A MOBILE PLATFORM FOR REMOTE INSPECTION INSIDE ESRF TUNNEL

J. M. Chaize, D. Robinson, L. Hardy, ESRF Grenoble France
J. Mattila, A. Hahto, Tampere University of Technology, Finland.

Abstract

A light source has to provide beam 24h/24h x 7 days. Numerous sensors have been installed to detect hardware failures, fires, water leaks etc... Unfortunately, with aging, we are sometimes faced to false alarms. Then, visual inspection becomes necessary to confirm or evaluate an alarm. ESRF in collaboration with the Tampere University of Technology (IHA)* and expertise from ROVIR# is developing a autonomous vehicle remotely controlled via WiFi. It is able to travel all along the tunnel while it is closed to human being, and transmit live image of a high definition video camera. Thanks to virtual reality software, the operator is able to send the platform to any location of the tunnel. The platform should be able to get energy autonomy, to automatically recharge its battery, to react to unforeseen situations, to avoid collisions, and to do self learning of its environment. One of the goals of the collaboration is to design this tool in such a way that it can become a commercial product available at reasonable cost for any light source.

NEEDS AND CONSTRAINTS

The Context

The ESRF is operating a particle accelerator to produce a continuous flux of hard X ray beam to about 40 laboratories located around the accelerator for doing various types of experiments.

The Storage Ring tunnel is a ring of 844m circumference in which a lot of equipments are installed. The Storage Ring is operating 24 hours a day for periods of 2 months. During this time, due to high level of radiation, the access of the tunnel is forbidden. Once a week, the beam is killed for a few hours of controlled access for maintenance.

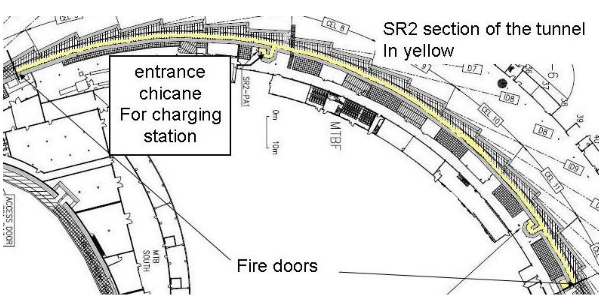

Figure 1: general shape of the tunnel.

The tunnel is full of equipments. A free way 90 cm width with a narrow place of 60 cm is available all along the tunnel. (See figure 2)

*Dept of Intelligent Hydraulics and Automation: http://www.iha.tut.fi/
#Remote Operation and Virtual Reality: http://www.hermia.fi/rovir/

Figure 2: inside the tunnel.

Facilities and Constraints

All the tunnel area is covered by a IEEE802.11g WiFi network. To protect the vehicle from the high level of X ray radiation, it will be put away behind a concrete shielding in a chicane door when unused. Several chicane doors are distributed over the ring. (see figure 3). The electronic parts should be shielded by a foil of lead.

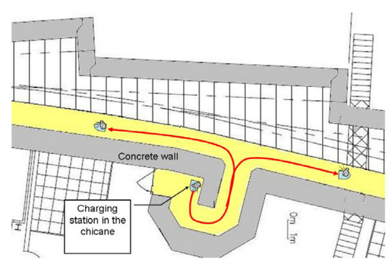

Figure 3: A chicane door.

Energy Autonomy

The vehicle should be operational one week without human intervention; to guaranty this autonomy, an automatic battery recharging system is necessary.

Navigation Autonomy

It should be much more than a remotely guided vehicle. It should be able to answer to macro commands and to behave autonomously in case of temporary unavailability of the WiFi signal. In case of unforeseen obstacle it should take the best decision.

The positioning system should be done without any modification of the environment. The system should be based only on on-board devices such as gyroscope, laser scanner, and odometers. (No GPS, no active wire, no transponder etc...)

Openness

The navigation and control software should be open enough to allow API programming and integration of the vehicle as a device of the accelerator control.

THE PROJECT

In the recent past with the fast technology improvement, we can find many kind autonomous vehicles on the market. However, there is a high gap in price and performance as soon as we want an open system or a modular system.

The competences and expertise necessary to build such a vehicle are very wide (mechanic, robotics, navigation, software, shielding ...)

ESRF has chosen to share the development with well-known experts of the domain. Tampere University of Technology, Department of Intelligent Hydraulics and Automation (IHA) has a long experience in developed of remotely controlled devices for ITER-project and various outdoor mobile machines. IHA is working highly networked manner is supported by Remote Operation and Virtual Reality Center (ROVIR) and General Intelligent Machines GIM project funded by Academy of Finland. IHA is interested in developing demanding high-end products for that may become a standard for synchrotron facilities.

A contract has been signed between ESRF and IHA.

ESRF is providing the requirement and the testing facility and a mechanical expert, IHA provide technical expertise. Both experts collaborating in building the best vehicle

DESIGN FEATURES

Background

Design of mobile robot platform with camera manipulator including Pan and Tilt (PT) mechanism was a very challenging task due to demanding design specification given by ESRF. A brief summary of key requirements is given as follows:

1) The width of the platform should not exceed 50 cm to allow crossing the narrowest points of tunnel and for not blocking the tunnel in the case of emergency
2) A mobile camera should be able to observe tunnel equipment from 40 cm to 180 cm high
3) Payload capacity of 10-15 kilos should be reserved for lead shielding
4) Mobile platform should have high level of autonomy

The key design challenge was a platform modular design for minimizing number of electrical parts to be protected by lead shielding. X-ray radiation aging of electrical and other sensitive platform materials like wires is expected to take place. Therefore, the modularity of the platform design greatly affects the Reliability, Availability, Maintainability and Safety (RAMS) of the platform operation. Tunnel geometry requires relatively narrow but yet powerful platform for which differential drive tricycle platform was chosen after design tradeoffs analysis of platform with parameters like: platform manoeuvrability, high and low velocity stability and robustness of design. Moreover, due to long distances to be travelled in Storage Ring tunnel results relatively high platform velocity requirement. A special design for platform manipulator operating relatively heavy lead and lead glass protected camera with PT-mechanism was carried out and is under test. Several design iteration rounds was carried out for adjusting the platform centre of gravity with different platform module locations including lead shielding. Moreover, as expected the camera manipulator design and weight distribution e.g. base position greatly affects the resulting drivability and manoeuvrability of platform.

Control System Software

IHA currently has many modules in its portfolio, designed to fit the ITER's requirements in the area of remote handling. For controlling the hardware, a real-time software package is developed including the generation of various movement sequences, navigation and user interfaces.

For operations management and task planning, IHA has a hierarchical tool (IHAPlanner) designed to manage and design the instruction flows.

All the 3D visualization and simulation is done by IHA3D, which is used to build virtual models about the environment and the robots using their CAD models. All the joint values and position data can be transferred from the real devices using a standard network connection.

For machine vision and camera controlling, IHAView is used. The software includes object recognition and tracking features.

LabRat is an integrative component, designed to gradually tie together the previously mentioned modules and know-how from them. See (figure 4).

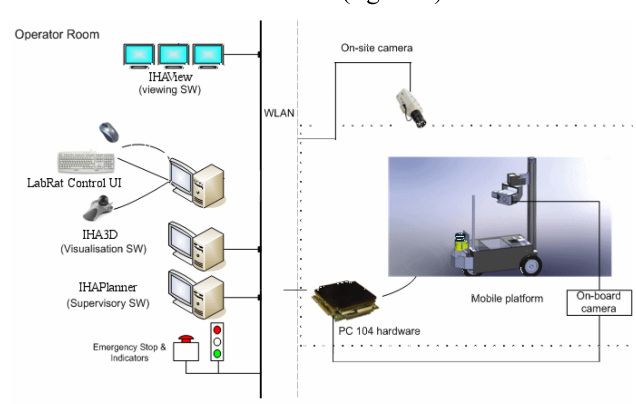

Figure 3: Sub-systems integration.

The same time it serves as a show-case to demonstrate the technology outside ITER usage, and as a physical actuator utilizing the same software back-end. As most of the ITER robots are anything else than mobile, it's valuable to prove that the technology scales down to smaller sizes and is usable in commercial products.

Modularity

It is possible to attach new sensors or actuators, according to the specific operation environments. The platform is easily converted to different needs in hand and the parts used are off-the-shelf whenever it's possible.

Reliability

The software runs on top of the Linux operating system, extended with a real-time kernel. The OS itself is prone to be reliable [1] and the running of programs, WLAN connection, etc. is monitored by a watchdog. An industrial grade PC/104 computer is used as computing hardware.

As the device is specifically intentioned to operate under hazardous environments with radiation, ESRF provides its expertise with the radiation protection and mechanics, testing the device intensively in the actual synchrotron tunnel with continuous usage. All these real world usage experiences are directly reflected to the design.

Operation

The robot maintains a wireless WiFi IEEE802.11g link to the operator end, when available.

While within a well covered range, the robot can be manually driven by the operator, assisted by live high resolution video stream and laser scanner mapping data. While the link is active, new operation instructions can be uploaded to the vehicle. During operation, some areas of the tunnel have a very weak WiFi connectivity due to High level of electromagnetic noise. The instructions are then executed autonomously when entering the blind spot areas, or while performing routine tasks requiring no manual driving.

For simple events, such as collision detection, the behaviour is purely reactive (compare to human reflexes) and for some complex tasks, the computing resources of the remote operator end can be utilized. The high-level planning is done in the remote end with comparably unlimited computing resources, and all the details are executed locally (see figure 5)

The sensor data is used to deduce the vehicle position by a predictive filter, effectively reducing the noise. The trajectory generator is driving the vehicle to the next route coordinates, provided by a route planning algorithm.

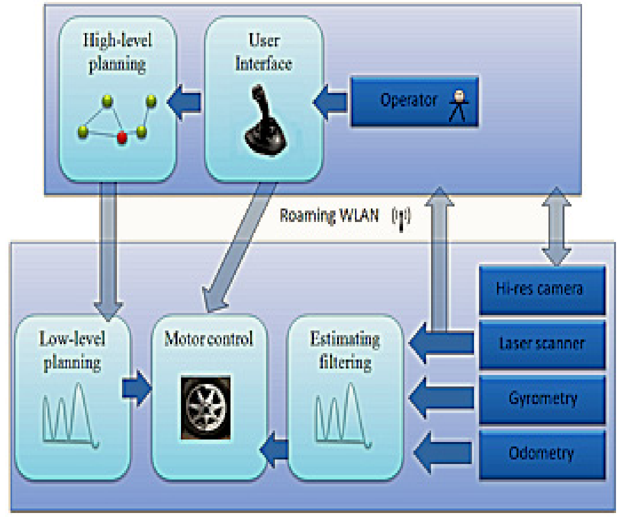

Figure 4: Software architecture.

FURTHER DEVELOPMENTS

In the future, most of the modules may be separated so, that different navigation and planning algorithms can be tested and compared to the base implementation with an ease. The integration to other IHA modules is currently under way.

It would be interesting to implement an ANFIS (Adaptive-Network-based Fuzzy Inference System, [2]) as a main controller. Hypercube-based NEAT (NeuroEvolution of Augmenting Topologies, [3]) could be used to train a neural network mimicking biological brain's visual cortex areas, in order to perform localization directly from the video image. Most of the artificial intelligence development will move away from specific application areas, to general biologically inspired algorithms performing the same tasks in a more robust way, one of the authors predict.

From the hardware point of view, active stereo vision is feasible and it adds to the user experience.

CONCLUSIONS

Stepping aside from pure algorithms and techniques, this project is all about real world usage providing direct benefit for its application area. That is why, it's important to derive ideas and co-operation directly from the interested parties and to establish a common platform with still enough flexibility to suit the individual needs.

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