# Control Strategy of Hardware-in-the-Loop Simulator EPOS 2.0 for Autonomous Docking Verification

**Melak Zebenay**[1,*], **Roberto Lampariello**[2,], **Toralf Boge**[1,], and **Rainer Krenn**[2,]

[1] GSOC,Germany Aerospace Center (DLR)
[2] Robotics and Mechatronics, Germany Aerospace Center (DLR)

This paper briefly describes the hybrid simulator system called European Proximity Operation Simulator (EPOS 2.0) and the development of the hardware-in-the-loop (HIL) docking simulation concept. A critical requirement for the docking simulation of this HIL simulator is that the 6-DOF robots in the loop have to exactly mimic the dynamic response of the two satellites during a contact operation. The main challenges to meet this requirement are in the stiffness of the robots, which is unlike that of the satellites, as well as the time delay in the HIL simulator. The paper mainly presents the impedance parameter identification concept for matching the impedance between the satellites impact model and the EPOS robots. In addition it presents the contact dynamics model used, and the control strategies to meet the requirements of the docking simulator. Finally it presents the preliminary results and future work.

## 1 Introduction

In the concept of the EPOS 2.0 system [1] the dynamics of the two docking satellites,including the micro-gravity condition, is computed via a mathematical model. On the other hand, dynamic motions and the contacts are simulated by the real EPOS 2.0 hardware. Therefore, the HIL simulation concept is a combination of both math-model based software simulation and hardware based physical impacts.
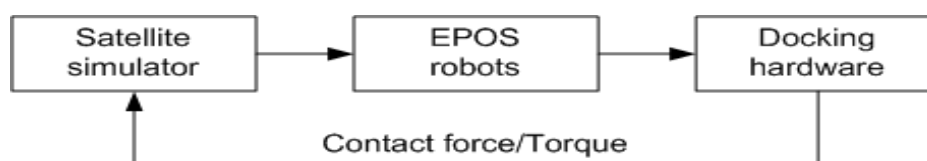


**Fig. 1** Three primary parts of the HIL contact-dynamics simulator EPOS 2.0

The concept of such a general robotics-based, contact-dynamics test facility is illustrated by the diagram shown in Fig. 1. It consists of three basic parts or subsystems:

- A real-time computer simulator used to compute the dynamic response of the two satellites during an impact.

- Two 6-DOF robots used to physically simulate the computer-generated 3D motion of the two satellites.

- A hardware mockup and probe of the docking mechanism of the satellites, which will make physical contact operations and provide a feedback to the satellite simulator, via force measurements.

## 2 One-DOF docking model

One of the challenges of the docking simulation is to reproduce the impedance properties for a specific satellites docking case with the ground facility. In this paper a new method is proposed in order to determine the required end-effector or Cartesian impedance of the ground facility robots , based on the mathematical model of the satellite impact dynamics.

$$\Delta \ddot{x} = -(\frac{M_1 + M_2}{M_1 M_2})(b_{cs}\Delta\dot{x} + k_{cs}\Delta x) \tag{1}$$

$$m_1\ddot{x_1} = -k1(x_1 - \int V_{cm}dt) - b_1(\dot{x_1} - V_{cm}) + k_c(x_2 - x_1) \tag{2}$$

$$m_2\ddot{x_2} = -k2(\int V_{cm}dt - x_2) - b_2(\dot{x_2} - V_{cm}) - k_c(x_2 - x_1) \tag{3}$$

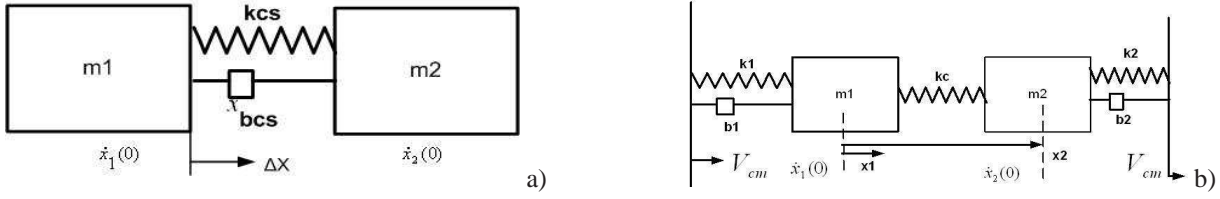* Corresponding author: email melak.zebenay@dlr.de, phone +49 815 328 1237, fax +49 815 328 1450

**Fig. 2 a** Ideal One-DOF satellite contact model and **b** equivalent impedance model of EPOS 2.0 robots.

where $V_{cm}$ is the center-of-mass velocity of the system at the start of the simulation. The dynamic equation (1) represent the ideal case of the two satellites in space, shown in Fig.2a , and the equivalent system on ground, shown in Fig. 2b, and modeled by equation (2) and (3). It is assumed that the satellites model is given, which includes mass, stiffness and damping for the spring-dashpot [3] contact dynamics model. The impedance parameters are then identified to reproduce the same properties of the two impacting satellites and will be implemented on the EPOS 2.0 robots as first suggested in [2].

## 3 Impedance Model Parameter Identification

An impedance behaviour which is equivalent to that of the ideal satellites,results in the same dynamic response, such as the same contact force, final velocity, final position and contact duration. The identification equations of the unknowns $k_1,b_1,k_2$,and $b_2$ are derived for given satellite masses $m_1$ and $m_2$, given contact parameters $k_{cs}$ and $b_{cs}$ and also given stiffness $k_c$ of the force sensor. In addition,the impedance model masses are given the same value as the corresponding ideal satellite masses. Hence the unknowns can be determined using the equations below, by equating the states of the ideal satellites to those of the impedance model,at two different times $t_1$ and $t_2$ see equations below. These times are chosen in the range of the contact duration.

$$\begin{bmatrix} k_1 \\ b_1 \end{bmatrix} = \begin{bmatrix} -x_1(t_1) + vt_1 - \dot{x}_1(t_1) + V_{cm} \\ -x_1(t_2) + vt_2 - \dot{x}_1(t_2) + V_{cm} \end{bmatrix} \begin{bmatrix} m_1\ddot{x}_1(t_1) - k_{cs}(x_2(t_1) - x_1(t_1)) \\ m_1\ddot{x}_1(t_2) - k_{cs}(x_2(t_2) - x_1(t_2)) \end{bmatrix}$$

$$\begin{bmatrix} k_2 \\ b_2 \end{bmatrix} = \begin{bmatrix} -x_2(t_1) + vt_1 - \dot{x}_2(t_1) - V_{cm} \\ -x_2(t_2) + vt_2 - \dot{x}_2(t_2) - V_{cm} \end{bmatrix} \begin{bmatrix} m_2\ddot{x}_2(t_1) - k_c(x_2(t_1) - x_2(t_1)) \\ m_2\ddot{x}_2(t_2) - k_c(x_2(t_2) - x_2(t_2)) \end{bmatrix}$$

## 4 Results and Conclusion

The identification method is validated in simulation in an example. Figure 3 shows the expected result such as for the comparison of forces, positions and velocities respectively between the ideal satellite contact model and the impedance contact model.
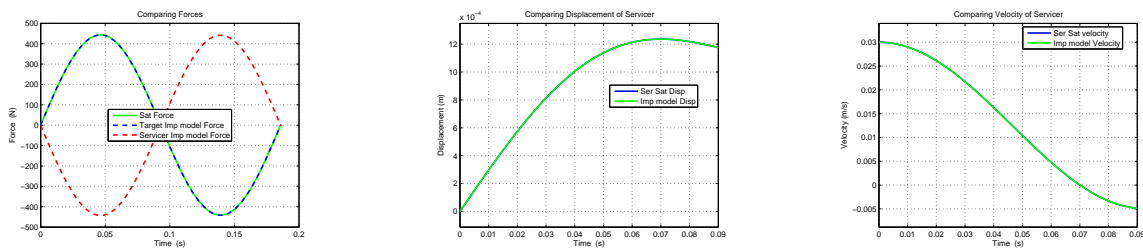


**Fig. 3** Comparisons of contact forces,final positions and velocities after contact between ideal satellite and impedance model contact of the chaser satellite and chaser robot impedance .

This identification method can be used to identify the equivalent impedance parameter for specific satellites and contact scenario for 1-DOF. This method will be extended to 3-DOF contact scenarios and used to implement impedance control in the EPOS 2.0 facility for docking simulation.

## References

[1] T. Boge, Th. Rupp, K. Landzettel, T. Wimmer,Ch. Mietner,J. Bosse, B. Thaler Hardware-In-The-Loop Simulator for Rendezvous- and Dockingmanover, Aachen, Germany. In Proceedings of **DGLR-conference**, (2009).
[2] T. Boge, T. Wimmer, O. Ma, M. Zebenay EPOS-A Robotics-Based Hardware-in-the-Loop Simulator for Simulating Satellite RvD Operations,Sapporo,Japan **i-sarias2010**, (2010).
[3] G. Gilardi, I. Sharf, Literature Survey of contact dynamics modeling, **Volume 37, Issue 10**, 1213-1239 (2002).