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Motion Cueing Algorithms: A Review

Algorithms, Evaluation and Tuning

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ABSTRACT

Robotic motion platforms are commonly used in motion-based vehicle simulation. However, the reproduction of realistic accelerations within a reduced workspace is a major challenge. Thus, high-level control strategies commonly referred to as motion cueing algorithms (MCA) are required to convert the simulated vehicle physical state into actual motion for the motion platform. This paper reviews the most important strategies for the generation of motion cues in simulators, listing the advantages and drawbacks of the different solutions. The motion cueing problem, a general scheme and the four most common approaches – classical washout, adaptive washout, optimal control and model predictive control – are presented. The existing surveys of the state-of-the-art on motion cueing are usually limited to list the MCA or to a particular vehicle application. In this work, a comprehensive vehicle-agnostic review is presented. Moreover, evaluation and tuning of MCA are also considered, classifying the different methods, and providing examples of each class.

KEYWORDS

Algorithm, Evaluation, Motion Cueing, Review, Tuning, Vehicle Simulation, Virtual Reality

INTRODUCTION

Brief History

Modern vehicle simulation history dates back to the era of the World Wars, when massive pilot training started to be a necessity. Link Trainer (Page, 2000) was one of the first electro-mechanic vehicle simulators of all time. It was created in 1927 by simulation pioneer Edwin A. Link. This simulator was used for around 20 years and about 500.000 allied air force pilots were trained using Link Trainer (Allerton, 2009). Unfortunately, Link's device did not correctly simulate the forces experienced in flight. Therefore, most of the simulators designed in the early years of the post Second World War era were ground-fixed. Boeing 377 Stratocruiser, manufactured in 1947 for Pan American Airways (SimUser, 2016), was the first commercial airliner simulator. However, it had several drawbacks as it did not move and had no visual system. Afterward, video-based visual systems (prerecorded or mockup-based) were developed and used until digital computers allowed creating synthetic images in the 1970s. Nevertheless, realistic visual systems were not designed until the 1990s. Due to the difficulty of generating motion cues, motion-based simulators were not seriously considered until late 1950s or early 1960s, when the necessity of solving this problem was finally established. Comet IV simulator (Royal-Aeronautical-Society, 1979) was developed in 1958, allowing only pitch motion – 1 degree of freedom (DoF). Later, the 6-DoF Stewart-Gough design (Stewart, 1965) was proposed and was

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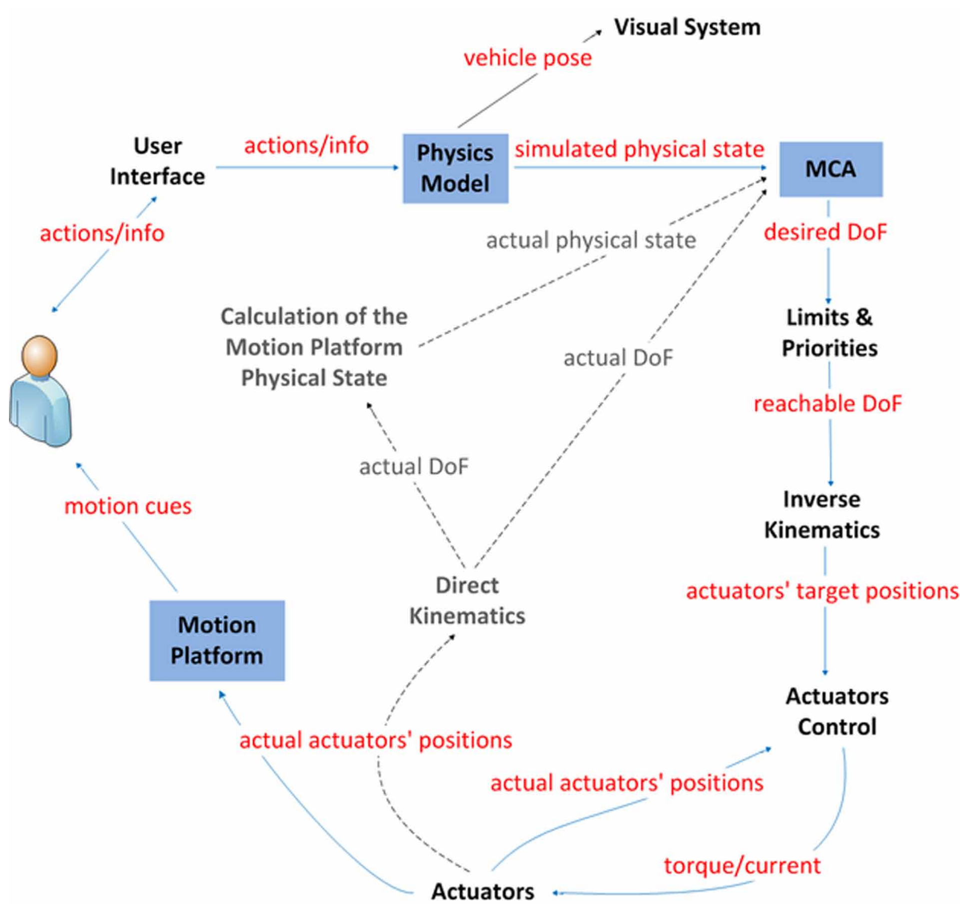
gradually adopted in vehicle simulators. Thus, the problem of finding suitable algorithms for motion-based vehicle simulators was raised. In the following years, costs reduction and the microprocessor era, allowed motion-based vehicle simulation to be available for the automotive industry (Slob, 2008) and other areas. Nowadays, motion-based systems are used for all kinds of vehicles other than aircraft (Nehaoua, Arioui, Espie, & Mohellebi, 2006), (Avizzano, Barbagli, & Bergamasco, 2000), (Casas, Rueda, Riera, & Fernández, 2012) and applications, even in entertainment and gaming.

Problem Description

Several elements are required for the generation of motion cues in vehicle simulators, including: a physics model, a motion platform, and a motion cueing algorithm. The physics model is responsible for the vehicle dynamics calculation through reading the operator (pilot/driver) actions on the vehicle controls. It calculates the simulated physical state of the vehicle by solving the differential equations of motion (Witkin & Baraff, 1997). This physical state is (partially) reproduced on the operator's position in the simulator by moving a motion platform usually placed under the vehicle operator's seat. To perform this operation, high level control strategies commonly referred to as motion cueing algorithms (MCA) are necessary to convert the simulated physical state into actual motion for the motion platform, whenever possible. The process is summarized in Figure 1.

Figure 1. Motion cueing generation in vehicle simulators



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