2.1 - Project name

Participation in the ITER project

2.2 - Project team

Please fill the table below with the team data. Add more rows if required.

Name	Degree	% participation
Alberto Vale	Doctorate researcher	100 %
Bruno Gonçalves	Doctorate Researcher	5%
Daniel Fonte	Master Researcher	100%
Elsa Silva	Quality Manager	10%
Filipe Valente	Master Software developer	100%
Isabel Ribeiro (*)	Doctorate Researcher	40%
João Bivar	Master Software developer	75%
João Ferreira	Master Software developer	100%
Ricardo Oliveira	Graduated and Master Student	20%
Rodrigo Ventura (*)	Doctorate Researcher	20%

(*) Affiliated with the Institute for Systems and Robotics (ISR), Associate Laboratory of IST.

2.3 - Summary and highlights of research achievementes

Provide a concise description of the main research achievements during the year.

Figures, tables, graphics etc must have captions.

Graphic files must be submitted separately from the text (i.e. not embedded), and have a resolution of at least 150 dpi.

2.3.1 Introduction

The main scientific activities on Remote Handling (RH) in ITER were enrolled on the grant F4E-GRT-276-01, related with the trajectories for the Cask and Plug Remote Handling System (CPRHS), Cask Transfer System (CTS) and Rescue cask in the Tokamak Building (TB) and Hot Cell Building (HCB). A total of 536 optimized trajectories were evaluated (232 in TB and 304 in HCB) and 46 CPRHS volumes were analyzed in TB, including trajectory optimization and trajectory validation studies. The results were achieved based on software specially developed for the purpose of trajectories studies.

Additional scientific activities also related with RH were achieved, as the studies of techniques for the localization of casks during RH operations and the development of a small prototype of a rhombic like vehicle with kinematics similar to the CTS.

The following sections summarize the scientific activities.

2.3.2 Remote handling

Analysis of CAD models of the buildings and casks

ITER buildings (TB and HCB) and vehicle models (different typologies of CPRHS, CTS and Rescue casks) were provided by F4E through Configuration Management Models (CMM).

Studies of the CMM related with HCB and with TB identified the main issues and incompatibilities of RH operation with CPRHS, CTS and Rescue casks in the ITER scenarios. The main conclusions were reported to F4E. These studies analyzed the volumes reserved by ITER organization for the operation of the CPRHS, CTS and rescue casks discussing the possibility of having an optimal trajectory fully contained inside them.

Trajectory optimization

Trajectory optimization evaluates the best trajectory (best path with the optimized velocity profile) in terms of the shortest distance between the starting and target points, the maximum distance to the closest obstacles of the 2D considered map along the journey and guaranteeing smoothness.

The trajectory optimization procedures are divided in different activities:

- Same path for both wheels (targeted to line guidance control systems).
- Different paths for each wheel (targeted to free roaming control systems), in such a way as to explore the full flexibility of the rhombic kinematics of the CTS, this being one the upgrades achieved in 2011.
- Integration of maneuvers in trajectories.
- Maximization of common parts of different trajectories, minimizing the total area occupied by all the casks in all RH operations.
- Doors proposal configurations in TB (aperture direction and angle). In several situations presented by ITER Organization in CMM, the doors are in collision with casks along the trajectory or may compromise the functional tolerance.

Trajectories were optimized for CPRHS, CTS, Parking and for Rescue operations in levels B2, B1, L1 and L3 of HCB and for CPRHS, CTS and Rescue cask for all ports and for the “rings” (around the Tokamak) in levels B1, L1 and L2 in TB.

All the trajectories were individually analyzed reporting the minimum distances between the cask and the closest obstacles along the path to verify it the required functional tolerance is accomplished. The left image of Figure 1 illustrates an optimized trajectory for the CPRHS to port 8 in level B1 of TB. The right image of Figure 1 illustrates minimum distances between the CPRHS and the closest obstacles in the environments along the optimized trajectory.

The line guidance approach provides the ability to set a common path for both wheels, useful to implement in a line guidance system. However, in some situations, it is not possible or not recommended to implement a common path for both wheels as illustrated in Figure 2.

The line guidance approach is improved including maneuvers in the trajectories, i.e., points where the cask stops and changes its motion direction, as illustrated in Figure 3.

There are several trajectories in each level for the TB or for the HCB and different trajectories may have a long common part. The trajectory optimization algorithms also maximize the common part between

different trajectories. In TB, each trajectory is maximized with the trajectory of the ring in the respective level of TB, as illustrated in Figure 4.

Most of the optimized trajectories are not compliant with the aperture configuration of the port cell doors, as illustrated in Figure 5. The proposed modifications were reported to F4E for all doors in all levels of TB.

All the trajectories were validated though the EADS 3D Trajectory Validation software developed by ASTRIUM.

Feasibility analysis of the occupied volumes in CMM

The Configuration Management Models (CMM) provided by F4E included the occupied volume of the casks during the RH operations in ITER evaluated by the ITER Organization (IO). These volumes correspond to the space reserved for the movements of the casks to avoid collisions and to satisfy a functional tolerance. One of the activities carried out in 2011 was the feasibility analysis of the occupied volumes in CMM, achieved through the generation of trajectories using a 2D virtual map resulting from the 2D projection of the CMM occupied volumes for each vehicle type.

The main conclusions are that several volumes proposed by IO are not feasible or are feasible but cannot be accomplished with smooth paths, which may compromise a real implementation, as illustrated in Figure 8.

Software development

The Trajectory Evaluator and Simulator (TES) is a software application that receives the 2D models of the scenario (e.g. a level of TB or HCB) and evaluates an optimal trajectory for each mission using line guidance approach or free roaming. The TES is able to gather the relevant information on a trajectory, in particular the volume occupied by the CPRHS/CTS/Rescue cask and the corresponding functional tolerance provided in CATIA format, the minimum distance to the nearest obstacles to the 2D considered map along the entire trajectory, the identification of potential clashes, and the identification of zones of risk in the scenario. This information can be directly exported to CATIA or in XLS format. The TES is also able to provide automatically and entire report of each trajectory.

The TES supports different typologies of CPRHS, CTS or Rescue cask and provides the ability to guide automatically or manually the vehicle. The interface between the TES and CATIa and the corresponding inputs and outputs are illustrated in Figure 9.

The TES, upgraded in 2011, include:

- Modifications in the Graphical User Interface (GUI) to easily handle the ITER buildings and their modifications, and the different CTS and CPRHS typologies models. The GUI was redesigned taking into account the behavior of digital and analog controller devices for manual driving of rhombic like vehicles. A preview of the GUI is presented in left image of Figure 10.
- Integration of a new algorithm to optimize independent trajectories for each wheel to fully explore the maneuverability flexibility provided by the rhombic configuration of the CTS.
- Integration of a tool to optimize the possible common segments of multiple paths.
- A tool to export 2D optimized trajectories and 3D swept volumes and functional tolerance to the software CATIA V5R19, as illustrated in right image of Figure 10.
- Generation of the essential information for the trajectory analysis (e.g., evolution of the minimum distance to obstacles along a path, velocity profile) and images.
- A User Manual was written explaining all the features.

Techniques for the localization of casks during RH operations

In ITER environment, the cask transports contaminated loads with may affect the electronic devices. On the other hand, and irrespectively of the navigation methodology that will be adopted, the real time evaluation of the vehicle's location is required. Therefore, techniques for the localization of casks were studied taking into account a network of sensors installed in the environment and spread along it. In addition, it was studied the best type of sensors to be used in this scenario. Laser range sensors were considered the best option.

An algorithm was proposed to optimize a laser range sensor network, i.e., the number of sensors and the best places to install them for maximizing the coverage area according to the scenario configuration and the sensors specifications were studied.

Based on a laser range sensors network, two different localization algorithms, based on probabilistic approaches, were developed to estimate the pose of the vehicle in the ITER: Extended Kalman Filter and Particle Filter. These approaches were compared, with respect to the localization performance and the robustness for a real implementation.

Development of a small prototype

The design and development of a rhombic like vehicle took place in 2011. It is a prototype at a scale 1:25 of the real cask dimensions, as illustrated in Figure 11. This prototype can be programmed and remotely operated by Bluetooth protocol to test the trajectory optimization algorithms and the techniques for the localization of casks.

Please fill the following pages according to the format shown and the examples provided.

It is suggested that for each section you start by copying as many items as required.

General recommendations:

A. Publications

Papers in international refereed scientific journals

Author(s)	Ribeiro I., C. Damiani, A. Tesini, S. Kakudate, M. Siuko, C. Neri
Paper title	The Remote Handling Systems for ITER
Journal name	Fusion Engineering and Design
Volume, page	86, 471–477
Year	2011

Author(s)	Valente F., A. Vale, D. Fonte, I. Ribeiro
Paper title	Optimized Trajectories of the Transfer Cask System in ITER
Journal name	Fusion Engineering and Design
Volume, page	86, 1967–1970
Year	2011

B. Publications and contributions in conferences and workshops

Papers in conference proceedings

Author(s)	**Vale A., I.Ribeiro**
Paper title	**Mobile Robot Navigation for Remote Handling operations in ITER**
Conference	**III Workshop de Robótica: Robótica Experimental, 28-29 Noviembre 2011. Escuela Superior de Ingenieros de la Universidad de Sevilla - España.**
Volume, page	
Year	**2011**

Author(s)	Fonte D., F. Valente, A.Vale, I. Ribeiro
Paper title	Path Optimization of Rhombic-Like Vehicles: An Approach Based on Rigid Body Dynamic
Conference	Proceedings of the 15th IEEE International Conference on Advanced Robotics (ICAR 2011) Tallinn, Estonia, June 20-23, 2011.
Volume, page	106-111
Year	2011

Author(s)	Bivar J., A. Vale

Paper title	Behavior of Digital and Analog Controller Devices for Manual Driving of Rhombic like Vehicles
Conference	Proceedings of the 19th IEEE Mediterranean Conference on Control and Automation (MED 2011), 1065-1070, Corfu, Greece, June 20-23 2011
Volume, page	1065-1070
Year	2011

Oral contributions

Conference	III Workshop de Robótica: Robótica Experimental
Start-end date	28-29 Noviembre 2011
Location	Escuela Superior de Ingenieros de la Universidad de Sevilla – España
Author(s)	Alberto Vale, Isabel Ribeiro
Talk title	Mobile Robot Navigation for Remote Handling operations in ITER

Conference	15th IEEE International Conference on Advanced Robotics (ICAR 2011)
Start-end date	June 20-23, 2011
Location	Tallinn, Estonia

Author(s)	Daniel Fonte, Filipe Valente, Alberto Vale, Isabel Ribeiro
Talk title	Path Optimization of Rhombic-Like Vehicles: An Approach Based on

Conference	19th IEEE Mediterranean Conference on Control and Automation (MED 2011)
Start-end date	June 20-23, 2011
Location	Corfu, Greece
Author(s)	João Bivar, Alberto Vale
Talk title	Behavior of Digital and Analog Controller Devices for Manual Driving of Rhombic like Vehicles

Rigid Body Dynamic

Conference	19th IEEE Mediterranean Conference on Control and Automation (MED 2011)
Start-end date	June 20-23, 2011
Location	Corfu, Greece
Author(s)	João Bivar, Alberto Vale
Talk title	Behavior of Digital and Analog Controller Devices for Manual Driving of Rhombic like Vehicles

Technical reports

Isabel Ribeiro, Alberto Vale, Filipe Valente, Daniel Fonte, Rodrigo Ventura, Pedro Lima, Bruno Gonçalves, Elsa Silva, Pierre Ruibanys, Christophe Reig, " Optimization of trajectories for the Cask and Plug Remote Handling System in the Tokamak Building and Hot Cell" Final, Parts I, II, III, and IV – F4E-GRT-276-01 (MS-RH), European Joint Undertaking For ITER « Fusion For Energy » Work Programme 2010, December 2011.

Laboratorial prototypes

Alberto Vale, Ricardo Oliveira, Rodrigo Ventura, "Development of prototype of a rhombic like vehicle with a scale 1:25 of the real Cask and Plug Remote Handling System to be used in the ITER for Remote Handling operations; this prototype is a test bed for the trajectory optimization algorithms and localization techniques."

Computational and numerical codes

Authors: Alberto Vale, Daniel Fonte, Filipe Valente, João Ferreira

Title: Trajectory Evaluator and Simulator (TES) developed under MATLAB environment, able to receive CAD models of the ITER building scenario and return the optimized trajectories for nominal operations of remote handling operations.

November 2011

Master's theses completed

Daniel Alexandre Leal Espinha Fonte, " Motion Planning for a Rhombic-Like Vehicle Operating in ITER Scenarios" Master Thesis, Instituto Superior Técnico, June 2011.

Supervised by:

Assistant researcher Alberto Vale (IPFN/IST)
Professor Miguel Afonso Dias de Ayala Botto (IST)

Refereeing of scientific publications

Example: N. Surname served as referee for Journal X.

Isabel Ribeiro served as referee for Fusion Engineering and Design

Alberto Vale served as reviewer for the 2012 IEEE International Conference on Robotics and Automation (CRA2012), for the 15th Portuguese Conference on Artificial Intelligence (EPIA2011).

Alberto Vale was PhD thesis committee member of D. Diego A. López García, at University of Huelva, Spain (title of the thesis: Development of new approaches for path planning of non-holonomic vehicles) and reviewer of the PhD thesis of Josep Aulinas from University of Girona (ttle of the thesis: Selective Submap Joining SLAM for autonomous vehicles).

Projects/funding awarded

I. Ribeiro, "Activities related to the optimization of trajectories for the Cask and Plug

Remote Handling System in the Tokamak building and Hot Cell", European Union's Joint Undertaking for ITER and the Development of Fusion Energy (F4E), F4E-GRT-276 (April 201 – October 2011).

Individual fellowships awarded

J. Ferreira received an honorable mention in Portuguese Robotics Society award 2011 for his master thesis.

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2.3.7 System integration