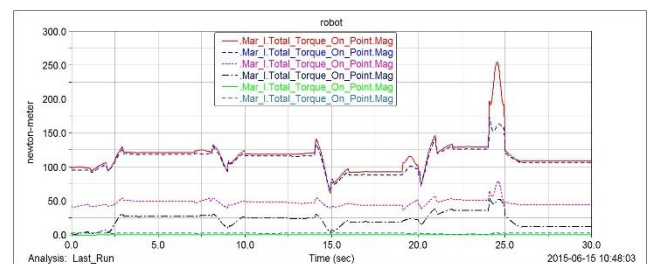


Fig.4 Calculated torque using material “steel”

TABLE III
COMPARISON OF CALCULATED TORQUE BY USING MATERIALS “GLASS_FIBER_PLASTIC” & “STEEL” OF MOTOR 1

Points	Time [sec]	Torque [newton-meter]	
		glass_fiber_plastic	steel
1	2.94	70.29	129.99
2	8.16	71.29	133.18
3	14.1	75.91	141.97

4	14.94	30.14	61.14
5	20.16	37.44	72.33
6	24.54	140.80	255.79

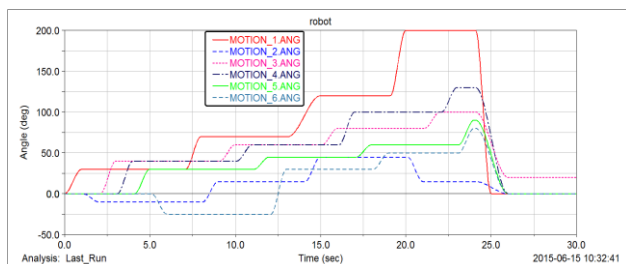


Fig. 5 Estimated joint angles along with rotational axes

Fig 4. Shows the estimated rotations or displacement of each joint with respect to simulation time.

IV. CONCLUSIONS

This technique made the simulation results more accurate and increases the design reliability. The co-simulation method can provide integrity, systematic, high-efficient means for analyzing and evaluating Manipulator system. Traditional design technique included the mechanical and control system has been separately designed which is overcome by co-simulation technique.

In this we analyzed, the torque requirement is increased with higher stiffer material with respect to time. Also the angular displacement is calculated with co-simulation technique. Debugging of virtual prototype model instead of physical mechanical model is more cost and time effective which improves efficiency of electromechanical system.

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