From video games multiple cameras to multi-robot teleoperation in disaster scenarios.

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***Abstract*— Success of teleoperation tasks for mobile robots in disaster scenarios depends largely on the skills of the operator. This article proposes a solution to facilitate this task with two UGVs working together in a master-slave structure. The slave robot is used as an external mobile camera, being able to select the best view for each situation, as you can do in video games. This method has several advantages for overcoming challenging situations that can be found in the mission and it has been tested in the Eurathlon Challenge with good results, completing the tasks in less time and with less stress for operators.**

I. Introduction

The teleoperation of mobile robots has been widely studied in all kind of applications. However, when working on complex tasks or scenarios, the skill level needed by the human operator is still very high. Furthermore, when the task is carried on in a disaster scenario, several additional difficulties emerge. This paper proposes a system that incorporates a second robot, capable of offering an image of the *main* robot from an external point of view, obtaining the far-view commonly used in video games. Furthermore, by using a team of two robots, the system not only provides the advantage of having a second camera with unlimited points of view, but it can also take advantage of all sensors, communications devices and other equipment on-board the second robot.

Several strategies to improve the navigation abilities with Unnamed Ground Vehicles (UGV's) based on the use of external vision systems have been developed. Some initial approaches employed single [1], [2] or multiple [3] cameras placed at fixed locations to get a global perception of the environment and help navigating the robots. However, this solutions are highly constrained as result of its dependence on the fixed camera arrangement. This lead to the use of mobile cameras [4], which provide a more flexible and realistic approach despite the inherent complexity of their positioning and control.

In the past few years a wide range of applications using Unnamed Aerial Vehicles (UAV's) as a tool to increase the visual information available to ground robots, have been developed [5], [6], [7], [8], [9]. Nevertheless, there are some drawbacks when using UAV's: Firstly, due to battery restrictions they cannot operate in long term missions, also, the top-down view provided may not be helpful in cluttered scenarios or when a low height roof is present, finally it is necessary to solve their Guidance, Navigation and Control difficulties, which may be very complex in disaster scenarios. There have also been attempts to improve the vision and navigation capabilities through cooperative behaviours between UGV's. These solutions show promising results in grasping tasks with mobile manipulators [2], [10] and assisted navigation for robots with viewing limitations [11], [12]. The approach presented in this paper is similar to those, however it differs in several aspects such as: an improvement of teleoperation tools is achieved with the selective view change provided by multi-robot visual assistance, it is obtained higher robustness in search and rescue missions through a muti-robot system with interchangeable roles and, finally, the system was widely tested in outdoor scenarios.

The work presented here resulted from the experience of the SARRUS Team in the robotic competition *EuRathlon 2015* which required a team of land, underwater and flying robots to work together to survey the scene, collect environmental data, and identify critical hazards in a disaster scenario inspired by the 2011 Fukushima accident. SARRUS team, is focused on Unmanned Ground Robots (UGV), therefore, it took part in the single domain Land Trials.

To participate in the land trials, it was decided to use a team of two UGVs. The first robot acted as master and was intended to solve the mission,the second one, acting as slave, had the objective of aiding the master by providing an external camera as well as other sensors, and at the same time acting as a communications relay. It may seem that, using two robots and therefore two operators would increase the difficulty of the mission, however, the experience showed that it was quite the opposite, missions were performed in less time and with a lower stress load on the operators, as demonstrated by the good results obtained by team SARRUS in the challenge.

The paper is organized as follows: Section II presents the *EuRathlon 2015* challenge and the description of the land trials. Section III describes in detail the proposed solution and Section IV presents some tests and results from the challenge. In Section V an approach to automating the process is presented and finally conclusions of the work are provided in Section VI.

II. Challenge and trials description

A brief introduction to the EuRathlon competition as well as the required tasks for the Trials $L1$ and $L2$ will be presented in this section, for more detailed information please visit the challenge web site[1].

A. EuRathlon Challenge 2015

The main goal of the Eurathlon competition is encourage developing robotic solutions for disaster assistance in the Sea (S), Air (A) and Land (L) domains. Consequently, the organizers have proposed challenging realistic scenarios in order to evaluate the performance of unmanned vehicles for each domain. The competition was held around the thermal power plant belonging to Enel S.P.A. in Piombino, Italy. There, the "*Tor de Sale*" building represented a nuclear power plant with a reactor inside its own machine room, the challenge required to survey the scene, collect environmental data, and identify critical hazards using a team land, underwater and flying robots.

B. Land Trials (L1, L2) description

Two single domain land trials where defined by the organization: Land Trial ($L1$): Reconnaissance in urban structure and Land Trial ($L2$): Mobile Manipulation Both of them were designed to evaluate four significant capabilities for carrying out rescue operations with UGVs:

- *2D mapping:* defined as the ability to generate a digital representation of the environment that can be used in other tasks.
- *Object Recognition:* understood as the perception, classification and location of OPIs (Objects of Potential Interest).
- *Object Manipulation:* described as the ability to manipulate objects.
- *Obstacle Avoidance:* understood as the ability of the UGV to perform a task while it avoids colliding with static and dynamic obstacles.

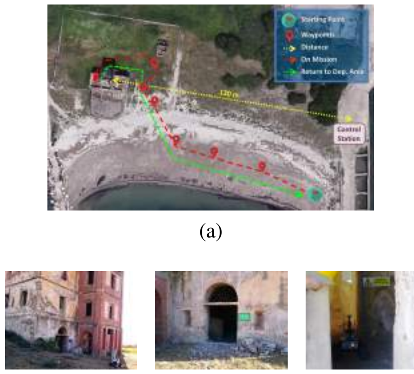
Another important objective was to localise OPIs, they need to be taken them into account for the task development and saved. Also live information about state, position and imagery should be transmitted to the control station. The Trials should be done with the highest autonomy and less human intervention possible, under high safety restrictions and in a time slot of 45 minutes. The specific tasks for $L1$ listed in Table I.

Task	**Description**	**Area**
1	From the starting point find and follow a safe path (guided by georeferenced waypoints) to an unobstructered entrance of the building.	Outdoor
2	Enter the building and inspect the inside.	Indoor
3	Find a safe and unobstructed path to reach the machine	Indoor
4	Enter the machine room.	Indoor
5	Return to the deployment area.	

TABLE I: Tasks of Land Trial ($L1$): Reconnaissance in urban structure.

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

Additionally, a graphical description of the $L1$ trial, including some images of its execution and of the OPIs, is presented in Figure 1.



(a)

(b) (c) (d)

Fig. 1: Graphic description of trial L1 and images of its execution including some of the OPIs. (1b) Approaching the building.(1c) Entrance of the building. (1d) Entering the machine room.

In a similar manner, the required tasks for the $L2$ Trial are described in Table II and they are complemented with a graphical description and some images of its execution shown in Figure 2.

Task	**Description**	**Area**
1	From the entrance of the building reach the machine room where the valves and the canister are located.	Indoor/ Outdoor
2	Close the valves and the steam leaks	Indoor
3	Pick up the canister from the ground and drop it into the barrel. If possible, close the barrel.	Indoor
4	Return to the deployment area.	

TABLE II: Tasks of Land Trial ($L2$): Mobile Manipulation.

It is noteworthy that the robots had to be monitored and controlled only from the control station, which was at a distance of $120\,m$ for trial $L1$ and $85\,m$ for $L1$. That constraint and the fact that in land trials it was possible to use up to two robotic platforms were the main reason that drove us to develop the solution presented in this paper and that will be described in detail in Section III.

III. Proposed Solution

As aforementioned, the proposed solution was based on the idea of translating the race-car video games approach to the mobile robot teleoperation tasks. Furthermore, the objective is to have the ability of changing the point of view of the player/operator as can be done in most car-racing video games (See Fig.3).

From Figure 3 it can be observed that the external camera (Fig. 3d) offers much more information from the environment surrounding the vehicle. It provides a viewing angle of $360°$ instead of the $120°$ of the cockpit view (Fig. 3a). It is also possible to appreciate the exact position of the car in the

(a)

(b)

(c)

(d)

Fig. 2: Graphic description of trial L2 and images of its execution including some of the OPIs. (2b) Entering the machine room.(2c) Inside the machine room. (2d) Return to the starting point.

(a) Inside cockpit

(b) Front of the vehicle

(c) On board

(d) External camera

Fig. 3: Differents views in DiRT Rally video-game.

road, or whether or not it is drifting or breaking, even more, a further region of the road can be watched. The cockpit view on the other hand, presents other advantages. It is possible to see the indicators such as the speed or RPMs, and also see if the motor has any damage or not, moreover it also allows to see the rear-view.

However, this views can not be directly translated to mobile ground robots. Most of them only use an on-board camera, which usually has *Pan-Titl-Zoom* (PTZ) capabilities. The robots are also normally complemented with other sensors such a laser-scanners, LIDAR or TOF cameras. Nevertheless, those sensors do not always provide enough information about the elements surrounding the robot or its status in a given situation, because those sensors are always on-board and therefore it is not possible to have an external view.

The solution proposed here is based on the incorporation of a second robot, that works as an external mobile camera, helping the robot that will be performing the main search and rescue tasks. The use of a second robot, in a master-slave configuration, increases the complexity of the system. However it is clearly justified, because it allows to have a mobile external view of the robot, moreover, it provides some extra benefits, such as a mobile communication relay and a backup in case of failure. Even more, by using identical or very similar robots, it is possible to switch their role continuously, changing from master to slave according to the punctual needs of the mission. Lets suppose, for example, that the robots are moving in a narrow corridor and after a turn the master discovers a blocked entrance, it may be useful to switch roles and go back using its view to help the other robot which will be now ahead, this scenario is depicted on Figure 4.

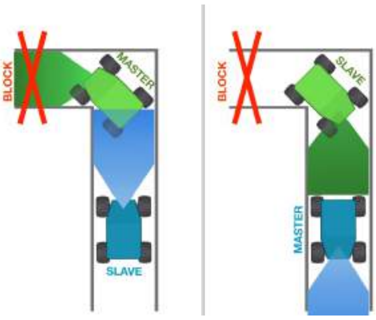


Fig. 4: Master-Slave System with change on their roles.

IV. Tests and Cases of Use

The mobile platform used for the challenge, as well as some cases of use of the proposed system will be presented in this section. Those cases have been extracted from the experience of the participation on the Eurathlon challenge.

In figures 1 and 2 the areas where the trials were performed can be seen. The distance from the control station to the area of the disaster (reactor building) was considerably large ($85\,m$ and $120\,m$). But, besides the distance, other difficulties were also encountered: because of the slopes there was not a clear line of sight, and the humidity and airborne salinity act as a wireless signal attenuator, therefore the communications were far from optimal, thus rendering the effectiveness of the proposed system much more important. The cases of use presented, are a clear test of such capabilities and performance, even in such adverse conditions.

It is important to emphasize that, before the competition, SARRUS team have developed algorithms for autonomous navigation through waypoints [13] and for the exploration of an unknown area. However, upon arrival to the competition scenario it was found that they were no usable for the challenge, because of noisy measurements of the TOF cameras and the localization sensors. The initial goal of the team was to execute the trial only by providing each robot with the list of waypoints. But because of the aforementioned problems, the team decided to perform all the tasks in a teleoperated way.

A. *Mobile platform*

Two similar mobile platforms were used for the challenge in the roles of master and slave, they are based on the Summit XL robotic platform by Robotnik®. Which has skid-steering kinematics, and is based on four high efficiency motors. The robot is equipped with a small form factor PC which allows processing data and running SLAM or navigation algorithms on-board the robot.

Various sensor modalities are also present. The odometry is provided by an encoder on each wheel and a high precision angular sensor assembled inside the chassis. Also an Hokuyo laser rangefinder is mounted at 60 centimeters over the ground in the central part of the robot, it can scan a 270 degrees semicircular field, with a range that goes from 0.1 to 30 meters and a maximum output frequency of 40Hz. The UGVs are also equipped with GPS and IMU sensors. Finally both robots have a PTZ and TOF cameras and they are capable of providing real-time imagery and data to the control station. An image of the robot with all the aforementioned equipment mounted is shown in figure 5.

Fig. 5: Summit XL Robotic platform, including the equipment used in the challenge.

B. *Crossing a bridge*

The first critical situation that arose was the access to the emergency zone in $L1$ trial. It was a small wooden bridge where the robot had only a $5\,cm$ margin on each side. Moreover, the bridge had a slope of more than $30°$ and it was covered with sand from the beach, resulting in a very challenging combination. In addition to that, it is necessary to be very careful with the direction of the robot, because it can easily skid or turn and therefore fall by the side of the bridge. Which will result on a failure of the mission.

The fact that access is made through an inclined plane is also a drawback when using only the on-board image for teleoperation. Furthermore, there is a critical situation when the robot is near the end of the bridge, and the change the inclination will prevent the operator from having a visual reference of the ground in emergency zone, this case is exemplified in figure 6.

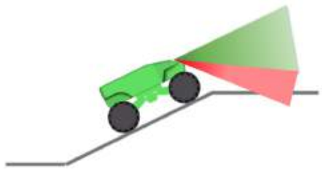


Fig. 6: Critical situation when the robot is over the bridge. The green beam shows the field of view of the on-board camera, which does not give a ground reference.

TABLE III: Slave robot tasks for crossing a bridge

Slave robot task	**Provided View**
Help at the beginning of the bridge	Lateral
Avoid falling from the bridge	Rear
Help to complete the bridge	Lateral

To cross the bridge, three tasks were ordered to the slave robot. The first one was to provide a parallel projection view of the scene, similar to the side view that can be used in a video game. In this position, the slave robot offers a lot of information to the operator of the master robot, specifically about when and how the master robots starts to move over the wooden bridge. The second task for the slave robot was to provide a rear view of the master robot crossing the bridge, to obtain this, the slave robot had to change its position and be placed at the beginning of the bridge, providing an image similar to the rear view camera in a video game. This view was useful for guiding the master robot and correcting possible skidding or sliding when moving over the bridge, so as to prevent it from falling off the bridge. The third task is to provide the same image as the first one, in this case the interest is when the master robot is at the end of the bridge and is going to access to the emergency zone. As discussed above, this is a critical moment because the on-board camera does not provide information about the status of the robot with respect to the ground, rendering the information provided by the slave robot much more important. The list of task is summarized on table III.

Once the master robot has crossed the bridge, the roles can be switched, therefore, the robot that has already crossed can now help the other robot to cross as well, this ensures the safety of both robots and increases the chances of completing the mission. An example of images from external and on-board cameras while crossing the bridge are presented on Figure 7.

C. *Passing through a door*

As it was explained in Section II, both trials required for the robot to enter the building. The challenging task was not to find the correct door, but to overstep it. As can be seen in Figure 8, the entrance had a slope made of debris and there was a wall just in front of the door, so it required a very precise maneuver in order to prevent damages to the robot's sensors or the building. Therefore, the robot was driven very slowly, due to slippage caused by the low grip of the debris, and while advancing it was necessary to make a turn to the right to avoid the wall and enter the main hallway.

This situation is very similar to that of a car driver when doing a tight turn with his car. In this case the driver relies on the side mirrors of the car to pass it successfully. However,

(a) Situation

(b) On-board Camera

(c) External Camera

Fig. 7: Master robot crossing the bridge.

since the robot has no side mirrors or cameras, and despite the PTZ camera being able to rotate 360 degrees, it has blind spots in the passage of the wheels relative to the doorway, and therefore its image is not useful enough for this task.

Once again, in order to overcome this issue, the slave robot was used to act as the side mirrors of the car, focusing at the standpoint necessary that the operator of the master robot requires. In this cooperation there were two key moments, the first preventing the robot to collided against the side of the door opening or passage between the wheels would be caught. And the second showing when the robot has entered completely and must stop accelerating to proceed to turn. Figure 8 shows an image of the robot while performing this tasks.

Fig. 8: Master robot crossing the entrance of the reactor.

V. Approach to automating the process

As aforementioned, the objective the work presented in this paper is to facilitate the control and operation of the a master robot by providing the operator with more than one point of view, based on the use of a second robot as an external sensor. However, the system, so far, relies on manually operating both master and slave robots. This section presents an approach, currently under development, to automate this process by having the slave or secondary robot moving autonomously according to the needs of the master robot.

In order to do this, the slave robot requires to autonomously perform two main tasks. The first one is to track and follow (pursue) the master robot. The second one is to strategically position itself in order to provide the best view modes and therefore facilitate the control the main robot.

The first task (pursuit) is reached by recognizing the master robot with the sensors on board the slave robot, therefore a feature recognition and tracking is necessary. Then, the slave robot must perform the necessary movements in order to maintain an optimal distance to the master robot so it always keeps it on the field of view.

Actually, the slave robot is capable of tracking the master robot keeping a minimum distance of safety. And the next objective is to providy the slave robot the ability to detect the master robot without any visual mark.

As it is shown in Figure 9, an area $A1$ is defined between two radio arches ($R1$, $R2$) that subtends a central angle α. The master robot must be inside the $A1$ region at all moments. This situation is achieved by the linear and angular movements of the slave robot.

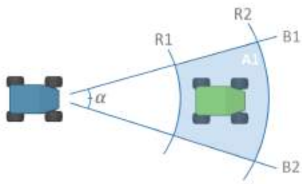


Fig. 9: Definition of the $A1$ area for the main task.

Two lines B1 and B2 are defined as the boundaries of the region of interest. When the main robot exceeds this lines, the slave robot must perform a rotational movement. When the distance between the robots increases or decreases, the number of pixels in the image changes, so the slave robot must accelerate, stop or reversing depending on the situation. Also, the distance can be extracted directly from the TOF camera.

When an obstacle is presented between the two robots or when the team goes across corners, there is a great probability to lose the line of sight. Thus, is necessary to execute an additional task which can detect the near obstacles and can predict the position of the master robot in a near future. This prediction uses the velocity and direction of both robots taken from the main control loop and from the movements detected for the slave robot in the main task. The near obstacles are detected with the TOF camera. With this information, a possible occlusion can be detected. Situation that requires to update the slave robot trajectory to locate it in a strategic position which allows a better view of the scene.

As figure 10 shows, a point O is a future master robot position that will be out of the line of sight from the slave robot if the current trajectory continues. In this case is necessary to calculate a position LP that has a large probability to have the O point in the line of sight. Once the LP point is calculated, a simple trajectory planning is executed in order to reach this point.

Additionally, when the master robot is close to pass through a door or to cross a bridge, is necessary to posi-

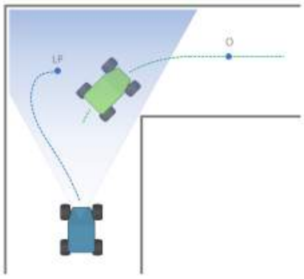


Fig. 10: Secondary task, definition of O and LP points.

tioning the slave robot in a place that gives a lateral view of the scene. On demand of the operator, the system gives two possible positions located on the sides of the $A1$ area as shown in figure 11. The system choose a final decision based in the closest objects. A place with less objects should be preferred, so the slave robot takes position in any place of the regions.

When the master robot starts to cross the bridge the slave robot continues with the normal execution of the primary and secondary tasks as necessary.

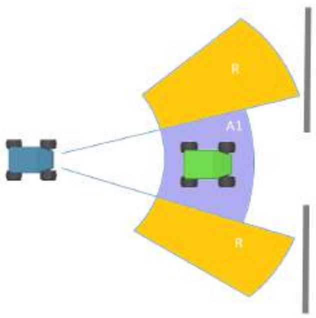


Fig. 11: R areas for lateral position.

A third line of work, also under development, is the algorithm capable of automatically switching the roles of master and slave. At the moment is the operator who designate each role. The algorithm is based on detecting blockages, by timeouts in reaching a given waypoint or by detecting dead-ends. Then, the robot's roles are changed, the operator is informed, and he or she takes control of the slave robot.

VI. Conclusions

This paper presents a multi-robot system whose main objective is to facilitate the use of mobile robots in challenging disaster scenarios. The proposed solution and the experiments carried out, shown that using the multi-camera option of video games, with two UGVs in a master-slave configuration, is a suitable manner of facilitating and improving the tele-operation capabilities of the system in rescue tasks. Some realistic cases of use, during the *Eurathlon* challenge, have been solved by using the multiple point of view approach described. Finally, the work under development show promising results for automating the process, which has proven even more difficult in this application.

Appendix

The video link accompanying this paper illustrates the experiments developed during the *EuRathlon 2015* challenge: `https://youtu.be/maP04Wqc_p8`

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