

Thesis title: Multi-view SLAM for the control of space robots

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1 Motivation

The objective of this thesis is to develop techniques for the autonomous navigation of space robots in complex environments. This will involve using multi-view visual information to perform simultaneous localisation and mapping (SLAM).

Indeed there is an important and ever increasing demand for autonomous robots that are capable of executing tasks in an autonomous way within varying environments (space, urban, natural, military, industrial) and for numerous applications (aero-spatial, exploration of remote or dangerous environments, cartography, transport, agriculture, cleaning, inspection, surveillance, cartography,...). Autonomous navigation has become a key technology for interplanetary exploration. An important development effort has been performed by the European Space Agency and industrials like Thales Alenia Space to bring new technologies to maturity for space exploration. Examples of applications are rover navigation, safe landing with hazard avoidance, or proximity operations around an asteroid. In all cases, the environment is largely unknown and the dynamics are very uncertain.

A key difficulty of autonomous navigation is the localisation and mapping of the environment. Visual navigation is particularly well adapted to such exploration tasks. Vision sensors provide relative velocity information between the terrain and the robot, which is critical for automatic landing [17, 8]. Safe landing on a planet, like Mars for example, will also rely on the autonomous identification of hazards (strong slopes or large rocks) and if necessary re-targeting toward a safe site [14]. These operations must be completed in real-time. Whilst visual sensors are very performant in a wide range of scenarios, certain difficulties must be overcome including changing illumination conditions or the fact that landmarks are initially unknown.

For missions to asteroids (see Fig 1) or comets with low gravity, the time constraint is much less stringent [13]. These types of missions usually start with the construction of a shape model of the object (a coarse global map and several refined local maps), using SLAM techniques. This mapping can be performed before proximity operations or landing actually takes place, so on-line hazard detection and avoidance does not need to be handled entirely during the landing phase.

The main aim of this project is therefore to study navigation techniques within uncertain, partially known and restrictive environments without making hard a-priori assumptions about space vessel trajectory or about the interaction of the robot within dynamic environments. In order to achieve this it will be necessary to tightly couple multi-view measurements within a closed-loop visual servoing control scheme.

2 Context

In general, the entry, descent and landing (EDL) of spatial robots can be modeled via various complex physical systems that can be difficult to control without the use of appropriate sensors and models of their complex interaction between one another. Indeed, the use of visual sensors to control aerial robotic systems has recently seen a boom in activity for all types of drones (micro, mini, heavy or lighter than air [3]) and in all possible configurations (fixed wing [5], gyrating [2, 19, 18, 1, 20, 16, 11, 6], vibrating for flapping wings). In space applications, binocular optical navigation is very common for rover navigation, however, it has never been used for other space applications [13, 17, 8]. Optical navigation is generally complemented by a ranging sensor (lidar or radar). It seems therefore pertinent to study this new approach and to demonstrate its efficiency when compared with existing systems. Clearly, the problem of exploiting the advantages of visual



FIG. 1 – View of an asteroid from the Thales-Alenia Space simulator.

sensors in an optimal manner for localisation and cartography is an essential problem for many different applications.

In the wider literature, whilst much research has been carried out on monocular visual servoing [7, 4, 16, 11, 6] for different systems, relatively few studies have focused on image-based closed-loop control using multi-view systems such as [15, 9] or in the context of visual SLAM [10]. Further to this, multi-view geometrical approaches have remained largely studied in the domain of visual perception [12], however, few attempts have been made that integrate this information directly within a differential feedback control loop. Closing this control loop promises not only to improve vehicle autonomy but also its real-time perception and subsequent interaction with the environment. Indeed, closed-loop control exploits both knowledge about the movement of the robot for better perception and simultaneously uses perceptual information to provide performant control so as to improve computational efficiency, robustness and precision.

This research proposal integrates perfectly with the scientific research project CNRS-PICS “Visual servo control of Unmanned Aerial Vehicles”, with the national project ANR SCUAV (Sensory control of unmanned aerial vehicles) both coordinated by the I3S research laboratory, along with the “Optical Observation and Science” research unit from Thales Alenia Space.

3 Description

As mentioned, this thesis subject concerns the development of simultaneous localisation and mapping (SLAM) techniques in real-time for navigation and space exploration with autonomous spacecraft.

The major part of this study concerns the localisation and will involve developing a multi-view visual servoing system for a space robot. The interest here will be to integrate multi-view differential geometric theory with closed-loop visual servoing control theory. It will be necessary to develop an analytic relationship between the movement of an aircraft and the movement perceived in multiple views. This will also include identifying pertinent control parameters that adhere to a rigorous set of criterion (robustness, stability, precision, efficiency) along with the choice of technical constraints such as the optimal placement of the cameras. In particular, it will be of interest to develop a global task function which allows the aircraft to behave correctly in accordance with the online dynamics (for example, the movement of an asteroid), changing illumination conditions (according to the luminosity and the visibility), perturbations (such as varying temperatures) or large differences in perceived scale of the environment.

The second part will involve developing algorithms for mapping the environment in an off-line learning phase that will allow to reduce the computational complexity of the online problem by performing the bulk of the computational effort off-line. This will involve creation of a navigational framework that allows the creation of image-based stereo maps within which a robot is to execute a global task. Given a set of training

measurements, task planning consists in constructing optimal representations of these maps in such a way that localisation and control of the aircraft may be performed precisely whilst remaining invariant to dynamic changes in the environment.

4 Required Competences

The implementation of the work will be integrated, tested and validated on robotic platforms available at the I3S laboratory and partner laboratories. Thales Alenia Space has a realistic simulator (see Figure 1) that will be available for testing the developed algorithms.

For this position, candidates must be enrolled in a Masters stream with a focus on computer vision, visual servoing, and/or automatic control. The candidate should have also good abilities for software development and report writing.

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