Designing a Mobile Manipulator using an Unmanned Aerial Vehicle

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Abstract

This paper describes the initial design of a mobile manipulator using an unmanned aerial vehicle and a highly dexterous arm and end effector. Current indoor aerial vehicles do not have the required lift to support high performance robotic arms. To simulate the unmanned aerial vehicle, we utilize a six degree-of-freedom gantry crane that provides the complete range of motion of a rotorcraft. A multiple degree-of-freedom manipulator attaches to the gantry system to perform grasping tasks in a cluttered, indoor environment. A motion capture system and visual servoing provide manipulator position feedback to the control hardware. To test and simulate our system, we leverage the OpenRAVE virtual environment and software architecture. Our design demonstrates a prototype for aerial manipulation that has many advantageous over ground based systems. The need exists for unmanned aerial vehicles to not only perform surveillance in indoor environments but also to manipulate objects in a similar manner ground vehicles do.

Unmanned Aerial Vehicles (UAV) continue to play an increasing role in military operations and have numerous civilian applications. Used primarily for surveillance and target acquisition, these vehicles can move quickly and avoid obstacles that would otherwise slow or impede the movement of a ground vehicle. Micro UAVs (MAV), particularly rotary-wing and lighter-than-air craft, can navigate indoors and move through narrow passages where larger, fixed-winged aircraft cannot. There have been great advances in indoor navigation, localization, and obstacle detection and avoidance where GPS is unavailable for these small UAVs. Electric co-axial helicopters, quadrotors, and hybrid duct-fan vehicles represent some of the better alternatives for reduced size while allowing stable flight and strong hover control.

In addition to autonomous indoor navigation, small air vehicles need to be able to manipulate or move objects they encounter. These objects could be debris that is blocking the view of a target of interest or an obstacle that is preventing the small UAV from continuing movement in a particular direction. UAVs currently lack the manipulator arm that most ground vehicles incorporate into the chassis. Ground robots typically either focus on mobility and sacrifice manipulation or vice-versa. In our design, we focus on the manipulator and simulate most of the UAV functionality using a stable mobility platform. High performance arms and end effectors usually weigh more than 20 kg which cannot be supported by most micro UAVs. We anticipate that payload capabilities will increase and arm weights will decrease; therefore, we believe that existing highly dexterous off-the-shelf manipulators will soon be supported by small-scale, indoor UAVs. We envision a near-term prototype using a hybrid duct-fan blimp and one to two highly dexterous arms.

A six-degree-of-freedom gantry system provides mobility and simulates the UAV in flight. The gantry used is known as the Systems Integrated Sensor Test Rig (SISTR). This hardware-in-the-loop test and evaluation environment is housed at the Drexel Autonomous Systems Lab (DASL). SISTR's motions are controlled through model-reference adaptive control. The net effect is a test rig that can rapidly and safely test and evaluate the UAV system. The manipulator prototype will be mounted on the underbelly of the gantry in a similar manner it would attach to an actual UAV. SISTR will then reproduce the velocities and motion of the unmanned aerial vehicle. This configuration allows testing of the manipulator system under typical flight conditions. A simulated Barrett Whole Arm Manipulator (WAM) will provide the manipulation capability. There are seven degrees-of-freedom (three in the shoulder, one in the elbow, and three in the wrist). The three-fingered Barrett hand is the current end effector. The WAM weighs a total of 27 kg and can reach out to 1 meter fully extended. All electronics for the control of the arm are built into the arm. To model the WAM, we utilize OpenRAVE, the Open-Source Cross-Platform Robotics Virtual Environment, for our simulation environment.

In this paper, we describe an early phase towards using an unmanned aerial vehicle to perform mobile manipulation. First, we look at related work in this research area. Next, we discuss our approach and overall design of the system. Since the design uses a highly dexterous arm, we need to use a gantry system in order to support this payload and model the movement of the UAV. We detail the hardware system, software infrastructure, sensor suite, and simulation environment. We also propose a hybrid lighter-than-air duct-fan vehicle as a platform that can support a multi-degree-of-freedom manipulator arm. Test and simulation results are presented. Finally, we chart our future work and conclusions.

The paper is relevant to the conference, as our goals focus on applied research towards mobile manipulation. We propose a practical design for implementing manipulation techniques using a UAV platform.

Major Christopher Korpela is an Assistant Professor in the Department of Electrical Engineering and Computer Science at the United States Military Academy, West Point. A U.S. Army Engineer and Network Engineering officer, he received his M.S. in Electrical Engineering from the University of Colorado in 2006 and is a senior member of the Institute of Electrical and Electronic Engineers.

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