

Port-based Telemanipulation Control of Underactuated Flying Vehicles

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Recently, the interest in the field of unmanned aerial vehicles (UAVs) is increasing due to the existence of diverse potential applications in civilian sector. These applications often require high level reasoning, which, in some cases, need specialist in the led. The step forward towards achieving constant interaction between the UAV and the human operator is to provide the pilot with the feel of the local environment of the UAV. The implementation of force feedback, with the aim of maximizing the telepresence of the pilot, meets the challenge of maintaining the stability of the overall telemanipulation loop, which might end up in compromising the telepresence. In addition, challenges, such as pervasive dissipation, lack of measurement and finite stroke of the haptic interface, are also faced.

The telemanipulation algorithm, originally proposed in[1], uses the concept of virtual slave UAV, which has an equivalent dynamics as the real UAV except that it flies in a gravityless and frictionless environment. This algorithm is based on port-based approach, where components of the dynamic system interact with others through power ports.

To achieve passivity of the closed system in face of variable time delays, it was proposed to use the concept of energy tank, which enforces passivity by associating an energy cost to each action of the virtual slave and allowing it only if there is energy available in the tank. This energy exchange between the virtual slave and the energy tank can be easily implemented using the port-Hamiltonian formalism.

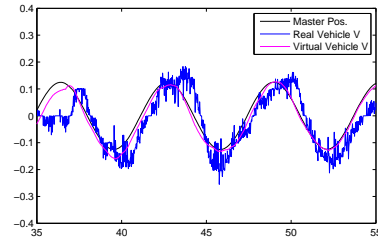
The telemanipulation loop in the slave side is closed by additional visco-elastic coupling between the virtual and the real vehicle. In this coupling, the state of the virtual vehicle is used as reference for the real vehicle and, on the other hand, the negative of the force, which acts on the real vehicle due to the action of its controller, acts on the virtual slave. An additional force, due to the desired reference from the master side and the action of the virtual slave controller, acts on it.

The last point is the energetic coupling between the master and the virtual slave. This is done by mapping the finite position of the haptic device to a bounded velocity of the virtual vehicle. This is chosen as a consequence of the incompatible workspace of the master and virtual slave device. However, in cases where the desired workspace of the virtual slave is limited, proportionally scaled position-to-position mapping is possible. The force feedback is based

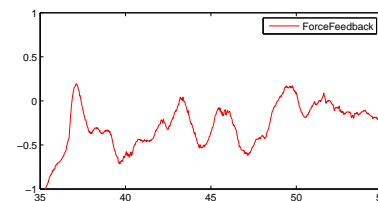
This work has been funded by the European Commission's Seventh Framework programme as part of the project AIRobots under grant no. 248669.

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(a) Master position and virtual and real slave velocity



(b) ForceFeedback

Fig. 1. Experimental result of the teleoperation control algorithm

on virtual forces driven from the state of the system. It can be based on velocity error of the vehicle. By grasping the haptic device at the desired point, a force feedback is felt by the user whose magnitude depends on how large the actual velocity of the vehicle deviates from the desired velocity and the direction of the applied force indicates which direction the actual vehicle velocity is deviating.

The telemanipulation algorithm discussed and validated through simulation has been physically implemented on a real UAVs. In the experiment, the telemanipulation algorithm was implemented on the ducted fan UAV [2]. In the test, only the z-axis was telemanipulated while the low level controller controls the other DOFs. Fig. 1 shows the position of the master device and the velocities of both the actual and the virtual vehicle along the z-axis. It can be observed that the desired velocity of the actual vehicle, derived from the velocity of the virtual vehicle and commanded by the position of the master device, is tracked with a certain lag. At the start of the telemanipulation, the tracking performance is low because of the difference between the initial velocity of the actual vehicle and the virtual vehicle. However, later on, the tracking performance improves. The force feedback renders the actual environment of the UAV, more specifically based on the velocity of the virtual vehicle with respect to the position of the haptic interface.

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