Toward autonomous airships: research and developments at LAAS/CNRS

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Abstract

A wide community of researchers coming from various disciplines are considering autonomous robotics, and more generally machine intelligence, as a challenging goal of their work. Thanks to technical progresses in the area of sensing, actuating and especially computing, and thanks to years of efforts on theoretical and practical topics related to robotics, research in this area has reached a maturity that makes spin-offs and applications realistic in various domains. In this paper, we sketch various problems related to the development of unmanned airships, and present the activities related to such applications that we are beginning to consider in our research group.

1. Introduction

The Robotics and Artificial Intelligence research group at LAAS/CNRS [1] has been leading research on autonomous mobile robots for over 25 years, for both indoor and outdoor applications. Our group is concerned with a wide spectrum of problems related *to machine intelligence*, focusing especially on autonomous vehicles: our research ranges from environment perception to decisional autonomy, via motion planning and motion execution control. Besides these theoretic topics, we have always maintained a will to implement and integrate our work into *real robots*: this is the best way to ensure the realism of the studies and to tackle the *integration* of the various scientific disciplines involved, from either a theoretical, organizational or practical point of view. Up to now, most of our research and developments were dedicated to manipulators and mobile robots (indoor vehicles [2] and outdoor rovers [3]). Very recently, we started an internal project concerning the autonomous control of airships. Indeed, numerous potential applications of such vehicles can benefit from the development of autonomous capacities. Moreover, airships have properties that make them an exciting support for research on intelligent machines.

In this paper, we sketch various issues raised by the development of autonomous airships. The first section explains our acceptation of *machine intelligence*, and discusses the interest of developing autonomous airships. In the following section, we present in more details how some studies and developments related to mobile robotics can be transferred to the case of airships, and how the consideration of such platforms brings forth new challenges for roboticists. A brief description of the topics we are currently beginning to study concludes the paper.

2. Autonomous robotics, machine intelligence and unmanned airships

Everyone has in mind the images of industrial manipulator robots dedicated to assembly, painting or welding tasks. The dynamic, precise and sometimes elegant motions of these machines, and the fact that they substitute for man in many tasks is appealing. But these robots execute specific and repetitive tasks, that have been pre-programmed and that do not require any initiative. The autonomy of such robots is *operational*, not *decisional*, they do not exhibit any robustness or adaptativeness with respect to little changes in their environment.

As opposed to these robots, an *intelligent robot* should be able to execute much more complex tasks, in unspecified, varying and sometimes unknown environments, which require analysis and decisional abilities [4,5]. Typically, the kind of tasks an intelligent robot can deal with are specified at a quite highly abstracted level (often referred to as « the mission level »), such as « Reach that goal », « Map that area », « Follow that person »... It is not fortuitous that the asks we mention here relate to mobile robots: indeed, research on machine intelligence (initiated in the late 60's) has rapidly focused to these kind of robots , as they have to evolve in wide, changing and not necessarily fully known environments. For such robots, *the autonomous navigation* task in initially unknown environments is regarded as a typical problem to be tackled, as it calls for the integration of wide spectrum of functionalities, from low level actuator servoing to high level decision making.

A lot of progresses have been accomplished in this area, from both the technological and scientific sides, and if intelligent robots appear more often in the media than in our everyday life (real intelligent robots have yet to go out from the labs), there is no doubt that their role will be growing in the near future. There are many different applications that will benefit from the development of such machines, from the particular cases where it is impossible or dangerous for a man to be present (*e.g.* planetary exploration, military reconnaissance or fire fighting), to more usual tasks such as driving or housekeeping.

2.1 Basics of robot autonomy

The various functionalities an autonomous mobile machine must be endowed with to be able to execute complex tasks can be grouped in three categories:

- Perception: the ability to perceive and build representations (models) of the environment is of course required for the machine to *adapt* its decisions and actions to the current state of the environment. This ability calls for several disciplines, such as signal processing (including computer-based vision of course), estimation theory, geometry, data fusion and uncertain data manipulation. It is required as well for taking high level decisions as for servoing the lowest level action execution.

- Action, mobility: generating motions commands and controlling their execution is the fundamental ability of robots. Developments related to trajectory planning, computational geometry and control theory are required for these purposes.

- Deciding, reasoning, scheduling and planning: under all these terms lie the decisional processes, that establishes the link between perception and action, while maintaining the achievement of a given mission.

Research on machine intelligence encompasses these functionalities in what is often referred to as the « perception/decision/action loop », and aims at *integrating* them within physical entities. The vast amount of work in this area, and the variety of approaches are so that it would require a whole book to present a synthetic view of the current achievements. Note that some other research topics (*e.g.* man/machine interface) also fit in the scope of research on machine intelligence.

2.2 Toward autonomous airships

If mobile robots have been initially considered as the main target of research on machine intelligence, a wide variety of vehicles are now considered, in various application fields (*e.g.* submarines, drones, helicopters...). Basically, the main advantages brought forth by machine autonomy are:

- the possibility to act at dangerous or unreachable places;

- the possibility to release the operator when the tasks are tedious or lasts very long;

- the possibility to tackle difficult problems that involves situation analysis and interpretation abilities, motion control and task scheduling in very complex situations;

- and finally operational cost reduction.

There are several kinds of missions for airships that the development of autonomous functionalities would enable to execute with little human intervention. For instance, the general advantages of machine autonomy just mentioned above can turn into the following ones:

- Data collecting applications (*e.g.* fire detection, pollution assessment, scientific data gathering), where an airship has to systematically sweep over a defined region, or to hover over a given place for hours or days, could be realized autonomously, in a cheaper and sometimes more efficient way than under pilot control.

- Autonomous airships could operate in meteorological conditions considered too dangerous for an operator to embark on.

- The development of autonomous functionalities could favor the use of rather small airships (blimps down to several tens of cubic meters), as only instruments dedicated to their autonomy and their mission would constitute the payload. Indeed, remotely piloting such airships requires direct visibility for the operator, or at least a ground control station to which all the informations necessary to pilot them would be transmitted. In this latter case, piloting requires high bandwidth communications between the control station and the airship, and also a well trained pilot (remotely controlling a vehicle on the basis of transmitted informations is not an easy task, whatever the vehicle is).

As with all the other kinds of vehicle whose «robotization » is considered by engineers and research scientists, *the autonomous navigation* task is a key one for airships: indeed, it is the basic task upon which can be defined complex autonomous missions, such as the mapping or surveillance of an area for instance.

To our knowledge, the most important and integrated work related to unmanned airships is the project AURORA, lead by the Automation Institute of the Informatics Technology Center in Brazil [8,9,10,11]. Other labs did consider some particular problems related to airship autonomy, considering essentially the lowest level functionalities from a control theory point of view (see [12]).

3. An overview of some problems related to airship autonomy

There is a bunch of autonomous functionalities to develop in order to endow an airship with autonomous navigation capabilities. They range from the lowest level controls, such as altitude, pitch or position stabilization - these tasks being more related to control theory and already widely developed on other commercial aerial vehicles, to higher level functions, such as planning a sequence of maneuvers, controlling motion execution on the basis informations provided by vision (to follow a given feature on the ground, to dock the airship to a pole), or monitoring the execution of the whole mission.

The general principles of machine intelligence to endow a vehicle with autonomy apply to airships, as on any other vehicles considered by the robotics community. Following the perception/decision/action loop briefly described in section 2.1, we discuss here the specificities brought forth by the consideration of autonomous airships.

3.1 Environment perception and modeling

Aerial navigation sensors are of course required to automatize the lowest level functions (stabilization of a given state parameter basically, this parameter being the altitude, the pitch, a velocity). They constitute what is often referred to as «proprioceptive perception » in the robotic community[1].

But to develop higher level autonomous functions, the perception of the environment over which the airship flies is required («exteroceptive perception»): this enables to detect features on the ground, to localize the airship with respect to these features, therefore enabling the execution of motions described relatively to such features (road or mobile target following for instance). Environment perception is also required for the highest level autonomous decisions, that monitors and controls all the lowest level functionality in order to execute a given mission: missions are indeed most of the times described relatively to the environment.

[1] The use of these words is actually inherited from life sciences.

Thanks to technological progresses, various sensors can provide relevant informations on the environment: computer vision of course[2], but also several kinds of radar sensors and laser range finders (LIDARS). Basically, the processes of these informations that conforms them into data structures adapted to the control and decisional processes can be split in two families:

- Feature extraction, that extracts relevant features from the acquired data, using signal processing functions (filtering, segmentation, model identification). Such features are most of the times sufficient to define and execute the lowest level actions (see section 3.2).

- Environment modeling, that gathers all the perceived data and extracted features into *global environment representations*, that are exploited by the highest level functions, to plan a sequence of motions in order to fulfill a given mission for instance (see sections 3.2 and 3.3). Note that if the building of these representations can be helped by the use of extracted features in the data, these representations can also be used as inputs for low level control actions.

Thanks to progresses made on signal processing and environment modeling in the communities of roboticists and aerial image processing, the tools and techniques to implement these processes are mature enough to allow the development of autonomous functionalities for airships.

3.2 Motion planning and motion execution control

Developments related to control theory are required to implement motion execution control (or more generally state parameter regulation) on airships. Undoubtly, it is in the domain of aerial vehicles that such developments gave birth to their nicest applications. However, airships have some «strange » properties that makes them still a challenging application for control theory. Indeed, taking into account all the physical phenomena that characterize airships (buoyancy, aerodynamic lift, inertia, plus other difficulties related to heating, payload changes), leads to a very complex dynamic model, not to mention the drastic model changes between aerodynamic and aerostatic flights. If thanks to years of efforts by pioneers in the blimp community, a vast literature is available on the identification of these phenomena and the establishment of dynamic airship models, the automatic control of airships has been yet seldom studied. Like most terrestrial vehicles (cars for instance), airships are under-actuated vehicles, and therefore their controllability is not trivial. To our knowledge, only few research teams have considered this problem [8,12]. Let's note however that the control of submarines, whose dynamic model is quite similar to an airship model, has been more widely considered [7].

Using exteroceptive informations to servo the motions of an airship, which makes a lot of sense for autonomous airships, makes the problem even more complex [12]. However, when using a single camera, this problem, referred to as ``visual servoing'' in the roboticists community, seems simpler in the case of airships, where the environment over which they fly can be faithfully represented by a planar structure (most of the difficulties with visual servoing in robotics comes from the fact that a single camera can not perceive the 3

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[2] Stereovision can be also considered: thanks to the usual big sizes of airships, large baseline stereovision camera pairs can be used, therefore allowing a precise estimation of the geometry (elevations) of the environment

dimensions of the environment in which the robot has to evolve in). Moreover, the sensors that allow to perceive the 3D geometry of the environment can ease these exteroceptivly servoed control tasks, especially at low altitude motions, to dock to a pole for instance, or to avoid a building.

Motion planning, which we can actually be considered as a decisional process (section 3.3), consists in finding a trajectory to reach a given goal, the trajectory and the goal being defined either at a geometric level or relatively to the environment. In the robotics community, big advances have been made in this area, considering a variety of vehicle kinematics and control constraints [13]. These advances and results seems mature enough to be transferred to airships: they can provide planning functions that allows the execution of higher level missions. For instance, the sequence of maneuvers to execute in order to dock to a pole, coming from a given direction at a given altitude, while avoiding a near building, can be produced automatically by a motion planner.

3.3 Decisional processes

It seems that airships do not bring forth any new problem concerning the highest level decision processes, that triggers and controls the various autonomous functionalities presented in the two sections above (perception, motion planning and motion execution control). These processes ensure the fulfillment of the given high level missions, such as « mapping the areas A and B before night, and docking back to the base », their implementation rely on generic developments in artificial intelligence (essentially task planning under resource constraint), and off course needs global environment models to reason on. The integration of all these processes is an important issue to mention, but again, the progresses made on machine intelligence already lead to generic solutions (*e.g.* see [14]).

It is however worth mentioning here a big scientific issue: it is the *cooperation* between several autonomous airships, or with some autonomous rovers on the ground (air-ground cooperative robotics [10]). It makes a lot of sense in several applications domains, and especially when it comes not only to gather informations, but to *intervene* on or in the environment. If multi-robot cooperation is becoming to be seriously studied (e.g. see [2]), a lot of serious problems arise when it comes to *multiple kinds* of robots cooperation, that have very different properties, from an action point of view (hovering or flying versus roving) or a perception point of view. The development of such complex autonomous systems requires however the availability of autonomous airships and rovers, and seems therefore a big challenge that will require years of work.

4. Current work at LAAS

To tackle the problems brought forth by autonomous airships development, we initiated a small project in our lab. We first started to consider the two following problems:

- Motion execution control, using essentially exteroceptive perception. There is a great interest in developing such functionalities, as they of course constitute the basis on which higher level autonomous functions must rely. Moreover, we believe that the use of exteroceptive sensors for the purpose of motion control will help to get rid of expensive and heavy 6 axis inertial platforms on airships (a 2 axis attitude sensor plus a magnetic compass would however ease the problem).

- Environment modeling, using low altitude aerial images. This is required at the motion or mission planning level, and can be tackled using results from aerial signal and image processing. We actually also consider the resolution of this problem in the context of autonomous rovers: the environment model build by the airship can be used by the rover to localize itself, and to plan and execute its missions. This can be considered as a first level of cooperation, the airship being considered as an external mean to provide informations to the rover (we are convinced that air-ground cooperative robotics developments will strongly rely on the share of environment representations between the robots).

To initiate our work, we recently acquired a 18 cubic meter blimp built by Zodiac (figure 1). It is originally a tethered blimp, not conceived to be used in aerodynamic flights: we will however restrict our first work on autonomous control using an aerostatic model, which we consider to be much simpler. We are therefore currently defining a motorisation based on two vectorized propellers mounted on the gondola, and on a tail rotor to control the heading. The proprioceptive sensors we will embark are the following: a two axis inclinometer, three accelerometers and a magnetic compass. We will use a pair of stereo cameras mounted on a large baseline, plus a third camera mounted on a two axis controllable turret. No processing will be be done on board for this first prototype: all the data will be transmitted to a ground computer using an Ethernet radio link, and the commands will be sent back to the blimp using the same mean. First flights, essentially to gather data, are scheduled for May 2000.

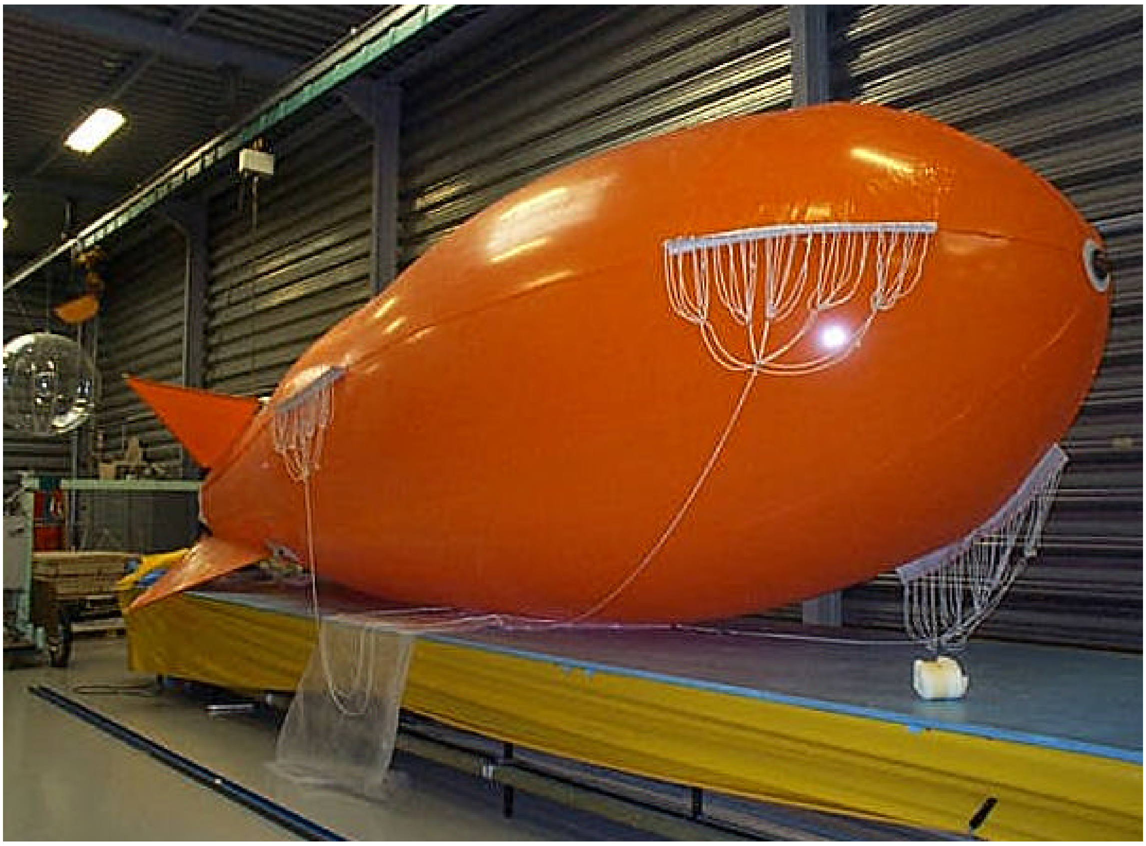

Figure 1: Obélix, the 18 cubic meters blimp which id the basis of our first prototype.

5. Conclusions

We have sketched in this article the advantages one could obtain with the opportunity to develop autonomous functions for airships. We briefly presented the general principles of the development of intelligent/autonomous machines, and evaluated the key points to be studied when it comes to consider airship autonomy.

We strongly believe that machine intelligence is a challenging scientific and technological frontier that is currently being crossed by roboticists. It will give birth to a new generation of machines able to safely assist men in the execution of a variety of tasks. It is very likely that exchanges and integration between researchers and engineers coming from the robotics, airship and airborne sensing communities will lead to the development of applications of autonomous airships in the coming years.

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