Proposal Overview

Distributed and Integrated Air-Ground Robotic Co-Manipulation
(DIAGRoM): A Resilient Hybrid Assistive Solution

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Overview
Collaborative “hybrid” multi-robot systems made by an intelligent functional fusion of aerial and ground robots interacting with humans are unmet needs for transporting, and manipulating objects
during physically complex. Such systems can assist human in conduction of tasks especially relevant
in future industrial applications such as transportation, construction, and warehouse management,
where efficiency at scale and safety are to be secured concurrently.
In this project, we address the fundamental problem of designing and controlling of a hybrid human-centered robotic system in a distributed fashion composing of a heterogeneous team of aerial and ground robots that physically interact and collaborate with each other and with a human operator during a complex manipulation task. Physical collaboration between a human and a group of heterogeneous aerial and ground robots in an active, and fluent manner has not yet
been realized. We will study the algorithmic foundations and methodological frameworks to exploit
the heterogeneous nature of multi-robots involved in a complex aerial-ground manipulation to go beyond the capabilities of conventional single robots or classic human-robot interaction systems.
Keywords: Human-Robot Interaction, Control, Manipulation, Multi-Robot

Facilities, Equipment, and Other Resources

Experimental validation will be accomplished using aerial and ground robot equipped with manipulators. The test environment will be housed at the new indoor space in the Aerial Robotics
and Perception Lab (ARPL) at New York University and the MERRIT lab lead by PI Loianno and Atashzar respectively. Both laboratories are located at NYU-Tandon School of Engineering.
Laboratories and Equipments: The ARPL (see Figure 1) includes an indoor lab space (800 sqft) with a large desk area and a flying arena, which is equipped with 10 Vicon V8 cameras to validate the precision and accuracy of the localization approaches as well as control and planning
approaches. It is large enough to fly concurrently 7-10 vehicles. The main mission of the ARPL is to create autonomous robots that can navigate by themselves and interact with humans helping
them to solve complex tasks. For this project, we will also leverage our recent work on autonomous
navigation and cooperative aerial transportation, where we employed aerial platforms using on board sensors or motion capture system. We will employ similar COTS components where each

vehicle is also equipped with on board camera sensors. The ARPL at NYU has a fleet of 18 small scale vehicles endowed with different vision-based sensor suites as depicted in Fig. 2 such as
Qualcomm® SnapdragonTM FlightTM Pro including some recent designed in-house racing robots.
The lab has also multiple NVIDIA TX2 bundles for additional on board drone GPU computation.
The ARPL lab is also equipped with virtual reality headsets (2 Microsfot Hololens) and eye-tracking

Figure 1: An overview of the Agile Robotics and Perception Lab desk (left) and experimental (right) spaces.

Figure 2: The fleet of Micro Aerial Vehicles at NYU.

glasses (Tobii Pro) and has already shown relevant experience in this area in a recent work enabling
spatial tasking of an autonomous quadrotor with human gaze1
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The lab is equipped as well with a Kinova Gen3 robot arm as shown in Fig. 3 and with the latest GPU computation capabilities for deep learning purposes with a Lambda Labs computer with 4 GPUs RTX 2080 Ti 11G accessible as well as a remote server. Finally, the lab has multiple
i7 desktop and laptop stations to provide students and researchers the latest computing capabilities
to develop and debug algorithms. The lab is supported by the equipment startup package provided
by NYU for designing a unique research venue focused on autonomous robotics and human-machine
interface.

Figure 3: The Kinova Gen 3 arm on a Clearpath jackal ground robot.

Figure 4: The deep leanirng GPU available at ARPL.

The MERIIT lab has an experimental area (800 sqft) and is focused on the design, implementa-tion, and evaluation of neurorehabilitation technologies. The lab is designed to be a reconfigurable

space with two strong haptics robotic systems, two high-definition 6DOF haptic devices for dexter-
ous and delicate manipulation, four classical 6DOF haptic devices. Also, the lab hosts a wireless

EEG system, a 192-channel EMG system, a 16 channel wireless Delsys system (EMG/IMU) for
1L. Yuan, C. Reardon, G. Warnell, and G. Loianno, “Human gaze-driven spatial tasking of an autonomous MAV,

sensing human neural and motor responses during functional tasks. The lab also has an advanced
3D head-mounted display for immersive virtual reality and a remote virtual environment using

which individuals can perform a wide range of complex simulated telerobotic tasks in virtual real-
ity while their motions, forces, and biological signals can be objectively collected and processed on

the fly. The lab is supported by the startup equipment budget available to Atashzar, which allows

for acquiring high-fidelity robotic systems, biosignal acquisition, various sensory systems, process-
ing modules, activity tracker systems, neurorobotic systems, and local high-performance computing

at MERIIT lab. The lab is supported by the equipment startup package provided by NYU for de-
signing a unique research venue focused on medical robotics and human-machine interface. In this

regard, the following equipment is available.

- Two 6DOF high-definition haptics-enabled robotic devices (which can be used for highly complexity functional delicate motions) from Quanser Inc. Available.
- Two Upperlimb High-force Haptics System for intense upper-limb exercises, made by Quanser Inc. Available.
- One Assistive Full Kinova Arm. Available.
- Four Leap Motion devices to capture the hand movements of the user in 3D. Available.
- Two advanced 3D printers that can print soft materials. Available.

- A pump station with ten independent small pneumatic pumps for soft robotic research. de-
veloped at MERIIT.

- High-density EEG/EMG system from OT Bioelettronica SRL. Available. The system has
  – 192-channel high-density EMG for decomposing the signals and getting access to motor unit action potentials
  – 64-channel wireless EEG system for measuring brain activity
  – 64-channel wireless EMG system for high-fidelity corticomuscular connectivity decoding
  – Full 16-channel Delsys Motion Tracker and EMG System from Delsys Inc. Available. It is one of the most advanced EMG and motion trackers. The system has the following sensors.
  – 16 channel wireless surface Electromyography
  – 16 channel 3-axis wireless IMU for kinematic measurement
  – One wireless EKG sensor
  – Four wireless Goinameter for upper limb joint measurements

– Four Mini-EMG sensors for small muscles
– Four 4-channel high-density wireless EMG modules
• A virtual reality HTC Vive EYE Pro VR headset, two wireless controllers, and two base stations programmable in Unity. This system has an eye-tracking feature. Available.
• Several advanced MEM vibration sensors, including IMUs, Accelerometers, Acoustic sensors, Piezoelectric sensors, in addition to microcomputers.

Figure 5: An overview of the upcoming shared space floor plan with the flying area (left) depicted in dark blue and
an overview of the upcoming outdoor flying space (right).

All personnel and students whose project will be related to this project will also have access to other research and development facilities at two departments (both ECE and MAE) and two centers (NYU WIRELESS and NYU CUSP). This is because both PIs have a cross-appointment in the two departments and two centers, allowing for having wider access of the students to existing facilities. An indoor 4000 square-foot robotics space, as shown in Fig. 5 (left), shared between four faculty members (2 PIs of this proposal) is under construction and will be ready early 2022 and can be leveraged to advance this project. Space will incorporate a large flying arena of 1200 square feet equipped with a motion capture system dedicated to ARPL activities as well as an area for physical human-robot interaction and medical robotics area of 1000 square feet for the MERIIT activities. The flying space will feature 22 vicon motion capture system cameras for validation purposes. This will represent a unique cross–disciplinary experimental space in New York state as well as in the overall USA. The space will incorporate, in addition to a large flying arena, 3 different robot testing areas, and additional desk space for students. Starting by the end of 2021, as shown in Fig. 5 (right), a new outdoor aerial and ground experimental space will be set up to extend robotics activities including the ones related to this proposal. This has a similar size to a basketball court with 60 m height. This is a unique facility located on the roof of the same building with multiple buildings surrounding it. This location will certainly be a valuable and unique testbed to perform experiments replicating unique urban navigation scenarios.

Adidtional Major Facilities: The NYU Tandon school of engineering is also equipped with a maker-space2

, a 10, 000 square feet design and fabrication facility shown in Figure 6, with multiple Mojos, Elites, and Fortus 3D printers, Universal and Epilog laser cut, multiple CNC machines, and soldering stations. With a unique blend of conventional design and fabrication machinery, along with prototyping equipment, this facility allows development of quick prototypes or final end products. The machines can then be leveraged to fabricate 3D parts for our robots and to repair them. A complete list of available machines can be found at http://makerspace.engineering.nyu.edu/machines/. Multiple software tools are available for prototyping such as Fusion 360,

Netfabb, AutoCAD, SolidWorks, Rhino 6, Mimics, Adobe Illustrator, Adobe Photoshop, Arduino, ArcGIS, OrCAD, ANSYS.
The Advanced Manufacturing and Electronics CTP support researchers with custom design and manufacturing of parts and equipment by utilizing using both additive (3D printing) and reductive (CNC) techniques. The five-axis computed tomography (CT) system can scan objects of up to 24” for accurate reproduction. All facilities on NYU’s global campuses are also available to the
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http://makerspace.engineering.nyu.edu/

Figure 6: An overview of the NYU Tandon maker space.

investigators and collaborators in this project. NYU has made significant investments in creating the Core Technology Platforms, which provide equipment and services for research in various fields,
including biology, chemistry, engineering, and linguistics. For example, the following core facilities
and equipment will also be available for all students.
NYU’s High-Performance Computing3

(HPC) have several supercomputer clusters with hun-
dreds of GPUs with 2 Terabytes per user space with speeds that exceed 4 petaflops with quadrillion

calculations per second. These clusters support a variety of job types and sizes, including jobs re-
quiring multiple CPU cores, multiple GPU cards, terabytes of memory, to single core serial jobs.

Graphics processing units and visualization nodes included in the system are used for specialized
functions. Students in this project will be given free admission to NYU-HPC facilities, which are

specifically designed for researchers and scholars whose work is computer-intensive. NYU-HPC ser-
vices include shared cycles on several high-performance clusters equipped with a variety of research

software packages.
Finally, we will also leverage the equipment and facilities available at New York University’s (NYU) Center for Urban Science and Progress (CUSP) that is a multi-sector, interdisciplinary research collaboration of partners from academia, industry, and the City of New York (the City) with the mission to make cities more productive, livable, equitable, and resilient part of the NYU

Tandon School of Engineering. Specifically, CUSP’s Research Computing Facility (RCF) is a sig-
nificant resource for research hosted on CUSP internal servers and will be leveraged to support this

project. The RCF is associated with a data center server room in CUSP's Brooklyn office configured to support research. It features dedicated large servers for intense computing (64 Intel cores,

1 TB RAM), secure file transfer dedicated servers, enterprise level Windows Remote Desktops, and
other infrastructure; a HADOOP Cloudera Cluster with 20 nodes, totaling 1280 CPU cores, 5.1 TB

memory, and 100TB HDFS (Hadoop Distributed File System) storage; an IBM SAN storage controller with 4 expansions with capacity of 505.086 TB (1PB raw storage); an ESXI VMware testing

servers for multiple customized Virtual Machines; a Citrix XenServer for production VMs; IBM Enterprise level backup system and Tape library with high capacity up to 500TB; and ultra-fast network cables and switches 10-40GB.

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https://www.nyu.edu/life/information-technology/research-and-data-support/high-performance-computing/high-performance-computing-clusters.html