World Academy of Science, Engineering and Technology
International Journal of Biomedical and Biological Engineering
Vol:16, No:07, 2022

A Hardware-in-the-loop Simulation for the Development of Advanced Control System Design for a Spinal Joint Wear Simulator

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Abstract : Hardware-in-the-loop (HIL) simulation is an advanced technique for developing and testing complex real-time control systems. This paper presents the benefits of HIL simulation and how it can be implemented and used effectively to develop, test, and validate advanced control algorithms used in a spinal joint Wear simulator for the Tribological testing of spinal disc prostheses. spinal wear simulator is technologically the most advanced machine currently employed For the in-vitro testing of newly developed spinal Discimplants. However, the existing control techniques, such as a simple position control Does not allow the simulator to test non-sinusoidal waveforms. Thus, there is a need for better and advanced control methods that can be developed and tested Rigorouslybut safely before deploying it into the real simulator. A benchtop HILsetupis was created for experimentation, controller verification, and validation purposes, allowing different control strategies to be tested rapidly in a safe environment. The HIL simulation aspect in this setup attempts to replicate similar spinal motion and loading conditions. The spinal joint wear simulator containsa four-Barlinkpowered by electromechanical actuators. LabVIEW software is used to design a kinematic model of the spinal wear Simulator to Validatehow each link contributes towards the final motion of the implant under test. As a result, the implant articulates with an angular motion specified in the international standards, ISO-18192-1, that define fixed, simplified, and sinusoid motion and load profiles for wear testing of cervical disc implants. Using a PID controller, a velocity-based position control algorithm was developed to interface with the benchtop setup that performs HIL simulation. In addition to PID, a fuzzy logic controller (FLC) was also developed that acts as a supervisory controller. FLC provides intelligence to the PID controller by By automatically tuning the controller for profiles that vary in amplitude, shape, and frequency. This combination of the fuzzy-PID controller is novel to the wear testing application for spinal simulators and demonstrated superior performance against PIDwhen tested for a spectrum of frequency. Kaushikk Iyer is a Ph.D. Student at the University of Leeds and an employee at Key Engineering Solutions, Leeds, United Kingdom, (e-mail: k.iyer@key-es.co.uk, phone: +44 740 541 5502). Richard M Hall is with the University of Leeds, the United Kingdom as a professor in the Mechanical Engineering Department (e-mail: r.m.hall@leeds.ac.uk). David Keeling is the managing director of Key Engineering Solutions, Leeds, United Kingdom (e-mail: d.g.keeling@key-es.co.uk). Results obtained are successfully validated against the load and motion tolerances specified by the ISO18192-1 standard and fall within limits, that is, ±0.5° at the maxima and minima of the motion and ±2 % of the complete cycle for phasing. The simulation results prove the efficacy of the test setup using HIL simulation to verify and validate the accuracy and robustness of the prospective controller before its deployment into the spinal wear simulator. This method of testing controllers enables a wide range of possibilities to test advanced control algorithms that can potentially test even profiles of patients performing various dailyliving activities.

Keywords : Fuzzy-PID controller, hardware-in-the-loop (HIL), real-time simulation, spinal wear simulator
Conference Title : ICBBR 2022 : International Conference on Biomechatronics and Biomedical Robotics
Conference Location : Zurich, Switzerland
Conference Dates : July 28-29, 2022

Open Science Index, Biomedical and Biological Engineering Vol:16, No:07, 2022 publications.waset.org/abstracts/142898.pdf