IN PARTNERSHIP WITH:
CNRS
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Activity Report 2015

Project-Team LAGADIC

Visual servoing in robotics, computer vision, and augmented reality

IN COLLABORATION WITH: Institut de recherche en informatique et systèmes aléatoires (IRISA)

RESEARCH CENTERS
Rennes - Bretagne-Atlantique
Sophia Antipolis - Méditerranée

THEME
Robotics and Smart environments

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Project-Team LAGADIC

Creation of the Project-Team: 2004 December 06

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5.1. - Factory of the future
5.6. - Robotic systems
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2. Overall Objectives

2.1. Overall Objectives

Historically, research activities of the Lagadic team are concerned with visual servoing, visual tracking, and active vision. Visual servoing consists in using the information provided by a vision sensor to control the movements of a dynamic system. This research topic is at the intersection of the fields of robotics, automatic control, and computer vision. These fields are the subject of profitable research since many years and are particularly interesting by their very broad scientific and application spectrum. Within this spectrum, we focus on the interaction between visual perception and action. This topic is significant because it provides an alternative to the traditional Perception-Decision-Action cycle. It is indeed possible to link more closely the perception and action aspects, by directly integrating the measurements provided by a vision sensor in closed loop control laws. Our objective is thus to design strategies of coupling perception and action from images for applications in robotics, computer vision, virtual reality and augmented reality.

This objective is significant, first of all because of the variety and the great number of potential applications to which can lead our work (see Section 4.1). Secondly, it is also significant to be able to raise the scientific aspects associated with these problems, namely modeling of visual features representing in an optimal way the interaction between action and perception, taking into account of complex environments and the specification of high level tasks. We also work to treat new problems provided by imagery systems such as those resulting from an omnidirectional vision sensor or echographic probes. We are finally interested in revisiting traditional problems in computer vision (3D localization) through the visual servoing approach.

Thanks to the arrival of Patrick Rives and his students in the group in April 2012, which makes Lagadic now localized both in Rennes and Sophia Antipolis, the group now also focuses on building consistent representations of the environment that can be used to trigger and execute the robot actions. In its broadest sense, perception requires detecting, recognizing, and localizing elements of the environment, given the limited sensing and computational resources available on the embedded system. Perception is a fundamental issue for both the implementation of reactive behaviors, as is traditionnaly studied in the group, and the construction of the representations that are used at the task level. Simultaneous Localization and Mapping (Slam) is thus now one of our research areas.

Among the sensory modalities, computer vision, range finder and odometry are of particular importance and interest for mobile robots due to their availability and extended range of applicability, while ultrasound images and force measurements are both required for our medical robotics applications. The fusion of complementary information provided by different sensors is thus also a central issue for modeling the environment, robot localization, control, and navigation.

Much of the processing must be performed in real time, with a good degree of robustness so as to accommodate with the large variability of the physical world. Computational efficiency and well-posedness of the methods developed are thus constant preoccupations of the group.

3. Research Program

3.1. Visual servoing

Basically, visual servoing techniques consist in using the data provided by one or several cameras in order to control the motions of a dynamic system [1]. Such systems are usually robot arms, or mobile robots, but can also be virtual robots, or even a virtual camera. A large variety of positioning tasks, or mobile target tracking, can be implemented by controlling from one to all the degrees of freedom of the system. Whatever the sensor configuration, which can vary from one on-board camera on the robot end-effector to several free-standing cameras, a set of visual features has to be selected at best from the image measurements available, allowing to control the desired degrees of freedom. A control law has also to be designed so that these visual features $\mathbf{s}(t)$ reach a desired value $\mathbf{s}^*$, defining a correct realization of the task. A desired planned trajectory $\mathbf{s}^*(t)$ can also be tracked. The control principle is thus to regulate to zero the error vector $\mathbf{s}(t) - \mathbf{s}^*(t)$. With a vision sensor providing 2D measurements, potential visual features are numerous, since 2D data (coordinates of feature points in the image, moments, ...) as well as 3D data provided by a localization algorithm exploiting the extracted 2D features can be considered. It is also possible to combine 2D and 3D visual features to take the advantages of each approach while avoiding their respective drawbacks.

More precisely, a set $\mathbf{s}$ of k visual features can be taken into account in a visual servoing scheme if it can be written:

$$\mathbf{s} = \mathbf{s}(\mathbf{x}(\mathbf{p}(t)), \mathbf{a}) \tag{1}$$

where $\mathbf{p}(t)$ describes the pose at the instant t between the camera frame and the target frame, $\mathbf{x}$ the image measurements, and $\mathbf{a}$ a set of parameters encoding a potential additional knowledge, if available (such as for instance a coarse approximation of the camera calibration parameters, or the 3D model of the target in some cases).

The time variation of $\mathbf{s}$ can be linked to the relative instantaneous velocity $\mathbf{v}$ between the camera and the scene:

$$\dot{\mathbf{s}} = \frac{\partial \mathbf{s}}{\partial \mathbf{p}}\, \dot{\mathbf{p}} = \mathbf{L_s}\, \mathbf{v} \tag{2}$$

where $\mathbf{L_s}$ is the interaction matrix related to $\mathbf{s}$. This interaction matrix plays an essential role. Indeed, if we consider for instance an eye-in-hand system and the camera velocity as input of the robot controller, we obtain when the control law is designed to try to obtain an exponential decoupled decrease of the error:

$$\mathbf{v}_c = -\lambda \widehat{\mathbf{L_s}}^{+} (\mathbf{s} - \mathbf{s}^*) - \widehat{\mathbf{L_s}}^{+} \widehat{\frac{\partial \mathbf{s}}{\partial t}} \tag{3}$$

where λ is a proportional gain that has to be tuned to minimize the time-to-convergence, $\widehat{\mathbf{L_s}}^{+}$ is the pseudo-inverse of a model or an approximation of the interaction matrix, and $\widehat{\frac{\partial \mathbf{s}}{\partial t}}$ an estimation of the features velocity due to a possible own object motion.

From the selected visual features and the corresponding interaction matrix, the behavior of the system will have particular properties as for stability, robustness with respect to noise or to calibration errors, robot 3D trajectory, etc. Usually, the interaction matrix is composed of highly non linear terms and does not present any decoupling properties. This is generally the case when $\mathbf{s}$ is directly chosen as $\mathbf{x}$. In some cases, it may lead to inadequate robot trajectories or even motions impossible to realize, local minimum, tasks singularities, etc. It is thus extremely important to design adequate visual features for each robot task or application, the ideal case (very difficult to obtain) being when the corresponding interaction matrix is constant, leading to a simple linear control system. To conclude in few words, **visual servoing is basically a non linear control problem. Our Holy Grail quest is to transform it into a linear control problem.**

Furthermore, embedding visual servoing in the task function approach allows solving efficiently the redundancy problems that appear when the visual task does not constrain all the degrees of freedom of the system. It is then possible to realize simultaneously the visual task and secondary tasks such as visual inspection, or joint limits or singularities avoidance. This formalism can also be used for tasks sequencing purposes in order to deal with high level complex applications.

3.2. Visual tracking

Elaboration of object tracking algorithms in image sequences is an important issue for researches and applications related to visual servoing and more generally for robot vision. A robust extraction and real time spatio-temporal tracking process of visual cues is indeed one of the keys to success of a visual servoing task. If fiducial markers may still be useful to validate theoretical aspects in modeling and control, natural scenes with non cooperative objects and subject to various illumination conditions have to be considered for addressing large scale realistic applications.

Most of the available tracking methods can be divided into two main classes: feature-based and model-based. The former approach focuses on tracking 2D features such as geometrical primitives (points, segments, circles,...), object contours, regions of interest...The latter explicitly uses a model of the tracked objects. This can be either a 3D model or a 2D template of the object. This second class of methods usually provides a more robust solution. Indeed, the main advantage of the model-based methods is that the knowledge about the scene allows improving tracking robustness and performance, by being able to predict hidden movements of the object, detect partial occlusions and acts to reduce the effects of outliers. The challenge is to build algorithms that are fast and robust enough to meet our applications requirements. Therefore, even if we still consider 2D features tracking in some cases, our researches mainly focus on real-time 3D model-based tracking, since these approaches are very accurate, robust, and well adapted to any class of visual servoing schemes. Furthermore, they also meet the requirements of other classes of application, such as augmented reality.

3.3. Slam

Most of the applications involving mobile robotic systems (ground vehicles, aerial robots, automated submarines,...) require a reliable localization of the robot in its environment. A challenging problem is when neither the robot localization nor the map is known. Localization and mapping must then be considered concurrently. This problem is known as Simultaneous Localization And Mapping (Slam). In this case, the robot moves from an unknown location in an unknown environment and proceeds to incrementally build up a navigation map of the environment, while simultaneously using this map to update its estimated position.

Nevertheless, solving the Slam problem is not sufficient for guaranteeing an autonomous and safe navigation. The choice of the representation of the map is, of course, essential. The representation has to support the different levels of the navigation process: motion planning, motion execution and collision avoidance and, at the global level, the definition of an optimal strategy of displacement. The original formulation of the Slam problem is purely metric (since it basically consists in estimating the Cartesian situations of the robot and a set of landmarks), and it does not involve complex representations of the environment. However, it is now well recognized that **several complementary representations are needed to perform exploration, navigation, mapping, and control tasks successfully. We propose to use composite models of the environment that mix topological, metric, and grid-based representations.** Each type of representation is well adapted to a particular aspect of autonomous navigation: the metric model allows one to locate the robot precisely and plan Cartesian paths, the topological model captures the accessibility of different sites in the environment and allows a coarse localization, and finally the grid representation is useful to characterize the free space and design potential functions used for reactive obstacle avoidance. However, ensuring the consistency of these various representations during the robot exploration, and merging observations acquired from different viewpoints by several cooperative robots, are difficult problems. This is particularly true when different sensing modalities are involved. New studies to derive efficient algorithms for manipulating the hybrid representations (merging, updating, filtering...) while preserving their consistency are needed.

3.4. Scene modeling and understanding

Long-term mapping has received an increasing amount of attention during last years, largely motivated by the growing need to integrate robots into the real world wherein dynamic objects constantly change the appearance of the scene. A mobile robot evolving in such a dynamic world should not only be able to build a map of the observed environment at a specific moment, but also to maintain this map consistent over a long period of time. It has to deal with dynamic changes that can cause the navigation process to fail. However updating the map is particularly challenging in large-scale environments. To identify changes, robots have to keep a memory of the previous states of the environment and the more dynamic it is, the higher will be the number of states to manage and the more computationally intensive will be the updating process. Mapping large-scale dynamic environments is then particularly difficult as the map size can be arbitrary large. Additionally, mapping many times the whole environment is not always possible or convenient and it is useful to take advantages of methods using only a small number of observations.

A recent trend in robotic mapping is to augment low-level maps with semantic interpretation of their content, which allows to improve the robot's environmental awareness through the use of high-level concepts. In mobile robot navigation, the so-called semantic maps have already been used to improve path planning methods, mainly by providing the robot with the ability to deal with human-understandable targets.

4. Application Domains

4.1. Application Domains

The natural applications of our research are obviously in robotics. In fact, researches undertaken in the Lagadic group can apply to all the fields of robotics implying a vision sensor. They are indeed conceived to be independent of the system considered (and the robot and the vision sensor can even be virtual for some applications).

Currently, we are mostly interested in using visual servoing for aerial and space application, micromanipulation, autonomous vehicle navigation in large urban environments or for disabled or elderly people.

We also address the field of medical robotics. The applications we consider turn around new functionalities of assistance to the clinician during a medical examination: visual servoing on echographic images, needle insertion, compensation of organ motion, etc.

Robotics is not the only possible application field to our researches. In the past, we were interested in applying visual servoing in computer animation, either for controlling the motions of virtual humanoids according to their pseudo-perception, or for controlling the point of view of visual restitution of an animation. In both cases, potential applications are in the field of virtual reality, for example for the design of video games, or virtual cinematography.

Applications also exist in computer vision and augmented reality. It is then a question of carrying out a virtual visual servoing for the 3D localization of a tool with respect to the vision sensor, or for the estimation of its 3D motion. This field of application is very promising, because it is in full rise for the realization of special effects in the multi-media field or for the design and the inspection of objects manufactured in the industrial world.

5. Highlights of the Year

5.1. Highlights of the Year

5.1.1. Awards

- The work of Lucas Royer and Alexandre Krupa concerning non-rigid target tracking in ultrasound images [47] (see Section 7.6.1) was awarded by the organizers of the MICCAI CLUST'15 challenge (MICCAI Challenge on Liver Ultrasound Tracking) as being the best method for real-time and accurate target tracking in 3D ultrasound sequences.
- Paolo Robuffo Giordano has been awarded as Best Associate Editor of ICRA'2015.

6. New Software and Platforms

6.1. DESlam

Dense Egocentric SLAM
KEYWORDS: Deph Perception - Robotics - Localisation
FUNCTIONAL DESCRIPTION

This software proposes a full and self content solution to the dense Slam problem. Based on a generic RGB-D representation valid for various type of sensors (stereovision, multi-cameras, RGB-D sensors...), it provides a 3D textured representation of complex large indoor and outdoor environments and it allows localizing in real time (45Hz) a robot or a person carrying out a mobile camera.

- Participants: Maxime Meilland, Andrew Ian Comport and Patrick Rives
- Contact: Patrick Rives
- URL: http://team.inria.fr/lagadic

6.2. HandiViz

KEYWORDS: Health - Persons attendant - Handicap
FUNCTIONAL DESCRIPTION

The HandiViz software proposes a semi-autonomous navigation framework of a wheelchair relying on visual servoing.

It has been registered to the APP ("Agence de Protection des Programmes") as an INSA software (IDDN.FR.001.440021.000.S.P.2013.000.10000) and is under GPL license.

- Participants: François Pasteau and Marie Babel
- Contact: Marie Babel
- URL: https://team.inria.fr/lagadic/

6.3. Perception360

Robot vision and 3D mapping with omnidirectional RGB-D sensors.
KEYWORDS: Depth Perception - 3D rendering - Computer vision - Robotics - Image registration - Sensors - Realistic rendering - 3D reconstruction - Localization
FUNCTIONAL DESCRIPTION

This software is a collection of libraries and applications for robot vision and 3D mapping with omnidirectional RGB-D sensors or standard perspective cameras. This project provides the functionality to do image acquisition, semantic annotation, dense registration, localization and 3D mapping. The omnidirectional RGB-D sensors used within this project have been developed in Inria Sophia-Antipolis by the team LAGADIC.

- Contact: Patrick Rives
- URL: https://team.inria.fr/lagadic/software-eng.html

6.4. Sinatrack

KEYWORDS: Computer vision - Robotics
FUNCTIONAL DESCRIPTION

Sinatrack is a tracking software that allows the 3D localization (translation and rotation) of an object with respect to a monocular camera. It allows to consider object with complex shape. The underlying approach is a model-based tracking techniques. It has been developed for satellite localization and on-orbit service applications but is also suitable for augmented reality purpose.

- Participants: Antoine Guillaume Petit, Éric Marchand and François Chaumette
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6.5. UsTk

Ultrasound Toolkit
KEYWORDS: Echographic imagery - Image reconstruction - Active contours - Medical robotics
FUNCTIONAL DESCRIPTION

UsTk, standing for Ultrasound Toolkit, is a cross-platform library for two- and three-dimensional ultrasound image processing. Written in C++, UsTk provides tools for ultrasound image acquisition, processing and display of these images. Combined with the UsSimulator software that simulates a virtual ultrasound probe interacting with a 3D ultrasound volume and the UsGraphCut library that allows real-time segmentation of ultrasound images, it can serve as an useful framework for developing and testing new visual servoing approaches based on ultrasound images.

- Participants: Alexandre Krupa, Pierre Chatelain and Christophe Collewet
- Partners: Université de Rennes 1 - IRSTEA
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- URL: https://team.inria.fr/lagadic/

6.6. ViSP

KEYWORDS: Augmented reality - Computer vision - Robotics - Visual servoing (VS)

SCIENTIFIC DESCRIPTION

Since 2005, we develop and release ViSP [5] , an open source library available from http://visp.inria.fr. ViSP standing for Visual Servoing Platform allows prototyping and developing applications using visual tracking and visual servoing techniques at the heart of the Lagadic research. ViSP was designed to be independent from the hardware, to be simple to use, expandable and cross-platform. ViSP allows to design vision-based tasks for eye-in-hand and eye-to-hand visual servoing that contains the most classical visual features that are used in practice. It involves a large set of elementary positioning tasks with respect to various visual features (points, segments, straight lines, circles, spheres, cylinders, image moments, pose...) that can be combined together, and image processing algorithms that allow tracking of visual cues (dots, segments, ellipses...) or 3D model-based tracking of known objects or template tracking. Simulation capabilities are also available.

FUNCTIONAL DESCRIPTION

ViSP provides simple ways to integrate and validate new algorithms with already existing tools. It follows a module-based software engineering design where data types, algorithms, sensors, viewers and user interaction are made available. Written in C++, ViSP is based on open-source cross-platform libraries (such as OpenCV) and builds with CMake. Several platforms are supported, including OSX, Windows and Linux. ViSP online documentation allows to ease learning. More than 250 fully documented classes organized in 16 different modules, with more than 200 examples and 35 tutorials are proposed to the user. ViSP is released under a dual licensing model. It is open-source with a GNU GPLv2 license. A professional edition license that replaces GNU GPLv2 is also available.

- Participants: François Chaumette, Éric Marchand, Fabien Spindler, Aurélien Yol and Souriya Trinh
- Partners: Université de Rennes 1 - CNRS
- Contact: Fabien Spindler
- URL: http://visp.inria.fr

This year, a new ViSP 2.10 release was produced in February. The corresponding source code tarball was downloaded 1290 times. With the help of the community, this release was packaged for Debian and Ubuntu 14.04. We also designed a new modular software architecture where ViSP capabilities are grouped in several modules (core, io, gui, vision...). As a result, the user will find several shared or static libraries, one for each module. In the mean time we continued our efforts to improve the software by ensuring the compatibility with third-party libraries that continue also to evolve like CMake and OpenCV. We also fixed some issues, allowed the markerless 3D model-based hybrid tracker to consider cylinders and introduce a new algorithm to determine face visibility. Moreover, we improve the object detection algorithm based on keypoints that is able to return the pose of a learned object. We improved the documentation by providing new tutorials and by updating the existing ones. ViSP 3.0.0 will be released these days.

Concerning ROS community, all the existing packages in "`vision_visp`" ROS stack (see http://wiki.ros.org/vision_visp) were updated and ported to jade build system. To ease ViSP usage in the ROS framework, the releases of the year were packaged for ROS.

ViSP is used in research labs in France, USA, Japan, Korea, India, China, Lebanon, Italy, Spain, Portugal, Hungary, Canada. For instance, it is used as a support in graduate courses at IFMA Clermont-Ferrand, University of Picardie in Amiens, Télécom Physique in Strasbourg and ESIR in Rennes.

6.7. bib2html

FUNCTIONAL DESCRIPTION

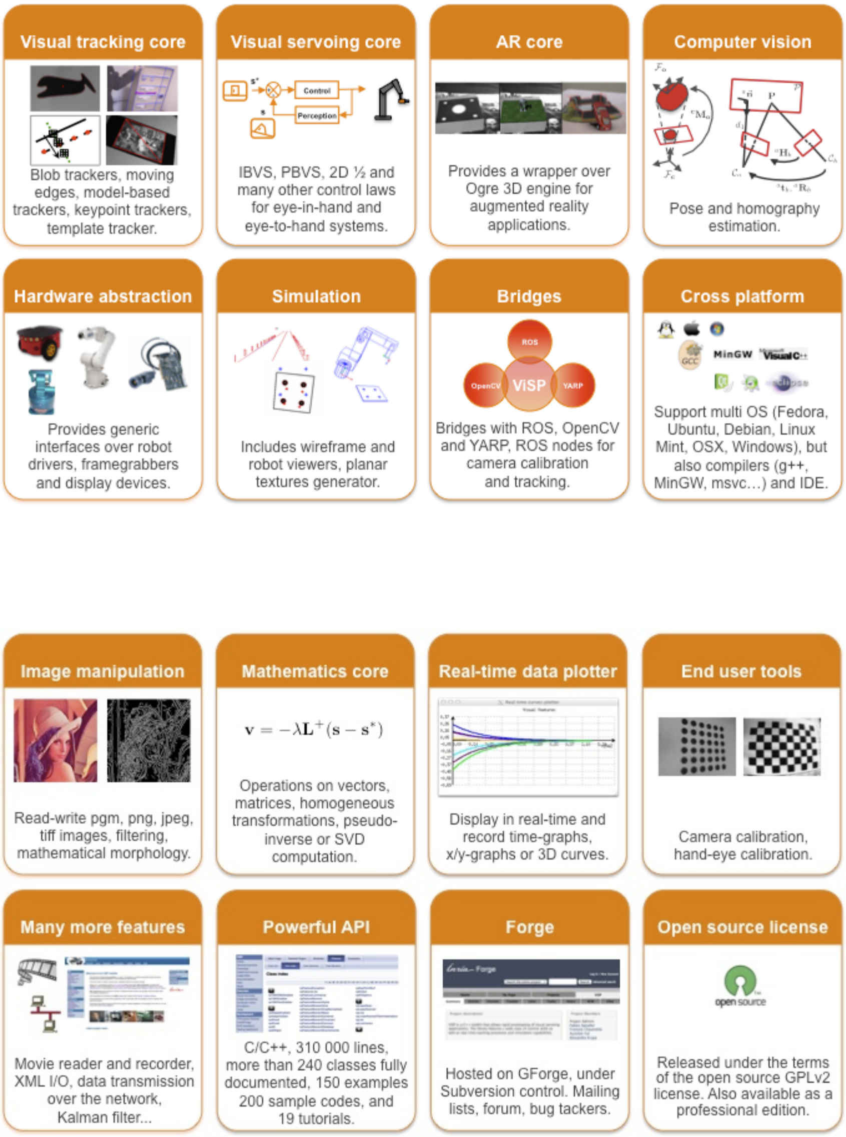


Figure 1. This figure highlights ViSP main capabilities for visual tracking, visual servoing, and augmented reality that may benefit from computer vision algorithms. ViSP allows controlling specific platforms through hardware abstraction or in simulation. ViSP provides also bridges over other frameworks such as OpenCV and ROS. All these capabilities are cross-platform. Moreover, for easing the prototyping of applications, ViSP provides tools for image manipulation, mathematics, data plotting, camera calibration, and many other features. ViSP powerful API is fully documented and available on Inria's forge as an open source software under GPLv2 license.

The purpose of this software is to automatically produce html pages from BibTEX files, and to provide access to the BibTEX entries by several criteria: year of publication, category of publication, keywords, author name. Moreover cross-linking is generating between pages to provide an easy navigation through the pages without going back to the index.

- Contact: Éric Marchand
- URL: http://www.irisa.fr/lagadic/soft/bib2html/bib2html.html

6.8. Robot vision platform

Participant: Fabien Spindler [correspondant].

We exploit two industrial robotic systems built by Afma Robots in the nineties to validate our researches in visual servoing and active vision. The first one is a Gantry robot with six degrees of freedom, the other one is a cylindrical robot with four degrees of freedom (see Fig. 2). These robots are equipped with cameras. The Gantry robot allows also to embed grippers on its end-effector.

Five papers published by Lagadic in 2015 enclose results validated on this platform [30][53][29][31][50].

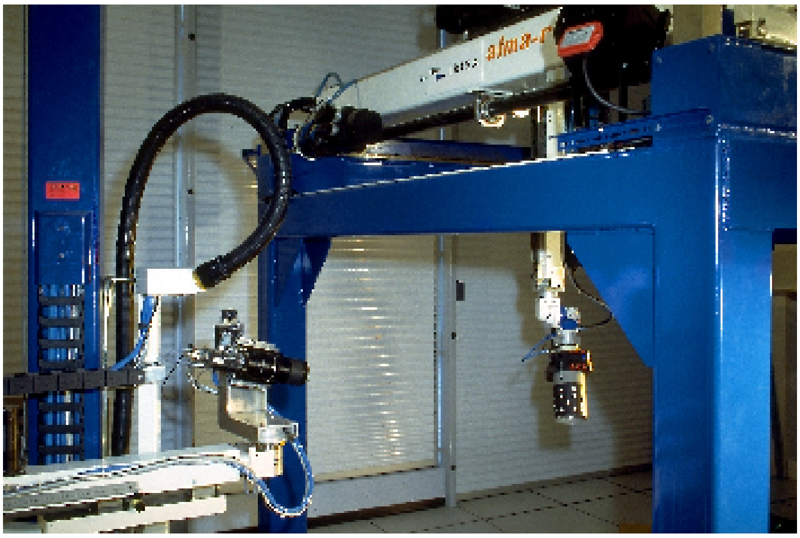


Figure 2. Lagadic robotics platform for vision-based manipulation

6.9. Mobile robotics platforms

Participants: Fabien Spindler [correspondant], Marie Babel, Patrick Rives.

6.9.1. Indoor mobile robots

For fast prototyping of algorithms in perception, control and autonomous navigation, the team uses Hannibal in Sophia Antipolis, a cart-like platform built by Neobotix (see Fig. 3.a), and, in Rennes, a Robotino from Festo (see Fig. 3.b) and a Pioneer 3DX from Adept (see Fig. 3.c). These platforms are equipped with various sensors needed for Slam purposes, autonomous navigation and sensor-based control.

Moreover, to validate the researches in personally assisted living topic (see 7.3.3), we have in Rennes a six wheel electric wheelchair from Penny and Giles Drives Technology (see Fig. 3.d) and a five wheel electric wheelchair from You-Q (see Fig. 3.e). The control of the wheelchair is performed using a plug and play system between the joystick and the low level control of the wheelchair. Such a system lets us acquire the user intention through the joystick position and control the wheelchair by applying corrections to its motion. The wheelchairs have been fitted with cameras and eleven ultrasound sensors to perform the required servoing for assisting handicapped people.

Note that 5 papers exploiting the indoors mobile robots were published this year [14][22][28][56][27].

6.9.2. Outdoor vehicles

The team exploits also Cycab urban electrical cars (see Figs. 3.f and 3.g). Two vehicles in Sophia Antipolis and one in Rennes are instrumented with cameras and range finders to validate researches in the domain of intelligent urban vehicle. Cycabs were used as experimental testbeds in several national projects in the past. This year we decided to donate the Cycab in Rennes to the INSA engineer school were it started a second live.

The camera rig can also be fixed to a standard car (see Fig. 4), which is driven at a variable speed depending on the road/traffic conditions, with an average of 30 km/h and a maximum speed of 80 km/h. The sequences are recorded at a frame rate of 20 Hz, where the six global shutter cameras of the stereo system are synchronized, producing spherical images with a resolution of 2048x665 (see fig. 4). Such sequences are fused offline to obtain maps that can be used later for localization or for scene rendering. (in a similar fashion to Google Street View) as we show in the accompanying video [1].

Four papers published by Lagadic in 2015 enclose experimental results obtained with these outdoor vehicles [20][37][10][42].

6.10. Medical robotics platform

Participants: Fabien Spindler [correspondant], Alexandre Krupa.

This testbed is of primary interest for researches and experiments concerning ultrasound visual servoing applied to probe positioning, soft tissue tracking or robotic needle insertion tasks described in Section 7.6.

This platform is composed by two Adept Viper six degrees of freedom arms (see Fig. 5.a). Ultrasound probes connected either to a SonoSite 180 Plus or an Ultrasonix SonixTouch imaging system can be mounted on a force torque sensor attached to each robot end-effector.

We designed an experimental setup to test an autonomous robotic needle insertion method based on visual servoing 7.6.2. The experimental setup is composed with a gelatin phantom simulating soft tissues, a flexible biopsy needle actuated by an Adept Viper arm and a 3D ultrasound probe held by the second Adept Viper arm (see Fig. 5.b).

This year, 5 papers enclose experimental results obtained with this platform [49][48][47][33][32].

6.11. Humanoid robot platform

Participants: Giovanni Claudio, Fabien Spindler [correspondant].

Romeo is a humanoid robot from Aldebaran Robotics which is intended to be a genuine personal assistant and companion. For the moment only the upper part of the body (trunk, arms, neck, head, eyes) is working. This research platform is used to validate our researches in visual servoing and visual tracking. We continue to improve the work initiated last year to grasp a box and deliver it to a human introducing especially joint limits avoidance (see Fig. 6). We started also to work on a visual servoing framework able to control both arms to manipulate an object using only vision.

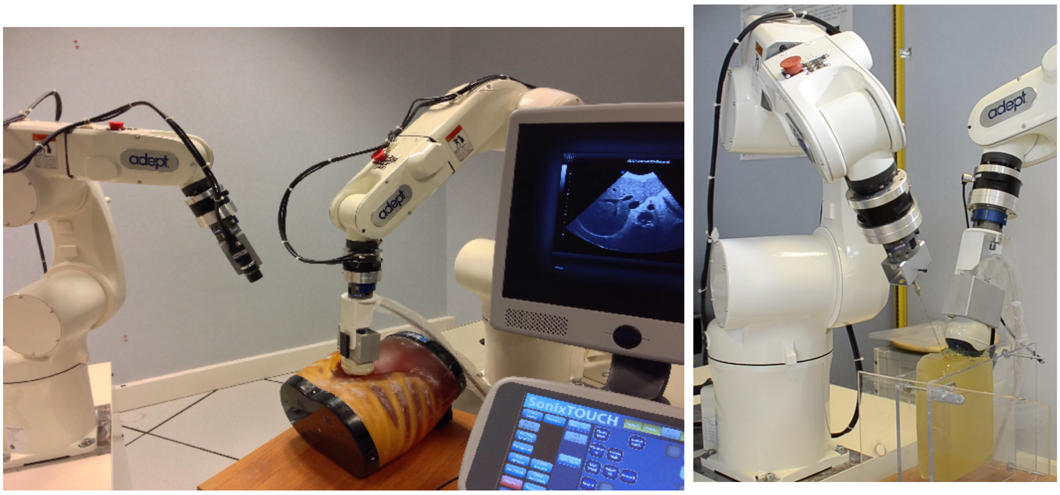
This year one paper encloses experimental results obtained with this platform [54].

[1] video url:(www-sop.inria.fr/members/Renato-Jose.Martins/iros15.html)

(a) (b) (c) (d) (e) (f) (g)

Figure 3. a) Hannibal platform, b) Robotino, c) Pioneer P3-DX robot, d) wheelchair from Penny and Giles Drives Technology, e) wheelchair from You-Q , f) Cycab available in Rennes, g) one of the Cycabs available in Sophia Antipolis.

Figure 4. Globeye stereo sensor and acquisition system.



(a) (b)

Figure 5. a) Lagadic medical robotics platforms. On the right Viper S850 robot arm equipped with a SonixTouch 3D ultrasound probe. On the left Viper S650 equipped with a tool changer that allows to attach a classical camera or biopsy needles. b) Robotic setup for autonomous needle insertion by visual servoing.

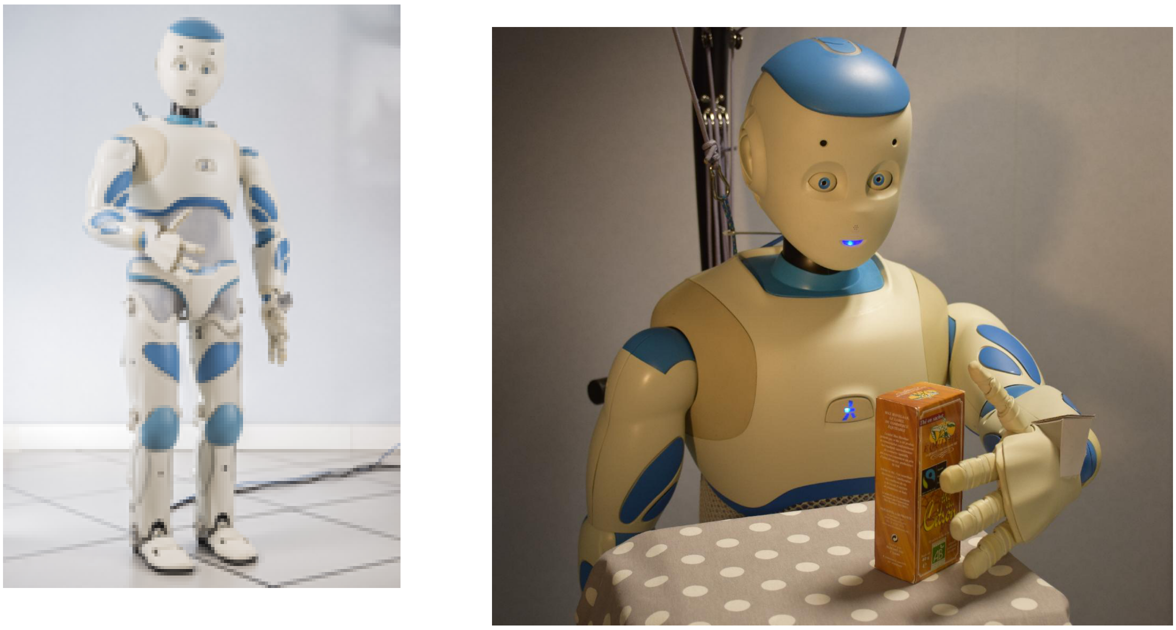
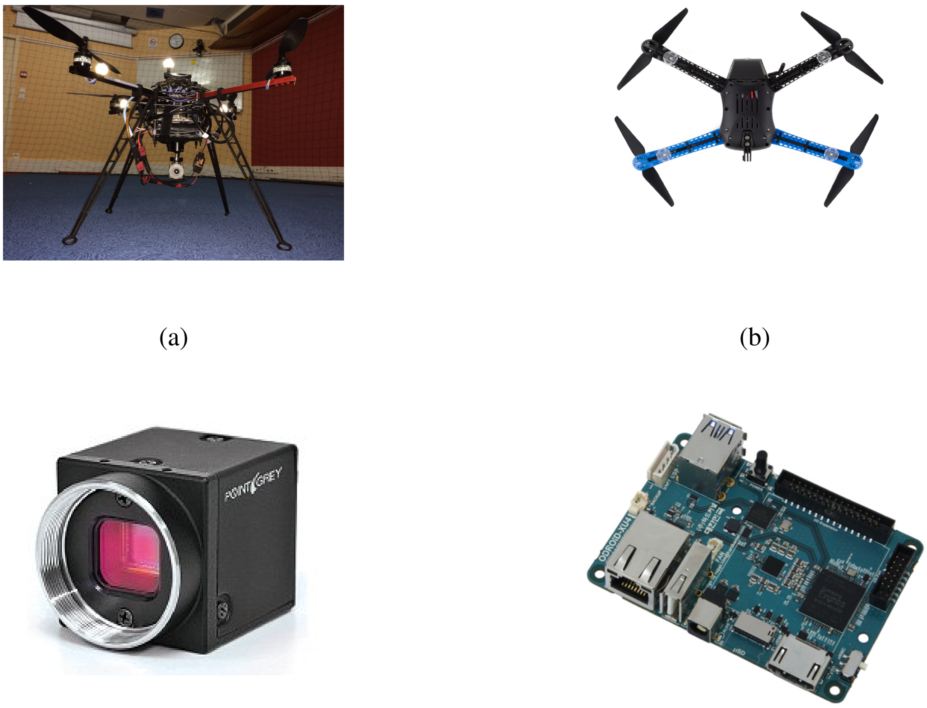


Figure 6. Romeo experimental platform.

6.12. Unmanned Aerial Vehicles (UAVs) platform

Participants: Thomas Bellavoir, Paolo Robuffo Giordano [correspondant].

From 2014, the team also started some activities involving perception and control for single and multiple quadrotor UAVs, especially thanks to a grant from "Rennes Métropole" (see Section 9.1.5) and the ANR project "SenseFly" (see Section 9.2.4). To this end, we purchased four quadrotors from Mikrokopter Gmbh, Germany (Fig. 7.a), and one quadrotor from 3DRobotics, USA (Fig. 7.b). The Mikrokopter quadrotors have been heavily customized by: (i) reprogramming from scratch the low-level attitude controller onboard the microcontroller of the quadrotors, (ii) equipping each quadrotor with an Odroid XU4 board (Fig. 7.d) running Linux Ubuntu and the TeleKyb software (the middleware used for managing the experiment flows and the communication among the UAVs and the base station), and (iii) purchasing the Flea Color USB3 cameras together with the gimbal needed to mount them on the UAVs (Fig. 7.c). The quadrotor group will be used as robotic platforms for testing a number of single and multiple flight control schemes with a special attention on the use of onboard vision as main sensory modality.



(a) (b) (c) (d)

Figure 7. a) Quadrotor XL1 from Mikrokopter, b) Quadrotor Iris from 3DRobotics, c) Flea Color USB3 camera, d) Odroid XU4 board

7. New Results

7.1. Visual tracking

7.1.1. Object detection

Participant: Eric Marchand.

We addressed the challenge of detecting and localizing a poorly textured known object, by initially estimating its complete 3D pose in a video sequence [45]. Our solution relies on the 3D model of the object and synthetic views. The full pose estimation process is then based on foreground/background segmentation and on an efficient probabilistic edge-based matching and alignment procedure with the set of synthetic views, classified through an unsupervised learning phase. Our study focuses on space robotics applications and the method has been tested on both synthetic and real images, showing its efficiency and convenience, with reasonable computational costs.

7.1.2. Registration of multimodal images

Participant: Eric Marchand.

This study has been realized in collaboration with Brahim Tamadazte and Nicolas Andreff from Femto-ST, Besançon. Following our developments in visual tracking and visual servoing from the mutual information [3], it concerned mutual information-based registration of white light images vs. fluorescence images for micro-robotic laser microphonosurgery of the vocal folds. Nelder-Mead Simplex for nonlinear optimization has been used to minimize the cost-function [43].

7.1.3. Pose estimation from RGB-D sensor

Participant: Eric Marchand.

RGB-D sensors have become in recent years a product of easy access to general users. They provide both a color image and a depth image of the scene and, besides being used for object modeling, they can also offer important cues for object detection and tracking in real-time. In this context, the work presented in this paper investigates the use of consumer RGB-D sensors for object detection and pose estimation from natural features. Two methods based on depth-assisted rectification are proposed, which transform features extracted from the color image to a canonical view using depth data in order to obtain a representation invariant to rotation, scale and perspective distortions. While one method is suitable for textured objects, either planar or non-planar, the other method focuses on texture-less planar objects [18]

7.1.4. 3D localization for airplane landing

Participants: Noël Mériaux, François Chaumette, Patrick Rives, Eric Marchand.

This study is realized in the scope of the ANR VisioLand project (see Section 9.2.2. In a first step, we have considered and adapted our model-based tracker [2] to localize the aircraft with respect to the airport surroundings. Satisfactory results have been obtained from real image sequences provided by Airbus. In a second step, we have started to perform this localization from a set of keyframe images corresponding to the landing trajectory.

7.2. Visual servoing

7.2.1. Histogram-based visual servoing

Participants: Quentin Bateux, Eric Marchand.

Classically visual servoing considers the regulation in the image of a set of visual features (usually geometric features). Direct visual servoing schemes, such as photometric visual servoing, have been introduced in order to consider every pixel of the image as a primary source of information and thus avoid the extraction and the tracking of such geometric features. This year, we proposed a method to extend these works by using a global descriptor, namely intensity histograms, on the whole or multiple sub-sets of the images in order to achieve control of a 6 degrees of freedom (DoF) robot [30][53].

7.2.2. Photometric moment-based visual servoing

Participants: Manikandan Bakthavatchalam, François Chaumette.

This work also belongs to the class of direct visual servoing. Its goal was to use photometric moments as visual features in order to increase the convergence domain of this approach by reducing the non linearity of the control problem. In order to cope with appearance and disappearance of some parts of the environment during the camera motion, a spatial weight has been introduced in the definition of photometric moments. Thanks to a particular design of this weight, the analytical form of the interaction matrix has been obtained, from which it was possible to select a set of moment combinations to control all the six degrees of freedom of the system. Satisfactory experimental results have been obtained [29][8], even if the loss of invariance properties makes the optimal design of visual features still an open problem.

7.2.3. *Model predictive visual servoing*

Participants: Nicolas Cazy, Paolo Robuffo Giordano, François Chaumette.

The goal of this work is to exploit Model Predictive Control (MPC) techniques for dealing in a robust way with loss of features during a IBVS task. The work [31] provides an experimental validation of different correction schemes able to cope with loss of features due to occlusions of limited camera field of view. The reported results show the effectiveness of the proposed techniques during the servoing of four point features.

7.2.4. *Nanomanipulation*

Participants: Le Cui, Eric Marchand.

Following our work related to scanning electron micro- scope (SEM) calibration [12] we considered the control of a micro robot using a direct photometric visual servoing that uses only the pure image information as a visual feature, instead of using classic geometric features such as points or lines. However, in micro-scale, using only image intensity as a visual feature performs unsatisfactorily in cases where the photometric variation is low, such as motions along vision sensor's focal axis under a high magnification. In order to improve the performance and accuracy in those cases, an approach using hybrid visual features is proposed in this paper. Image gradient is employed as a visual feature on z axis while image intensity is used on the other 5 DoFs to control the motion. A 6-DoF micro-positioning task is accomplished by this hybrid visual servoing scheme [34].

We also considered a full scale autofocus approach for SEM [35]. The optimal focus (in-focus) position of the microscope is achieved by maximizing the image sharpness using a vision-based closed-loop control scheme. An iterative optimization algorithm has been designed using the sharpness score derived from image gradient information. The proposed method has been implemented and validated using a tungsten gun SEM at various experimental conditions like varying raster scan speed, magnification at real-time.

7.2.5. *Audio-based control*

Participants: Aly Magassouba, François Chaumette.

This study is not concerned with visual servoing, but to the application of the same principle of sensor-based control to audio sensors. It is made in collaboration with Nancy Bertin from Panama group at Irisa, Inria Rennes-Bretagne Atlantique. In a first step, we have determined the analytical form of the interaction matrix of audio features based on the time difference of arrival on two microphones. From this modeling step, we have determined the different virtual linkages that can be realized in function of the number and configuration of sources [41]. First experimental results using two microphones monunted on the Pioneer mobile robot (see Section 6.9) have been recently obtained.

7.3. Visual navigation of mobile robots

7.3.1. *Visual navigation from straight lines*

Participants: Suman Raj Bista, Paolo Robuffo Giordano, François Chaumette.

This study is concerned with visual autonomous navigation in indoor environments. As in our previous works concerning navigation outdoors [4], the approach is based on a topological localization of the current image with respect to a set of keyframe images, but the visual features used for this localisation as well as for the visual servoing is not based on points of interest, but straight lines that are more common indoors. Satisfactory experimental results have been obtained using the Pioneer mobile robot (see Section 6.9) [23].

7.3.2. *Autonomous navigation of a wheelchair and social navigation*

Participants: Vishnu Karakkat Narayanan, François Pasteau, Marie Babel.

Navigating within an unknown indoor environment using an electric wheelchair is a challenging task, especially if the user suffers from severe disabilities. We presented in [22] a framework for vision-based autonomous indoor navigation in an electric wheelchair capable of following corridors, and passing through open doorways using a single doorpost. The designed control schemes have been implemented onto a robotized wheelchair and experimental results show the robust behaviour of the designed system.

We then introduced in [40] a task-based control law which can serve as a low-level system for equitably joining interacting groups, while confirming to social conventions. The system uses the position and orientation of the participating humans with respect to a rigid sensor frame in order to control the translational and rotational velocity of a wheelchair so that the robot positions itself aptly at the meeting point

7.3.3. *Semi-autonomous control of a wheelchair for navigation assistance*

Participants: Vishnu Karakkat Narayanan, François Pasteau, Marie Babel.

To address the wheelchair driving assistance issue, we proposed in [56][28] a unified shared control framework able to smoothly correct the trajectory of the electrical wheelchair. The system integrates the manual control with sensor-based constraints by means of a dedicated optimization strategy. The resulting low-complex and low-cost embedded system is easily plugged onto on-the-shelf wheelchairs.

The robotic solution has been then validated through clinical trials that have been conducted within the Rehabilitation Center of Pôle Saint Hélier (France) with 25 volunteering patients presenting different disabling neuro-pathologies. This assistive tool is shown to be intuitive and robust as it respects the user intention, it does not alter perception while reducing the number of collisions in case of hazardous maneuvers or in crowded environment [27].

7.4. 3D Scene Mapping

7.4.1. *Structure from motion*

Participants: Riccardo Spica, Paolo Robuffo Giordano, François Chaumette.

Structure from motion (SfM) is a classical and well-studied problem in computer and robot vision, and many solutions have been proposed to treat it as a recursive filtering/estimation task. However, the issue of *actively* optimizing the transient response of the SfM estimation error has not received a comparable attention. In the work [50] we have addressed the active estimation of the 3D structure of an observed planar scene by comparing three different techniques: a homography decomposition (a well-established method taken as a baseline), a least-square fitting of a reconstructed 3D point cloud, and a direct estimation based on the observation of a set of discrete image moments made of a collection of image points belonging to the observed plane. The experimental results confirmed the importance of actively controlling the camera motion in order to obtained a faster convergence for the estimation error, as well as the superiority of the third method based on the machinery of image moments for what concerns robustness against noise and outliers. In [51] the active estimation scheme has been improved by considering a set of features invariant to camera rotations. This way, the dynamics of the structure estimation becomes independent of the camera angular velocity whose measurement is, thus, no longer required for implementing the active SfM scheme. Finally, in [46] the issue of determining online the 'best' combination of image moments for reconstructing the scene structure has been considered. By defining a new set of weighted moments as a weighted sum of traditional image moments, it is indeed possible to optimize for the weights online during the camera motion. The SfM scheme then automatically selects online the best combination of image moments to be used as measurements as a function of the current scene.

7.4.2. Scene Registration based on Planar Patches

Participants: Eduardo Fernandez Moral, Patrick Rives.

Scene registration consists of estimating the relative pose of a camera with respect to a scene previously observed. This problem is ubiquitous in robot localization and navigation. We propose a probabilistic framework to improve the accuracy and efficiency of a previous solution for structure registration based on planar representation. Our solution consists of matching graphs where the nodes represent planar patches and the edges describe geometric relationships. The maximum likelihood estimation of the registration is estimated by computing the graph similarity from a series of geometric properties (areas, angles, proximity, etc..) to maximize the global consistency of the graph. Our technique has been validated on different RGB-D sequences, both perspective and spherical [14].

7.4.3. Robust RGB-D Image Registration

Participants: Tawsif Gokhool, Renato José Martins, Patrick Rives.

Estimating dense 3D maps from stereo sequences remains a challenging task where building compact and accurate scene models is relevant for a number of tasks, from localization and mapping to scene rendering [20], [10] . In this context, this work deals with generating complete geometric and photometric "minimal" model of indoor/outdoor large-scale scenes, which are stored within a sparse set of spherical images to asset photo-geometric consistence of the scene from multiple points-of-views . To this end, a probabilistic data association framework for outlier rejection is formulated, enhanced with the notion of landmark stability over time. The approach was evaluated within the frameworks of image registration, localization and mapping, demonstrating higher accuracy and larger convergence domains over different datasets [39].

7.4.4. Accurate RGB-D Keyframe Representation of 3D Maps

Participants: Renato José Martins, Eduardo Fernandez Moral, Patrick Rives.

Keyframe-based maps are a standard solution to produce a compact map representation from a continuous sequence of images, with applications in robot localization, 3D reconstruction and place recognition. We have present a approach to improve keyframe-based maps of RGB-D images based on two main filtering stages: a regularization phase in which each depth image is corrected considering both geometric and photometric image constraints (planar and superpixel segmentation); and a fusion stage in which the information of nearby frames (temporal continuity of the sequence) is merged (using a probabilistic framework) to improve the accuracy and reduce the uncertainty of the resulting keyframes. As a result, more compact maps (with less keyframes) are created. We have validated our approach with different kind of RGB-D data including both indoor and outdoor sequences, and spherical and perspective sensors, demonstrating that our approach compares and outperforms the state-of-the-art [42].

7.4.5. Semantic Representation For Navigation In Large-Scale Environments

Participants: Romain Drouilly, Patrick Rives.

Autonomous navigation is one of the most challenging problem to address to allow robots to evolve in our everyday environments. Map-based navigation has been studied for a long time and researches have produced a great variety of approaches to model the world. However, semantic information has only recently been taken into account in those models to improve robot efficiency.

Mimicking human navigation is a challenging goal for autonomous robots. This requires to explicitly take into account not only geometric representation but also high-level interpretation of the environment [9]. We propose a novel approach demonstrating the capability to infer a route in a global map by using semantics. Our approach relies on an object-based representation of the world automatically built by robots from spherical images. In addition, we propose a new approach to specify paths in terms of high-level robot actions. This path description provides robots with the ability to interact with humans in an intuitive way. We perform experiments on simulated and real-world data, demonstrating the ability of our approach to deal with complex large-scale outdoor environments whilst dealing with labelling errors [37].

Mapping evolving environments requires an update mechanism to efficiently deal with dynamic objects. In this context, we propose a new approach to update maps pertaining to large-scale dynamic environments with semantics. While previous works mainly rely on large amount of observations, the proposed framework is able to build a stable representation with only two observations of the environment. To do this, scene understanding is used to detect dynamic objects and to recover the labels of the occluded parts of the scene through an inference process which takes into account both spatial context and a class occlusion model. Our method was evaluated on a database acquired at two different times with an interval of three years in a large dynamic outdoor environment. The results point out the ability to retrieve the hidden classes with a precision score of 0.98. The performances in term of localisation are also improved [36].

7.5. Control of single and multiple Unmanned Aerial Vehicles

7.5.1. Single UAV

Participant: Paolo Robuffo Giordano.

Over the last years the robotics community witnessed an increasing interest in the Unmanned Aerial Vehicle (UAV) field. In particular quadrotor UAVs have become more and more widespread in the community as experimental platform for, e.g., testing novel 3D planning, control and estimation schemes in real-world indoor and outdoor conditions. Indeed, in addition to being able to take-off and land vertically, quadrotors can reach high angular accelerations thanks to the relatively long lever arm between opposing motors. This makes them more agile than most standard helicopters or similar rotorcraft UAVs, and thus very suitable to realize complex tasks such as aerial mapping, air pollution monitoring, traffic management, inspection of damaged buildings and dangerous sites, as well as agricultural applications such as pesticide spraying.

Despite these clear advantages, a clear shortcoming of the quadrotor design lies in its inherent underactuation (only 4 actuated propellers for the 6 dofs of the quadrotor pose). This underactuation limits the quadrotor flying ability in free or cluttered space and, furthermore, it also degrades the possibility of interacting with the environment by exerting desired forces in arbitrary directions. In [24], a novel design for a quadrotor UAV with tilting propellers which is able to overcome these limitations has been presented and experimentally validated. Indeed, the additional set of 4 control inputs actuating the propeller tilting angles can be shown to yield full actuation to the quadrotor position/orientation in space, thus allowing it to behave as a fully-actuated flying vehicle and to overcome the aforementioned underactuation problem.

Furthermore, the issue of estimating online the UAV self-motion from vision has been considered. To this end, a novel nonlinear estimation scheme able to recover the metric UAV linear velocity from the *scaled* one obtained from the decomposition of the optical flow has been proposed in [15]. The observability conditions (in terms of persistency of excitation) needed to ensure a converging estimation have also been studied. The reported experimental results confirmed the effectiveness of the estimation scheme in recovering a reliable and accurate estimation of the UAV self-motion (linear and angular velocities) in realistic conditions.

This work has been realized in collaboration with the Max Planck Institute for Biological Cybernetics, Tübingen, Germany.

7.5.2. Collective control of multiple UAVs

Participants: Fabrizio Schiano, Paolo Robuffo Giordano.

The challenge of coordinating the actions of multiple robots is inspired by the idea that proper coordination of many simple robots can lead to the fulfilment of arbitrarily complex tasks in a robust (to single robot failures) and highly flexible way. Teams of multi-robots can take advantage of their number to perform, for example, complex manipulation and assembly tasks, or to obtain rich spatial awareness by suitably distributing themselves in the environment. Within the scope of robotics, autonomous search and rescue, firefighting, exploration and intervention in dangerous or inaccessible areas are the most promising applications.

In the context of multi-robot (and multi-UAV) coordinated control, *connectivity* of the underlying graph is perhaps the most fundamental requirement in order to allow a group of robots accomplishing common goals by means of *decentralized* solutions. In fact, graph connectivity ensures the needed continuity in the data flow among all the robots in the group which, over time, makes it possible to share and distribute the needed information. However, connectivity alone is not sufficient to perform certain tasks when only *relative sensing* is used. For these systems, the concept of *rigidity* provides the correct framework for defining an appropriate sensing and communication topology architecture. Rigidity is a combinatorial theory for characterizing the "stiffness" or "flexibility" of structures formed by rigid bodies connected by flexible linkages or hinges. In a broader context, rigidity turns out to be an important architectural property of many multi-agent systems when a common inertial reference frame is unavailable. Applications that rely on sensor fusion for localization, exploration, mapping and cooperative tracking of a target, all can benefit from notions in rigidity theory. The concept of rigidity, therefore, provides the theoretical foundation for approaching decentralized solutions to the aforementioned problems using distance measurement sensors, and thus establishing an appropriate framework for relating system level architectural requirements to the sensing and communication capabilities of the system.

In [26], a decentralized gradient-based rigidity maintenance action for a group of quadrotor UAVs has been proposed and tested in real experimental conditions. By starting in a rigid configuration, the group of UAVs is able to estimate their relative position from sole relative distance measurements, and then use these estimated relative positions in a control action able to preserve rigidity of the whole formation despite presence of sensor limitations (maximum range and line-of-sight occlusions), possible collisions with obstacles and inter-robot collisions. Furthermore, in [52] the novel case of *bearing rigidity* for directed graphs has been considered: here, rather than distances the measurements are the 3D bearing vectors expressed in the local body-frame of each agent. The theory has been developed for the case of planar agents in $SE(2)$ and a 'scale-free' bearing controller has been proposed, able to steer the robot group towards a desired bearing formation.

These works were realized in collaboration with the robotics group at the Max Planck Institute for Biological Cybernetics, Tübingen, Germany and with Technion, Israel.

7.5.3. Cooperative localization using interval analysis

Participants: Vincent Drevelle, Ide Flore Kenmogne Fokam.

In the context of multi-robot fleets, cooperative localization consists in gaining better position estimate through measurements and data exchange with neighboring robots. Positioning integrity (i.e., providing reliable position uncertainty information) is also a key point for mission-critical tasks, like collision avoidance. The goal of this work is to compute position uncertainty volumes for each robot of the fleet, using a decentralized method (i.e using only local communication with the neighbors). The problem is addressed in a bounder-error framework, with interval analysis and constraint propagation methods. These methods enable to provide guaranteed position error bounds, assuming bounded-error measurements. They are not affected by over-convergence due to data incest, which makes them a well sound framework for decentralized estimation. Encouraging results have already been obtained for multi-robot underwater positioning with acoustical range measurements. Ongoing work focuses on cooperative localization in a multi-UAV fleet with image-based measurements (bearings).

7.6. Medical robotics

7.6.1. Non-rigid target tracking in ultrasound images combining dense information and physically-based model

Participants: Lucas Royer, Alexandre Krupa.

This study concerns the real-time tracking of deformable targets within a sequence of ultrasound (US) images. The proposed approach combines dense information with a physically-based model and has therefore the advantage of not using any fiducial marker. The physical model is represented by a mass-spring damper system driven by external and internal forces. The external forces are obtained by maximizing an image similarity metric between a reference target and the deformed target along the time. The internal forces of the mass-spring damper system constrain the deformation to be physically plausible and therefore efficiently reduce the sensitivity to the speckle noise. This approach was first validated from simulated and real sequences of 2D US images [49]. It was then extended for deformable target tracking in a sequence of 3D ultrasound volumes and tested on a robotic setup used to apply deformation on an organic phantom [48]. The performance of this deformable 3D target tracking approach was evaluated with visual assessment combined with robotic odometry ground truth. This method was also tested and compared with respect to state-of-the-art techniques by using 3D image databases provided by MICCAI CLUST'14 and CLUST'15 challenges [47] (MICCAI Challenge on Liver Ultrasound Tracking). It was awarded by the organizers of the CLUST challenges as being the best method for accurate target tracking in 3D ultrasound sequences. We recently improved our approach in order to increase its robustness to the presence of ultrasound shadows, local illumination changes and image occlusions.

7.6.2. 3D steering of flexible needle by ultrasound visual servoing

Participants: Pierre Chatelain, Jason Chevrie, Marie Babel, Alexandre Krupa.

The objective of this work is to provide robotic assistance during needle insertion procedures such as biopsy or ablation of localized tumor. In previous work, we designed a control approach based on a duty cycling technique for steering a beveled-tip flexible needle actuated by a robotic arm in such a way to control the needle curvature in 3D space and reach a desired target by visual servoing. In this preliminary work, the control approach was validated by using visual features extracted from 2 images provided by 2 orthogonal cameras observing a translucent gelatin phantom where the needle was inserted. This year, we have pursued our work towards this needle steering robotic assistance by developing a new algorithm able to track in real-time a flexible needle in a sequence of 3D ultrasound images (volumes). The flexible needle modeled as a polynomial curve is tracked during the automatic insertion using particle filtering. This new tracking algorithm enables real-time closed-loop needle control with 3D ultrasound feedback. The target to reach was manually defined by the user in the US image and can be on-line tracked thanks to the template tracking algorithm proposed in [21] based on ultrasound dense visual servoing [7]. Experimental results of an automatic needle tip positioning in a home-made gelatine phantom demonstrate the feasibility of 3D ultrasound-guided needle steering for reaching a desired target by ultrasound visual servoing [33]. Recently a new control law for needle steering that uses both direct manipulation of the needle base and the duty cycling method has been studied. It is based on a 3D model of a beveled tip needle using virtual springs that characterize the needle mechanical interaction with soft tissue. From this model, a measure of the controllability of the needle tip degrees of freedom was proposed in order to mix the control between the direct base manipulation and the duty cycling technique. Preliminary simulations show that this hybrid control allows better targeting capabilities in terms of larger needle workspace and reduced needle bending.

7.6.3. Optimization of ultrasound image quality by visual servoing

Participants: Pierre Chatelain, Alexandre Krupa.

This study focuses on a new ultrasound-based visual servoing approach that optimizes the positioning of an ultrasound probe manipulated by a robotic arm in order to improve the quality of the acquired ultrasound images. To this end, we use the recent framework of ultrasound confidence map, developed in the Chair for Computer Aided Medical Procedures and Augmented Reality of Prof. Nassir Navab, which aims at estimating the per-pixel quality of the ultrasound signal based on a model of sound propagation in soft tissues. More specifically, we treat the ultrasound confidence maps as a new modality and designed a visual servoing control law for image quality optimization. We illustrated our approach with the application of robotic tele-echography where the in-plane rotation of a 2D probe is visually servoed by the confidence map and the other degrees of freedom are teleoperated by the user. Experiments performed on both an ultrasound examination training phantom and ex vivo tissue samples validated this new concept [32]. Currently, we consider the confidence-driven servoing of other degrees of freedom, in particular out-of-plane motions that were controlled in our previous works from image moments [6], which could provide finer control of the image quality.

7.6.4. Visual servoing based on ultrasound elastography

Participants: Pedro Alfonso Patlan Rosales, Alexandre Krupa.

This study concerns the use of the ultrasound elastography as a new image modality for the control of the motion of an ultrasound probe actuated by a robotic manipulator. Elastography imaging is performed by applying continuous stress variation on soft tissues in order to estimate a strain map of the observed tissues. It is obtained by estimating, from the RF (radio-frequency) signal along each scan line of the probe transducer, the echo time delays between pre- and post-compressed tissue. Usually, this continuous stress variation is performed manually by the user who manipulates the US probe and it results therefore in a user-dependent quality of the elastography image. To improve the US elastography imaging, we recently developed an assistant robotic palpation system that automatically moves an ultrasound probe in such a way to optimize ultrasound elastography. The main originality of this preliminary work concerns the use of the elastography modality directly as input of the robot controller thanks to an innovative ultrasound elastography-based visual servoing approach.

7.6.5. Visual servoing using shearlet transform

Participants: Lesley-Ann Duflot, Alexandre Krupa.

Similar to wavelet transform, shearlet transform is usually used in the field of signal or image compression. At the best of our knowledge these image representations were never used directly as feedback of a closed-loop control scheme. The objective of this work is to study the feasibility of using the coefficients of shearlet transform of the observed ultrasound image directly as the visual features of an image-based visual servoing. In this study we estimated numerically the interaction matrix that links the time variation of the coarsest coefficients of the shearlet to the motion of the ultrasound probe. This shearlet-based visual servoing was experimentally tested for automatically positioning a 2D US probe, held by a robot, on a desired section of an abdominal phantom. The first results demonstrated promising performances.

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

8.1.1. Robocortex

Participants: Souriya Trinh, Fabien Spindler, François Chaumette.

no. Inria Rennes 8492, duration: 22 months.

This contract with the Inria spin off company Robocortex started in March 2014. It is devoted to the visual tracking and 3D localization of some particular targets.

8.2. Bilateral Grants with Industry

8.2.1. Astrium EADS

Participants: Tawsif Gokhool, Patrick Rives.

no. Inria Sophia 7128, duration: 36 months.

The objective of this project that started in February 2012 was to investigate the general problem of visual mapping of complex 3D environments that evolve over time. This contract supported Tawsif Gokhool's Ph.D. (see Section 7.4.3).

8.2.2. ECA Robotics

Participants: Romain Drouilly, Patrick Rives.

no. Inria Sophia 7030, duration: 36 months.

This project started in May 2012. It aimed at specifying a semantic representation well adapted to the problem of navigation in structured environment (indoors or outdoors). This contract was devoted to support the Cifre Convention between ECA Robotics and Inria Sophia Antipolis regarding Romain Drouilly's Ph.D. (see Section 7.4.5).

8.2.3. Technicolor

Participants: Salma Jiddi, Eric Marchand.

Univ. Rennes 1, duration: 36 months.

This project funded by Technicolor started in October 2015. It supports Salma Jiddi's Ph.D. about augmented reality.

8.2.4. Pôle Saint Hélier

Participants: Louise Devigne, Marie Babel.

no. Insa Rennes 2015/0890, duration: 36 months.

This project started in November 2015. It will address the following two issues. First, the idea is to design a low-cost indoor / outdoor efficient obstacle avoidance system that respects the user intention, and does not alter user perception. This involves embedding innovative sensors to tackle the outdoor wheelchair navigation problem. The second objective is to take advantage of the proposed assistive tool to enhance the user Quality of Experience by means of biofeedback as well as the understanding of the evolution of the pathology.

9. Partnerships and Cooperations

9.1. Regional Initiatives

9.1.1. HandiViz project - SATT Ouest Valorisation

Participants: François Pasteau, Marie Babel.

duration: 12 months.

This project started in June 2014. Thanks to a strong collaboration with Ergovie Company and the rehabilitation center Pôle Saint Hélier (Rennes), the semi-autonomous navigation solution designed for wheelchair systems (see Section 7.3.3) has been medically validated and tested by patients. The resulting technology is currently under transfer towards Ergovie (SATT/INSA funding). This technology, compliant with any off-the-shelf electrical wheelchair, is expected to be commercialized at mid 2016. We expect that this technology should be helpful for many handicapped people. In particular, intensive clinical trials have shown that such a system can lift the medical interdiction to drive wheelchairs for people who suffer from severe handicap such as hemispatial neglect or cerebral palsy.

9.1.2. ARED NavRob

Participants: Suman Raj Bista, Paolo Robuffo Giordano, François Chaumette.

no Inria Rennes 8033, duration: 36 months.

This project funded by the Brittany council started in October 2013. It supports in part Suman Raj Bista's Ph.D. about visual navigation (see Section 7.3.1).

9.1.3. ARED DeSweep

Participants: Lesley-Ann Duflot, Alexandre Krupa.

no Inria Rennes 8033, duration: 36 months.

This project funded by the Brittany council started in October 2014. It supports in part Lesley-Ann Duflot's Ph.D. about visual servoing based on shearlet transform. (see Section 7.6.5).

9.1.4. ARED Locoflot

Participants: Ide Flore Kenmogne Fokam, Vincent Drevelle, Eric Marchand.

no Inria Rennes 9944, duration: 36 months.

This project funded by the Brittany council started in October 2015. It supports in part Ide Flore Kenmogne Fokam's Ph.D. about cooperative localization in multi-robot fleets using interval analysis. (see Section 7.5.3).

9.1.5. "Equipement mi-lourd Rennes Metropoles"

Participant: Paolo Robuffo Giordano.

no Irisa CNRS Rennes 14C0481, duration: 36 months.

A grant from "Rennes Métropole" has been obtained in June 2014 and supports the activities related to the use of drones (quadrotor UAVs). The platform described in Section 6.12 has been purchased in part thanks to this grant.

9.2. National Initiatives

9.2.1. ANR P2N Nanorobust

Participants: Le Cui, Eric Marchand.

no. UR1 11FA310-06D, duration: 48 months.

This project started in November 2011 and will end in March 2016. It is composed of a consortium managed by Femto-ST in Besançon with LPN and Isir in Paris, Thalès and Lagadic group through the "Université de Rennes 1". Nanorobust deals with the development of micro- and nano-manipulation within SEM (Scanning Electron Microscope). We provided visual servoing techniques for positioning and manipulation tasks with a micrometer precision.

9.2.2. ANR Contint Visioland

Participants: Noël Mériaux, Patrick Rives, François Chaumette.

no Inria Rennes 8304, duration: 48 months.

This project started in November 2013. It is composed of a consortium managed by Onera in Toulouse with Airbus, Spikenet Technology, IRCCyN, and Lagadic. Its aim is to develop vision-based localization and navigation techniques for autonomous landing on a runway (see Section 7.1.4).

9.2.3. ANR Platinum

Participants: Patrick Rives, Vincent Drevelle.

duration: 42 months.

This project started in November 2015. It is composed of a consortium managed by Litis in Rouen with IGN Matis (Paris), Le2i (Le Creusot) and Lagadic group through Inria Sophia Antipolis. It aims at proposing novel solutions to robust long-term mapping of urban environments.

9.2.4. ANR SenseFly

Participants: Paolo Robuffo Giordano, Riccardo Spica, Thomas Bellavoir, Muhammad Usman.

no Irisa CNRS 50476, duration: 36 months.

The ANR "Jeune Chercheur" project SenseFly started in August 2015. Its goal is to advance the state-of-the-art in multi-UAV in the design and implementation of fully decentralized and sensor-based group behaviors by only resorting to onboard sensing (mainly cameras and IMU) and local communication (e.g., bluetooth communication, wireless networks). Topics such as individual flight control, formation control robust against sensor limitations (e.g., limited field of view, occlusions), distributed estimation of relative positions/bearings from local sensing, maintenance of architectural properties of a multi-UAV formation will be touched by the project. Part of the platforms described in Section 6.12 has been purchased thanks to this grant.

9.2.5. PEA Decsa

Participants: Aurélien Yol, François Chaumette, Eric Marchand.

no Inria Rennes 6630, duration: 36 months.

This project started in November 2011 and ended in November 2015. It was composed of a consortium managed by Astrium/Airbus with the Novadem, Sirehna, Spot Image and Magellium companies, and with the Inria Lagadic and Steep groups (Peter Sturm). It was devoted to the development of navigation and perception algorithms for small drones in urban environment.

9.2.6. Oseo Romeo 2

Participants: Nicolas Cazy, Suman Raj Bista, Fabien Spindler, François Chaumette.

no Inria Rennes 7114, duration: 48 months.

This project started in November 2012. It is composed of a large consortium managed by Aldebaran Robotics. It aims at developing advanced control and perception functionalities to a humanoid robot. It supports in part Suman Raj Bista's Ph.D. about visual navigation (see Section 7.3.1), as well as Nicolas Cazy's Ph.D. about model-based predictive control for visual servoing (see Section 7.2.3).

9.2.7. Equipex Robotex

Participants: Fabien Spindler, François Chaumette.

no Inria Rennes 6388, duration: 10 years.

Lagadic is one of the 15 French partners involved in the Equipex Robotex network. It is devoted to get significative equipments in the main robotics labs in France. In the scope of this project, we have got the humanoid robot Romeo (see Section 6.11).

9.3. European Initiatives

9.3.1. FP7 & H2020 Projects

9.3.1.1. FP7 Space RemoveDEBRIS

Participants: Aurélien Yol, Eric Marchand, François Chaumette.

Instrument: Specific Targeted Research Project

Duration: October 2013 - September 2016

Coordinator: University of Surrey (United Kingdom)

Partners: Surrey Satellite Technology (United Kingdom), Astrium (Toulouse, France and Bremen, Germany), Isis (Delft, The Netherlands), CSEM (Neuchâtel, Switzerland), Stellenbosch University (South Africa).

Inria contact: François Chaumette

Abstract: The goal of this project is to validate model-based tracking algorithms on images acquired during an actual space debris removal mission. [38]

9.3.1.2. Comanoid

Participants: Paolo Robuffo Giordano, François Chaumette.

Title: Multi-contact Collaborative Humanoids in Aircraft Manufacturing

Programm: H2020

Duration: January 2015 - January 2019

Coordinator: CNRS (Lirmm)

Partners: Airbus Groups (France), DLR (Germany), Universita Degli Studi di Roma La Sapienza (Italy)

Inria contact: François Chaumette

Comanoid investigates the deployment of robotic solutions in well-identified Airbus airliner assembly operations that are laborious or tedious for human workers and for which access is impossible for wheeled or rail-ported robotic platforms. As a solution to these constraints a humanoid robot is proposed to achieve the described tasks in real-use cases provided by Airbus Group. At a first glance, a humanoid robotic solution appears extremely risky, since the operations to be conducted are in highly constrained aircraft cavities with non-uniform (cargo) structures. Furthermore, these tight spaces are to be shared with human workers. Recent developments, however, in multi-contact planning and control suggest that this is a much more plausible solution than current alternatives such as a manipulator mounted on multi-legged base. Indeed, if humanoid robots can efficiently exploit their surroundings in order to support themselves during motion and manipulation, they can ensure balance and stability, move in non-gaited (acyclic) ways through narrow passages, and also increase operational forces by creating closed-kinematic chains. Bipedal robots are well suited to narrow environments specifically because they are able to perform manipulation using only small support areas. Moreover, the stability benefits of multi-legged robots that have larger support areas are largely lost when the manipulator must be brought close, or even beyond, the support borders. COMANOID aims at assessing clearly how far the state-of-the-art stands from such novel technologies. In particular the project focuses on implementing a real-world humanoid robotics solution using the best of research and innovation. The main challenge will be to integrate current scientific and technological advances including multi-contact planning and control; advanced visual-haptic servoing; perception and localization; human-robot safety and the operational efficiency of cobotics solutions in airliner manufacturing.

9.3.1.3. Romans

Participants: Paolo Robuffo Giordano, Nicolo Pedemonte, Firas Abi Farraj, François Chaumette.

Title: Robotic Manipulation for Nuclear Sort and Segregation

Programm: H2020

Duration: May 2015 - May 2018

Coordinator: Univ. Birmingham (UK)

Partners: NLL (UK), CEA (France), Univ. Darmstat (Germany)

CNRS contact: Paolo Robuffo Giordano

The RoMaNS project aims at advancing the state of the art in autonomous, tele-operative and shared control for remote manipulation. This has far reaching cross-sector applications in nuclear, aerospace, oil and gas, space, food and agriculture. Within the nuclear industries of multiple EU states, it applies across the entire sector, such as waste processing, decommissioning, asset care, maintenance, repair, characterization and sampling. The novel technology that will be produced within this project will be applied to a very challenging and safety-critical nuclear “sort and segregate” industrial problem, which is driven by urgent market and societal needs. The purpose of nuclear sort and segregate is to place low-level waste in low-level storage containers, rather than occupying extremely expensive and resource intensive higher level storage containers and facilities.

Also, Waste Requiring Additional Treatment (WRAT) will be either decontaminated, recycled, compacted, incinerated or grouted. Finally, any unstable waste items are sorted into a more suitable storage state. Indeed, it can be noted that cleaning up the past half century of nuclear waste, in the UK alone (mostly at the Sellafield site), represents one of the largest environmental remediation projects in Europe. Most EU countries have similar challenges. Many older EU nuclear sites (> 60 years in UK) contain large numbers of legacy storage containers, many of which have contents of mixed contamination levels, and sometimes unknown contents. Some of this waste have been temporarily stored in containers, which may need to be disrupted or cut open, to investigate their contents, before sorted and segregated. Any country that possesses a nuclear plant, even without a current backlog of legacy waste, will face similar challenges when they begin decommissioning. Vast quantities of highly contaminated plant machinery and infrastructure will have to be demolished, cut and resized, and the parts sorted and segregated. Much of this work can only be done by remote manipulation methods, because the high levels of radioactive material are hazardous to humans. In this respect, the RoMaNS project will address the following points: (i) development of novel hardware, and improvement the TRL level of existing experimental hardware, to enable robot arms and grippers with advanced capabilities, but which are suitable for deployment in high radiation environments; (ii) development of advanced autonomy methods for highly adaptive and generalizable automatic grasping and manipulation actions; (iii) development of hardware and software solutions for advanced bi-lateral tele-operation of arms and grippers; (iv) combination of autonomy and tele-operation methods using state-of-the-art understanding of mixed initiative planning, variable autonomy and shared control approaches; (v) delivery of a TRL 6 demonstration in an industrial plant-representative environment at the UK National Nuclear Lab Workington test facility, in close proximity to the Sellafield nuclear site.

9.4. International Initiatives

9.4.1. Inria Associate Teams not involved in an Inria International Labs

Participants: Marie Babel, Vishnu Karakkat Narayanan.

Sampen (Self Adaptive Mobile Perception and Navigation) is an Inria associated team with the Iceira Lab supervised by Prof Ren C. Luo at the National University of Taiwan. It has been accepted in 2014 for 2 years. The coordinator of the team for Inria is Anne Spalanzani from UPMF University at Grenoble. The other French participants are Marie Babel, Daney David (Phoenix group in Bordeaux) and Christian Laugier (e-Motion group in Grenoble).

The aim of the project is to propose a self-adaptive system of perception combined with a system of autonomous navigation. Usually, systems of perception rely on a set of specific sensors and a calibration is done in a specific environment. We propose to develop some methods to make perception systems adaptive to the environmental context and to the set of sensors used. This perception, that can be embedded on the mobile robot as well as on home structures (wall, ceiling, floor), will be helpful to localize agents (people, robot) present in the scene. Moreover, it will give information to better understand social scenes.

In the scope of this project, Marie Babel and Vishnu Karakkat Narayanan spent a one-week visit in Iceira Lab in April 2015. Vishnu Karakkat Narayanan was then invited to spend a three-month visit from August till November 2015 in that lab.

9.4.2. Inria International Partners

9.4.2.1. Informal International Partners

- As a follow up to the long term collaboration with the “Centro de Tecnologia da Informação Renato Archer” (CTI) in Campinas (Brazil), Renato José Martins benefits a Ph.D. grant from the CNPq (2013-2017). He is co-directed by Patrick Rives and Samuel Siqueira Bueno from “Divisio de Robotica e Viseo Computacional” at CTI.

- Alexandre Krupa has a collaboration with Nassir Navab from the Technische Universität München concerning the joint supervision of Pierre Chatelain's Ph.D.
- Patrick Rives has a collaboration with Javier Gonzales-Jimenez from the University of Malaga (Spain). Eduardo Fernandez-Moral who received his Ph.D. in Malaga by September 2014, is currently on a Postdoctoral position in Sophia Antipolis.

9.4.3. Participation In other International Programs

The Lagadic group is one of the few external partners of the Australian Center for Robotic Vision roboticvision.org. It groups QUT in Brisbane, ANU in Canberra, Monash University and Adelaide University. In the scope of this project, Riccardo Spica spent a six-month visit at ANU collaborating with Prof Rob Mahony, and François Chaumette spend a short visit at QUT and ANU in November 2015.

9.5. International Research Visitors

9.5.1. Research stays abroad

- Pierre Chatelain spent a nine-month visit in Nassir Navab's lab at TUM, Germany, in the scope of his Ph.D. (see Section 9.4.2).
- Ricardo Spica spent a six-month visit in Rob Mahony's lab at ANU, Canbera, in the scope of the Australian Center of Robotic Vision (see Section 9.4.3).
- Vishnu Karakkat Narayanan spent a three-month visit in Ren Luo's lab at Iceira Lab, National Taiwan University, Taiwan, in the scope of his Ph.D as well as the SAMPEN associated team (see Section9.4.1).

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific events organisation

10.1.1.1. General chair, scientific chair

- Patrick Rives was the co-organizer and the scientific chair of the Journées Nationales de la Recherche en Robotique (JNRR'15) held in October at Cap Hornu.

10.1.1.2. Member of the organizing committees

- Paolo Robuffo Giordano co-organized the 7-th International Workshop on Human-Friendly Robotics, Pontedera, Italy

10.1.2. Scientific events selection

10.1.2.1. Member of the conference program committees

- François Chaumette: ICRA'2015, RSS'2015, ICRA'2016
- Eric Marchand: Orasis'15, IROS'2015, ICRA'2016
- Patrick Rives: ICRA'2016, RFIA'2016
- Paolo Robuffo Giordano: ICRA'2015, ICRA'2016

10.1.2.2. Reviewer

- Marie Babel: ICRA 2016 (2), IROS 2015 (1)
- François Chaumette: IROS'2015 (3), Humanoids'2015 (1)
- Vincent Drevelle: IROS'2015 (4)
- Alexandre Krupa: IROS'2015 (2), ISBI'2015 (1), ICRA'2016 (4)

- Eric Marchand: Orasis’15 (3), ICRA’2015 (3), IROS’2015 (2), ICRA’2016 (2)
- Patrick Rives: ICCV’2015 (2), ICRA’2015 (3), IROS’2015 (3), IV’2015 (1), MVIGRO’2015 (1)
- Paolo Robuffo Giordano: ICRA’15, IROS’15, IROS’15, MED’15

10.1.3. Journal

10.1.3.1. Member of the editorial boards

- François Chaumette: Editorial Board of the Int. Journal of Robotics Research, Senior Editor of the IEEE Robotics and Automation Letters
- Alexandre Krupa: Associate Editor of the IEEE Robotics and Automation Letters
- Eric Marchand: Associate Editor of the IEEE Robotics and Automation Letter, Guest Editor (with Peter Corke and Jana Kosecka) of a Special Issue of the Int. Journal of Robotics Research on Robot Vision.
- Paolo Robuffo Giordano: Associate Editor of IEEE Trans. on Robotics, Area Chair of RSS 2015

10.1.3.2. Reviewer - Reviewing activities

- Marie Babel: Autonomous Robots (1)
- François Chaumette: IEEE Trans. on Robotics (4), Robotics and Autonomous Systems (1)
- Patrick Rives: IEEE Trans. on Robotics (1), Robotics and Autonomous Systems (1), TSI (2)
- Paolo Robuffo Giordano: IEEE Trans. on Robotics (2)

10.1.4. Invited talks

- Marie Babel and François Pasteau were invited to give a talk during the final workshop of the Interreg 4A France Channel COALAS project at Kent University, UK, in May 2015.
- François Chaumette: Plenary talk at DICTA’2015, Adelaide, Australia [58]; Tutorial at SIDRA’2015 (Ph.D. Summer School on Robot Control), Bertinoro, Italy
- Eric Marchand: Plenary talk at Orasis’2015, Amiens, France.
- Paolo Robuffo Giordano. Invited Talk: Control of Quadrotors in Unstructured Environments. RSS 2015 Symposium: Frontiers of Robotics, April 2015
- Fabien Spindler: Plenary talk and visual servoing atelier at RPRA’2015 summer school (Recent Progress in Robotics Applications), Alicante, Spain

10.1.5. Leadership within the scientific community

- François Chaumette and Patrick Rives are members of the scientific council of the “GdR Robotique” and JNRR.
- François Chaumette has been elected to serve in the Administrative Committee of the IEEE Robotics and Automation Society (RAS). He chaired the 2015 IEEE RAS Chapter of the year Award Committee and served in the 2015 IEEE RAS Fellow Nomination Committee. He also served in the Advisory Board of the Peraspera project. This project funded by the EC is in charge of drafting the roadmap of the EC Strategic Research Cluster on Space Robotics.
- Alexandre Krupa is a member of the GestChir project at the IRT b<>com in Rennes.
- Eric Marchand is in the board of the “Images et réseaux” competitivity cluster. He is also a member of the scientific council of the “École supérieure d’ingénieurs de Rennes” (ESIR).
- Patrick Rives has represented Inria’s robotic community at European Robotics Forum 2015 for the election of the Board of Directors of euRobotics AISBL.

10.1.6. Scientific expertise

- François Chaumette and Patrick Rives served in the jury to select the best French Ph.D. thesis in robotics.

- François Chaumette served as a Panel member for the ERC PE7 consolidator grants. He also served as evaluator of the FP7 Euroc project and reviewed a set of ANR proposals.
- Eric Marchand served in the jury to select the best French Ph.D. thesis in image processing and computer vision.
- Patrick Rives served as a member of the Inria evaluation committee until July 2015. He also served in the local CR2 (Rocquencourt) and national DR2 recruitment juries.
- Paolo Robuffo Giordano served as External Reviewer for the EU FP7 Sherpa Project.

10.1.7. Research administration

- Marie Babel is a member of the "Comité de Centre" of Inria Rennes-Bretagne Atlantique.
- François Chaumette serves as the president of the committee in charge of all the temporary recruitments ("Commission Personnel") at Inria Rennes-Bretagne Atlantique and Irisa. He is also a member of the Head team of Inria Rennes-Bretagne Atlantique.
- Eric Marchand served as secretary in the board of the "Association Française pour la Reconnaissance et l'Interprétation des Formes (AFRIF)". He isalso in charge of the Irisa Ph.D. students in the committee in charge of all the temporary recruitments ("Commission Personnel") at Inria Rennes-Bretagne Atlantique and Irisa.
- Alexandre Krupa is a member of the CUMIR ("Commission des Utilisateurs des Moyens Informatiques pour la Recherche") of Inria Rennes-Bretagne Atlantique.

10.1.8. Patents

- François Pasteau and Marie Babel are the main authors of a patent (No FR 3 021 400) entitled "Méthode de correction d'une trajectoire dans un dispositif d'aide au déplacement de personnes".
- Lucas Royer, Alexandre Krupa and Maud Marchal (Hybrid group at Inria Rennes-Bretagne Atlantique and Irisa) submitted a patent application (No. FR15/60541) to INPI entitled "Process for tracking a clinical target in medical images".

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

Marie Babel:

Master INSA3: "Statistical Signal Processing", 24 hours, M2, INSA Rennes

Master INSA1: "Architecture", 30 hours, L3, INSA Rennes

Master INSA2: "Computer science project", 30 hours, M1, INSA Rennes

Master INSA2: "Image analysis", 18 hours, M1, INSA Rennes

Master INSA1: "Remedial math courses", 50 hours, L3, INSA Rennes

François Chaumette:

Master ESIR3: "Visual servoing", 8 hours, M2, Ecole supérieure d'ingénieurs de Rennes

Vincent Drevelle:

Master CTS: "Instrumentation, localization, GPS", 6 hours, M2, Université de Rennes 1

Master Info: "Mobile robotics", 38 hours, M2, Université de Rennes 1

Master GLA: "Terrain information systems", 16 hours, M2, Université de Rennes 1

Master Info: "Artificial intelligence", 12 hours, M1, Université de Rennes 1

Alexandre Krupa:

Master SIBM (Signals and Images in Biology and Medicine): “Medical robotics guided from images”, 4.5 hours, M2, Université de Rennes 1, Brest and Angers

Master FIP TIC-Santé: “Ultrasound visual servoing”, 6 hours, M2, Télécom Physique Strasbourg

Master INSA3: “Modeling and engineering for Biology and Health applications”, 12 hours, M2, INSA Rennes

Master ESIR3: “Ultrasound visual servoing”, 9 hours, M2, Esir Rennes

Eric Marchand:

Master Esir2: “Colorimetry”, 24 hours, M1, Esir Rennes

Master Esir2: “Computer vision: geometry”, 24 hours, M1, Esir Rennes

Master Esir3: “Special effects”, 24 hours, M2, Esir Rennes

Master Esir3: “Computer vision: tracking and recognition”, 24 hours, M2, Esir Rennes

Master MRI: “Computer vision”, 24 hours, M2, Université de Rennes 1

Master MIA: “Augmented reality”, 4 hours, M2, Université de Rennes 1

Paolo Robuffo Giordano:

Master in Robotics: “Analysis and Control of Multi-Robot Systems”, 16 hours, M2, Department of Computer and System Sciences, University of Rome “La Sapienza”

10.2.2. Supervision

Ph.D.: Manikandan Bakthavatchalam, “Utilisation des moments photométriques en asservissement visuel”, defended on March 2015, supervised by François Chaumette [8]

Ph.D.: Tawsif Gokhool, “Représentations valides à long terme pour la navigation et l’apprentissage des modèles 3D”, defended on June 2015, supervised by Patrick Rives [10]

Ph.D.: Romain Drouilly, “Représentation hybride métrique, topologique et sémantique d’environnement 3D pour la localisation temps réel”, defended on June 2015, supervised by Patrick Rives [9]

Ph.D.: Riccardo Spica, “Contributions to Active Visual Estimation and Control of Robotic Systems”, defended on December 2015, supervised by Paolo Robuffo Giordano and François Chaumette [11]

Ph.D. in progress: Le Cui, “Nano-manipulation by visual servoing”, started in October 2012, supervised by Eric Marchand

Ph.D. in progress: Lucas Royer, “Visual tool for percutaneous procedures in interventional radiology”, started in September 2013, supervised by Alexandre Krupa, Maud Marchal (Hybrid group at Inria Rennes-Bretagne Atlantique and Irisa) and Guillaume Dardenne (IRT b<>com)

Ph.D. in progress: Pierre Chatelain, “Multi-modal visual servoing for intra-operative imaging”, started in September 2013, supervised by Alexandre Krupa and Nassir Navab (Technische Universität München)

Ph.D. in progress: Vishnu Karakkat Narayanan, “Semi-autonomous navigation of a wheelchair by visual servoing and user intention analysis”, started in September 2013, supervised by Marie Babel and Anne Spalanzani (e-Motion group at Inria Rhône-Alpes)

Ph.D. in progress: Suman Raj Bista, “Visual navigation of a humanoid robot”, started in October 2013, supervised by Paolo Robuffo Giordano and François Chaumette

Ph.D. in progress: Nicolas Cazy, “Model predictive visual servoing of a humanoid robot”, started in October 2013, supervised by Paolo Robuffo Giordano, François Chaumette and Pierre-Brice Wieber (Bipop group at Inria Rhône-Alpes)

Ph.D. in progress: Renato José Martins, “Robust navigation and control of an autonomous vehicle”, started in November 2013, supervised by Patrick Rives and Samuel Siqueira Bueno (CTI)

Ph.D. in progress: Aly Magassouba, “Audio-based control”, started in December 2013, supervised by François Chaumette and Nancy Bertin (Panama group at Inria Rennes-Bretagne Atlantique and Irisa)

Ph.D. in progress: Jason Chevrie, “Control of a flexible needle by visual servoing using B-mode ultrasound images”, started in September 2014, supervised by Alexandre Krupa and Marie Babel

Ph.D. in progress: Quentin Bateux, “Visual servoing from global descriptors”, started in October 2014, supervised by Eric Marchand

Ph.D. in progress: Fabrizio Schiano, “Collective control with onboard sensors for multiple quadrotor UAVs”, started in October 2014, supervised by Paolo Robuffo Giordano

Ph.D. in progress: Pedro Patlan-Rosales, “Robotic insertion of a biopsy needle by visual servoing using elastography images”, started in October 2014, supervised by Alexandre Krupa

Ph.D. in progress: Noël Mériaux, “Landing by visual servoing”, started in October 2014, supervised by François Chaumette, Eric Marchand and Patrick Rives

Ph.D. in progress: Lesley-Ann Duflot, “Soft tissue deformation tracking using optical coherence tomography (OCT) and ultrasound imaging”, started in November 2014, supervised by Alexandre Krupa and Brahim Tamadazte (Minarob group at FEMTO-ST, Besançon)

Ph.D. in progress: Firas Abi Farraj, “Shared Control Architectures for Visual Servoing Tasks”, started in October 2015, supervised by Paolo Robuffo Giordano

Ph.D. in progress: Salma Jiddi, “Analyses géométrique et photométrique pour des applications de réalité mixte”, started in October 2015, supervised by Eric Marchand and Philippe Robert (Technicolor)

Ph.D. in progress: Ide Flore Kenmogne Fokam, “Cooperative localization in multi-robot fleets using interval analysis”, started in October 2015, supervised Vincent Drevelle and Eric Marchand

Ph.D. in progress: Bryan Penin “Model predictive visual servoing for UAVS”, started in October 2015, supervised by Paolo Robuffo Giordano and François Chaumette

Ph.D. in progress: Muhammad Usman, “Robust Vision-Based Navigation for Quadrotor UAVs”, started in October 2015, supervised by Paolo Robuffo Giordano

Ph.D. in progress: Louise Devigne, “Contribution d’une aide technique robotique à l’évaluation de pathologies neurologiques : Application à la navigation d’un fauteuil roulant”, started in November 2015, supervised by Marie Babel and Philippe Gallien (Pôle Saint Hélier)

Master internship: Marwan Osman from Master Erasmus Mundus Vibot, Le Creusot, “Visual servoing using the trifocal tensor”, supervised by François Chaumette

Master 1 internship: Pierre Le Bihan from Insa Rennes, “Camera-laser triangulation”, supervised by François Pasteau and Marie Babel

Bachelor internship: Grégoire Bonin from Université de Rennes 1, “Rigidity-based Formation Control for the case of Distance and Bearing Constraints”, supervised by Paolo Robuffo Giordano

10.2.3. Juries

- François Chaumette: Cédric Pradalier (HdR, reviewer, Laas, Toulouse), Julien Pettré (HdR, president, Irisa, Rennes), Augustin Manecy (Ph.D., reviewer, ISM, Marseille), Victor Rosenzveig (Ph.D., president, Irccyn, Nantes), Nathan Crombez (Ph.D., reviewer, Mis, Amiens), Don Joven Agravante (Ph.D., president, Lirmm, Montpellier)
- Alexandre Krupa: Ederson Antonio Gomes Dorileo (Ph.D., reviewer, Lirmm, Montpellier)
- Eric Marchand: François Chadebecq (Ph.D., reviewer, Institut Pascal, Clermont-Ferrand), Xialu Sun (Ph.D., reviewer, CVLAB EPFL, Lausanne), Datta Ramadasan (Ph.D., reviewer, Institut Pascal, Clermont-Ferrand), Zaynab Habibi (Ph.D., reviewer, MIS, Amiens), Manikandan Bakthavatchalam (Ph.D., president, Inria, Rennes)

- Patrick Rives: Francisco Moreno Dueñas (Ph.D, reviewer, Malaga, Spain), Danilo Alves de Lima (Ph.D, reviewer, Heudiasyc, Compiègne), Emilie Wirbel (Ph.D, president, Mines-Paritech, Paris), Guillaume Duceux (Ph.D, examiner, ENSTA, Paris)

10.3. Popularization

- Due to the visibility of our experimental platforms, the team is often asked to present its research activities to students, researchers or industry. Our panel of demonstrations allows us to highlight recent results concerning the positioning of an ultrasound probe by visual servoing, the construction of a tower by combining 3D model-based visual tracking and visual servoing techniques to pick up cubes that are assembled, vision-based detection and tracking for space navigation in a rendezvous context, the semi-autonomous navigation of a wheelchair, and augmented reality applications.
- Marie Babel, François Chaumette and Fabien Spindler participated to a "Café des Sciences" in Rennes in November 2015: http://www.espace-sciences.org/conferences/cafes-de-l-espace-des-sciences/les-robots-sont-partout
- Marie Babel and François Pasteau participated as exhibitors to the robotics exhibition "Innorobo" in Lyon in July 2015: http://innorobo.com/en/home/ and to the "Autonomic" exhibition dedicated to the handicap and the autonomy in Rennes in October 2015: http://www.autonomic-expo.com/
- Fabien Spindler is a member of the editorial board of "Ouest Inria", the internal journal at Inria Rennes-Bretagne Atlantique.

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