Intercontinental haptic control and advanced supervisory interfaces for groups of multiple UAVs

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I. INTRODUCTION

In this paper we describe applications of TeleKyb [1], an extensive software framework that helps in the development and testing of human-robot interaction experiments. In addition to providing useful libraries and tools, TeleKyb implements a closed-loop control abstraction (called *Core*) which separates distinct steps of the control mechanism into user-loadable modules. Various *State Estimators* generate the standardized robotic state message. A finite-state machine (FSM) enables the transition between user-defined *Behaviors* which can act as automatic planners and generate the desired trajectory to follow. *Trajectory Modules* provide an intrinsic safety by analyzing state and trajectory information and dynamically react to certain predefined conditions (e.g., battery status, obstacle avoidance, trajectory feasibility, actuator saturation). Lastly, the *Core* dynamically loads the *Trajectory Tracker* that either converts state and trajectory information into the appropriate low-level commands for the specific mobile robot, or directly drives the individual motor speeds. A separate library, *TeleKyb Interface*, enables run-time interactions with the *Core* in order to load and configure distinct modules or control *Behavior* changes (FSM transitions).

We utilized a touch-based device to interface several *Core* instances during UAV group experiments. This device visualizes the UAV pose in a rendered 3D scene and allows for the online inspection of defined parameters and of the overall state (e.g., control gains, battery voltage), as well as of the current active Behavior.

Our group has successfully applied TeleKyb in a variety of experiments, see, e.g., [2]. Here, we describe the bilateral teleoperation framework where a group of UAVs are controlled over an unreliable network with typical intercontinental time delays and packet losses [3]. This setting is meant to represent a realistic and challenging situation for the stability of the bilateral closed-loop system. In order to increase human telepresence, the system provides the operator with both a video stream coming from the onboard cameras mounted on the UAVs, and with a suitable haptic cue, generated by a force-feedback device, informative of the UAV tracking performance and presence of impediments on the remote site. The setup is composed of a semi-autonomous group of multiple quadrotor UAVs, a 3-DOF haptic interface, a touch-based device for the online supervision of each UAV and a network connection based on a VPN tunnel between Germany and South Korea (Fig. 1).

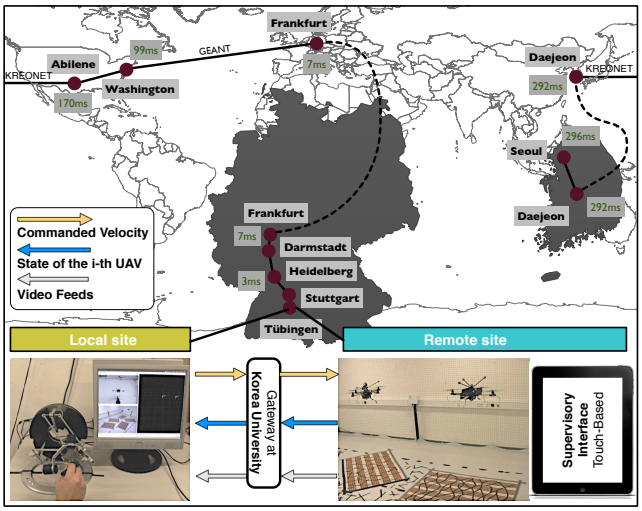

Fig. 1: Experimental setup for the intercontinental bilateral teleoperation of 2 quadrotor UAVs. Representation of the default packet routing and average delays between the MPI for Biological Cybernetics, Tübingen, and Korea University, Seoul. **Local Site**: The human operator is provided with a haptic interface in order to control the overall motion of the UAVs and 3 video streams: an onboard view, a global view, and a 3D representation of the UAV states. **Remote Site**: 2 quadrotor UAV in fixed topology formation. A touch-based device supervises the state of the experimental flow.

We successfully demonstrated the haptic control in an round-trip (average delay: 350 ms) and direct intercontinental setup ($\sim$ 175 ms) with either a constant or dynamic damping injection in order to guarantee stability of the system.

A video containing a detailed description of the intercontinental bilateral teleoperation experiment is available at `http://antoniofranchi.com/robotics/?q=node/119`

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