Manipulation of soft bodies with multiple drones

**Context**

The aerial manipulation is a robotics research field that proposes the integration of one or more robotic arms in multirotors, for allowing the manipulator(s) to perform certain operations in workspaces at high altitude or in areas out of the reach of standard fixed-based or mobile (but grounded) manipulator arms. Possible applications span many areas such as disaster response, maintenance of infrastructure, inspection of remote sites. However, aerial manipulation is a real challenge when considering that the gripping function is still one of the most complex to achieve even by classical robotic systems (e.g., fixed-base manipulators).

The most basic approach to obtain an aerial robot with the ability to grasp an object is simply to attach a gripper [5][6] under the aerial vehicle. This is most often not satisfactory because the handling capabilities remain limited due to the under-actuation of drones. Even the body of the multirotor may become the manipulator itself [9]. A second approach is to add a multi-dof manipulator arm [1][2][3][4] on the vehicle, a parallel manipulator [7], or a surface or a net carried by multiple quadrotors [8]. This second approach offers better handling capabilities but accentuates the problem of on-board loading (being the typical payload of aerial robots very limited). These two approaches could be valuable for small size objects, but are totally inadequate for objects of larger size. In this case, a possible third approach consists in using several drones connected to an object via cables. This would indeed allow grasping large objects, but managing the complex dynamics (and possible entanglements) of the cables/drones/object is highly challenging, and the action of an operator would still be necessary for hanging the cables to the object.

In order to grasp an object of large dimension, instead of using a big-size drone equipped with a gripper, which is a very costly solution, an alternative is to create a big-size gripper attached to several drones (see figure 1.a). The mechanism proposed in [11] is a first step towards the aerial grasping of large objects. However, it is designed for objects of spherical or cylindrical shapes and would hardly adapt to more complex objects.

A new class of grippers is currently being developed for industrial robots: soft grippers [10], i.e. underactuated grippers composed of flexible bodies able to sustain very large deformations (also called soft bodies), which have the ability to adapt themselves to any shape of the objects, thus allowing for the possibility of designing universal grippers. This idea is of interest in the context of the aerial grasping: (a) soft bodies are very lightweight, thus having less impact on the drone autonomy than a standard gripper, (b) their low weight allows the design of grippers of bigger size, thus being able to grasp bigger size objects, and (c) they can adapt to any kind of
objects and shapes, thus improving the robustness of the grasp in case inaccurate positioning of the drone occur (see figure 1.b).

However, soft grippers come with their own challenges. Being able to create and control such kind of gripper is indeed a long-term goal because of the many issues one is faced with, among which: the study of the grasping stability, the control and perception of the internal deformation of the gripper, the control of the system (drones+gripper+object), and so on.

Therefore, we propose as part of this thesis to work on the first elementary bricks, which corresponds to **the manipulation of a single soft body (a slender beam) by the combined action of two drones and force sensors at the gripper locations** (Figure 2). The scientific developments associated with this goal are the first elementary developments necessary in order to attain this promising grasping strategy.

![Figure 2. Manipulation of soft bodies (red body) with two drones in three steps: (1) Approaching phase, (2) Grasping phase and (3) Manipulating phase.](image)

Robotic manipulation of soft bodies is a complex and challenging problem. There are many issues that need to be addressed in soft bodies manipulation with drones: **modeling** (of the soft body but also of the full system (drones+soft body), which is necessary for the control of any aerial systems), **estimation** of the (drones+soft body) states (configurations, velocities), and **trajectory planning** and **controller design**. Another problem is the grasping of the object. However, in the scope of these theses, we will not work on this task and the bodies to be manipulated will be considered already grasped by the drones (they will be rigidly attached to them beforehand).

In this context, we offer **two PhD subjects** detailed as follows:

1. **PhD Topic 1 – Modeling, Estimation and Control of Soft Bodies**
   - Develop a **dynamic model** of the system (soft bodies attached to the drones) able to run in real time for being used in a control loop. Finding a good compromise for modelling the system (accuracy vs. computational time) will be crucial
   - **Observation** of the internal state: estimation of the soft bodies deformation based on the developed model and external sensors (e.g., vision)
   - **Control** of the soft bodies deformation using robust, adaptive or predictive strategies

2. **PhD Topic 2 – Reactive Trajectory Planning, Visual-based Estimation and Control of Multiple Drones**
   - **Trajectory planning** for generating a feasible trajectory for the whole system drones/soft body in order to displace the body to a desired location and attain a desired deformation state
• **Vision-based reactive trajectory tracking** for the system drones/soft body using as much as possible onboard vision. The approach will be based on the visual servoing paradigm and the online determination of a “deformation interaction matrix” that will link the variation of the object deformation to the velocity of the drone effectors.

• **Low-level control and relative localization** of the two drones during flight, using the possibility of exchanging information via communication or by physically exchanging forces through the manipulated body.

**Experimental validation**

Both theses will contribute to the implementation and experimental validation of the approach. The intended benchmark will consist of two drones manipulating a single soft rod with the aim of imposing a desired shape to the rod and to displace it to a desired location. The final experiment will represent a first concrete step towards the full grasping of an object with the system UAVs+soft body. For this, we are going to consider the following scenario as a starting point: surrounding a vertical pole with the soft body as in the following illustration.

![Figure 3. Final experimental scenario.](image)

**Staff**

- **PhD Topic 1**: the first PhD student will be co-supervised by S. Briot (ARMEN, CNRS researcher, expert in mechanical modeling for robotics), P. Robuffo Giordano (RAINBOW, CNRS director of research, expert in state estimation for robotics), and A. Chriette (ARMEN, Ass. Prof. at the Ecole Centrale Nantes, expert in UAV control and modeling).

- **PhD Topic 2**: the second PhD student will be co-supervised by A. Krupa (RAINBOW, INRIA researcher, expert in modeling and visual-based tracking of soft bodies), I. Fantoni (ARMEN, CNRS director of research, expert in the control of underactuated systems) and F. Chaumette (RAINBOW, INRIA director of research, expert in visual servoing).

**Skills**

- M.Sc. degree in computer science, robotics, engineering, applied mathematics (or related fields)
- Strong experience in C/C++ coding
- Familiarity with Matlab/Simulink is a plus
- Scientific curiosity, large autonomy and ability to work independently

Conditions
The positions are full-time for 3 years and will be paid according to the French salary regulations for PhD students.

Application Form for the PhD Position
Interested candidates are requested to apply via: https://team.inria.fr/rainbow/fr/appl-form-manip-soft-drone/

References