DM-UAV: Dexterous Manipulation Unmanned Aerial Vehicle

Alberto Torres[1], Francisco Candelas[2], Damian Mira[1] and Fernando Torres[2]
[1]Computer Science Research Institute, University of Alicante, Alicante, Spain
[2]Physics, Systems Engineering and Signal Theory Department, University of Alicante, Alicante, Spain

Keywords: Dexterous Robotic Manipulation, Aerial Grasping, UAV.

Abstract: This paper describes a novel aerial manipulation system, a DM-UAV which is composed of a drone with a robotic hand. The main objective is to grasp a target object with the robotic hand. We assume that the object position is known so the drone flies to this position and lands, then the robotic hand can grasp the target object. After of that, the drone can take off in order to transport the object to other location. This system can be very useful for different field applications, f.e. agriculture, to clean the trash on the field, to eliminate contaminating objects, etc.

1 INTRODUCTION

The aerial manipulation traditionally has been focused in drones with a simple gripper in the end of a 2-DOF manipulator. Most of the time this system is used to grasp cylinder objects or to hang the drone. In (Courtney, 2011; Thomas, 2013), an avian-inspired robotic system is presented in order to perch or to grasp a cylinder.

We don't know any experience with a robotic hand in a drone. In contrast with other robotic tools, a robotic hand has the main advantage of providing much more DOF, which enables it to make more complex manipulation tasks, such as catching complex shapes, grasping from different orientations, etc.

For more complex manipulation tasks, manipulators with more DOF's are used linked to a drone (Korpela, 2012; Orsag, 2012).

In some cases, a vision system is used to detect cylindrical structures in order to hang the drone (Thomas, 2016).

The system proposed in this paper is more complex: in the future, we plan to have a vision system in the drone for detecting a target object in order to grasp it with a complex robotic hand. Now, in this paper we assume that the object position is known.

The remainder of the paper is organized as follows. The next section describes the design of the system, and explains each individual part in detail. Section 3 describes the grasp planner proposed. This planner has been tested for the authors in others complex tasks too. Section 4 contains the results and the future works. Finally, the last section is dedicated to the conclusions.

Figure 1: DJI Spreading Wings S1000+ drone.

2 SYSTEM DESIGN

This section describes the robot, including the physical platform and the hardware architecture. The robot is based on a Spreading Wings S1000+ drone, and an Allegro hand.

2.1 The Spreading Wings S1000+ Drone

The Spreading Wings S1000+ (DJI, Shenzhen, China), which is shown in Figure 1, has a total weight without charge of 4.2 kg, but it is able to fly with a total weight of 11 kg. Thus, there are 6.8 kg

Torres A., Candelas F., Mira D. and Torres F.
DM-UAV: Dexterous Manipulation Unmanned Aerial Vehicle.
DOI: 10.5220/0006186701530158
In *Proceedings of the 9th International Conference on Agents and Artificial Intelligence (ICAART 2017)*, pages 153-158
ISBN: 978-989-758-219-6

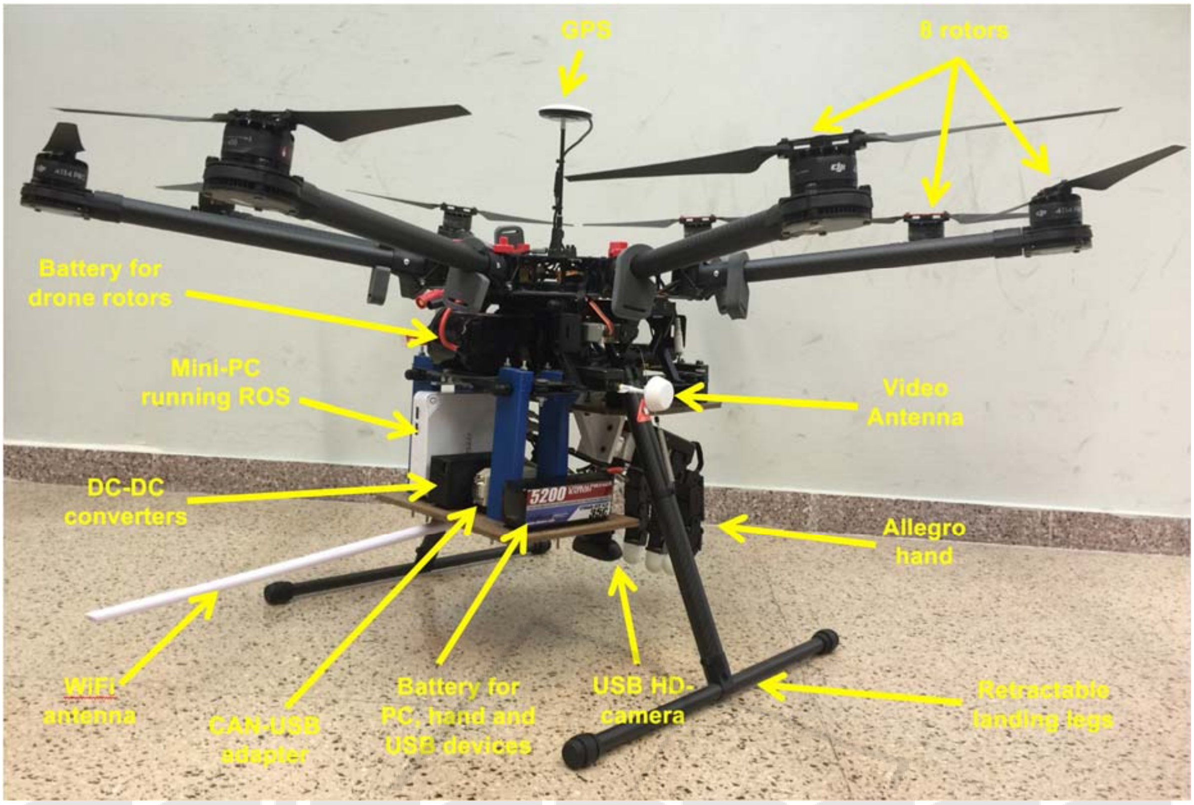

Figure 2: Main additional equipment added to the drone.

free for the Allegro hand, the rest of the necessary equipment, and the target object. Figure 2 details the additional equipment included in the drone in order to command the robotic hand, apart from its own hand.

Among this equipment, a mini-PC (MSI Cubi-007XEU with Intel Pentium 380SU 1,9GHz) works as the hand controller, and, for that, it executes ROS Indigo on Ubuntu 14.04 LTS. As the Allegro hand has a CAN serial interface, a CAN-USB adapter (Peak PCAN-USB) is required to connect the mini-PC to the hand. Also, the tactile sensors of the hand are connected to the mini-PC, in this case directly by USB. Moreover, the mini-PC communicates with a ground station through a wireless link. Currently this radio link is based on a WiFi WLAN, which is enough for a first prototype and testing, although we are working on replacing it by a dedicated long distance radio-link. Thus, the system includes a high power WiFi-USB interface with a high-gain antenna (Approx APPUSB150H3).

The system also has two cameras as follows: a frontal camera used mainly for manual piloting, and an USB HD-camera oriented vertically to the ground. The field of view of the last camera includes also the workspace of the hand. These cameras presently is used only for manual piloting, in the future will be used not only for recognition of structures on the ground, but also for grasping tasks.

In addition to the original GNSS receiver of the drone, we have connected other low-cost high-precision GNSS with compass (Ublox M8N) to the mini-PC by means of a serial-USB converter. This is necessary, because the closed architecture of the drone makes very difficult to access to flight data from its original hardware. Finally, the equipment also includes a dedicated battery and two DC-DC converters to power the hand, the PC and the USB devices.

As commented before, the original hardware of the drone has a closed architecture, and, thus, it is difficult to access to data from the flight controller or to send commands directly to it. Thus, in order to get the automatic flight of the drone, we use currently a ground station which receives real-time information from the drone such as flying and positioning data, and commands the drone by means of a RC (remote controller) according to the received information and previously-planned general paths. More specifically, the ground station is a PC which is communicated with, on the one hand, the computer aboard the drone thought the wireless link described previously, and, on the other hand, the training port available on a 14SG RC from Futaba which enables the PC to manage all the drone controls. The connection with RC is not direct, and it is based on an Arduino board which works as a bridge translating commands from USB to PWM signals required by the training port of the RC. The ground station also provides real-time information to the human operator about the trajectories and tasks that the drone is performing, while allows operator to define paths and tasks, or even take the control of the drone for a manual piloting.

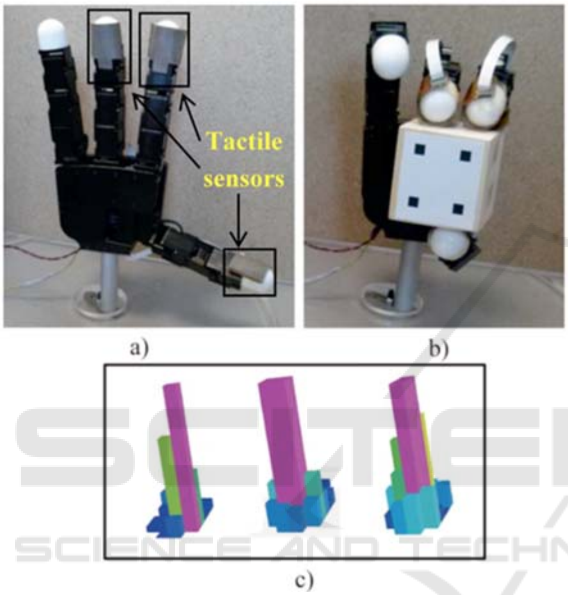

Figure 3: (a) Allegro hand with the tactile sensors installed in the fingertips' surface. (b) Allegro hand grasping the object to be manipulated. (c) Different 3D representation of the pressure measurements registered by the arrays of tactile sensors.

2.2 The Allegro Robotic Hand

The robotic manipulation system is based on the Allegro robotic hand (Wonik Robotics Seoul, Korea) (see Figure 3). This hand has four fingers and sixteen independent torque-controlled joints (four dof per each finger). This robotic hand has a lightweight and portable anthropomorphic design very suitable for low-cost dexterous manipulation in research. The hand weight is 1.09 kg. It is capable of holding up to 5 kg and it has support for real-time control and online simulation. In addition, a set of tactile sensors is employed as additional tool in the manipulation system (see Figure 3a). These sensors are installed in an extrinsic configuration (Tegin, 2005) on the Allegro hand. The sensors are located at the three hand fingertips that will be used during the manipulation (furthermore, only the three last degrees of freedom of each finger will be controlled, resulting in a non-redundant system). The tactile sensors are pressure sensing arrays, type PPS RoboTouch (Pressure Profile Systems, Inc., Los Angeles, CA, USA), which can register pressure values in the range 0–140 kPa with a frequency of 30 Hz and a sensitivity of 0.7 kPa. Figure 3c shows a 3D representation of the pressure measurements registered by these sensors during a manipulation task. The force exerted by the fingertip is computed using the pressure measurements of the tactile sensors. These measurements are multiplied by the area of each sensor, 25 mm^2, so the forces are obtained. The mean of these forces is considered as the force applied by the fingertip. Moreover, the contact points are supposed to be in the sensor of maximum pressure exerted.

3 GRASP PLANNER

This section presents the general structure of the manipulation planner. This manipulation planner uses the geometric model of the object and the fingers in order to determinate the contacts between the fingers of the robotic hand and the manipulated object.

3.1 Kinematics Formulation

We consider the robotic hand as a set of k fingers with three degrees of freedom. Each finger holds an object considering contact points with friction and without slippage. In order to firmly grasp and manipulate the object, the grasp is considered to be an active form closure. Thus, each fingertip i is exerting a fingertip force $f_{Ci} \in \Re 3$ within the friction cone at the contact point. The grasping constrain between the robot and the object is done by the grasp matrix $J_G=[J^T_{G1} \dots J^T_{Gk}]^T \in R^{3k\times 6}$ (Murray, 1994) which relates the contact forces $f_C = [f_{C1}^T \dots f_{Ck}^T]^T$ at the fingertips to the resultant force and moment $\tau^o \in \Re^6$ on the object:

$$\tau_o=J_G \cdot f_C \tag{1}$$

where f_C and τ_o are both expressed in the object coordinate frame S_0 fixed to the object mass center. This equation derives the kinematics relation between velocity of the object $\dot{x}_o \in \Re^6$ and velocity of the contact point $v_{Ci} \in \Re^6$:

$$v_{Ci}=J_{Gi} \cdot \dot{x}_o \tag{2}$$

where x_o denotes the position and orientation of the object in the contact point from S_0. Extending Equation (2) for all the contact points and considering the object velocity with respect the camera coordinate frame, the resulting expression is:

$$v_C = J_{GC} \cdot \dot{x}^C_o \quad (3)$$

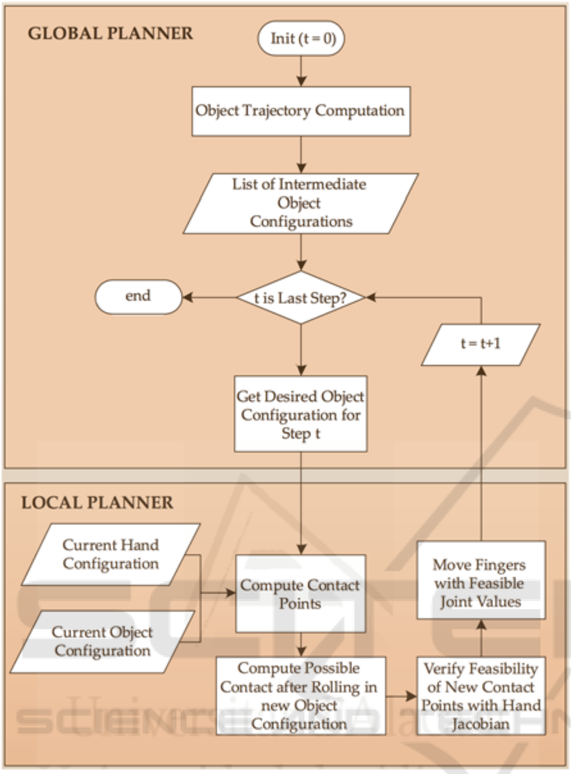

Figure 4: Diagram of the geometric manipulation planner.

where $v_C = [v_{C1}^T \ \ldots \ v_{Ck}^T]^T$ is the vector which contains all the contact points velocities.

Also, a camera is fixed at the workspace in an eye-to-hand configuration in order to observe a set of features located at the surface of the manipulated object. The kinematics formulation has been studied in (Jara, 2014).

3.2 The Geometric Manipulation Planner

The planner receives as input a given grasp and a desired final configuration of the object. From these input parameters, the planner has to compute the changes of the fingers joint angles that drive the object from the initial grasp towards the final desired configuration. During this process, the planner should take into account not only the maintenance of the contacts of all the fingers which are touching the object in the initial grasp configuration but also the kinematic restrictions of the fingers caused by the limits of their workspaces. The planner has been organized in two main levels: a global planner and a local planner shown in the Figure 4.

The main goal of the global planner is to obtain a group of intermediate object configurations which are able to join the initial state of the object with its final state by applying affine transformations.

The local planner is responsible for computing the movements of the fingers which have to be applied in order to move the object from the current configuration to the desired intermediate configuration. Firstly, it determines the current contact points between the object and the fingers and the corresponding pair of contacting primitives. Secondly, it supposes that the object is in the desired intermediate configuration and it computes all the possible variations of the contact points. Thirdly, it uses the pseudo-inverse of the Jacobian of each finger in order to verify which contact configurations are kinematically feasible. Finally, the local planner moves the fingers towards the feasible configuration which involves a smaller joint rate so that the movements of the fingers are minimized. When these movements are executed, the global planner will recover the control of the planner in order to process the next intermediate object configuration (Corrales, 2011).

4 RESULTS AND FUTURE WORKS

Figure 5 shows the target used for testing the prototype: a soda can. We are currently working on automatic detection of the target by computer vision using the images obtained by the drone during a planned flight. Our research group have some experience in detecting objects from aerial images (Alacid, 2016). In this paper, we assume that the location of the object has already known.

The drone lands in this location and then the robotic hand can grasp de target object. For grasping we use the planner presented in section 3. Figure 6 shows how the drone is landed and then the allegro hand grasps the object. Next, the drone can take off in order to transport the object to the destination.

More detailed pictures of the grasping task can be seen in Figure 7 and Figure 8.

We are now working on more complex tasks, when a dexterous manipulation is necessary and it would be impossible to do with a simple gripper. In these cases it is essential to use a robotic hand.

Figure 5: The target object.

Figure 6: The drone with the Allegro hand grasps the object.

In the future we will also study the grasp stability during takeoff and flight, when there would be external forces that must be countered, for example (Backus, 2014; Korpela 2011).

5 CONCLUSIONS

In this paper we describe a novel aerial manipulation system (DM-UAV) composed of a drone with an robotic hand. For this contribution, it is assumed that the object position is known so the drone flights to

Figure 7: Grasping detail.

Figure 8: Grasping detail.

this position and lands, then the robotic hand can grasp the target object. After of that, the drone can take off in order to transport the object to other location. The structure of a first prototype, the configuration of the robotic hand and its tactile sensors, and the grasping planner has been described in the manuscript with more detail.

The proposed system can be used for different applications, f.e. agriculture, to clean the trash on the field, to eliminate contaminate objects, etc.

In the literature, there is not any similar experience, considering a drone with a complex robotic hand in order to make dexterous aerial manipulation (DM-UAV). This paper describes the first step of our research, but we continue working to make more complex manipulation tasks.

ACKNOWLEDGEMENTS

Research supported by the Valencia Regional Government, PROMETEO/2013/085.

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