A Survey of Applied Robotics for the Power Industry in Brazil

Walter Fetter Lages
Department of Electrical Engineering
Federal University of Rio Grande do Sul
Porto Alegre, RS, 90035-190 BRAZIL
E-mail: fetter@ece.ufrgs.br

Vinícius Menezes de Oliveira
Center for Computational Sciences
Federal University of Rio Grande
Rio Grande, RS, BRAZIL
E-mail: vinicius.oliveira@furg.br

***Abstract*—Currently, the power industry in Brazil is a system with many public and private companies competing by market rules and regulated by an specific agency (ANEEL). The legal mark for the power industry defines the Research and Development (R&D) Program of the Power Sector. By a Federal Law companies operating under concession, permission or authorization of the government in distribution, transmission or power generation should apply a minimum percentage of their net operational revenues in research and development. The power companies have the decision on which project to fund, but they do not conduct the R&D themselves. Instead, they should apply the resources by contracting a national research and development institution. The results are evaluated by ANEEL, an if not considered appropriate, the resources are considered as not applied and should be applied again in another project in the next year. A significant amount of resources from the R&D programs, have been used to fund the development of robotic devices. This paper presents a survey of those developments.**

I. Introduction

Over the past 15 years, the power industry in Brazil changed from a system totally owned and operated by the state to a system with many public and private companies competing by market rules and regulated by the, then recently created, Agência Nacional de Energia Elétrica (ANEEL).

The new legal mark for the power industry also created, in the year 2000 the Research and Development (R&D) Program of the Power Sector as a way to encourage a constant search for innovation by the new companies and to cope with the new technological challenges in the industry. By the Federal Law n. 9.991/2000 companies operating under concession, permission or authorization of the government in distribution, transmission or power generation should apply a minimum percentage of their net operational revenues in research and development. That percentage has varied over the years, but currently (until December,2015) it is 0.5% for distribution companies and 1% for generation and transmission companies. From that amount, 40% go to a national fund for scientific and technological development (FNDCT), 20% go to the Ministry of Mines and Energy to apply in planning of the expansion of the power system and the remaining 40% should be applied by the utility company in its R&D program accordingly to ANEEL rules. Hence, distribution companies are forced by law to apply at least 0.20% of their net operational revenues in R&D. Transmission and power generation companies, should apply 0.40% of their net operational revenues in R&D. The values are accounted for in yearly base, and companies should report to ANEEL what were the R&D projects funded.

The power companies have the decision on which project to fund, but they do not conduct the R&D themselves, instead, they should apply the resources by contracting a national research and development institution, which should be registered with the Ministry of Science and Technology (MCT), or an university or other higher education institution, which should be registered with the Ministry of Education (MEC). Since the power companies decide about the R&D projects, they should have well defined objectives and results. The results are evaluated by ANEEL, an if not considered appropriate, the resources are considered as not applied and should be applied again in another project in the next year.

A significant amount of resources from the R&D programs, from many companies, have been used to fund the development of robotic devices. This paper presents a survey of those developments.

II. Robot for Insertion and Removal of Aircraft Warning Spheres

One of the first robots was developed by Centrais Elétricas de Minas Gerais (CEMIG) and Universidade Federal de Minas Gerais (UFMG), even before the mandated R&D programs [1]. It was a semi-autonomous robot for insertion and removal of aircraft warning spheres on aerial power lines and is shown in figure 1. Once on the cable, the robot is capable of full autonomous operation, but due to the characteristics of the task, tele-operation is used to move the robot to the desired position. Insertion and removal of spheres are performed autonomously.

Hybrid systems methodology was used to model the basic modes of operation of the robot and a custom made gripper was used to accomplish the task. The robot is actuated by four motors. Two of them are used for locomotion, on is used to move the screwdriver used remove the spheres and the other is used to turn the screwdriver. The system is powered by two 12V rechargeable batteries. The robot developers argue that the failure rate for complete insertion and removal tasks was below 1% and the electrical company support personal the system is easy to transport, setup an use.

Fig. 1. CEMIG/UFMG robot for insertion and removal of warning spheres.

III. Aerial Power Lines Inspection Robots

A system for service in power lines and robotic maintenance of guard cables was developed in the earlier cycles of the R&D program (2001/2002) with funding from Companhia de Transmissão de Energia Elétrica Paulista (CTEEP) and Escola Politécnica da Univeridade de São Paulo (EPUSP) [2]. The robot, shown in figure 2, is able to overcome the towers in the power line and has a visual camera for inspection of cables, insulator and clearances the power line. Insertion and removal of warning spheres were included as well. Its design has considered wind effects [1], [3]. In a second R&D cycle (2002-2003) the robot was improved to repair damaged cables.

Fig. 2. CETEEP/EPUSP robot for inspection of cables.

Another robot for inspection of power lines was developed by Companhia Estadual de Energia Elétrica (CEEE), which contracted Universidade Federal do Rio Grande do Sul (UFRGS) in the 2004/2005 cycle. A brachiating type of motion was proposed for that robot [4]–[7], which is shown in sketch in figure 3, , thus requiring advanced control methods such as model predictive control. Although that type of motion was later abandoned, that project made developments in the the inspection of cables by thermography [8].

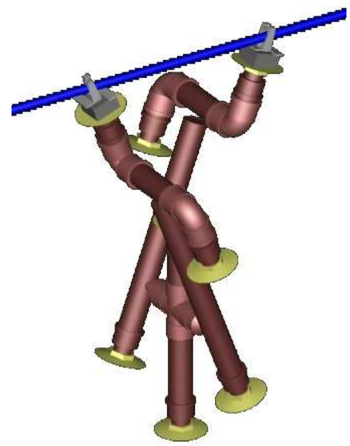


Fig. 3. Sketch of the CEEE/UFRGS robot for inspection of cables.

IV. Underground Robotized Cable Inspection

The TATUBOT project [9] is a robotic platform designed to monitor underground distribution lines and is presented in figure 4. It is equipped with sensors and actuators that make it capable of acting within electrical ducts. The project objective is develop an autonomous robotic system intended to optimize the cable maintenance procedure and access the actual state of each cable by using sensors that collect data for analyzing the insulation status. This robot, which has to move autonomously in the duct, uses an autonomous navigation system, which enables the platform to monitor the power lines. Such a system should take into account the following requirements:

- structured environment: comprising rectilinear cables whose structure can guide the robot navigation;
- partially known environment: cables arranged in different conformations within the duct should be perceived by the robot in its online navigation
- long and monotonous tasks: monitoring is comprised of long missions of the robot along ducts;

Due to its mechanical structure, the robot can adapt to many duct diameters, and autonomously transition between them. Figure 5 shows a scenery with a variation in duct diameter. The robot should transverse from a lower diameter ($D1$) to a higher diameter ($D2$) duct.

The angle of each traction wheel is actuated by an independent motor, as shown in figure 6. This angular motion enables to robot to rotate while inside the duct, as shown in figure 7. This way, the robot can correct its position with respect to the horizontal plane and overcome points with overlapped cables.

V. Robotized Monitoring of Reservoirs

A low cost underwater Remote Operated Vehicle (ROV) was developed by Ampla Energia e Serviços and Coordenação de Projetos, Pesquisas e Estudos Tecnológicos (COPPETEC)

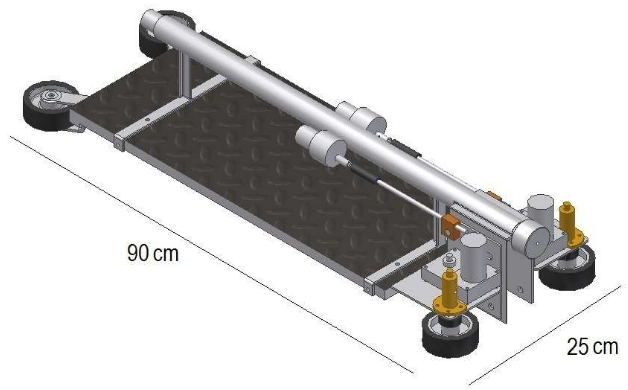


Fig. 4. Sketch of the TATUBOT robot for inspection underground cables.

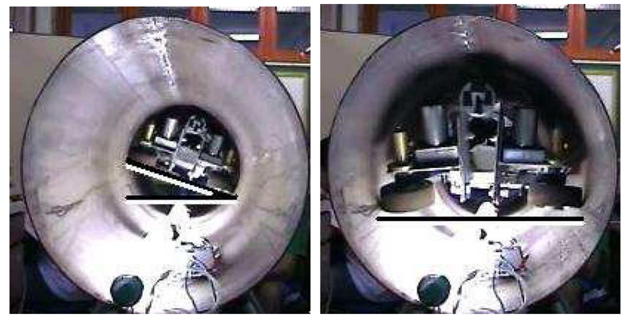
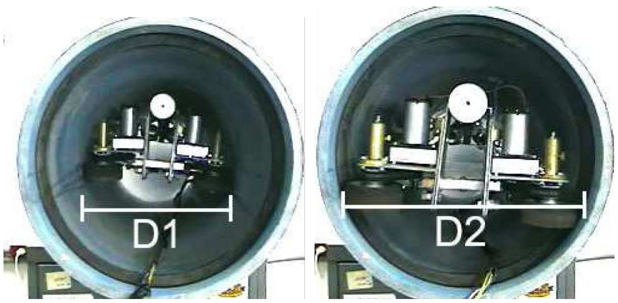


Fig. 7. Position correction by rotation.



(a) Lower diameter ($D1$). (b) Higher diameter ($D2$).

Fig. 5. Mechanical structure adaptation for duct diameter variations.

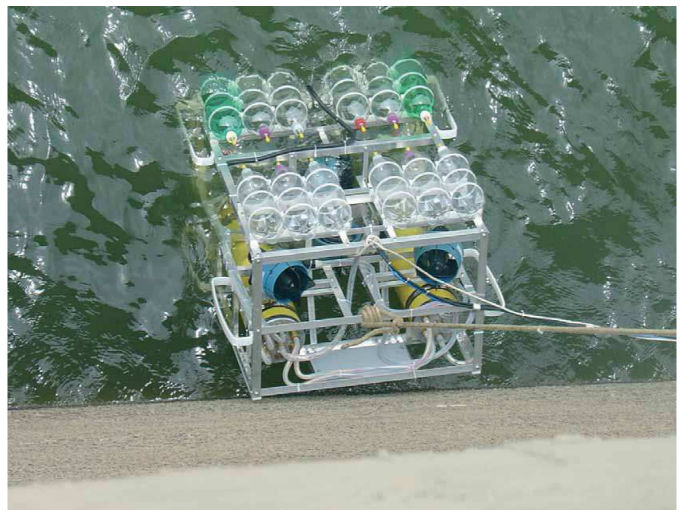


Fig. 8. Low cost underwater ROV developed by Ampla and COPPETEC.

[10], in the 2003/2004 cycle, for inspection of adduction tunnels with turbid waters. The robot is based on recycled PET bottles, as shown in figure 8.

Despite its low cost, images from the robot cameras can be used to detect structural problems in walls (fissures and cracks), accumulation of debris in the bed and other problems, without the need to empty the tunnels, which is a dangerous and time-consuming operation. The system has four propellers, an automatic navigation system and the capture of images is supported by a LED-based lighting system.

A system for monitoring reservoirs was developed by Companhia Energética de São Paulo (CESP) and USP based on an Unmanned Aerial Vehicle (UAV) [11] in the 2006/2007 cycle. The system is integrated with a Geographic Information System (GIS), such that images taken from the UAV camera are confronted to images from satellite in order to detect changes in the vegetation of the area, as shown in figure 9.

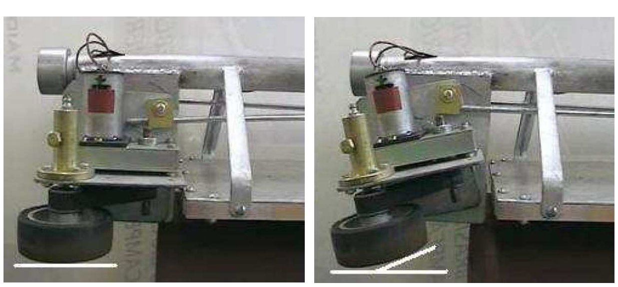


Fig. 6. Variation of the angle of traction wheel.

VI. Integrated Monitoring System

An integrated system for monitoring and prediction of the life-time of conductors in distribution and transmission lines is in development by Universidade Federal do Rio Grande (FURG), Universidade Federal do Rio Grande do Sul (UFRGS) and Universidade Federal do Rio Grande do Norte (UFRN), with funding from FNDCT. The system is based on a network of mobile sensors and is composed of 6 modules: 4 for monitoring the cables, one for diagnosis and prediction of failures and other for user interfacing and visualization. Each monitoring module uses a different technology. The first one is based on a grid of sensors mounted on surfaces of underground ducts and around aerial distribution and transmission lines. The other monitoring modules are based on robots: a robot for inspection of underground ducts, moving above the cables, much like a pig used in the oil industry, an UAV for monitoring aerial lines and a robot moving the cables, for inspection of specific spots. Data from all sensors are integrated by statistical inference methods to produce a diagnosis of the line.

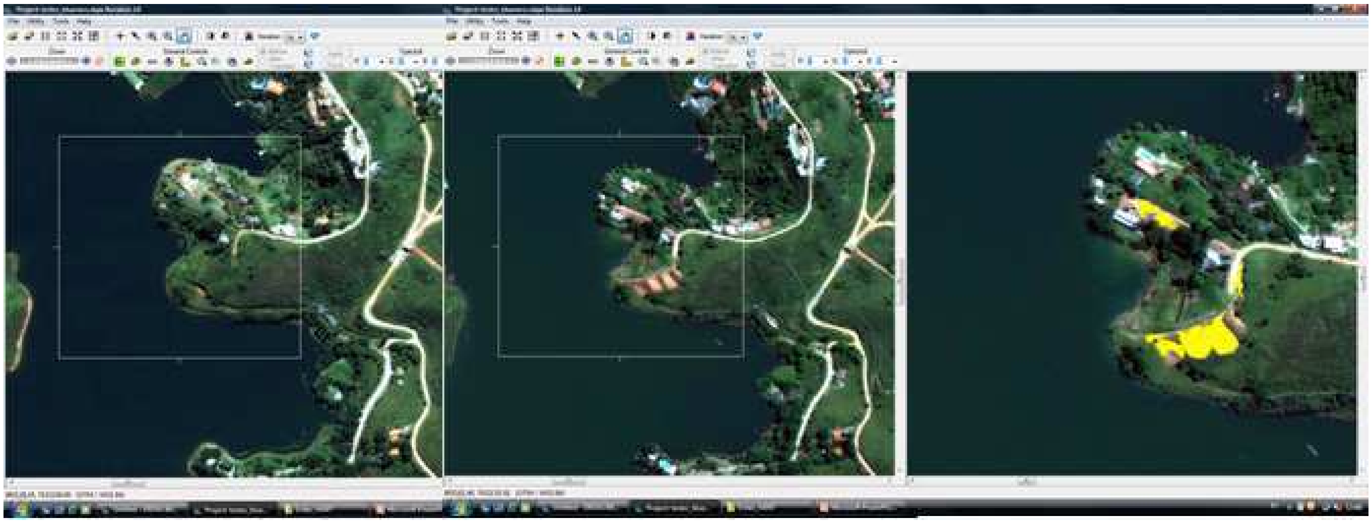


Fig. 9. Detection of change in vegetation areas.

VII. Conclusion

The last report from ANEEL about R&D project under development revels that there are 15 projects related to applied robotics that started between 2009 and 2011, as shown in table I. The target of 9 of them is the inspection of power lines, reservoirs or chimney of thermoelectric plants. From those, 5 propose the use of UAV. Other projects include robots for duct welding, cleaning of cables, cleaning of insulators and scare birds.

TABLE I
Applied robotics projects started between 2009 and 2011.

Utility	Subject	Segment	Start date	End date
TRACTEBEL	Duct welding	Gen.	03-15-2009	06-14-2011
NTE	Power line inspection	Trans	07-01-2009	09-29-2012
COPEL-DIS	UAV for power line inspection	Dist.	N/A	N/A
RLE	UAV for reservoir inspection	Gen.	04-10-2010	04-09-2013
CESP	Underwater inspection in hydroelectric plants	Gen.	01-31-2011	07-31-2014
COELCE	Cable cleaning	Dist.	10-01-2011	09-30-2013
CEMIG-D	UAV for multiple applications	Dist.	06-16-2010	09-15-2011
CHESF	Substation monitoring by infrared	Trans	N/A	N/A
CEMIG-D	Power line inspection	Dist.	04-27-2011	04-26-2014
UTNF	Inspection of chimney for thermoelectric plants	Gen.	06-01-2011	11-29-2013
ELEKTRO	Power line inspection	Dist.	03-17-2011	03-16-2013
COELCE	Autonomous insulator cleaning	Dist.	N/A	N/A
CELG-D	UAV for power line maintenance	Dist.	11-1-2011	10-31-2014
CELPE	Automated tree trimming	Dist.	07-15-2011	07-14-2013
ITAPEBI	UAV for multiple inspections	Trans.	10-01-2011	09-30-2013

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