New technology perspectives for the autonomous and teleoperated vehicles: the experience of Antartica robots and the expected spin-off

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New Technology perspectives for the autonomous and teleoperated vehicles: the experience of Antarctica Robots and the expected spin-offs

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Abstract

The paper is aimed at presentation of the results achieved by the Technology Section of the National Programme on Antarctica Researches in the area of autonomous robotics for hostile environment. The goals of the paper is the description of the two robots RAS and SARA, the largest autonomous systems realised and tested up to now in the Antarctica environment. Special highlight is devoted to the original technological results obtained within the project, to the presentation of the capabilities of the Intelligent Systems and to the discussion of the possibility of future developments and further spin-offs based on that technology.

The PNRA project, (Progetto Nazionale di Ricerche in Antartide) launched, since 1994, a dedicated activity for technology developments with the aim of supporting scientific researches in the Antarctica continent. This activity, currently one of the eleven areas of the Italian mission in Antarctica, includes a number of different projects ranging from the reliable electrical power generation during winter time to the test and exploitation of self standing hydroponics greenhouse.
Since the beginning, anyway, the most important economical effort has been devoted to the realisation of autonomous robots, able to operate in extreme conditions and intended as facility for scientific experiments and for the logistical activities.
After a preliminary investigation phase, two robots have been addressed to operate in the Italian base and in the scientific campaigns: a terrestrial rover, called RAS ("Robot Antartico di Superficie") and a marine AUV called SARA ("Sottomarino Antartico Robotico Autonomo").
The main development activity lasted up to the recent Antarctica campaign of 2002-2003. Within this mission the basic functions of the autonomous AUV SARA have been tested. A considerable amount of work still remains to be carried out on both the vehicles, but the general understanding is that the necessary improvements will be carried out within the new projects devoted to the investigation of the many unresolved problems of the Antarctica continent. These improvements will be specifically devoted to the customer application.

The objective of the present work is to give an idea of the results achieved on the two programs RAS and SARA and the perspectives of their current prosecution RUISS. PNRA has pushed these developments with more than 6 MEuro within 8 years and the know how spread on the Italian operators that participated to this effort (more than ten Academies and almost the same number of high tech industries) is expected to find spin-off applications and initiatives in other fields.

RAS

The RAS, "Robot Antartico di Superficie", is intended to operate in a hostiles and generally unknown environments. In these conditions the ability of sensing obstacles or special features (crevasses, sastrugi, composition of the soil) can represent the key point for a successful operation and a satisfactory completion of the required mission. Failures can be determined by many different causes: wind storms (together with many other atmospheric phenomena giving rise to white out) can make useless optical sensing equipment; ice microcrystals can penetrate practically everywhere, causing failures in many components; magnetic storms can blind GPS and radio equipment and so on.

Fig 1 – Tests of RAS on the Alps (by courtesy of "Paradiso" and "Carosello Tonale" societies)

Thus, the "environmental hardening" and the "redundancy" of the sensing subsystem have been choosed as key point for the RAS architecture. The last mandatory choice, indeed quite expensive, has caused the creation of an extremely rich sensing unit, able to investigate the outside environment with many "eyes" and in many ways.

The sensing architecture of RAS includes the following units:

- ✓ Two laser range finders (LRF), able to scan an angle of 120° in front of the vehicle and to give fast and precise scene analysis (1 point per ms, 10 cm precision) up to 100 m. in range;
- ✓ A radar range finder, to integrate the data coming from the LRF or to act as a emergency backup system when the weather doesn't allow the LRF operation;
- ✓ An odometric subsystem, able to estimate the speed of the tracks from the maximum speed of the carrier down to about 3 cm/sec with accurate filters;
- ✓ A very sensitive inertial equipment, for the measurement of the X-Y-Z accelerations, of the two rotations and inclinations along the X and Y axes;
- ✓ An artificial vision subsystem, based on a stereo pair of TV cameras that can be operating on visible or infrared range of optical light spectrum. The system will be charged with several tasks, but currently able to track the position of other vehicles on the scene and to follow the traces left from the previous vehicle (in a caravan);
- ✓ A differential, RTK GPS system, able to give centimetre precision during the movement for several purposes (control, record of special positions, execution of precision positioning works, docking, etc…)
- ✓ A "speed over ground" optical sensor, entirely developed at ENEA and defined "Speckle Velocimeter". It has demonstrated to reach in the best conditions precisions close to 0.1% in the simultaneous measurement of X and Y components also on a contrast lacking surface as the snow;
- ✓ A GPR (Ground Penetrating Radar) equipment, specialised for the detection of the soil structure in the first ten meters in depth and therefore especially able to detect crevasses, surface lakes, but also small surface or low depth meteorites.

Additional cameras are foreseen to integrate the previously sensing equipment for a more effective teleoperation (the stereo pair has some limitations in the viewing area because the rear and lateral part of the vehicle are hidden by the cockpit structure), but aren't yet installed. A weather monitoring box is also foreseen to allow the best data fusion coming from the many sensing units, but not yet implemented.
The whole sensing system is represented in the next fig. 1.

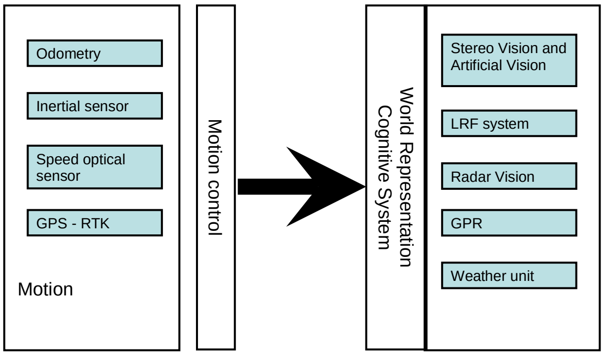

Fig. 1 – simplified sensing architecture of RAS

Fig. 2 – Laser tests on the snow

The aspects of the integration and utilisation of data coming from the different sensors are not discussed in this paper. Some pictures of the LRF [1-3], and of the results obtained in the Artificial Vision [4-8] and in the Speckle Velocimeter development [9-14] can be viewed in the figs. 2 to 4 with some basic explanation. The AV artificial vision represent of course one the main sensors of RAS. It is based on a stereo camera pair and has the task to support the drive of the vehicle in the following conditions: traverse operation (see sketch in the following), docking, scouting in dangerous conditions.

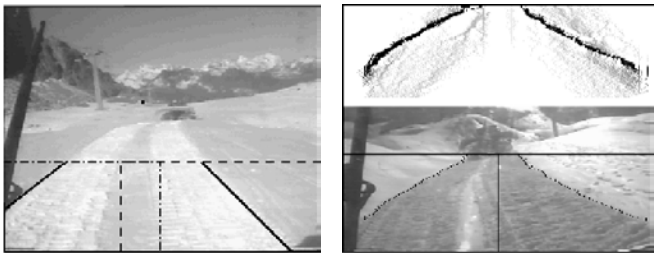

Fig. 3 – Examples of the AV results obtained with the Hough transform algorithm and with ACO (Ant Colony Organisation) algorithm. The result is the detection of the path to follow during a multivehicle raid.

The next progresses in the AV subsystem research are related to the exploitation of IR cameras. That is expected to be especially useful for detection of breaks in the ice coverage (including crevasses and borders of floating marine ices) and should be carried out within next project .

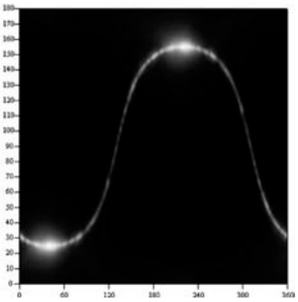

Fig. 4 – Speckle Velocimeter is based on the classical idea of the relative speed calculation starting from regular or quasi-regular terrain textures and is developed with the idea of applying a laser-induced speckle pattern to surfaces texture-free like the snow can become. Speed vs Angle plot for a laboratory experimental test of the Speckle Velocimeter

Apart from the work carried out on the sensing subsystem, RAS is targeted to apply a considerable skill in its movement capability and researches have been carried out (and are still under development) to comply with this specification.
It is a common experience, in fact, the difficulty to move on a low friction surface, as the snow or (worst case) the ice. Snow cat human drivers are considerably skilled operators and the driving system of RAS, in the most of cases, has to supply performances comparable with those of a human driver.
This is an hard requirement that comes from a very key point in the technological projects of PNRA: these projects are in fact not just mere researches, but very advanced realisations that must be succesfully exploited in science experiments.
Motion control is differently applied following three operation modes: the first mode is the simple direct PD control of tracks motion, as it happens when the driver is personally present in the cockpit; in this mode no inertial compensations to the trajectory are applied, but the driver cannot sense the acceleration as it happens in the cockpit. The second one (assisted teleoperation) is oriented to the remote drive under the supervision of a human operator. In this mode the system is controlled through high level commands, basically direction and speed, whereas the aspects of kinematics and dynamics of the vehicle are solved in local control. High level navigation aspects, like path planning and strategies aimed at circumnavigate obstacles, are delegated to the human operator.
In the autonomous mode, the third one, also the high level strategies and path planning are delegated to the control. Both in second, but especially in the third mode, motion problems exist, coming from real operating conditions. Some of these problems, and not some marginal ones, ask for "expert mode" control and for a suitable data fusion from the sensing equipment before mentioned that are still under development.
We will mention here two of these cases as an example.
First case. During the movement, the action of the tracks moves the snow toward the back of the vehicle and when some conditions arise (excess snow softness or excess in the terrain slope) the vehicle can dig deep traces and be forced to back drive to escape from the hole itself caused. This kind of condition is happened very often during the driving tests and could be probably sensed through a suitable analysis of the sleighing amount, extracting from the overall data some "observing parameter" coming from inertial, odometric and slope data. In such a condition, adequate strategies "expert mode" can be applied in the autonomous drive case, whereas specific alarms can be sent to the human driver in case the second mode of control (assisted teleoperation).
Second case. During narrow curved trajectories, a good way to maintain the tracks in the best operating conditions, preventing excess of tension on the tracks and maintaining a good level of friction with the terrain, is to insert the counter rotation mode for a short while. This is a intermediate control level, operated during the motion control, that can be adopted both within the assisted teleoperation and within the autonomous mode of operation.

Motion control has been tested and improved during tests carried out both in Antarctica (beginning of 2002) and in Alps measurement campaigns (beginning of 2001 and 2003).
In particular, during the Antarctica mission the weather environmental conditions met within the mission were so critical that it was impossible to test the carrier on the continental ices (Browning Pass – see the map of the operation site) and only functional tests of first and second operation mode has been possible around the area of Baia Terranova Italian base without ice covered terrains (see next picture).

Fig 5 – Autonomous drive operation of RAS in Antarctica

Within the mission carried out in Italy in April 2003 significant data relevant to the RAS motion under poor friction conditions have been collected and the analysis should be completed within a couple of months. The short time available to carry on the measurements (limitations are given by the melting of snows caused by the season and at the opposite by the need to wait the ending of the skiing time) has lightly affected the significance of the data and more advanced algorithms are expected to be tested for the end of the year.

SARA

The Autonomous Antarctic Robot Submarine (SARA) [15] project is concerning with a new autonomous underwater vehicle (AUV) torpedo-like specifically designed to operate in the Antarctic Sea (Ross Sea). A photo of SARA is reported in fig. 6.

Fig.6 Robot sottomarino antartico autonomo (SARA)

In recent years a strong increase was observed in the demand, both by the scientific and the commercial community, for AUV able to perform automatically scientific measurements or survey job. The aim of the robot SARA is the substitution of human researchers, concerning, oceanology and environmental problems, in long and repetitive missions together with the possibility to operate jobs up to 1000m depths fully autonomously.
In a typical SARA scientific mission the following class of measurements must be carried out:

- Hydrologic (conductivity, temperature, depth, water speed, etc…).
- Chemical (Ph, oxygen content, light transmission, etc…).
- Biologic (chlorophyll content, food content, etc…).
- Geological (sea floor morphology, topography, etc…).

By these needs the following feature are required:

- Max depth 1000m.
- Speed cruise 2 m/sec.
- Autonomies 250 Km.
- Max duration 35 h.
- Hovering capability

SARA is a torpedo shaped vehicle 5.5m long and 0.7m diameter. It is composed of three main sections: a pressure vessel in the middle and two free flooding fairings of composite material fore and aft.
The pressure vessel houses the batteries, the computer and other electronic equipments. As relevant task it also guarantees a neutrally buoyant condition by compensating the weight into water of the items located in the flooded sections. One main thrusters and four manoeuvre thrusters compose the propulsion system.
The qualifying element of the project is the possibility to change the parameters of the mission in the meanwhile of the performance because of an “intelligent supervisor” system. In case of failure of some instruments, as example, the full mission will be re-planned to carry out a reduced mission optimising the performance, using the remaining resources. Our aim is to build an AUV able to manage difficulties in hostile environmental using rule table like “If…Then”. Later we give to the AUV the possibility to increase both the number of the rule and their weight in the table. This could be obtained defining appropriate “state variables”, indicative of the health of the system, and working about their relationship. The “experience of the system” which is the most difficult task, will be simulate by the massive use of computers. The system should be able to learn from simulation tests how to react in forecast and, hopefully, quite unpredictable situations.

Practically the following steps need to be performed:

- Data collection.
- Data structured (knowledge).
- “State variable” evaluation. Stability analysis.
- “Efficiency state” evaluation, using fixed rule algorithm.
- Change of the rules by expert system.
- New structured preferences based on the new rules.
- Choose of the task to do in the decisions space.

The instruments actually installed on SARA are the following:

- 4 Echosunder for obstacle avoidance
- Doppler Velocimeter Log 300 Khz to measure velocity with respecto the ground and/or to the water.
- Inertial Motion Unit to measure the X-Y-Z accelerations
- Global Position System to be used on the surface
- Deepmether

- Giro Compass inclinometer
- CTD (Conductivity, Temperature and deepmeter as scientific payload)
- Radio modem to communicate on the surface (eventually)
- Acoustic modem to communicate in the shallow water (eventually)

Currently SARA has performed some navigations trials, always under the supervison of humans both in protected basins and in the nearby of the Italian base of Baia Terranova in Antarctica (see fig. 7) . The system for remote control adopted is an original product of the project technological developments: Human-robot interface was in fact another key point [16] for the control of the torpedo. Its realisation has been under the responsibility of ENEA that is working on similar themes since many years.

Fig.7 - SARA tests in the Ross Sea

Other initiatives

The National Scientific Commission for Antarctica (CSNA), the technical board that manages the italian initiative in Antarctica has also funded some preliminary studies for an autonomous RPV (fig. 8). This studies have been carried out by Turin and Rome Universities and are still under development. Scientific activities of monitoring and survey may require observation of large areas by means of aircraft or satellites. In many cases use of satellites is limited by poor resolution in spatial domain and/or because they do not supply real-time information. As for aerial vehicles, the severe Antarctic environment, where ground or sea level temperature is already very low and significant variation of wind and visibility may occur is an extremely short time, crew safety represents a challenging problem due to reduced radio and/or radar assistance to navigation. Recent studies have shown that use of RPVs in the so-called D3 (Dull, Dangerous, Dirty) types of missions is safer, less expensive and more efficient in comparison with manned aircraft. RPV development is a sound reality in the aerospace industry as there are many RPV systems in operations world wide, mostly for military market and roles. Nevertheless, in the last decade interest in RPVs has also grown in the academic community where, without the constraints of fixed marketing objectives, several small vehicles have been developed as research platforms and to demonstrate innovative capabilities in providing thee-dimensional mobility to dedicated sensors. In this context, the vertical take-off and landing (VTOL) RPV here proposed is the only original project to-date in Italy of an aerial platform to be used for developing and testing maturing technologies in civil applications. Range and payload characteristics allow the RPV to be used for scientific missions in the harsh environment in A. with a sensor package highly integrated with onboard avionic system. Further relevant applications of the RPV in A., to be envisioned in this study are: Not contaminating (as by ground vehicles) survey, and crevasses detection and research/rescue where a major goal is also to improve safety of ground personnel. Expected result of the program concerns the development and dissemination in the scientific community of advanced technologies in the fields of communication, robotics, control system design for RPVs, as well as remote sensing, miniaturization and onboard integration of scientific sensors.

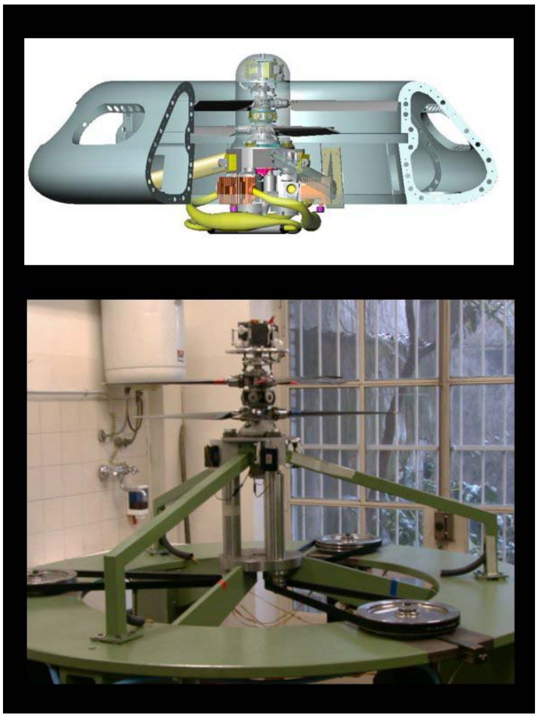

Fig.8 – Preliminary design of the RPV and tests of the propulsion system

Conclusions and future perspectives

ENEA has been the main operator in both the projects before described and therefore has played a central role in the definition of the strategy in designing the technical objectives and, more important, in the identification of a role of these projects in a wider national strategy.

RAS and SARA are, basically, two realisations of autonomous Intelligent Systems that are intended to take place outside the classical research environment and find application in supporting *real* human activity, in this case Scientific Researches in Antarctica. It is common understanding of PNRA, the national Project for Researches in Antarctica and ENEA, the project leader and the principal investigator both for RAS and SARA that these realisations have to be exploited in spin-off applications outside of the Antarctica environment.

The technology of Intelligent Systems is foreseen to represent a growing market within next ten years up to become one of the major business, probably comparable, following the forecast of many international analysts, with the automotive industry. It is important to consider that Robotics in general and in particular the Intelligent Systems owns, beyond of an enormous potential impact in specific market segments (for instance systems for elders and disable assistance), also the characteristics of "pervasive technology". In other words the technological results become embedded in other technology products like the car itself, household appliances, the entertainment and many others.

The fundamental message that should be perceived is that this field represents one of the few possibilities for our Country to play an important role in the future high-tech market: Intelligent Systems are in fact not affected in a heavy way by previous infrastructural investments. A classical example that can be mentioned is the case of the micro and nano technologies and its most famous example: microelectronics.

In all of these cases the need to fill the gap already created with respect to the leading countries becomes almost impossible owing to the fact that existing producer countries have the possibility to reinvest the enormous incomes of the market to increase more and more the technological gap with respect to the others.

This is not the case of Intelligent Systems and, in addition it is important to remember that in automation and robotics appliances Italy is still now (low tech products) one of the main world producers.

This has been already stated by many authors in the recent I Conference on Advanced Robotics and Intelligent System held in Frascati in October 2002.

For this reason ENEA is willing to increase its effort on the development of these Antarctica robots and to maintain open the know-how gained in this experience.

Currently, the next step on the Antarctica Technology initiative, is the RUISS project. This project, based on the facilities RAS and SARA, has the objective of explore the deep bed of the Ross Sea, under the marine pack and under the ice sheets of the continental glaciers.

The main challenge of this objective is represented by the need to navigate under the ices for tent or hundred of kilometers maintaining a precise positioning, without the possibility to make use of GPS or similar positioning systems. The hope that we are investigating is in the possibility to maintain, as long as possible, some communication with the surface vehicle that could operate both as communication link and as a rough positioning system.

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