# AUTONOMOUS SYSTEMS & SAFETY ISSUES: THE ROADMAP TO ENABLE NEW ADVANCES IN INDUSTRIAL APPLICATIONS

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## ABSTRACT
The paper addresses the safety issues related to the development of new solutions based on autonomous systems for industrial applications and the necessity to develop experimental environments for investigating these cases; a set of examples is proposed in order to provide cases and challenges as well as to suggest approaches to address these problems.

Keywords: Autonomous Systems, Safety, Industrial Plants, Security, Modeling and Simulation

## 1. INTRODUCTION
Industry 4.0 integrates all automation technologies and, among others, also the new category of the so-called UxVs (Unmanned Vehicles), i.e. all those remote ground, aquatic (surface or underwater) or aerial (fixed or rotary wing) vehicles operating with different levels of autonomy, from remotely operated to fully autonomous. Unmanned vehicles are characterized by many advantages, ranging from their agility and speed in reaching places that would be otherwise difficult to access, to their potential in replacing humans in the presence of dangers, to their expendable nature; due to these characteristics, UxVs are becoming popular and spreading exponentially among many different application fields, with special attention to the most light and less expensive models (Salvini 2017). Such versatility is reflected by their dissemination which is monitored and studied with great interest by the authorities and agencies involved in security and prevention in all areas, and therefore also by INAIL, in particular by DIT, the Department of Technological Innovations (Clarke et al. 2014; Di Donato 2017).

Figure 1 – IDRASS Simulator operating Autonomous Systems inside Industrial Plants

In Italy, DIT is also assessing its potential through research work aimed at promoting its diffusion for reducing the workers exposure to high risks and difficult tasks, where human presence was supposed to be indispensable up to now and to ensure safe inspections and monitoring to maintain the safety of hard-to-access structures and work equipment (Spanu et al. 2016).

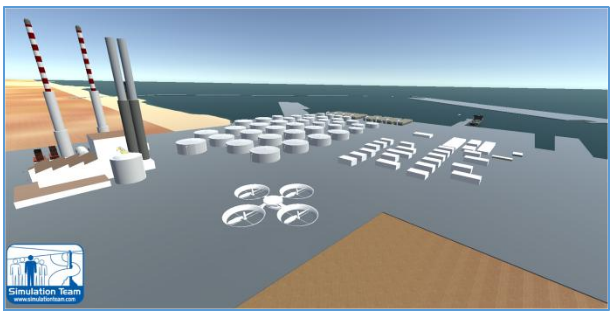
Figure 2 – UAV overview within Critical Infrastructure Protection Simulator, T-REX

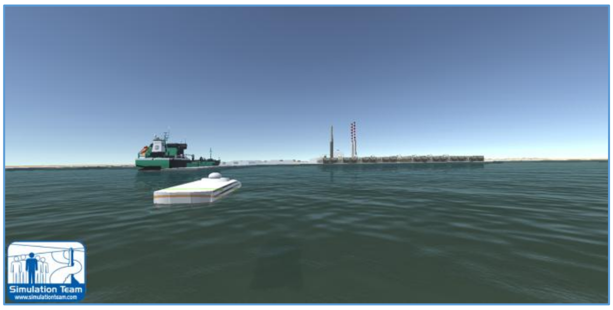

Figure 3 – T-REX combined protection of Port Framework by USV and other Autonomous Systems

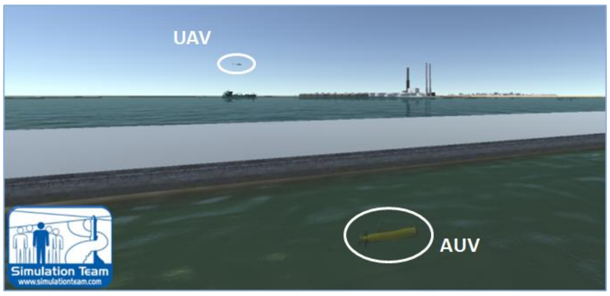


Figure 4 – AUV patrolling around the Critical Infrastructure in cooperation with UAV

Today efforts are made to promote the spread of Autonomous Systems, given their possible employment for prevention on safety, therefore it is not possible to ignore the fact that the introduction of such a new technology, even though one of its objectives is Risk reduction, can result itself a carrier of new risks and dangers that require to be investigated.
In this paper, it is proposed a set of case studies related to use of UAV (Unmanned Aerial Vehicles), UGV (Unmanned Ground Vehicle), USV (Autonomous Surface Vehicles) and AUV (Autonomous Underwater Vehicles) in industrial applications where safety and security are two main streams; these cases propose opportunities and challenges for the introduction of this technology in industrial sectors as well as the need to fix requirements for the equipment, the procedures and the training programs.

## 2 UxV & SAFETY

Safety is a major issue as well as one of the major driver, along with security, for the extensive use of UxV in civil and military applications; in facts their low operational cost and expendable nature make them ideal for being used in dangerous environments and almost all case studies proposed in the paper deal with these topics (Apvrille et al.2015; Merwaday & Guvenc 2015; Altawy et al. 2016). Due to the complexity of these context the use of M&S (Modeling and Simulation) is considered often the most promise methodology for investigating modern UxV problems (Bruzzone et al. 2016a).
In facts, Simulation Team is an International Network of Excellence working on up-to-date simulation technologies and has acquired a large experience in autonomous systems within a broad set of applications with special attention to collaborative multi domain cases (Bruzzone et al. 2014, 2016b). Along last years, the Simulation Team has activated several projects for Industry and major Agency in using UxV in industrial plants (Bruzzone et al. 2016a).
From another point of view, INAIL-DIT is a Department that, in line with its mission, is approaching these new UxV and remote pilot systems while also keeping in mind the safety aspect. The safety measures to be taken in the design and use of drones are just some of the topics that will need to be addressed in order to get products up to all applications where they can be effectively used; among these topics for instance it could be useful to develop studies on materials suitable for protecting the drone itself as well as the people around, or the development/adoption of sufficiently advanced safety equipment, beyond the ones required to fulfil the functional requirements of the drone (Valavanis et al. 2014; Sanchez-Lopez et al. 2016). Finally, it is desirable that regulatory and technical standards follow, or rather support, this innovative process within Industry 4.0 and its technologies, including remote pilot systems (Kehoe et al.2015). INAIL-DIT is committed to being ready to support the National Authorities in every step when collaboration would be necessary. For instance, the use of remote pilot systems involves remote control by a human and, sometimes, the presence of other personnel engaged in carrying out work in close proximity to the areas where autonomous vehicle operations take place; this introduces issues about training among the others. In addition this scenario implies also the need to apply the relevant legislation for the protection of the health and safety of workers, as well as the rules of transposition of applicable product and other relevant National or International regulations (Djellal & Gallouj 1999). This implies that the authorities and bodies involved are plural; in addition to the European Commission, which is responsible for the issuance of directives/product regulations, many National Departments and Ministries as well as Public Organizations are involved, such as, for instance in Italy, the Ministry of Labour and Social Policies, the Health and Safety of Workers, the Ministry of Labour Infrastructure and Transport, for Aviation Security or Navigation and the National Agency for Civil Aviation. In the following it is proposed an overview of different application fields for UxV where remotely operated vehicles and autonomous systems might positively affect the health and safety of workers. Given the succession of serious and fatal accidents occurred over the past few years during the conduct of activities in suspected or confined environments (Spillane et al. 2012; Nano et al.2013; Leão et al. 2015), which in many cases highlights an inadequate risk assessment of the possible presence of hazardous substances, one of the first uses of remote pilot systems is definitely about air quality control in confined environments such as silos, tanks, holds, and other environments (Valavanis et al. 2014).

In this case, it might be useful to equip drones with "smart" sensors for evaluation, for example, of the conditions that may allow operators to enter in dangerous areas (Floreano & Wood 2015). It is clear that, in order to operate these systems, it is necessary to carefully consider the characteristics that these systems to check consistency with presence of liquids, vapours or dust and, more generally, hazardous areas (such as areas subject to the ATEX Directive). These analysis and requirements are devoted to ensure safe and adequate use of UxVs under critical conditions that may occur in confined environments, or in general, within the areas where they should operate during emergencies; for instance in avoiding the accident escalation from fire scenarios in case of upper tier Seveso plants (Palazzi et al. 2017).

in order to ensure its safe and adequate use in difficult conditions that may occur in confined environments or in general in environments where drones should intervene for emergency management (e.g. in case of Accidents at high risk companies). Another useful application of UAVs for the protection and safety of workers is their use for inspections at relevant heights or at least in difficult-to-reach areas for structures and equipment in order to check their integrity and stability through a visual examination assisted by optical systems (cameras, thermal sensors etc.) or checks performed using other equipment (Jones 2006).In addition, UAVs can be utilized for environment surveys through high-resolution photographic capture, enabling visual 3D mapping and thus the knowledge of orographic features (e.g. slopes of the ground) as well as to detect, in real time, the presence of obstacles and particular conditions of danger determined, for example, by climatic factors which may change the orographic conditions already observed (Siebert & Teizer 2014). Another important, but less known application of UxV is monitoring of infrastructure using GPR (Ground Penetrating Radar). Unlike other mentioned types of sensors, the GPR allows to control conditions of infrastructures hidden under soil; for instance it is possible to detect flooding or voids, furthermore, being installed on a UAV, the GPR allows to perform this operation in short time (Kovacevic et 1l. 2016). Of course drones could operate not only individually, but also in a swarm which allows to install different kinds of sensors on the platforms and it could enhance drastically data acquisition capabilities of the whole system; this swarm collaborative use represents one of most promising directions of research in this field (Burkle et al. 2011). The data acquired in this way are available for being communicated instantly to the control unit of a bulldozer or any other moving machine that, through the help of a GPS system, could "alert" the driver if it is approaching to danger zones; it becomes possible also to develop a smart guiding support, in an assisted way, by providing automatic corrective actions, such as speed reduction until stopping or finding an alternative route, as a dynamic new risk point or area is approaching (Kim et al. 2015).

To do this, the remote pilot system should be equipped with appropriate instrumentation (sensors, radar, cameras, etc.), now largely present on the market, which can be utilized with the specific task.

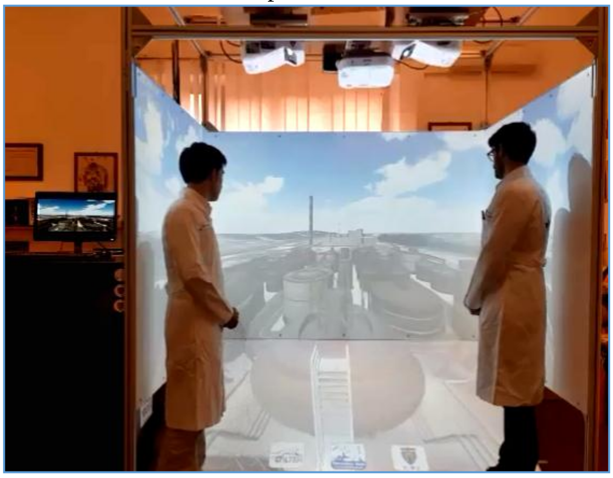

Figure 5 – Man on the Loop Supervising Operations within SPIDER special CAVE

As already mentioned, another useful area of employment is the acquisition of information through drones for the management of emergency relief activities (Doherty et al. 2007).

In facts, aerial reconnaissance with drones allows to have a direct view of the situation of places where it is not easy to access, at least for a first assessment process to drive first responders, thus facilitating assistance and recovery through, for example, identification of a possible access path to the affected area.

Other possible applications are those related to the evaluation of the various emissions of the machines and machineries (Gardi et al. 2016).

This includes also the use of microphone on drones that could prevent the placement of microphones on fixed positions difficult to be implemented due to the constraints of the machineries themselves (Ishiki et al. 2014). In addition, it has been studied the possibility to use drones to evaluate drift of fertilizers applied to irrigation machines in herbaceous and tree crops (Pulina et al. 2016).

This kind of testing could involve drift tracking using UAV equipped with high definition (HD) visual recording systems (Pizzarella 2014); the related images could be acquired by different profiles: from top, back and side, by using a water-based liquid mixed with a red powdered food for distribution analysis; once the drift motion is tracked the same is replicated graphically through the GIS support on an aerial photo.

More replicated tests in different climatic conditions could simulate different drift situations. In these cases further focused analysis could be carried out on the specific weight of the distributed product, as the weight of the treated molecules that have different behaviour even with same meteorological conditions.

In facts, it is now possible to extend the scope and use of new autonomous system technologies, including the remote pilot systems, to increase safety and health levels through specific studies and research that allow to evaluate and promote their effectiveness.

## 3 CASE STUDIES ON UxV SIMULATORS

The challenges presented in this paper represent often new application fields for UxV or specific implementations of new solutions; so it is evident that to complete their test and experiment and to evaluate related risks in terms of safety, it is necessary to recreate a realistic mission environments. Usually this requires to be addressed by M&S (Modeling and Simulation) in order to be effective (Bruzzone et al. 2014); in facts the adoption of MS2G paradigm (Modeling, interoperable Simulation and Serious Games) represents a very strategic advantage allowing to combining different models, simulators and also real equipment within a common synthetic environment. These simulation environments should be intuitive and interactive by using most advanced Mixed Reality solutions such as the SPIDER (Simulation Practical Immersive Dynamic Environment for Reengineering), developed by Simulation Team, in order to support the Subject Matter Experts (Bruzzone et al. 2016a). In the following case studies are proposed.

### *3.1 IDRASS*

Indoor Operations in industrial Plants are critical especially in case the environment is contaminated, so they represent an ideal example to apply UxV; from this point of view, the support during disasters in industrial facilities is a very popular area for R&D on UxV due to the challenges represented by these environments (Bruzzone et al. 2016a); some of the authors developed IDRASS (Immersive Disaster Relief and Autonomous System Simulation) to address this context in case of CBRN (Chemical, Biological, Radiological and Nuclear) contamination due to accidents or man-made disasters (see figure 1); IDRASS simulates both operations indoor and outdoor within different industrial facilities such as chemical and nuclear plants (Bruzzone et al.2016a). In these contexts it is usually necessary to introduce many actors to reproduce the whole crisis scenario and, obviously, the use of IA (Intelligent Agents) is a fundamental resource for being able to develop realistic mission environments. The safety issues in using drones within industrial facilities deals with the challenges due to these context (Mobley 2001): cables, cable trays, pipelines, tanks are physical obstacles that populate the area with high density. Therefore in several cases there also relief venting systems and safety valves that could create streams challenging for UxV in terms of blast as well as temperature; in the plants often the atmosphere could include dusts, corrosive agents as well as high temperature elements dangerous in terms of irradiations. It is evident that there are solid, thermal and gaseous barriers not easy to detect and creating complex environments; sometime the UxV could be required to operate also in confined environments where the air mix could turn to be dangerous for explosions respect the characteristics of some of the robotic system components. In facts, the whole industrial plant could include several systems that could create risks and domino effect in case of UxV collision or even just interaction; indeed the electronic interference between UxV controls and DCS (Digital Control System) could affect plant safety. In facts, it is also necessary to remind the very crucial aspect of electromagnetic compatibility. These aspects are common just to the presence of high voltage lines and equipment in the industrial plant and becomes even more intense in presence of ionizing radiation caused by nuclear spills and contamination, which could lead to loss of connection as well as drone malfunctions in case of its insufficient radiation hardening (McCurry 2017). In addition it is also necessary to consider the presence of “natural” communication barriers, caused by reflection and interference of electromagnetic waves due to the high density of metallic infrastructures; these are affecting UxV communications and operations.

From this point of view, it is expected to require an high level of autonomy to the UxV considering the risk to loose contact with central control.

In IDRASS also the issue related to battery autonomy are raised, considering that to move within an industrial plant and to carry out data collection and sensor measures it could challenging to have time to complete the whole mission, especially when moving indoor and/or in confined spaces. Finally the industrial plants include presence of humans and the UxV should be able to operate avoiding to injure them by collision or indirectly by generating other accidents.

### *3.2 T-REX*

In references to the necessity to address On-Shore Critical Infrastructure Protection, Simulation Team developed an innovative simulation defined T-REX (Threat network simulation for REactive eXperience) that recreates, into a virtual immersive interactive environment, these complex scenarios (Bruzzone et al. 2016b). T-REX simulator has been used to address different problems and involves combined used of UAV, UGV, USV and AUV to protect an industrial complex that provide strategic services (i.e. power, water, oil) to a region involving different towns as proposed in figures 2, 3 and 4.

The multi domain coordination is very crucial in critical infrastructure protection that are located in coastal area requiring to take care of threats from air, ground, sea surface and underwater. In this extended maritime framework, it is fundamental to develop coordination capabilities (Tether 2009).

Very promising results have been achieved, along last decade, in UAV coordination arriving to complete successfully complex operations such as air refueling (Richards et al. 2002; Ross 2006).

Therefore today one major challenge is related to create a network of collaborating autonomous systems that operate over different domains (Vail & Veloso 2003; Tanner 2007a; Shkurti et al. 2009; Maravall et al. 2013). In facts in order to be successful, it becomes necessary to develop a capability to control an heterogeneous network of different resources (Feddema et al. 2002; Ferrandez et al. 2013; Bruzzone et al. 2013c).

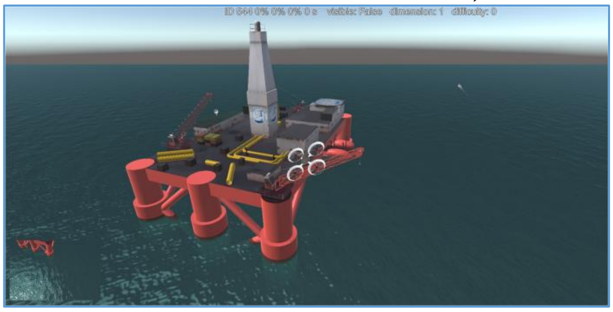

Figure 6 – SO2UCI with Drone supervision of the Off-Shore Platform

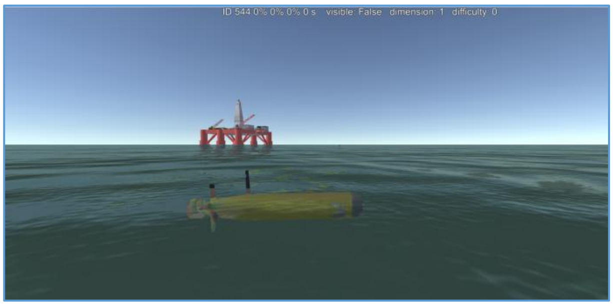

Figure 7 – AUV in SO2UCI patrolling around the Off-Shore Platform

From this point of view, an interesting idea is to assign the role of supervisor to humans instead than directly making them to pilot each single UxV as expressed by the man-on-the-loop concept supported by SPIDER solution as seen in figure 5 (Magrassi 2013).
This is a great opportunity, reducing drastically the number of people required to support complex operations, but also a challenge for safety and security and introduce new challenges in terms of technological solutions and training (Bruzzone et al. 2016a). In the case of critical infrastructure protection a major issue is related to false alarms; indeed, the large majority of suspect events are related to case dealing with harmless conditions due to general traffic, civilian unintentional infractions, birds or animal misclassification, etc (Bass 2000; Cardenas et al.2011). In addition to these considerations it is also possible to face sensor errors and failures that could create critical conditions in the protection systems (Merabti et al.2011).
In facts, this problem requires to cover 24/7 in presence even of challenging weather and boundary conditions (Kastek et al.2012).
Indeed the use of UxV could be useful to reinforce the protection of critical infrastructures, considering that could be a robust solution supported by multiplatform, multisensory data fusion and that could allow to conduct further investigations directly approaching to the alerts in order to discriminate real threats from false alarms.
Obviously these elements suggest specific requirements in terms of collaboration capabilities, redundancy and responsiveness of the multi UxV system.

### *3.3 SOU2CI*

Operation on board of Off-Shore Platforms are very complex and the environment inside and outside the rig is very challenging due to the complexity of the platform and to the extreme boundary conditions where it operates (e.g. sea and weather); in this case the use of USV, UAV and AUV/UUV, in combined way, could be very useful (see figures 6 & 7); due to these reasons it is interesting to investigate the capabilities of heterogeneous networks of autonomous systems within this application field (Bruzzone et al. 2013c).
Indeed the coordination among UxV operating in different domains is a crucial element for addressing these kinds of complex missions (Stilwell et al. 2004; Shafer et al. 2008; Tanner et al. 2007b.
In facts in this case the use of AUV coordinated with air assets is fundamental (Grocholsky et al. 2006; Bruzzone et al.2016c); therefore the use of UUV (Underwater Unmanned Vehicles), such as gliders, introduces additional challenges due to the difficulties related to the underwater communications (Jans et al. 2006).
The collaboration capabilities are strongly related with the introduction of advanced AI solution and potentially by the human on the loop concept already mentioned (Sujit et al.2009; Bruzzone et al.2013c).

## 4 CONCLUSIONS

The proposed examples represent already a quite interesting set of cases where safety issues that need to be addressed in order to guarantee diffusion of the UxVs in these new roles and application fields.
Obviously, it is challenging to investigate all the different elements that concur in safety as well as the effectiveness of policies and technologies to prevent and mitigate risks.
Therefore M&S is for sure the most promising technique being able to run large and complex scenarios affected by stochastic factors involving new applications of UxVs and it is expected that these simulation environments will further evolve by applying intensively MS2G paradigm.
This approach is crucial to support the development of intensive collaboration among the different stakeholders in this context over a common and understandable virtual experimentation framework.

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