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Towards an extensible simulator of real motion platforms

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ABSTRACT

The limitations of a real motion platform will not normally be discovered until it is completely built and tested. Late identification of its limitations imposes the necessity of a redesign of the motion platform. This, in turn, incurs important and significant economic costs for the manufacturer. Note that any change in the original design of the motion platform requires an investment in resources, money and time in order to perform the redesign of the platform. The main contribution of this paper is to address this problem by creating a virtual motion platform (VMP). This virtual motion platform is a computer-based simulation of a real motion platform which produces the same outputs as the real platform when it receives the same inputs. The VMP has been designed to easily replace the real platform in order to avoid damage to the real system, avoid the potential for human injuries and reduce costs, among other advantages. The model is extensible, enabling the simulation of different kinds of real motion platforms in real-time. The VMP has been validated against a real system implementation. This prototype has been validated against two real motion platforms that we have in our labs: a T3R3 (6DoF) and a T1R2 (3DoF) platform. Extensive empirical tests have been performed and the results show that the VPM exhibits a deviation of less than 3% with respect to the real motion platform, which is a really reasonable result considering the complexity of the simulation. We have also demonstrated that our simulation is capable of running faster than real-time being able to perform batch simulations on many different design iterations.

1. Introduction

A motion platform (MP) is a powered, mechanical and self-contained complex motion system. Motion platforms are used for immersive applications and motion simulation in a wide range of scenarios and applications. Most MPs come in the form of parallel structures [14] like, for example, the Stewart platform [23] and many works focus their efforts doing kinematics analysis [25] or dynamics analysis [5] of different manipulators. Examples of the application of motion platforms are real-time flight [24] and driving simulators [20], hazardous chemicals transportation simulators [6], industrial equipment training [12] or medical rehabilitation [7].

Our work at the Institute of Robotics and Information Technology (IRTIC) [11] includes an intensive use of real MPs to build a wide range of simulators. From our empirical experience, we have identified an important limitation in the design process for current simulators with MPs. The main issue is that the limitations of a real MP (when it is used to simulate a

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particular vehicle) cannot be discovered until it is completely built and tested and integrated with the vehicle simulation. This problem affects all organizations, universities and institutes involved in the design and development of simulators with motion platforms and it can lead to important and significant losses in revenue and capability for the motion platform designers and users. It is clear that any change in the original design of a motion platform requires considerable investment in resources, money and time in order to perform the re-design of the platform.

The main contribution of this paper is to address this problem and to significantly reduce the costs and risk associated with the re-design of new MPs. We have solved this problem by creating a virtual motion platform (VMP). A virtual motion platform is a computer-based simulation of a real motion platform. This virtual simulator provides similar outputs as the real one when it receives similar inputs. The virtual motion platform model can be configured to simulate various kinds of real motion platforms and is able to simulate such platforms in real-time. In a previous publication, the authors addressed the problem of executing a VMP faster than real-time being able to perform batch simulations on many different design phases of washout algorithms [4]. Here we focus on describing an interface that allows the actual MP to be replaced by a VMP. We have designed the virtual motion platform in order to allow us to:

- Test the behaviour of real motion platforms against particular simulation environments without the need to physically building them.
- Perform changes in the motion platform design without significantly increasing the cost.
- Perform multiple tests without any risk of damaging or wear the platform hardware.
- Perform multiple tests without endangering human occupants.
- Perform tests faster than real-time.

The rest of the paper is organised as follows: Section 2 reviews previous works on motion platform simulation. Section 3 gives a detailed description of the architecture of the proposed virtual motion platform simulation. Following this, Section 4 provides a complete explanation of the internal engine used for the simulation. In Section 5 we present a detailed description of the prototype implementation. Then, comprehensive validation evidence including comparisons with real motion platforms is given in Section 6. Finally, Section 7 provides conclusions and further work.

2. Related work

There are few examples of virtual motion platforms that simulate the complete system and behaviour of real motion platforms available in the literature or as commercially available software applications.

Although there are several examples where researchers have attempted to come with models based on analytical methods predicting the behaviour of motion platforms, but they have not implemented a complete simulation system. For example, A 3DoF parallel manipulator [22] and a Stewart platform [9] have been simulated using ADAMS ™ [17] software. A simulator that allows interactive kinematic analysis of spherical parallel mechanisms is presented by Gosseling et al. [8]. Another example is the work realised by Li et al. [13] to perform a kinematic and dynamic simulation of a 3DoF spatial parallel manipulator. While all these research works are good contributions, they all have several limitations. (i) They use analytical models to study the behaviour of a real motion platform. These analytical models do not accurately represent the real system. Also, they assume that inputs (target motor angles) can be set directly in the real MP which is not the case, since the real MP is only aware of the torque of the corresponding engine, etc. (ii) They have not been released the VMP as a substitute of a real MP.

In this work, we address the problem from a different perspective. The model we present acts as a virtual motion platform that is able to simulate a real motion platform so that the use of either of them provides really similar results and behaviours. The key issue is that the simulator is able to fully substitute its real counterpart. That means that the virtual motion platform should receive exactly the same inputs and provide the same outputs as the real motion platform.

Hulme et al. [10] provides a solution closer to our approach where a 6DoF motion platform simulator is presented. Specifically, this simulator implements a Moog 2000E platform [16]. Hulme's simulator is not extensible and cannot, therefore, be reconfigured to represent any other motion platform. However, Hulme's simulator uses a detailed CAD model to provide a visual representation of motion platform behaviour which is similar to our approach. Furthermore, Hulme's simulator is not based on forward kinematics [15]. Instead, it uses inverse kinematics, i.e. the simulator computes the desired inputs from a given set of user-define outputs. Our approach is significantly different because our intention is to simulate the behaviour of a real MP based on the input values provided to the system.

3. Architecture of the virtual motion platform

For the sake of simplicity, we will assume that all motion platforms use rotational motors that move connecting rods, pistons and joints in order to fulfil a desired set of movements. The extension to translational motors should be quite straightforward. In fact, a translational motor is a rotational motor with a joint that transforms angular motion into displacement, so it may also be simulated with a rotational motor.

Fig. 1 shows the conceptual diagram of the proposed VMP. The inputs of the VMP are the desired target angles for the motors. These inputs are provided by an external application that generates the desired angles, in our case, a simulator.