A New Classification and Aerial Manipulation Q-PRR Design

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Abstract

This paper presents a new designation and classification of system with UAV and robot manipulator where a new nomenclature is recognized as being the first contribution in the bibliography of design and systems. Several papers deal a problem of manipulation with a different unmanned aerial vehicle, robot arms and also with different naming of their systems, where the difficulty for locate and finding items and a good paper with its title or even by keywords, multirotor equipped with n-DoF robotic arm is the expression among the most widely used to describe that system. Aerial manipulation formula is presented and proved with a large example in the literature.

keywords: UAVs, Multirotor, Aerial Robot, Flying manipulation, General Naming, Classification

1. INTRODUCTION

Unmanned Aerial Vehicles (UAVs) becomes an important scientific field, interesting applications would be filming scenes and snapshots, exploring a wide area, observing aspects for civil and military tasks, then recently in the road traffic. The beginning of the robotics was to help the industrialists to make complex tasks in a fast and precise way, the environment was the ground, when the flying machines appeared, the researchers discovered another field of exploitation, the interaction with the environment was difficult, It began with the use of cameras and remote sensors without having direct contact with the environment or the target. Researchers are on the use of different mechanisms to interact on targets, this is where they created the domain of flying manipulators.

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In the last few years, it has emerged a need for the interaction of that UAVs with the environment that is not easily accessible by humans, for this, the researchers have used for transporting, manipulation and grasping a payload, several tools are used: magnet, cables, grippers and manipulators, also a combination of all that, to ensure the target tasks.
Almost systems in the literature consider a Quadrotor with manipulator arm and for a *n* DOF, a robot arm with revolute joints, And they place the system support which they can't generate large angles for the first joint, and the result will be a reduced workspace with an joint limit. Therefore it will be found that from second joint to *n*, are the real joints to generate a real workspace of the robot arm where the UAV be in the stable position.

Until now, papers as review and survey have received much attention to describe and cited related works in the aerial manipulation systems, paper [46] aims to provide an overview on aerial manipulation of SRURSs (Small-scale rotocraft unmanned robotic systems) and provides a literature review of the last 10 years (2008-2017), in the [47] literature review of general aerial robotics and space manipulation is presented. The general review for UAV systems is described in [23], authors attempted to summarize all types of UAV with methods and applications, a heavier than air and lighter than air UAV are detailed with several classification tables, without devoting a part of their research to the naming problem of the flying machine equipped with a manipulator.
Previous works have only focused on the design and control, without asked a question to find a real title for theirs works and trying to generalized a nomenclature of aerial manipulation field. This problem is the major cause of this paper, and it is organized as follow, in the section 2, A several project in the word that deals the aerial manipulators are founded, from conception to control, as an example, the ARCAS project, (Aerial Robotics Cooperative Assembly System)for assembly and structure construction,with multi-link manipulators, the AIRobots, Innovative aerial service robots for remote inspections by contact and the AIROARMS aerial robotic system with multiple arms for inspection

and maintenance.

This paper is organized as follows, The next section looks at investigates the question of how the name of aerial manipulation system is given. In section **III** the classification of aerial manipulator systems by keywords is analysed. The main contribution of this paper is outlined in the section **IV**. Some conclusions are drawn in the final section.

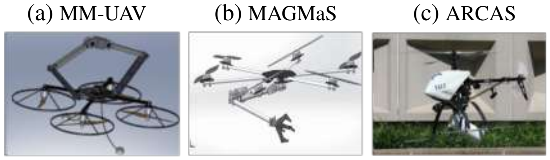
2. Aerial manipulator naming

In order to classify the different aerial manipulator, three main classes can be made for describe a flying manipulator according to the attached tools. UAV transporting payload with a flexible cable, in [9] the cable is modelled as a serial connection of arbitrary number of links. Grasping, the multirotor is equipped with magnet to grasp object, or with a simple gripper (1-DOF)[12], also in [39], the authors are used a non prehensile manipulation with a single Dof to push an object in the desired direction. In [37] authors are used a novel mechanical design with a single DOF for tentacle system for object grasping, that structure is cable-driven. UAV with a manipulator robot arm from $2..n-DOF$, can be subdivide that in the two sub-classes: 1) Non-redundant robot arms with a degree of freedom $n<6$, the most papers are deals that structure, for 2-DOF in [3, 20], and in [29, 1] authors used a 3-DOF robot arm with revolute joints, for 4-DOF in [15] authors used a robot arm placed at the upper part of the UAV for bridge inspection, in [21] a 5-DOF manipulator attached to the helicopter for interacting with environment is used. 2) Redundant robot arm $n>6$: A robot arm with 7-DOF in [14], an industrial manipulator based on a main-tail-rotor helicopter, in [11] the Hyper-redundant manipulator with 9-DOF mounted on UAV gives a large reachable spaces. UAV with a different structure for grasping, transporting or objects manipulation, in the literature a delta structure fixed on side of UAV is used rarely [13], and aerial parallel manipulator in [8, 10]. For interacted with object where forces and torques are applied, authors used a dual 4-dof arm on UAV [22].
A team of UAVs collaborate for a target tasks with a common attached tools, in [36] a team of Quadrotor equipped with a 2-DOF robot arm for cooperative tasks is used. A heterogeneous system UAV collaborate with other robot structure, like mobile robot, or in [33] the system composed by a ground manipulator and one aerial robot. Team of Quadrotors connected with an airborne base where the Robot Arm is fixed in the system centre [19], also the FlyCrane in [26] is an aerial towed-cable system inspired for a SkyCam structure, author in [30] presents a structure basic units made of two UAVs linked by rigid beams, and a fixed robot arm in the top one of them and the end effector operates in the same plane as the UAV fixed arm. In [28], author inspired another gripper from climbing robot structure, a claw mechanism for perching. Furthermore, there are a structure of UAV with two legs with 2-DOF, fixed on the bottom, not for conventional mission,grasping or manipulation, but just for landing UAV on the uneven ground [6], other they mounted a dual 3 links with a prismatic joint for grasping the different size of objects [4].
The control of such system is extremely difficult, where the interaction between manipulator arm and UAV generates forces and torques that disturb overall system,researchers are designed several control schemes based on three approach. UAV and robot arm as a united structure with a single dynamic model[24]. Robot arm interact with the UAV base and generates a forces and torque that disturb the system. The modified inertial parameters of the UAV to maintain the global system in a stable situation, to control it without having an important disturbance on the UAV base, for that, researchers developed a structure with moving UAV battery in one direction to maintain the CoG of that in a position as close as possible to the vertical axis that through centre gravity of overall system[32], in [21] authors used helicopter equipped with robot arm, the movement of the manipulator CoG while compensating the displacement of helicopter. The drawback of such structure,it's that we must mounted a robot arm with a specific UAV designed just for manipulation, where the battery movement is very limited when the end-effector tried to reach a desired position and battery position can't ensure the alignment of CoM of UAV and robot arm.
Other names given to the systems for designing the aerial manipulators type, we find researchers who assign direct names, in [27] **AIRobots** Figure 1a, in [42] **AMUS** octoquad Figure 1b, for the researchers in [16] it was the **QURM1** Figure 1c, the system in [5] **ASCTEC Pelican** equipped with **PUL5AR** designate the type of multirotor and manipulator arm used. Similarly, there are some who use an abbreviation for their system, in [22] is the **MM-UAV** for Mobile Manipulating unmanned aerial vehicle Figure 2a, also **RUAVs** for Rotary- wing Unmanned Aerial Vehicle in [38] and **MAGMaS** for Multiple Aerial Ground Manipulator System [33] Figure 2b, **MMAR** for multi-propeller multifunctional aerial robot in [43] Figure 2d, the **RFR** for Rotor Flying Robot, Figure 2f illustrates this principle detailed in [45], **CAVIS** for the cooperative aerial multi-manipulator [2]. Others assigned the project name to system design like in [24] the system **ARCAS**.

(a) AIRobots (b) AMUS (c) ASCTEC

Figure 1: Used name for aerial manipulation systems

(a) MM-UAV (b) MAGMaS (c) ARCAS



(d) MMAR (e) RUAVs (f) RFR

Figure 2: Used abbreviation for aerial manipulation systems

3. Keywords combination

The first step to have a state of the art on a research topic is to search with appropriate keywords. The type of the flying machine, the model of the manipulator arm, the intended task and the command used are the major criteria for choosing and finding the requested paper. Results using search engines are mostly based in the title of paper with introduced keywords.These titles and appellation in the majority of paper and systems are not well understood, each researcher make the naming of architecture with system description, the name of multirotor, the number of joints or degrees of freedom and the task or mission. A study on this problem is made to build a database on the subject of aerial robotics (see table 1).

To describe the multirotor platform and a manipulator

Table 1: Combination of aerial manipulation keywords

UAV	Manipulator	joint kind	task
Quadrotor	Robot arm	Rotoide	Transporting
Flying wing	Parallel robot	Prismatic	Grasping
Helicopter	Cable	Rigid	Inspection
Multirotor	hand	Flexible	Manipulation
UAV	Robotic platform	*n*DoF	Cooperative
Aerial	Manipulator	Multi DoF	Perching

arm, a set of keywords are usually used in the title of papers. For example, keywords such as UAV + manipulator + parallel refers to the paper [10], Quadrotor + Hand + DoF + Grasping refers to the work published in [41], UAV + Cable + Transporting is for [9]..etc

4. Approach of the new classification

A very interesting publication in [49], where the authors designed a system consisting on several quadrotors with a single manipulator arm in common, they used the term **SmQ** for spherically connected multiquadrotor, this code gives just the number of the multirotor used without any information on the type of manipulator arm attached nor the degree of freedom. in [18, 44] authors use an expression that can give a number of legs and the joints type as *nRRR* for a parallel robots. In the following paragraph we have created a real codification that treats all systems with more information and details about the system used. Due to the difficulty to elaborate research to often a state of art about aerial manipulation, or to find data about a general manipulator. In the following paragraph a real codification that treats all systems with more information and details is created about the used system. In order to complete the actual state of art on aerial manipulator classification a new general name for the system composed by UAV and manipulator is created. The main idea is to resume the most used UAV and the joints type of manipulator and its links number, on a general and a unique name, where any researcher can get informations when he reads the name. In [23] authors categorized UAVs in a table since 2001 and presented a common UAV types. Based on this work, this paper interests for wing and rotor types for the system that are heavier than air (Blimp and balon, aerials that are lighter-than-air are neglected). To answer to this problem, a new way to classify UAV and rotors types systems, based on the main designation in the column 1 table 2, the second column define a new abbreviation for the most used of them, A set of significant names will be described later.

Table 2: New abbreviation describing UAVs type

UAV	Short name
Fixed wing	FXW
Flying wing	FLW
Helicopter	HEL
Quadcopter	QUA
Hexacopter	HEX
Octocopter	OCT

The method principle is to cite a three letter from

UAV type name see Table 2, with n symbols in the beginning as a UAV number, and m denotes a number of manipulators chain attached on the flying system, where Y detailed a type of joints for one leg in the manipulator, with R as revolute joints, P prismatic joints and C for cable link between UAV and payload, examples for more details are given in the table 3.

$$nXXX - mYY..Y \quad (1)$$

Assumption 1 *if $n = m = 1$ the number will be hidden.*

Assumption 2 *The Q letter is more used in literature to design a Quadrotor, therefore,*
if $\boldsymbol{XXX = QUA \Longrightarrow XXX = Q}$

Table 3: Database of aerial manipulation keywords

Reference	Old Naming	New Naming
[35]	Flying Robot **RFR**	**HEL-RRR**
[19]	SmQT	**3Q-RR**
[31]	MM-UAV	**Q-3RP**
[42]	AMUSE	**OCT-RRRRRRR**
[16]	QURM1	**Q-RRR**
[48]	HADAS	**HEX-2RRRR**
[4]	YAMG	**HEL-2PRR**
[2]	CAVIS	**2Q-2RRRRR**
[26]	FlyCrane	**3Q-2C**

In the literature there is a surprising number of aerial manipulators that can use this approach to simplify the title and make the system and its architecture more popularized and understandable for other researchers.
With this approach, group of the same structures in a single appellation and under the unique descriptive name is created. A set of Quadrotor with a 2 DoF robotic arm is under Q-RR appellation is illustrated in the table 4, and by the same way, for a Quadrotor with a 3 DoF robotic manipulator illustrated in the table 5.

Table 4: Example of Quadrotor with 2-DoF arm

Class	Name	Reference
Q-RR	drone and EF arm,	[34]
	Quad+2 DOF arm	[3]
	Qud+2dof arm	[50]
	Qud+2dof arm	[36]

Table 5: Example of Quadrotor with 3-DoF arm

Class	Name	Reference
Q-RRR	**QURM1**	[16]
	ASCTEC	[25]
	AMIS	[15]

5. The Q-PRR design

The structure of the proposed aerial manipulator is composed of two parts, the multirotor which has number of rotors $n_r \geq 4$ and the manipulator arm attached in the bottom. Their geometric centres are considered in the same z axis ($\vec{b_3}$) of the mobile frame $\vec{B}$ [17] . The manipulator is composed of three degrees of freedom (3-DOF), Prismatic-Revolute-Revolute joints, called (Q-PRR), the first joint is prismatic and its axis (x_1) is parallel to the x-axis of the multirotor mobile frame $\vec{B}$, this joint is considered actuated and it moves along the same axis, and it is bounded on both directions by a value r_0, the distance between two axes x_b and x_1 is denoted by (d_0), the second and third joints are revolute, its rotation axes (z_2) and (z_3), will be parallel to the (y) axis of frame $\vec{B}$, where the manipulator arm motions are considered in the plan composed by (x,z)-axes of the mobile frame $\vec{B}$ (see figure 3).

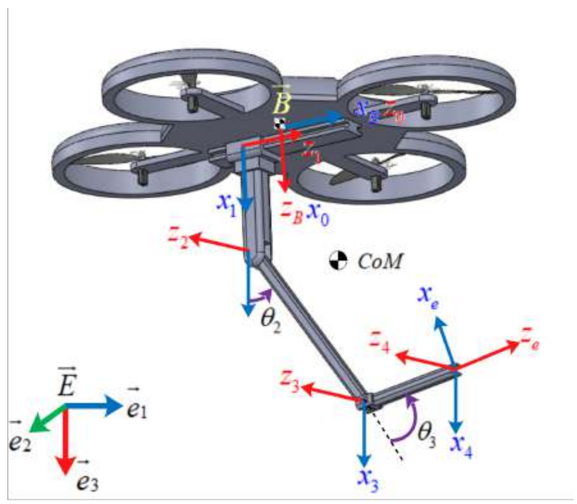


Figure 3: The structure of Q-PRR with main frames

In this work a new structure of robot arm with a 3-DOF is developed and designed with a CAD program. The alignment of CoG of the whole system with a simple movement of robot arm and with one joint along one axis can be done. This structure can be mounted one any UAV such as Quadrotor and helicopter or other heaving system, it offers several features such as: 1) It works independently of UAV,and can be fixed on any one, whatever the UAV structure. 2) Ensure a wide workspace and a good stability of UAV in flying. 3) Offers us a large possible configurations of robot arm, where we can choose the better for specified task and for desired position and orientation. 4)Can consider that for given time and elevation, a Prismatic first joint, with disturbance due to UAV oscillation,

will compensate small revolute joints displacement of second and third joints.
The system is stabilized by controlling the robot arm for a CoGs combinations, when in [24] they stabilized UAV CoG and robot arm by controlling the battery position. This strategy must have a combined kinematic model and decrease a number of possible solutions for position and orientation.
Only few works are using a prismatic joint in the literature. In [4] researchers designed a dual arm with a Prismatic-Revolute-Revolute joints (PRR), this architecture is considered as a gripper for objects handling, and it is adapted for different shapes and volumes. In this case each 3DOF robot arm is considered as a finger of a whole gripper. A light-weight prototype 3-arms manipulator is used in [31] to build an efficient system considered as legs of multirotor during the landing and handling operations. In [40] the authors have described the using of simplified 1D planar dynamic model, this allowed to provide an easy overview of the system dynamic, the proposed controller and the moving of the manipulator in a 1D plan. this works describe the appear of a prismatic articulation in the mathematical model of the system.
the next step is to establish a geometric and dynamic model by using a robot arm formulation like D-H and implement the system in the SimMechanics environment for a control part [7].

6. Conclusion

In this paper, a new naming of aerial manipulation systems is presented in order to simplify their classification. This new method describe any system composed by multirotor and manipulator and researches can consider as a way of simplification and recognition of any system using recognized symbols in the robotics field. It is the first time of a real contribution in the bibliography part, with a new classification and organization in the field of aerial manipulation. The main goal of this study is to suggest to researchers to use this new method and to generalize this classification naming. Moreover, a new aerial manipulator system with a prismatic joint is designed and constitutes an excellent application example. It's design shows the efficiency of the proposed architecture to stabilise a system for any task and configuration.

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