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A reconfigurable framework to turn a MAV into an effective tool for vessel inspection

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ABSTRACT

Vessels constitute one of the most cost effective ways of transporting goods around the world. Despite the efforts, maritime accidents still occur, with catastrophic consequences. For this reason, vessels are submitted to periodical inspections for the early detection of cracks and corrosion. These inspections are nowadays carried out at a great cost. In order to contribute to make ship inspections safer and more cost-efficiently, this paper presents a novel framework to turn a Micro-Aerial Vehicle (MAV) into a flying camera that can virtually teleport the human surveyor through the different structures of the vessel hull. The system architecture has been developed to be reconfigurable so that it can fit different sensor suites able to supply a proper state estimation, being at the same time compatible with the payload capacity of the aerial platform and the operational conditions. The control software has been designed following the Supervised Autonomy paradigm, so that it is in charge of safety related issues such as collision avoidance, while the surveyor, within the main control loop, is supposed to supply motion commands while he/she is concentrated on the inspection at hand. In this paper, we report on an extensive evaluation of the platform capabilities and usability, both under laboratory conditions and on board a real vessel, during a field inspection campaign.

1. Introduction

The importance of maritime transport for the international commerce is unquestionable. Different types of vessels are used depending on the kind of product that is to be carried: oil tankers, bulk carriers, container ships, etc. All of them can be affected by different kinds of defects that may appear due to several factors, such as structural overload, problems in the vessel design, the use of sub-standard materials/procedures, normal decaying of the metallic structures in the sea, etc. Regardless of its cause, cracks and corrosion are the two main defective situations that appear in vessel structures. Their presence and spread are indicators of the state of the vessel hull, so that an early detection can prevent major problems. For this reason, Classification Societies impose periodical inspection to assess the structural integrity of vessels.

Nowadays, to perform the inspection of a vessel, this must be situated in a dockyard (and sometimes in a dry-dock) where high scaffoldings are installed to allow the surveyors to reach all the plates and structures of the vessel. This procedure, together with the lost-opportunity costs due to the fact that the ship is not being operated, give rise to high expenses for the ship owner/operator. Furthermore, during this process, vessel surveyors may need to reach high-altitude areas or even enter into hazardous environments, putting at risk his/her own integrity.

In line with the aforementioned, the EU project INCASS[1] (finished in 2017) pursued to develop new technological tools with the aim of contributing to the re-engineering process of vessel inspection. Among them, this paper focuses on an aerial robotic tool that has been developed for the visual inspection of the inner vessel hull. The idea behind this device is to allow the surveyor to perform a proper inspection from a safe and comfortable position.

Regarding the latter, the robotics literature contains a number of contributions for vessel hull inspection involving robotic platforms. The majority of the existing approaches make use of underwater vehicles to inspect the submerged part of the hull. Some of them are based on the use of Remotely Operated Vehicles (ROV) (see for example [18,24]), while other approaches are based on the use of Autonomous Underwater Vehicles (AUV) which estimate their position with regard to the vessel hull using different devices and/or techniques. Apart from solutions based on free-floating AUVs (see for example [12,26]), in this group we can also find some approaches of hull-crawling vehicles which are attached to the hull by means of suction (see [1,23]). The

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[1] http://www.incass.eu

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robotics literature also reports on a reduced number of robotic platforms that operate magnetically attached to the vessel hull, what makes feasible the inspection above the water line (e.g. [3,13]).

To the best of the authors' knowledge, the only contributions about flying robots specifically devised for vessel hull visual inspection result from our research. Our first attempt for vessel visual inspection using a Micro-Aerial Vehicle (MAV) focused on providing a fully autonomous platform [4]. This robotic platform led to successful results in field tests performed in different types of vessels during the EU project MINOAS[2]~[11]. Nevertheless, the usability of this platform was limited due to the way how inspections had to be performed. To carry out a mission, this had to be previously specified in a "mission description file" which consisted in a list of waypoints to attain and actions to perform. Despite this way of operation is suitable to sweep a vessel surface, e.g. a bulkhead, and take a picture, for example, every half a meter, it is not appropriate to make the vehicle attain a specific point in the vessel structure with unknown coordinates. Furthermore, during the field trials, some surveyors demanded the capability of flexibly manoeuvring the vehicle with some kind of remote control. Besides, since this autonomous system is based on a position control loop, issues in the position estimate, i.e. due to a malfunction of the laser scanner used for the perception of the surrounding structure, may put the platform in trouble or jeopardize the execution of the inspection mission.

This paper presents a novel approach for the visual inspection of vessels which intends to overcome the shortcomings of our previous platform. Results for preliminary designs of the new MAV can be found in [5,7,25]. This paper focuses however on the next step of design and development, which consists in a reconfigurable framework intended to provide an existing MAV with the capabilities to become an effective and easy to use tool for the vessel inspection task. The resulting system is reconfigurable in the sense that it can incorporate different sensor suites depending on the payload capacity of the MAV and the operational conditions (such as the amount and kind of illumination or the presence of obstacles, e.g. consider the case of a cluttered environment). The present paper also provides an extensive evaluation of the performance and usability of the robotic device both under laboratory conditions and during a real inspection campaign on board a real vessel.

The paper is organized as follows: in Section 2, the system requirements are presented, including the requirements needed to accomplish the target tasks and also those necessary to improve the usability of the platform; Section 3 overviews the platform, introducing the key aspects of the approach and the operating paradigm; Section 4 reviews different sensor suites proposed to estimate the platform state estimation and perceive the environment; in Section 5, the control architecture design is detailed; Section 6 describes the pipeline that estimates the platform state from the sensor data; Section 7 provides the details for the implementation of the MAV; Section 8 reports on an extensive evaluation of the platform capabilities under laboratory conditions; Section 9 shows the performance and usability of the vehicle during inspection missions, including results from a campaign on board a real vessel; and, to finish, Section 10 draws some conclusions on the work described.

2. System requirements

A number of requirements have been defined in accordance to the target task. They focus on the design of a robotic device able to teleport the surveyor through the different inner and dry structures of the vessel, so that he/she can appropriately perceive the condition of the hull. Those requirements can be outlined as follows:

1. the vehicle must allow a close-up view of the inspected surface;
2. the vehicle must obey the commands indicated by the user/surveyor;
3. the vehicle must allow reaching the highest structures of the vessel hull;
4. the vehicle must be able to operate inside the vessel hull, including rather narrow spaces (e.g. inside a ballast tank), and
5. the vehicle must be able to operate in dark areas (e.g. inside a ballast tank or a tanker cargo hold, where daylight can not penetrate).

Additional requirements are defined to increase the usability of the platform and/or to reduce the mental workload of the surveyor in charge of the visual inspection:

1. the vehicle must implement self-preservation functions such as prevent collisions with the surrounding obstacles;
2. the vehicle must be operable by non-expert users who maybe have never used a robotic device, and
3. the vehicle should provide some autonomous functionalities to alleviate the inspection task to the surveyor, especially when performing repetitive operations or those prolonged in time.

Climbing rovers and robotized cranes, among others, share with MAVs a potential adequacy for the inspection task outlined above [20,30]. Among all three, MAVs exhibit shorter deployment times, what can make it very interesting for collecting in a fast way relevant amounts of data that permit the surveyor have a first impression about the state of the vessel compartment under consideration. Apart from that, a MAV is typically a small platform that can be introduced virtually in any area of interest inside the vessel, including those parts with exclusively manhole-sized entry points (typically 800×600 mm), such as a tanker cargo hold. MAVs are neither affected by surface discontinuities and/or the presence of excessive dust or rust particles over the structure, what can seriously jeopardize the navigation/adhesion capabilities of e.g. a crawler. Finally, reaching the highest points of the structure can mean almost no effort for a MAV, but can become non-trivial for a crane or a climber at difficult-to-approach points. Nevertheless, the other two platforms can certainly mean a difference when, apart from the visual inspection, one needs to take e.g. a thickness measurement using a by-contact probe, including cleaning the surface as a previous step. This situation is, however, not part of the requirements enumerated above.

3. System overview

The aerial robotic tool has been designed to fulfil the system requirements presented in the previous section. To this end, the system architecture has been reconsidered from scratch. Regarding the vehicle configuration, we have chosen to use a multirotor device. This kind of vehicle, in its different setups (quadcopter, hexacopter, octocopter, etc.), has been widely used in the recent years for visual inspection tasks (see of example [17,21,29]). Multirotors present the advantage that they require simple rotor mechanics for flying control. Unlike single and double-rotor helicopters, multirotors use fixed-pitch blades and the vehicle motion is achieved by varying the relative speed of each motor to change the thrust and torque that they produce. Among them, we focus on those which weigh less than 2 Kg. The reduced size of these MAVs, together with their capabilities for hovering and Vertical Take-Off and Landing (VTOL), make them suitable for operating in confined spaces and close to structures, which is a crucial feature for being able to achieve close-up visual inspection.

With this aim, the vehicle is equipped with cameras to take high resolution pictures and videos from the vessel hull surface. The inspection in dark spaces, such as ballast tanks or closed cargo holds, is possible thanks to the use of high power LEDs that illuminate the inspected surface. All the pictures are tagged with the estimated pose of the vehicle to perform an effective inspection of the vessel and to allow

[2] http://www.minoasproject.eu