

SYNCRBOTS: EXPERIMENTS WITH TELEPRESENCE AND TELEOPERATED MOBILE ROBOTS IN A SYNCHROTRON RADIATION FACILITY

R. Pugliese, A. Curri, F. Billè, R. Borghes, D. Favretto, G. Kourousias, M. Turcinovich, M. Prica, Elettra – Sincrotrone Trieste S.C.p.A, Trieste, Italy

Abstract

SincRobot is an autonomous mobile robot that supports the machine operators of Elettra [1], a synchrotron radiation facility, in tasks such as diagnostic and measurement campaigns being capable of moving in the restricted area when the machine is running. In general, telepresence robots are mobile robot platforms capable of providing two way audio and video communication. Recently many companies are entering the business of telepresence robots. This paper describes our experience with tools like sincrobot and also commercially available telepresence robots. Based on our experience, we present a set of guidelines for using and integrating telepresence robots in the daily life of a research infrastructure and explore potential future development scenarios.

INTRODUCTION

Current generation telepresence robots can be described as video conferencing systems on wheels. In the last years, companies [2-6] such as Adept MobileRobots, Willow Garage, Mantarobot, Double Robotics, Xaxoon and may others have produced these robots to be used in a wide variety of scenarios. We decided to evaluate these systems in scenarios happening daily in the context of a Synchrotron Radiation Facility (SRF). The result is a set of guidelines that we believe are essential for telepresence robots. The scenarios studied over a period of about 2 years allowed us to investigate the following different aspects:

- The impressions of the remote user, namely how easy it was to use the robots, to drive it somewhere, to interact with people and generally the remote environment;
- The impression of people co-located with the mobile robots, both who directly interacted with the robots and the bystanders during formal and informal meetings;
- The added value of mobility (i.e. what differentiates telepresence robots from video conferencing technologies);
- The possibilities to extend the basic functionalities of the telepresence robots, and to integrate them with the technological and control systems running in a Synchrotron Radiation facility.

The following list report the basic the features of the telepresence robots we used and planned to use in the scenarios we examined.

Table 1: Features of the Telepresence Robots used in the Experiments

Feature	Adept MobileRobots Patrolbot	Double Robotics Double	Mantarobots Teleme	Xaxxon Oculus
Purchase Price	\$36000	\$ 2499	\$1500	\$289
Top Speed	1.8 mph	n/a	1.2 mph	n/a
Band-width required	1 Mbit/sec	768 Kbps or better	1 Mbit/sec	768 Kbps or better
Video resolution	800x600	2048-by-1536	Based on Tablet Used	depends upon netbook
Run time	8 hours	8 hours	4 Hours (min)	1 -2 hours
Unique features	PeopleBot Gripper	automatic kickstands	Tablet Plugin	Vision upgradeable
Docking Station	No	No	No	Yes
Automated docking	No	No	No	Yes
Crash avoidance	IR Break Beam Sensors	none	Three infrared optical transceivers for obstacle and step detection	none
Autonom. navigation	Yes, Laser based	none	none	none
Integration API	Yes	Not Yet available.	Yes , NDA required.	Yes, telnet interf.

Prices and features of these systems are quite different. The *Patrolbot* is quite expensive, but really reliable, robust, extendible and complete. It is equipped with an advanced autonomous laser based navigation system with automated docking. It has been used to support the accelerator operators in the SINCROBOT scenario. The remote client is a java application.

The *Double* is equipped with a balancing system that makes it similar to a Segway. The height of the head can be remotely controlled. It is based exclusively on the Apple platform and doesn't have a docking station. It has been used in the SITVIP scenario. The remote client is web based and really well designed.

The *TeleMe* is easy to use, equipped with infrared sensor to signal obstacles. It has a docking station but not yet an automatic docking mechanism. It comes with an integration API. The remote client is available only on a

limited number of platforms. It has been used both in the SITVIP and in the remote surveillance scenario.

The Oculus is the less expensive as it is a sort of transport mechanism to a netbook. Surprisingly can be easily extended and has automated docking. The client is web based but there is also a version running on Android. It has been used in the remote surveillance scenario.

In the following sections, we will at first describe the test scenarios. A report of the guidelines will follow. A description of possible future challenging scenario will precede our final considerations.

SINCROBOT

Elettra Sincrotrone Trieste is a multidisciplinary Synchrotron Light Laboratory, open to researchers in diverse basic and applied fields. The laboratory is equipped with ultra-bright light sources in the spectral range from UV to X-rays. The experimental stations receive photons from light sources, namely accelerators. Elettra is a third-generation synchrotron radiation facility and it comprises two accelerators: a booster and a storage ring. FERMI is a single-pass FEL user-facility covering the wavelength range from 100nm (12eV) to 4nm (124eV). The advent of femtosecond lasers has revolutionized many areas of science from solid-state physics to biology.

The accelerators are operating 24x7 and each downtime has a financial cost, and wastes time for all the users doing experiments and measurements. With the cost of beamtime at around €300 per hour per beamline, this means that with 30 beamlines the cost of a downtime of the accelerator is about €9k per hour or €230k per day. To reduce downtimes, the EUROTeV project [7] provided the accelerators with a system that allows remote operations. Experts can access remotely the accelerator controls, the accelerator logbook, instruments, and high resolution camera streams as if they were in the accelerator site, using a web application called Virtual Control Room (VCR). Thus, they can give advice to the control room operators to decide what to do to solve the problem. The restricted area is equipped with a wireless network connected to the control room via the laboratory Local Area Network, and to the Internet via the VCR. If remote expert advice and remote intervention is not sufficient to solve the problem, human intervention is required and shutdown cannot be avoided, since, due to radiation, it is unsafe for humans to access the service areas when the accelerator is turned on.

An autonomous robot interacting with, and being controlled by, the control room operator and the remote expert can solve a set of problems without shutting down the machine (i.e. without human intervention). Moreover, special measurement campaigns (e.g. radiation thermal load, ionizing radiation levels) can be executed while the

accelerators remain turned on.

Elettra- Sincrotrone Trieste has been testing for the 2 past year a Patrolbot, named SincRobot (Fig. 2), which has been integrated in the VCR and can be commanded remotely by the control room operators to reach a specific position in the accelerator. The SincRobot is a high quality, differential drive robot designed for continuous use. With a Laser Mapping and Navigation System, SincRobot can map buildings and constantly update its position within a few centimeters while traveling within mapped areas. Using the VCR, it is possible to see the robot view and command it remotely [8]. In addition, a DockingStation allows for 24x7 operation, as the onboard software can navigate the robot to the charging station. In the current state, the autonomy of the robot is limited to its navigation. The environment of an accelerator is characterized by the presence of steps and stairs, elevators and sometimes also ladders, narrow platforms and spaces with steps and various kinds of obstacles such as cables on the floor. The wheels often pass with difficulties and some areas are not accessible by the SincRobot. The environment is not modelled a priori because it changes quite often. The space is also crowded from the ceiling as cables often come from there to reach the instrumentation. This makes operations and navigation even for a flying vehicle quite difficult.

SITVIP

SITVIP is an acronym that stands for integrated telepresence systems for Very Important People. In this scenario via an internally funded project we investigated the use of these systems to allow the President, Vice-President, CEO of our company, members of the strategic committee, of the administrative council and any other important people to participate to formal and informal meetings while travelling or abroad as if they were in the laboratory. In this scenario both the TeleMe and the Double have been used with success.

REMOTE SURVEILLANCE SCENARIO

Due to a failure happened to hydraulic pumps of a tri-generation power plant a zone was defined dangerous for people but the operator had yet to monitor what was happening in the plant to prevent potential further failures. We decided to try to see if a telepresence robot could do the job. The attempt was a real success and the operators enjoyed this new possibility. In these scenario both the TeleMe and the Oculus have been used. The latter in particular has performed well above our expectations and has demonstrated a very high cost-performance ratio due partly to its well designed and multiplatform web interface.

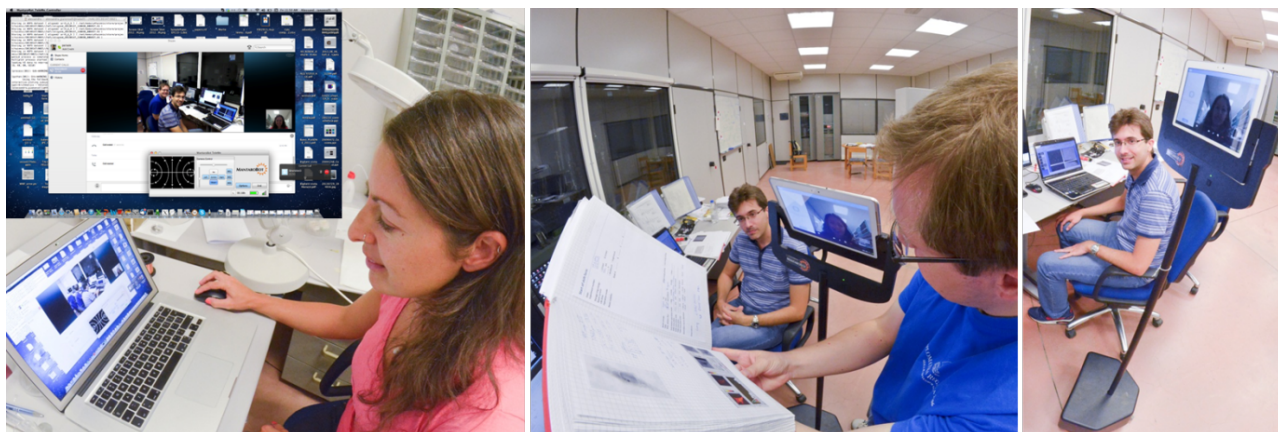


Figure 1: User telepresence for remote experiment coordination by means of a remote controlled robot in the TwinMic beamline in Elettra Sincrotrone Trieste.

REMOTE EXPERTS AT THE BEAMLINES

In order to evaluate the telepresence scenario in a synchrotron beamline, a case study plan was outlined. It involved the deployment of the robot in a working beamline during an experiment with external users and beamline personnel. The deployment was in the Control section of the Beamline TwinMic of Elettra (Fig. 1). The beamline scientist while present in a different lab, had to control the robot for positioning it suitably to permit teleconferencing with the visiting scientist and the colleague present in the beamline. The tasks included normal social interaction and coordinations of experiment related activities including remote examination of the local labbook.

The initial evaluation was positive. The use of standard teleconferencing software (Skype) was well received as the enduser had it already installed and was familiar with its functionality. The ability to move and position the system were its user wanted was greatly appreciated. On the other hand the control of the robot was found difficult and requires training. The current model of the robot assumes that the floor is clear even from the smallest obstacle (i.e. a laptop power supply cable can stop it). The navigation can be especially difficult if the remote user is not familiar with the layout of the room as the onboard camera does not provide a wide angle of view. Nevertheless the results were encouraging and suggest improvements that could make the final system better and a useful tool in the field. Further evaluation scenarios have been planned.

GUIDELINES

From the experience of using the four telepresence robots in the previously described usage scenarios we have extracted a set of guidelines and principles that have to be followed to select or design a really effective telepresence robot.

Video is critical in telepresence robots for both conversation and navigation due to their mobility. Video

streams constitute a significant portion of the data being transferred and can be adversely affected by the network connection. The guiding principle for video streams for telepresence robots is to have different video profiles when the robot is moving and when the robot is stationary. While driving the robots you sacrifice video quality for low latency and higher frame rates.

High video resolution is necessary when drivers need to read maps, numbers and codes in the SRF instrumentation. Video stream must self adjust to fluctuations in the bandwidth of the available network connection. If at some point the connection worsens and video can not be transmitted the robot should stop.

Audio is the most important component of communicating through a telepresence robot. The expected audio quality must be comparable to that of phone conversation both for the driver and for the person at the robot location.

The **user interface** must be simple, easy to use, not distracting, and provide the necessary functionality without overwhelming the driver. The interface should also be platform independent to ensure that the users can access the robots from any computer or device available to them. A web based user interface allows the user to start using the robot without any installation.

Sensor information is useful for the robot driver but too much information can overwhelm, be counterproductive and quickly ignored. Distance information and feedback is crucial but has to be provided in a timely fashion.

Incorporating a map in the user interface with an “you are here” dot is important to facilitate user orientation in unfamiliar locations and also to let the user provide a goal destination if the robot is equipped with autonomous navigation.

Ideally the **robot height** should be **remotely controllable** to facilitate human interaction at least to switch between sitting and standing conversations. The robots should be able to move at average human walking speeds of about 3 miles per hour even if this is not a must.

The robots must have at least **two cameras**, one forward facing camera to be used also as conversation camera and one showing the base of the robot for navigation. The forward facing camera should have a wide field of view to provides the driver with better situation awareness while navigating. An acceptable compromise can be a **movable pan-tilt-zoom camera** also as social cues, when in the meeting rooms the driver could point towards the person speaking to show attention and provide feedback.

Wi-fi access point switching should be also handled carefully to avoid blind zones in navigation even if this problem can be solved by preparing the environment and by a more and more efficient wireless equipment.

While autonomous behaviors can help mitigate the issue of safely controlling the robot, the video and audio streams will still be affected. To avoid these issue it is possible have two wireless interfaces not switching at the same time or support connecting to 4G networks.

Autonomous navigation is desirable because of safety reasons and for ease of use as driving the robot from one place to the other becomes quickly annoying after the first telepresence experience. Driving a remote robot is really cognitively demanding. Collisions generally occur when a driver does not have good awareness of the immediate surroundings. While adding more sensors can help but doesn't solve the problem due to cognitive overload. The robot should be at least equipped with autonomous obstacle avoidance mechanisms and assisted navigation for passing through doorways and going back to the charging station.

Certain behaviours like interacting with a person while moving are feasible only when autonomos navigation is available. With autonomous navigation the driver could instruct the robot to go to a specific meeting or to a specific place (e.g. go to power supply PS2.5). If a scheduling system or calendar existed for sharing telepresence robots, people could schedule robots for specific time slots and locations. The robot would then navigate on its own to the location by the specified time, thereby saving the driver the effort to drive the robot from the charging station to the meeting area. When the driver has finished with using the robot, the robot could simply drive itself back to the charging station or to the location of the next scheduled appointment. It would be ideal and adjustable autonomy, controllable by the driver who might want to directly teleoperate the robot when interacting with someone and simply defining the goal to navigate to the specified destination.

For social acceptance and also to respect **legal requirements** it is important for bystanders to know if a

telepresence robot is being used or not and by who via visual components (i.e. the face of the remote person visualized) and audible announcements (e.g. via text to speech).

Moreover, an open API is mandatory to be able to integrate the mobile robot with the control system of the accelerator, the access control system, to facilitate mobility and enhance effectiveness and quality or remote experience.

Similar considerations have been provided by other independent studies [9-12].

SYNDROID

In spite of the substantial progress made in the mechatronic development and control of humanoid robots [13-25] during the past 30 years there are still significant challenges to be overcome before robots (physical structure, actuation, sensing and control) can equal the motion and locomotion performance of the human body, particularly the agility, adaptability, and robustness. Recent developments in actuation technologies have suggested that at least in part these limitations can be put down to the traditional robot design template that emphasises and propagates a paradigm of actuation based on heavy, rigid mechanical structures, stiff transmission systems, combined with high gain PID servo controllers. This commonly adopted design philosophy seeks to minimize the mechanical elasticity and optimise position or trajectory tracking. The human body and motor system in contrast is highly elastic and exhibits superior motion agility, adaptability, and robustness. Very recently, the awareness of humanoid robots has gained renewed importance also in the US, as witnessed by the recently opened DARPA-BAA-12-39 Robotics challenge (DRC) aiming to develop advanced mobility and manipulation skills of humanoid robots.

To overcome the limitations of the mobilerobot discussed in SincRobot scenario, we submitted a project proposal to the EC FP7-ICT-2013-10 call. The SYNDROID project will develop the capacity of humanoid robots to operate in environments that are complex, have multiple obstacles and which change with time creating challenges similar to those in the DRC but having a real-world focus and application namely use in maintenance of a Synchrotron. It will exploit the interaction between humans, humanoid robots, simpler robots and other control systems to work together to accomplish tasks that could not be undertaken by any of these actors alone.



Figure 2: Scenes from within the Elettra accelerators related to the operating scenario of the SYNDROID: [1] Accelerator Control Room, [2] mechanical valves to manipulate, [3] buttons, switches to handle and displays to monitor [4] other valves and meters, [5] the SincRobot mobile robot, [6] stairs and obstacles, [7] electronics boards to substitute, [8] other boards, [9] stair details, [10] a typical walkway close to an insertion device.

It will be validated in a demanding, safety-critical environment (Fig. 2), the accelerator tunnels and service area of a Synchrotron radiation facility, which requires team working. Having reached and obtained access to the instrument, switch, etc, the technical operations that the SYNDROID should be able to do are:

- Resetting an instrument by pressing a button or by operating a switch when the instrument cannot be reached by the control system.
- Positioning of sensors such as infrared cameras, and radiation sensors at specific points that are difficult to access to measure data that would otherwise be impossible (the area is safe for a person only when the accelerator beam is off which means that the measurement is not meaningful).
- Open or adjust a hydraulic circuit through a knob or a standard water valve actuator re-establishing a normal flow.
- Substitute an electronic card or a particular board of a power supply. This will dramatically reduce the need for a shutdown and human intervention. A human can easily do these operations when the machine is turned off and there is no ionizing radiation danger, but shut-down is expensive.

expects technical solutions, and other collateral markets that will emerge as a side effect. Unfortunately the project proposal has not yet been funded but we firmly believe it is worth doing and are still looking for funding possibilities.

CONCLUSIONS

The feedback and experience acquired during some experiments with telepresence mobile robots in different operating scenarios was used to derive a set of guidelines and also to imagine future perspectives and usage scenarios. We hope these guidelines will be useful for the further design of next generation telepresence mobile robots.

The guidelines presented in this paper were derived from use cases for robots in the daily life of Synchrotron Radiation Facility. While the current version of telepresence robots are designed with very specific and limited scope, we firmly believe that telepresence robots are capable of providing true remote presence but have to be improved to become really effective. High quality communication protocols, client platform independence, extensibility, integrability with domotics and other control systems and autonomous navigation are mandatory for large scale adoption of telepresence robots in the corporate world and particularly in a research infrastructure.

The project idea starts from a real application requirement and has a real potential direct market behind it that

ISBN 978-3-95450-139-7

ACKNOWLEDGMENT

We would like to thank the staff of the Twinmic beamline and their users, the accelerators and the infrastructure groups, the Radiation Protection team and the legal office and all the other staff of Elettra who contributed with feedback and suggestions to the above mentioned use cases.

REFERENCES

- [1] Elettra – Sincrotrone Trieste SCpA, <http://www.elettra.eu>
- [2] Elettra Patrolbot by Adept Mobilrobots Inc. <http://www.mobilrobots.com>
- [3] Mantarobot TeleMe, <http://www.mantarobot.com>
- [4] DoubleRobotics Double, <http://www.doublerobotics.com>
- [5] Xaxxon Oculus, <http://www.xaxxon.com>
- [6] WillowGarage Beam, <https://www.suitabletech.com>
- [7] EuroTeV Project, <http://www.eurotev.org>
- [8] Elettra SincRobot. <http://www.youtube.com/watch?v=-mHEpEVEuMg>
- [9] M. Desai, K.M. Tsui, H.A. Yanco, C.Uhlik, “Essential Features of Telepresence Robots”, IEEE Conference on Technologies for Practical Robot Applications (TePRA), Woburn, MA, April 2011.
- [10] K. M. Tsui, M. Desai, H. A. Yanco, and C. Uhlik, “Exploring Use Cases for Telepresence Robots,” in Proceedings of the 6th ACM/IEEE International Conference on Human-Robot Interaction. ACM, 2011.
- [11] K. M. Tsui, M. Desai, H. A. Yanco, and C. Uhlik, “Telepresence Robots Roam the Halls of My Office,” in Human-Robot Interaction Workshop on Social Robotic Telepresence.
- [12] P. Salvini, C. Laschi, and P. Dario, “Design for Acceptability: Improving Robots Coexistence in Human Society,” International Journal of Social Robotics, pp. 1–10, 2010.
- [13] K. Akachi, K. Kaneko, N Kanehira, S. Ota, G. Miyamori, M. Hirata, S. Kajita and F. Kanehiro, “Development of humanoid robot HRP-3P”, Proc. of IEEE-RAS Int. Conf. on Humanoid Robots, pp. 50-55, 2005.
- [14] Asfour, T., Azad, P., Vahrenkamp, N., Regenstein, K., Bierbaum, A., Welke, K., Schröder, J. and Dillmann, R. (2008) Toward humanoid manipulation in human-centred environments. Robotics and Autonomous Systems, 56(11):54–65.
- [15] C. Böge, N. Vahrenkamp, T. Asfour and R. Dillmann. “Visual Servoing for Single and Dual Arm Manipulation Tasks in Humanoid Robots”, In at – Automatisierungstechnik, pp. 309-317, 2012.
- [16] K. Bouyarmane and A. Kheddar, “Humanoid Robot Locomotion and Manipulation Step Planning,” in Advanced Robotics, vol 26, pp. 1099-1126, 2012.
- [17] Do, M., Azad, P., Asfour, T. and Dillmann, R. (2008). Imitation of Human Motion on a Humanoid Robot using Nonlinear Optimization. In IEEE/RAS International Conference on Humanoid Robots, 545–552, Daejeon, Korea.
- [18] D. Gonzalez-Aguirre, J. Hoch, S. Rohl, T. Asfour, E. Bayro-Corrochano and R. Dillmann, “Towards shape-based visual object categorization for humanoid robots”, in IEEE International Conference on Robotics and Automation (ICRA), 5226-5232, 2011.
- [19] K. Hirai, M. Hirose, Y. Haikawa, and T. Takenaka, “The development of Honda humanoid robot,” in ICRA, pp. 1321-1326, 1998.
- [20] M. Hirose, Y. Haikawa, T. Takenaka, and K. Hirai, Development of Humanoid Robot ASIMO, in IROS 2001, Workshop.
- [21] Z.Li, N.Tsagarakis, D.G. Caldwell, “A Passivity Based Cartesian Admittance Control for Stabilizing the Compliant Humanoid COMAN”, 2012 IEEE-RAS International Conference on Humanoid Robots, IEEE Humanoids’12, Osaka, Japan Nov. 2012.
- [22] G. Metta, G. Sandini, D. Vernon, L. Natale, & F. Nori, The iCub humanoid robot: an open platform for research in embodied cognition. In Proceedings of the 8th workshop on performance metrics for intelligent systems, pp.50–56, 2008.
- [23] Raibert, M. H. and Hodgins, J. K. (1993). Legged robots. In Beer, R. D., Ritzmann, R. E., and McKenna, T. M., editors, Biological Neural Networks in Invertebrate Neuroethology and Robotics, pages 319–354. Academic Press.
- [24] L. Saab, P. Soueres, J.Y. Fourquet “Coupling manipulation and locomotion tasks for a humanoid robot,” Advances in Computational Tools for Engineering Applications, ACTEA '09., pp. 84-89, 2009.
- [25] N.G.Tsagarakis, G.Metta, G.Sandini, D.Vernon, R.Beira, F.Becchi, L.Righetti, J.S.Victor, A.J. Ijspeert, M.C.Carrozza and D.G.Caldwell, iCub –The Design and Realization of an Open Humanoid Platform for Cognitive and Neuroscience Research, International Journal of Advanced Robotics, Special Issue on “Robotic platforms for Research in Neuroscience”, Vol.21, No.10, pp, 1151-1175, 2007.