Jornadas Nacionales de Robótica
Spanish Robotics Conference
14-15 Junio 2018 http://jnr2018.eii.uva.es

New Steps towards the Integration of Robotic and Autonomous Systems in the Inspection of Vessel Holds

Alberto Ortiz*, Kai Yao, Francisco Bonnin-Pascual, Emilio Garcia-Fidalgo, Joan P. Company-Corcoles

Departament of Mathematics and Computer Science, Universitat de les Illes Balears (UIB), Cra. Valldemossa, km 7.5, 07122, Palma de Mallorca, Spain

Abstract

Vessels constitute one of the most cost effective ways of transporting goods around the world. Despite the efforts, maritime accidents still occur, sometimes with catastrophic consequences. Ships involved in these activities are periodically submitted to inspections for the early detection of the defective situations that precede service disruptions, personnel injuries and, ultimately, shipwrecks. These inspections are nowadays carried out by human surveyors at a great cost from both time and economical points of view. The recently initiated EU-funded H2020 project ROBINS pursues filling the technology and regulatory gaps that today still represent a barrier to the adoption of Robotics and Autonomous Systems (RAS) in activities related to the inspection of ships, starting from understanding end-user's actual needs and expectations as well as analyzing how existing or near-future technology can meet them. This paper overviews the ROBINS project, focusing on the main development activities to be carried out by the UIB, namely a re-designed Micro-Aerial Vehicle (MAV) specialized for the inspection of cargo holds and new tools for the analysis of the inspection data collected by the robotic platforms. *Copyright © 2018 CEA.*

Keywords:
Aerial Vehicle, Supervised Autonomy, Visual Inspection, Defect Detection, Machine Learning, Deep Learning
Project data:
Title: ROBINS (ROBotics technology for the INspection of Ships)
Reference: GA 779776 (ICT programme)
Main researcher: Alberto Ortiz (UIB)
Type of project: International
Funding entities: European Commission
From/to dates: 1/01/2018 – 31/12/2020

1. Introduction

With over 80 per cent of global trade by volume and more than 70 per cent of its value being carried on board ships and handled by seaports worldwide, the importance of maritime transport (particularly as regards trade and development) is unquestionable, and even more as the seaborne trade increases year after year pushed by the global economic growth (UNCTAD secretariat, 2017). This demand for maritime transport services is dealt by large-tonnage vessels specific for the kind of product to freight, namely oil tankers, bulk carriers, and general cargo or container ships, to name but a few. As any other installation or infrastructure, this type of vessels requires regular maintenance to avoid its deterioration due to a varied set of causes, ranging from design mistakes, use of sub-standard materials or procedures, structural overload or normal decaying of the metallic structures in the sea. Otherwise, i.e. proper maintenance procedures are not carried out, ship accidents can result, with catastrophic consequences for the crew (and passengers), environmental pollution or damage and/or total loss of the ship, its equipment and its cargo.

The presence and spread of defects such as corrosion and cracks are indicators of the state of the vessel hull, so that an early detection can prevent major problems. To avoid reaching such undesirable situation, inspections on board sea-going vessels are regular activities being initiated partly due to applicable classification and statutory regulations (imposed by the so-called Classification Societies), and partly because of the obvious interest of ship operators and ship owners in anticipating the defective situations, given the costs associated to unexpected disruptions of vessel service availability. Among others, visual inspections aiming at detecting the aforementioned defects (and others), through close-up surveys where the involved personnel has to get within arm's reach of the structural element under observation, are well established procedures included in any vessel maintenance programme.

To illustrate the enormity of the inspection task, a VLCC (Very Large Crude Carrier) can contain up to 600,000m^2 of steel, involving over 860m of web frames (primary stiffening members) and approximately 3.2km of longitudinal stiffeners. Furthermore, the inspection requires that many of the tanks of

---

*Corresponding author: Alberto Ortiz. This work is partially supported by project ROBINS (GA 779776) and by scholarship BES-2015-071804.

E-mail: `alberto.ortiz@uib.es` (Alberto Ortiz)

Figure 1: Access arrangements required during vessel inspection: scaffolding and cherry pickers.

the vessel (cargo, fuel, ballast, etc.) are emptied, ventilated (because of the presence of flammable and/or toxic gases) and cleaned prior to the inspection, and that suitable access is arranged, typically using scaffolding or cherry-pickers to reach heights of up to 20-30m (see Fig. 1). In the case of older ships, this preparation will also be useful to allow the repair crew to enter and access the element that has failed. However, in a younger well-run ship, the survey is likely to reveal no defects in the early years, the number of required repairs is small, and so the bulk of these arrangements are mostly required for the survey itself. Once you factor the vessel's preparation in the use of yard's facilities, cleaning, ventilation, and provision of access arrangements, the total cost of a single surveying can exceed $1M. In addition, the ship owner experience significant lost opportunity costs while the ship is inoperable. (A more detailed discussion can be found in (Ortiz et al., 2010).)

In line with the aforementioned, the EU-funded FP7 projects MINOAS (finished on 2012) and INCASS (finished on 2017) had among their goals the development of robotic devices to assist and simplify the inspection of vessels. Their respective outputs comprised new aerial platforms, responsibility of the UIB team, and climbing rovers, both specifically designed for ship inspection. This paper focuses on the EU-funded H2020 project ROBINS initiated in 2018, and in which the UIB team also participates. Starting from the multi-rotor platforms developed along projects MINOAS (Eich et al., 2014) and INCASS (Bonnin-Pascual y Ortiz, 2016), and taking into account the lessons learnt during the respective field trials, several options about structure, control approach, platform localization, capabilities and interface with the users are to be considered and integrated within the framework of project ROBINS to increase the TRL of the currently available platforms. New defect detection approaches and inspection assistance tools are as well to be developed as part of the activities to undertake within the ROBINS project.

The rest of the paper is organized as follows: Section 2 overviews the ROBINS project; Sections 3 and 4 discusses on the new developments to be accomplished by the UIB team within this project, respectively, a new multi-rotor platform specialized for the inspection of cargo holds and new image analysis and defect detection tools for surveyor assistance; Section 5 concludes the paper.

2. Overview of the ROBINS project

The ROBINS project aims at filling the technology and regulatory gaps that today still represent a barrier to the adoption of Robotics and Autonomous Systems (RAS) in activities related to the inspection of ships, starting from understanding end-user's actual needs and expectations as well as analyzing how existing or near-future technology can meet them. In this project, the focus is set mainly on operational scenarios that can be representative of a wide variety of applications. In particular, ROBINS focuses on inspections in bulk carrier holds and ballast tanks. The challenges to be faced in these environments can also be met in other ship types, like general cargos, container ships and tankers, even though some differences and limitations naturally arise. In these environments, inspections are actually carried out mainly by means of scaffolding, portable ladders, and cherry pickers, methods which are time-consuming, expensive, may cause damage to coating, and expose the surveyor at risk.

Specifically regarding robotics technology, the project has the following objectives: (1) improve the ability of RAS regarding sensing and probing; (2) enhance their capabilities as for navigation and localization, access to and mobility within the environment; (3) improve safety and dependability of RAS in harsh and dirty environments; and (4) provide new tools for processing images and data collected by advanced sensors, with special focus on augmented reality and on the production of 3D models for virtual tours.

The ROBINS project focuses on two types of RAS: aerial platforms and crawlers. This choice derives from the assumption that a survey, including those for statutory and class certification, normally consists of an overall visual examination of the items of interest for the survey, and detailed checks of selected parts, e.g. measurement of thickness, on a sampling basis. Aerial vehicles are taken into consideration essentially for tasks related to visual inspection, while the crawler is intended for thickness measurements and other close-up investigations.

Two main types of operational scenarios are considered for the aerial robots: wide volumes with a reduced number of obstacles and irregular surfaces, like cargo holds and cargo tanks, and very irregular, narrow, obstacle-rich spaces, like ballast tanks, forepeaks, cofferdams, etc. These two types of operational scenarios are representative of the two environments where costs and risks connected to inspection activities are more significant, namely wide volumes with significant heights, like bulk carrier's cargo holds, which require costly access means to reach high points, while large unobstructed heights between levels imply severe consequences for the safety of surveyors, and narrow spaces, on the other side, which mean hazards related to access, mobility, ventilation, cleanliness, toxic atmosphere, etc. In ROBINS, the requirements deriving from the two aforementioned operational scenarios are met by two different aerial vehicles with different features and capabilities: an advanced platform with rich sensory equipment and software technology for highly autonomous unsupervised navigation, able to smartly explore wide spaces, and a collision-tolerant flying robot allowing access to complex, cluttered indoor places.

The crawler is going to be used mainly in regular spaces, where its capabilities can be exploited at best, achieving good performance and cost effectiveness. The crawler is mainly used for thickness measurement and other probing activities in environments where the occurrence and type of obstacles are such that they can be overcome without the need of excessively time-consuming operations or frequent human intervention.

On the normative side, and concerning the regulatory aspects relevant to the use of RAS in ship inspection, ROBINS has the following objectives: (1) define criteria, testing procedures and metrics for the evaluation of RAS performance in terms of safety, functionality, dependability, security, data quality and economic viability; (2) design, implement and assess a Testing Facility (TF) where repeatable tests and measurements can be performed for the evaluation of the compliance between RAS and the requirements; and (3) provide a framework to assess the equivalence between the outcomes of RAS-assisted ship inspections and traditional inspection procedures.

The possibility to replace, or at least reduce, field trials by means of equivalent test protocols carried out in the TF, is one of the key concepts in ROBINS, and comes from the consideration that field trials on board ships are generally very difficult to be arranged, can be quite expensive and usually cannot be executed in controlled and reproducible testing conditions, what constitute severe limitations for the development of RAS platforms for ship inspection. Despite the aforementioned, field trials are not to be suppressed, but, to the contrary, are to provide feedback to revise the testing protocols and the TF itself, thus creating an iterative refining process that converges to a TF relevant for the assessment of RAS for ship inspection.

Finally, sensor data processing software tools also play a key role in ROBINS RAS-assisted inspections. This software is expected to: (1) build a 3D model of the environment under inspection from the sensor data collected by the robotic platforms; (2) permit virtual tours within the 3D model that allows the surveyor to examine accurately the details of interest, what in turn requires a detailed and viewpoint consistent rendering of the surface observed; and (3) identify critical or suspect areas from the analysis of the visual data acquired during the inspection and highlight such areas to provide a valuable guidance to the surveyor.

Finally, ROBINS adopts an iterative approach based on several feedbacks and loops, expected to significantly improve the quality of final results, giving valuable means to continuously monitor how effectively the solutions adopted meet the requirements.

3. Flying robot for the inspection of cargo holds

A number of recent works have considered the use of Micro-Aerial Vehicles (MAVs) within the context of the inspection and monitoring of industrial facilities and assets, for data collection at remote or safety-compromised areas, difficult to reach by humans and ground vehicles, and with large areas to be covered as fast as possible. The aforementioned works consider, among others, power plant boilers (Nikolic et al., 2013), dam walls and penstocks (Ozaslan et al., 2015), bridges (Jimenez-Cano et al., 2015), power lines (Araar y Aouf, 2014), wind turbines (Stokkeland et al., 2015), mines and tunnels (Gohl et al., 2014), petrochemical facilities (Huerzeler et al., 2012), and large-tonnage vessels (Ortiz et al., 2016).

This section reviews the sensors available and outlines the requirements and goals of the MAV to develop.

3.1. A navigation sensor suite for cargo hold inspection

In order for the previous platforms to be of practical use in the aforementioned cases, typically GPS-denied scenarios, sufficient on board sensors and computing power are needed to stabilize the platform and localize it within the environment, build maps, perceive and avoid obstacles, and plan flight trajectories. Solutions published so far mainly differ in the sensor(s) used, the amount of processing that is performed on-board/off-board and the assumptions made about the environment. Among the different sensing devices available nowadays, the following reviews those that can be of use for the case of cargo hold inspection given its character of rather larger, regular-shaped areas:

- *2D laser scanners.* 2D laser scanners have been extensively employed due to its accuracy and speed. For instance, (Dryanovski et al., 2013) proposed full navigation systems using laser scan matching and Inertial Measuring Unit (IMU) fusion for motion estimation embedded within Simultaneous Localization and Mapping (SLAM) frameworks. 3D laser scanners have also been incorporated in aerial applications (Kaul et al., 2016), using rotating 2D scanners as a lower-weight solution. In these cases, a 3D model of the environment is obtained without resorting to multi-level mapping approaches, such as the ones involved when using 2D laser scanners. Both laser-based solutions, however, require rather large platforms due to the weight and volume occupied by the main navigation sensor (higher for the 3D version).

- *Vision-based navigation.* Vision-based navigation has become quite popular for MAVs lately. Cameras' success in general robotics come mainly from the richness of the sensor data supplied, combined with low weight, low power designs and a relatively low price. Nevertheless, for the particular case of MAVs, the associated higher computational cost has required from researchers to find optimized solutions that can run over low-power processors. Besides, their use is limited in dark environments, even carrying low-power light sources. Among the most recent visual navigation solutions proposed so far, some propose visual SLAM solutions based on feature tracking, either adopting a frontal mono or stereo camera configuration, e.g. (Heng et al., 2014), or choosing a ground-looking orientation, e.g. (Weiss et al., 2013). Others focus on efficient implementations of optical flow calculations, either dense or sparse, and mostly from ground-looking cameras, e.g. (Grabe et al., 2012), or develop methods for landing, tracking and taking off using passive, e.g. (Eberli et al., 2011), or active markers, e.g. (Wenzel et al., 2011), also using a ground-looking camera. Finally, (Bonnin-Pascual et al., 2015) implements platform navigation by means of the combination of two optical flow sensors, such as the one described in (Honegger et al., 2013), in two orthogonal orientations, ground-looking and front-looking.

- *Depth and RGB-D cameras.* Depth and RGB-D cameras are the last type of sensor that has been incorporated to implement autonomous flight (Fang y Scherer, 2015). RGB-D cameras allow the capture of reasonably accurate mid-resolution depth and appearance information at high data rates, so that alignment between frames can be computed by jointly optimizing through both appearance and shape matching. These systems can accurately align and map large indoor environments in near-real time and are capable of handling situations such as featureless corridors and poorly lit rooms.

For the case of generic vessel inspection, and in order to fit likely scenarios, we have considered extreme cases, such as e.g.

the cargo holds of a bulk carrier, typically semi-indoors, well lit areas, and of an oil tanker, always indoors environments, fitted with a single manhole-sized entry point, and therefore in almost total darkness. In order for the MAV to be able to navigate under these circumstances, it is necessary to integrate an appropriate navigation sensor suite, not depending on the availability of GPS signal (i.e. operation in GPS-denied areas) nor depending on the quality of the illumination. Because of these limitations, our proposal is to combine a long-range laser scanner with a shorter-range RGB-D camera, together with an IMU and a suitable heightmeter. This sensor suite would be useful not only for navigation (localization and collision avoidance) but also to provide inspection data: partial point clouds and images (the vehicle is to carry its own light source).

Additionally, for the particular problem of pose estimation (i.e. not including collision detection), we plan to complement the previous selection of sensors with wireless-based localization (Liu et al., 2007). This technology has recently received a significant amount of attention as an alternative of GPS in poor signal reception areas, being a priori especially suited for the kind of scenarios which can be found in cargo holds. Among the different possibilities available nowadays, Ultra-Wide Band (UWB) systems have emerged as one of the leading positioning technologies because the UWB ultra-short pulses are resilient to frequency-dependent absorption, thanks to their large bandwidth, and because ultimate accuracy can be up to 2 cm (Bahr et al., 2012).

3.2. *New platform functionalities and capabilities*

In ROBINS, the focus is on addressing those issues that can prevent the incorporation of MAVs in routine cargo hold inspections and adopting specialized strategies for each issue that typically arises in this kind of environment.

First of all, as already discussed above, operating conditions in cargo holds, although being large areas in general, can change significantly from one case to another, from poorly lit (or even completely dark) environments with a single, man-hole sized entry point in oil tankers to open, wide areas under sun light in the case of bulk carriers (hatch door open) and containerships. This makes MAV navigation a challenge since a single sensor modality will not always be appropriate: e.g. dark environments do not permit using navigation solutions based on cameras, but other sensors, such as laser-, infrared-, sonar- or radar-based devices must be adopted; featureless scenarios also limit the effectiveness of vision-based motion estimation methods, while long corridors or walls (in comparison with sensor maximum range), where the environment does not present a discriminative shape that can be matched uniquely across scans, puts laser-based solutions in trouble, etc. In addition, a combination of relative and absolute localization is under consideration, e.g. laser-based navigation together with easy-to-deploy UWB technology.

Secondly, being one of the main goals the incorporation of these platforms into routine inspection procedures, platform usability and robustness become key aspects. In order to do so, a Supervised Autonomy (SA) approach (Cheng y Zelinsky, 2001) will be adopted (see Fig. 2). Under this paradigm, the robotic platform implements a number of behaviours that allows it to attain in a modular way different levels of autonomy and cover different kinds of tasks and situations, ranging from low- to medium-level complexity, without human intervention.

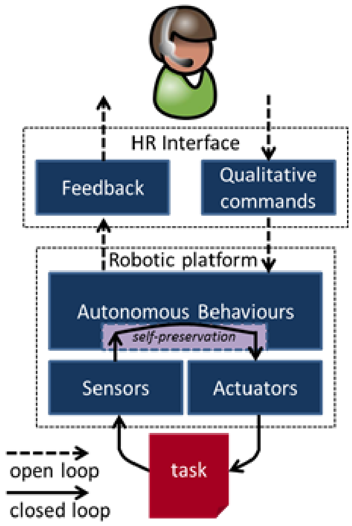

Figure 2: Illustration of the concept of Supervised Autonomy (SA).

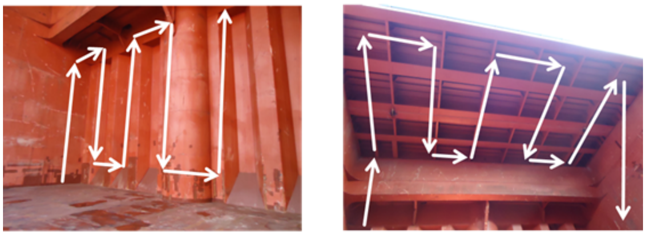

Figure 3: Example of path which could be followed by the MAV to ensure an adequate level of coverage of the structure under inspection.

The idea is not to switch from one mode of operation (total autonomy) to the other (teleoperation), but to implement a global approach under which a man is always in the loop, monitoring the progress of the task under execution, which if possible runs in autonomous mode, but allows him to take control whenever necessary. Besides, thanks to the behaviours running onboard the platforms, the operator does not need to deal with (nor to be trained about) the control complexities of the platform, but can interact through terse, intuitive commands. Consequently, situation awareness, human judgment and decision making takes place at the precise level where they are required, and with the proper support through the available technological means. In this way, the full system can attain a high level of robustness since those situations which can be worked out reliably are solved autonomously, while those of high complexity are supported by an operator through a friendly, useful interface. At the same time, the autonomy of the whole system is easily extensible. Precisely, ROBINS aims at incorporating new autonomous functionalities into the MAV control architecture.

One of these autonomous functions deals with ensuring a proper coverage of the structures under inspection, e.g. a bulkhead, so that the visual data collected (as well as other data modalities) can effectively contribute to the 3D reconstruction of the environment (Figure 3 illustrates this capability).

Finally, usability not only refers to the development of software that implements the functions actually needed by the user, but also means hardware that facilitates, in this case, the inspection procedures. To this end, we plan to proceed case by case, and adopt a modular structure, which permits exchanging components depending on the particular inspection to perform. This is to make compatible the different requirements with the payload restrictions. As well, this will mean a challenge, from not only the mechanical/electrical point of view, but also regarding the Control Software Architecture (CSA). It will need to be able to adapt to a number of configurations, both regarding the interaction with the current hardware and regarding the capabilities which that hardware fits the platform with. Easy transport and deployment are additional desirable features that have an impact on usability which will also have to be dealt with: e.g. easy deployment of UWB infrastructure, practical transport of the platform itself, etc.

3.3. *Implementation aspects*

Starting from the multi-rotor platforms developed along projects MINOAS and INCASS, and taking into account the lessons learnt during the respective field trials, several options about structure, control approach, platform localization, capabilities and interface with the users will be considered and integrated to increase the TRL attained after the activities undertaken within the respective frameworks of the previous projects.

All this entails re-design/development/integration at both the hardware (platform structure, sensors and computational devices) and software levels (low-, mid- and high-level control issues in isolation, and also as part of a global control software architecture). The focus will not be on a single platform able to deal with all possible situations, but on a multi-purpose, flexible, and robust vehicle which can adapt to the relevant scenarios, possibly exchanging components specifically suited for specific inspection cases, what requires the adoption of a modular approach during the design stage. This approach is adopted not only to take into account the payload restrictions of this kind of platforms, but also to put a particular emphasis on robustness by means of the use of specific solutions for specific problems. Easy/fast reconfiguration will be a must.

As mentioned before, the same high-level global control approach based on SA will be kept, what means the transfer/adaptation to the new platform of the high- and mid-level control layers developed for MINOAS and INCASS platforms, but being enhanced with further autonomous functionalities aiming at simplifying the inspection process as well as incorporating new ones required to support the posterior software tools available for the inspector.

4. Inspection data processing and analysis

The different steel surfaces that are part of a vessel's hull can be affected by different kinds of defective situations, such as coating breakdown, corrosion, and, ultimately, cracks. These defects are indicators of the state of the metallic surfaces and, as such, an early detection prevents the structure from buckling or fracturing. In this regard, the inspection task is to be simplified both if tools for conveniently visualizing the data collected by the robotic platforms are available and if potential defects are detected and highlighted so as to draw the attention of the surveyor to the relevant points of the structure.

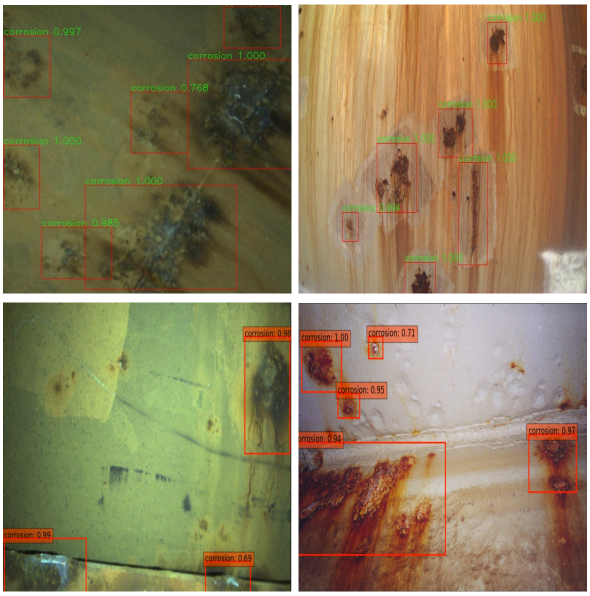

Figure 4: Examples of CBC detection results for Faster R-CNN (top) and SSD300 (bottom) DCNN approaches.

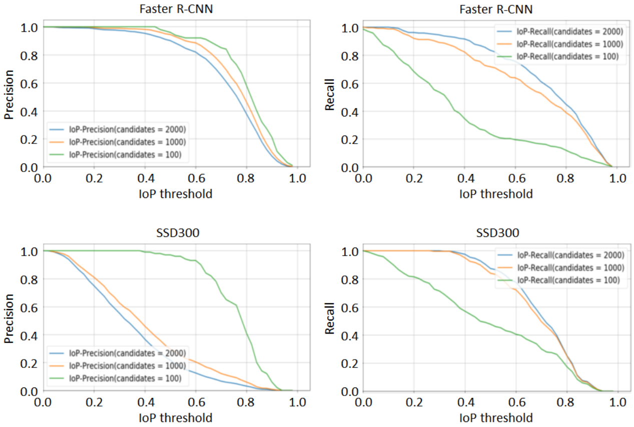

Figure 5: CBC detection: Precision and recall curves against the IoP threshold for Faster R-CNN (top) and SSD300 (bottom) DCNN approaches.

In ROBINS, we plan to adopt a different strategy for defect detection, contrary to the approaches followed in the previous projects MINOAS and INCASS, based on handcrafted feature extraction. This is to enhance defect detection capabilities as well as counteract complex lighting conditions and a great diversity of other conditions due to data obtained from different robots. Under these circumstances, the idea is to develop new solutions on the basis of highly robust machine-learning approaches such as Deep Convolutional Neural Networks (DCNN), which have already showed good results for object recognition in images (Maturana y Scherer, 2015) and looks promising for industrial inspection applications (Weimer et al., 2016). In contrast to manually designed image processing solutions, DCNN automatically generate powerful features, i.e. *learn the representation*, by hierarchical learning strategies from training data with a minimum of human interaction or expert process knowledge.

In this section, we report first results on Coating Breakdown and Corrosion (CBC) detection using DCNN within the context of transfer learning experiments (and hence training is only performed over the last fully connected layers). Figure 4 shows results for some example images and two well-known DCNN object recognition approaches named Single-Shot multi-box Detector (SSD) (Liu et al., 2016) and Faster R-CNN (Ren et al., 2015), being the latter combined with VGG16 (Simonyan y Zisserman, 2014). Detections are indicated as bounding boxes superimposed over the original images. On the other side, Fig. 5 plots precision (P) and recall (R) curves against the Intersection over Prediction (IoP) threshold and the number of region proposals predicted, where the IoP is a variant of the normally used Intersection over Union (IoU) metric normally employed for the assessment of object detection approaches:

$$\mathrm{IoP} = \begin{cases} \frac{A(b_{gt} \cap b_p)}{A(b_{gt})} & \text{if } A(b_{gt}) \geq A(b_p) \\ \frac{A(b_{gt} \cap b_p)}{A(b_p)} & \text{if } A(b_{gt}) < A(b_p) \end{cases}, \qquad (1)$$

where $A(\cdot)$ is the number of pixels of a rectangular image area, b_{gt} represents a bounding box from the ground truth and b_p refers to the predicted bounding box with largest overlapping with b_{gt}. The involved dataset comprises images from different real vessels, compartments and illumination conditions. We employ the IoP because, in these experiments, we value more highlighting the presence of a defect rather than predicting bounding boxes tightly corresponding to the ground truth. As can be observed, Faster R-CNN behaves better in general with precision curves well above SSD precision curves, while recall curves are quite similar. Best performance is for IoP ≥ 0.4 and 2000 region proposals, leading to $P > 0.9$ and $R > 0.9$.

5. Conclusions

This paper has overviewed project ROBINS, whose main goal is to fill the technology and regulatory gaps that nowadays represent a barrier to the adoption of RAS in ship inspection, and has outlined the different tasks that the UIB team has to undertake in order to contribute to the accomplishment of the aforementioned goals.

References

Araar, O., Aouf, N., 2014. Visual servoing of a quadrotor UAV for autonomous power lines inspection. En: Proc. IEEE Mediterranean Conf. on Control and Automation.

Bahr, A., Feldman, A., Colli-Vignarelli, J., Robert, S., Dehollain, C., Martinoli, A., 2012. Modeling and benchmarking ultra-wideband localization for mobile robots. En: Proc. IEEE Intl. Conf. on Ultra-Wideband.

Bonnin-Pascual, F., Ortiz, A., 2016. A flying tool for sensing vessel structure defects using image contrast-based saliency. IEEE Sensors Journal 16 (15), 6114–6121.

Bonnin-Pascual, F., Ortiz, A., Garcia-Fidalgo, E., Company, J. P., 2015. A micro-aerial platform for vessel visual inspection based on supervised autonomy. En: IEEE/RSJ Int. Conf. on Intell. Robots and Systems.

Cheng, G., Zelinsky, A., 2001. Supervised Autonomy: A framework for human-robot systems development. Autonomous Robots 10 (3), 251–266.

Dryanovski, I., Valenti, R. G., Xiao, J., 2013. An open-source navigation system for micro aerial vehicles. Autonomous Robots 34 (3), 177–188.

Eberli, D., Scaramuzza, D., Weiss, S., Siegwart, R., 2011. Vision based position control for MAVs using one single circular landmark. Journal of Intelligent and Robotic Systems 61 (1-4), 495–512.

Eich, M., Bonnin-Pascual, F., Garcia-Fidalgo, E., Ortiz, A., Bruzzone, G., Koveos, Y., Kirchner, F., 2014. A robot application for marine vessel inspection. Journal of Field Robotics 31 (2), 319–341.

Fang, Z., Scherer, S., 2015. Real-time onboard 6DoF localization of an indoor MAV in degraded visual environments using a RGB-D camera. En: IEEE Int. Conf. on Robotics and Automation.

Gohl, P., Burri, M., Omari, S., Rehder, J., Nikolic, J., Achtelik, M., Siegwart, R., 2014. Towards autonomous mine inspection. En: Proc. Intl. Conf. on Applied Robotics for the Power Industry.

Grabe, V., Bulthoff, H. H., Giordano, P. R., 2012. On-board velocity estimation and closed-loop control of a quadrotor uav based on optical flow. En: IEEE Int. Conf. on Robotics and Automation.

Heng, L., Honegger, D., Hee-Lee, G., Meier, L., Tanskanen, P., Fraundorfer, F., Pollefeys, M., 2014. Autonomous visual mapping and exploration with a micro aerial vehicle. Journal of Field Robotics 31 (4), 654–675.

Honegger, D., Meier, L., Tanskanen, P., Pollefeys, M., 2013. An open source and open hardware embedded metric optical flow cmos camera for indoor and outdoor applications. En: IEEE Int. Conf. on Robotics and Automation.

Huerzeler, C., Caprari, G., Zwicker, E., Marconi, L., 2012. Applying aerial robotics for inspections of power and petrochemical facilities. En: Proc. Intl. Conf. on Applied Robotics for the Power Industry.

Jimenez-Cano, A., Braga, J., Heredia, G., Ollero, A., 2015. Aerial manipulator for structure inspection by contact from the underside. En: IEEE/RSJ Int. Conf. on Intell. Robots and Systems. pp. 1879–1884.

Kaul, L., Zlot, R., Bosse, M., jul 2016. Continuous-time three-dimensional mapping for micro aerial vehicles with a passively actuated rotating laser scanner. Journal of Field Robotics 33 (1), 103–132.

Liu, H., Darabi, H., Banerjee, P., Liu, J., 2007. Survey of wireless indoor positioning techniques and systems. IEEE Transactions on Systems, Man and Cybernetics, Part C (Applications and Reviews) 37 (6), 1067–1080.

Liu, W., Anguelov, D., Erhan, D., Szegedy, C., Reed, S., Fu, C.-Y., Berg, A. C., 2016. SSD: Single shot multibox detector. En: Leibe, B., Matas, J., Sebe, N., Welling, M. (Eds.), European Conf. on Computer Vision.

Maturana, D., Scherer, S., 2015. Voxnet: A 3d convolutional neural network for real-time object recognition. En: IEEE/RSJ Int. Conf. on Intell. Robots and Systems.

Nikolic, J., Burri, M., Rehder, J., Leutenegger, S., Huerzeler, C., Siegwart, R., 2013. A UAV system for inspection of industrial facilities. En: Proc. IEEE Aerospace Conf.

Ortiz, A., Bonnin-Pascual, F., Garcia-Fidalgo, E., Company-Corcoles, J., 2016. Vision-based corrosion detection assisted by a micro-aerial vehicle in a vessel inspection application. Sensors 16 (12), article nr. 2118.

Ortiz, A., Bonnin-Pascual, F., Gibbins, A., Apostolopoulou, P., Bateman, W., Eich, M., Spadoni, F., Caccia, M., Drikos, L., 2010. First steps towards a roboticized visual inspection system for vessels. En: IEEE Int. Conf. on Emerging Technologies and Factory Automation. pp. 1–6.

Ozaslan, T., Shen, S., Mulgaonkar, Y., Michael, N., Kumar, V., 2015. Inspection of penstocks and featureless tunnel-like environments using Micro UAVs. En: Mejias, L., Corke, P., Roberts, J. (Eds.), Proc. Intl. Conf. on Field and Service Robotics.

Ren, S., He, K., Girshick, R., Sun, J., 2015. Faster r-cnn: Towards real-time object detection with region proposal networks. En: Proc. on Advances in Neural Information Processing Systems. pp. 91–99.

Simonyan, K., Zisserman, A., 2014. Very deep convolutional networks for large-scale image recognition. CoRR abs/1409.1556.

Stokkeland, M., Klausen, K., Johansen, T. A., 2015. Autonomous visual navigation of unmanned aerial vehicle for wind turbine inspection. En: Proc. Int. Conf. on Unmanned Aircraft Systems. pp. 998–1007.

UNCTAD secretariat, 2017. Review of Maritime Transport, United Nations Conference on Trade and Development, UNCTAD/RMT/2017.

Weimer, D., Scholz-Reiter, B., Shpitalni, M., 2016. Design of deep convolutional neural network architectures for automated feature extraction in industrial inspection. CIRP Annals 65 (1), 417–420.

Weiss, S., Achtelik, M. W., Lynen, S., Achtelik, M. C., Kneip, L., Chli, M., Siegwart, R., 2013. Monocular vision for long-term micro aerial vehicle state estimation: A compendium. Journal of Field Robotics 30 (5), 803–831.

Wenzel, K. E., Masselli, A., Zell, A., 2011. Automatic take off, tracking and landing of a miniature UAV on a moving carrier vehicle. Journal of Intelligent and Robotic Systems 61 (1-4), 221–238.