VISION BASED CLOSED-LOOP CONTROL SYSTEM FOR SATELLITE RENDEZVOUS WITH HARDWARE-IN-THE-LOOP VALIDATION AND TESTING

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ABSTRACT

The level of orbital space debris has been rising exponentially for the last 5 years, which poses a major risk for manned space missions, operational satellites and the International Space Industry as a whole. The U.S. Space Surveillance Network is responsible for tracking all space debris and uses a series of ground and space-based optical telescopes and radars. This is no trivial task with over 16000 objects of >10cm, consisting of defunct satellites, rocket stages, fragmentation debris and mission-related waste. As well as this, many operational satellites are approaching (15%), or have exceeded (57%), their design lifetimes and, when sufficiently low on fuel, will be decommissioned to a graveyard orbit and left to burn up.

Autonomous satellite rendezvous will enable the capturing of large debris and the docking of near-decommission, or dead, satellites. This will allow satellites to be refuelled, repaired or to become component donors, all of which have the potential to save companies, stakeholders and governments a large expenditure by providing an alternative to building a new satellite. This will also allow the dangerous orbits to be cleared up so they are more accessible. Satellite rendezvous and docking (RvD) is best completed autonomously because manned missions are expensive and potentially dangerous, and using an un-manned vehicle controlled by a ground station would be unwise due to the communications delay.

This project aims to develop a vision based closed-loop control system using the Real-time Attitude & Position Determination (RAPiD) software provided by Roke Manor Research, which is a model-based natural feature image recognition tracker using a series of arbitrarly positioned retroreflectors for initial target lock. The University of Bristol, England, RMR (Relative Motion Robotic) facility, which consists of two 6DoF industrial robots and a 7.7m track, has been used for Hardware-In-the-Loop (HIL) testing to validate the concept and test the created control systems. The system must cope with loss of tracking, a rotating target, the signal output from RAPiD and any delays associated with the system and testing hardware. The control system must act cognitively to ensure it doesn't guide the chase satellite onto a path that causes loss of visibility of the target satellite. The chase satellite must approach the target safely and in a controlled fashion for a successful rendezvous.

MATLAB and Simulink were used to design 1, 3 and 6 DoF control systems, which use a Stateflow Control Logic to govern the operation of the controllers, monitor the progress of the mission and react should there be any unforeseen circumstances. Numerous automated simulations were run using a Satellite Virtual Reality to ensure the control system wasn't

implemented prematurely on the robots. Data from the HIL tests was collected, at 250Hz, using a custom device on the National Instruments PXi box. The PXi was used to host the control system for the satellites and the supervisory system for the robots. An overview of the HIL system can be seen in Figure 1. HIL tests were completed for 1DoF, 3DoF, 6DoF, 3DoF rotating around the Z-axis and 6DoF rotating around the X-axis. The tests started with an initial separation of 7m and aimed for a 1.5m final separation. Signal filtering was necessary to reduce the required thrust and hence fuel usage. The low-pass filter used, while being simple, did remove the majority of noise in the signal and allowed the system to remain stable.

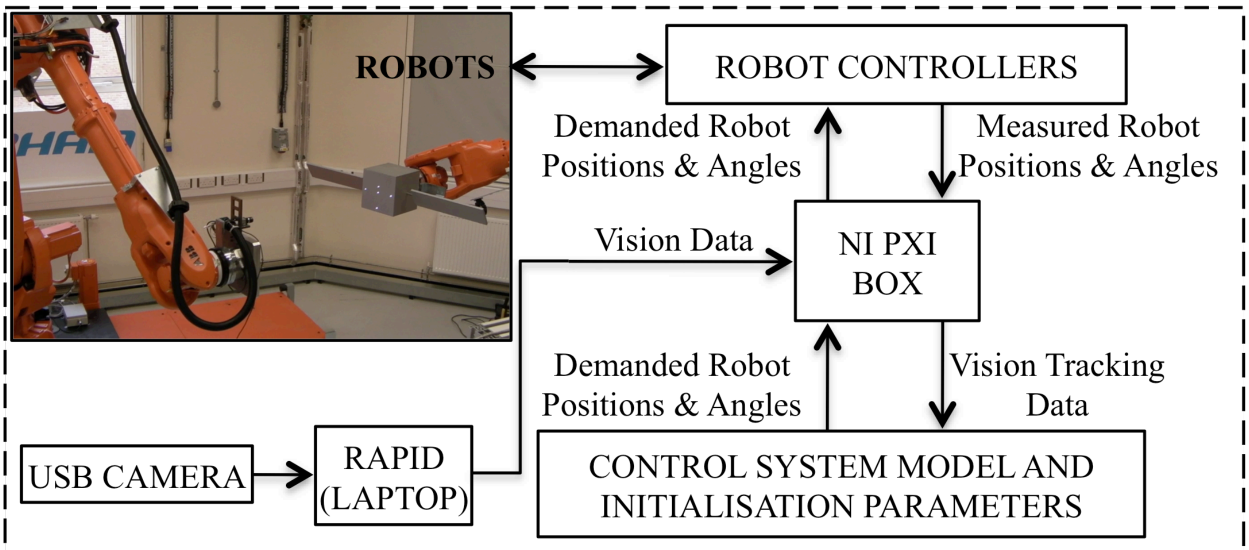

Figure 1: Overview of the system used for hardware-in-the-loop testing.

The 1, 3 and 6 DoF HIL testing stages were successful and the chase satellite reached the defined waypoints successfully in the majority of tests. The 3 and 6 DoF rotating HIL tests were also successful and after reaching the defined waypoints, the chase satellite successfully tracked the rotating target satellite, rotated with it and kept a continuous separation. The mean errors calculated between the known positions and the vision data were <2% range, <3% range, <1% range, $<1^o$, $<3^o$ and $<3^o$ for X, Y, Z, roll, pitch and yaw respectively. There were some tests were the tracker began the test without locking on to the target satellite properly, and occasionally this caused the chase satellite to move outside of the capability of the robots and automatically aborted the test. The target satellite used was very simple and it is thought that with a more complex and realistic target satellite, the tracker would be able to glean more information from the additional features and would be able to achieve a smaller final separation.

To conclude, model-based vision tracking is suitable for use as a rendezvous closed-loop sensor and gives a good level of accuracy for translation and rotation. The UoB RMR facility has been shown to be an ideal test bed for HIL satellite RvD experiments. The control systems put forward are robust enough to cope with the 573ms delay in the HIL system and the 1050ms lag for signal filtering and robot movement, and have enough functionality to work very well for rendezvous. They have been shown to cope with loss of tracking, a rotating target, the data from RAPiD and more importantly have allowed for successful safe rendezvous while ensuring that the target satellite is constantly in view.