IN PARTNERSHIP WITH:
CNRS

Institut national des sciences appliquées de Rennes

Université Rennes 1

Activity Report 2016

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

Table of contents

Project-Team LAGADIC

Creation of the Project-Team: 2004 December 06

Keywords:

Computer Science and Digital Science:

5.4.4. - 3D and spatio-temporal reconstruction
5.4.5. - Object tracking and motion analysis
5.4.6. - Object localization
5.4.7. - Visual servoing
5.6. - Virtual reality, augmented reality
5.10.2. - Perception
5.10.4. - Robot control
5.10.5. - Robot interaction (with the environment, humans, other robots)
5.10.6. - Swarm robotics

Other Research Topics and Application Domains:

2.4.3. - Surgery
2.5. - Handicap and personal assistances
5.1. - Factory of the future
5.6. - Robotic systems
7.2.1. - Smart vehicles
8.4. - Security and personal assistance

1. Members

Research Scientists

François Chaumette [Team leader, Inria, Senior Researcher, Rennes - Bretagne-Atlantique, HDR]
Alexandre Krupa [Inria, Researcher, Rennes - Bretagne-Atlantique, HDR]
Claudio Pacchierotti [CNRS, Researcher, from Dec 2016, Rennes - Bretagne-Atlantique]
Julien Pettré [Inria, Researcher, from April 2016, Rennes - Bretagne-Atlantique, HDR]
Patrick Rives [Inria, Senior Researcher, Sophia Antipolis - Méditerranée, HDR]
Paolo Robuffo Giordano [CNRS, Senior Researcher, Rennes - Bretagne-Atlantique, HDR]
Paolo Salaris [Inria, Researcher, Sophia Antipolis - Méditerranée]

Faculty Members

Marie Babel [INSA Rennes, Associate Professor, Rennes - Bretagne-Atlantique, HDR]
Vincent Drevelle [Univ. Rennes I, Associate Professor, Rennes - Bretagne-Atlantique]
Eric Marchand [Univ. Rennes I, Professor, Rennes - Bretagne-Atlantique, HDR]

Engineers

Fabien Spindler [Inria, Senior engineer, Rennes - Bretagne-Atlantique]
Thomas Bellavoir [CNRS, granted by ANR SenseFly project, Rennes - Bretagne-Atlantique]
Giovanni Claudio [Inria, granted by BPI Romeo 2 project and H2020 Comanoid project, Rennes - Bretagne-Atlantique]
Pierre-Marie Kerzerho [Inria, granted by ANR VisioLand, from Nov 2016, Rennes - Bretagne-Atlantique]
Andrea Peruffo [CNRS, granted by H2020 RoMans, until Apr 2016, Rennes - Bretagne-Atlantique]
Marc Pouliquen [Inria, granted by ADT UsTk, from Sep 2016, Rennes - Bretagne-Atlantique]
Souriya Trinh [Inria, granted by H2020 Comanoid project, Rennes - Bretagne-Atlantique]

Aurélien Yol [Inria, granted by ANR VisioLand project, Rennes - Bretagne-Atlantique]

PhD Students

Firas Abi Farraj [CNRS, granted by H2020 Romans project, Rennes - Bretagne-Atlantique]
Quentin Bateux [Univ. Rennes I, granted by MESR, Rennes - Bretagne-Atlantique]
Aline Baudry [INSA Rennes, granted by MESR and Brittany Council, from Oct 2016, Rennes - Bretagne-Atlantique]
Suman Raj Bista [Inria, granted by BPI Romeo 2 and Brittany Council, Rennes - Bretagne-Atlantique]
Julien Bruneau [Univ. Rennes I, granted by MESR, Rennes - Bretagne-Atlantique]
Nicolas Cazy [Inria, granted by BPI Romeo 2 project, Rennes - Bretagne-Atlantique]
Pierre Chatelain [Univ. Rennes 1, granted by ENS Cachan, Rennes - Bretagne-Atlantique]
Jason Chevrie [Univ. Rennes I, granted by ENS Cachan, Rennes - Bretagne-Atlantique]
Le Cui [Univ. Rennes I, granted by ANR Nanorobust, until Jan 2016, Rennes - Bretagne-Atlantique]
Quentin Delamare [Univ. Rennes I, granted by ENS Rennes, from Sep 2016, Rennes - Bretagne-Atlantique]
Louise Devigne [Pôle Saint Hélier, granted by Cifre, Rennes - Bretagne-Atlantique]
Lesley-Ann Duflot [Inria, granted by Femto-ST and Brittany Council, Rennes - Bretagne-Atlantique]
Hadrien Gurnel [Inst. de Recherche Technologique b<>com, from Oct 2016, Rennes - Bretagne-Atlantique]
Dayana Hassan [Inria, granted by Cifre, from Nov 2016, Sophia Antipolis - Méditerranée]
Salma Jiddi [Technicolor, granted by Cifre, Rennes - Bretagne-Atlantique]
Vishnu Karakkat Narayanan [Inria, granted by AEN Pal, Rennes - Bretagne-Atlantique]
Ide Flore Kenmogne Fokam [Inria, granted in part by Brittany Council, Rennes - Bretagne-Atlantique]
Axel Lopez Gandia [Univ. Rennes I, granted by MESR, from Oct 2016, Rennes - Bretagne-Atlantique]
Aly Magassouba [Univ. Rennes I, granted by MESR, Rennes - Bretagne-Atlantique]
Renato José Martins [CNPq,, Sophia Antipolis - Méditerranée]
Noël Mériaux [Inria, granted by ANR VisioLand, Rennes - Bretagne-Atlantique]
Pedro Alfonso Patlan Rosales [Conacyt, Rennes - Bretagne-Atlantique]
Bryan Penin [Inria, granted in part by DGA, Rennes - Bretagne-Atlantique]
Lucas Royer [Inst. de Recherche Technologique b<>com, Rennes - Bretagne-Atlantique]
Fabrizio Schiano [Inria, Rennes - Bretagne-Atlantique]
Muhammad Usman [CNRS, granted by ANR SenseFly, Rennes - Bretagne-Atlantique]

Post-Doctoral Fellows

Don Joven Agravante [Inria, granted by H2020 Comanoid project, Rennes - Bretagne-Atlantique]
Nicolò Pedemonte [CNRS, granted by H2020 Romans project, until Sep 2016, Rennes - Bretagne-Atlantique]
Riccardo Spica [CNRS, granted by ANR SenseFly, Rennes - Bretagne-Atlantique]
David Wolinski [Inria, until Nov 2016, granted by ANR Percolation, Rennes - Bretagne-Atlantique]
Panayiotis Charalambous [Inria, granted by ANR Percolation, until May 2016, Rennes - Bretagne-Atlantique]
Eduardo Fernandez Moral [Inria, granted by ANR Platinum, Sophia Antipolis - Méditerranée]

Administrative Assistants

Hélène de La Ruée [Inria, in common with I4S group, Rennes - Bretagne-Atlantique]
Christine Riehl [Inria, in common with Hephaistos group and Focus group at Univ. of Bologna, Sophia Antipolis - Méditerranée]

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 the perception and action aspects more closely, 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 our work can lead (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 the interaction between action and perception in an optimal way, 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 traditionaly 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 the error vector $\mathbf{s}(t) - \mathbf{s}^*(t)$ to zero. 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 a 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, etc. 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 application requirements. Therefore, even if we still consider 2D feature 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 [7]: 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

- Eric Marchand and Fabien Spindler co-authored with Prof. Hideaki Uchiyama (Kyushu Univ., Japan) a survey on pose estimation for augmented reality published in IEEE Trans. on Visualization and Computer Graphics [33].
- The second edition of the Springer Handbook of Robotics has been released this year. It contains an extended version of the chapter on visual servoing co-authored by François Chaumette, Prof. Seth Hutchinson (UIUC, Illinois) and Prof. Peter Corke (QUT, Brisbane, Australia) [77].

5.1.1. Awards

- The ANR project ENTRACTE, of which Julien Pettré is partner, has received the "ANR Grand Prix du Numérique 2016". The project is about anthropomorphic action planning and understanding: http://www.agence-nationale-recherche.fr/?Project=ANR-13-CORD-0002 (see also Section 9.2.3).
- Paper [71] has been selected has one of the five finalists for the ICARCV'2016 Best Paper Award.

- Lagadic is a member of the five finalist teams for the KUKA Innovation Award (https://www.kuka.com/en-de/press/events/kuka-innovation-award), together with the RIS group at LAAS (coordinator), the University of Siena, Italy, and the Seoul National University, South Korea. The goal is to address search and rescue operations in regions which are difficult to access or dangerous following disasters. For this, the team will explore the collaboration between a quadrotor UAV and a KUKA lightweight arm for cooperative transportation and manipulation of rigid objects (e.g., long bards), with a final peg-in-hole task to be demonstrated live at the Hannover fair during spring 2017.

6. New Software and Platforms

6.1. DESlam

Dense Egocentric SLAM
KEYWORDS: Deph Perception - Robotics - Localization
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 types 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: Francois 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. It provides the functionalities to do image acquisition, semantic annotation, dense registration, localization and 3D mapping. The omnidirectional RGB-D sensors used within this software have been developed at Inria Sophia Antipolis.

- Participants: Eduardo Fernandez Moral, Renato José Martins and Patrick Rives
- Contact: Patrick Rives
- URL: https://team.inria.fr/lagadic

6.4. Sinatrack

KEYWORDS: Computer vision - Robotics
FUNCTIONAL DESCRIPTION

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

- Participants: Antoine Petit, Eric Marchand and Francois Chaumette
- Contact: Eric Marchand
- URL: http://team.inria.fr/lagadic

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 and visual servoing based on ultrasound images. Written in C++, UsTk provides tools for ultrasound image acquisition, processing, and display, as well as control of ultrasound probe motion by ultrasound visual servoing. This year we started the development of a new version. The objective is first to consolidate existing developments, to improve the quality of the software, to add new state-of-the-art algorithms, and then to disseminate them within the community as an open-source software.

- Participants: Marc Pouliquen, Alexandre Krupa, Pierre Chatelain and Fabien Spindler
- Contact: Alexandre Krupa
- URL: https://team.inria.fr/lagadic/

6.6. ViSP

KEYWORDS: Computer vision - Robotics - Augmented reality - Visual servoing
SCIENTIFIC DESCRIPTION

Since 2005, we have been developing and releasing 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, Eric Marchand, Fabien Spindler, Aurélien Yol and Souriya Trinh
- Partner: Inria, Université de Rennes 1
- Contact: Fabien Spindler
- URL: http://visp.inria.fr

In December 2015, ViSP 3.0.0 new modular architecture was released. The corresponding source code tarball was downloaded 2138 times, much more than the previous 2.10.0 release that was downloaded 1412 times. This confirms that ViSP popularity is increasing and motivates the efforts we are doing since more than 10 years to improve the software. ViSP 3.0.0 last release was packaged for Debian, Ubuntu 16.04 LTS, Arch Linux, OSX and ROS. ViSP 3.0.1 next release is in preparation and should be released at the beginning of 2017. This release will be also packaged for iOS devices. In this new version we introduced new wrapper for USB-3 or GigE PointGrey cameras, Haption haptic device, ATI force/torque sensors, Intel RealSense RGB-D devices. We also make an effort to optimize some critical code sections using SSE and make possible cross-compilation for Raspberry PI and iOS targets, and also Nao, Romeo and Pepper robots from SoftBank Robotics. We also introduce a new version of the 3D model-based tracker dedicated to stereo tracking, fixed some issues, improved the documentation by providing new tutorials and by updating the existing ones.

Concerning ROS community, all the existing packages in "`vision_visp`" ROS stack (see http://wiki.ros.org/vision_visp) were updated and ported to kinetic 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, Canada, Japan, Korea, India, China, Italy, Spain, Portugal, etc. 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. Last August, during the Intel Developer Forum opening keynote, Intel CEO Brian Krzanich introduced the Intel Joule compute module. Using an Intel Joule with glasses from French company PivotHead, Intel demonstrated an augmented reality application that was using ViSP (https://www.youtube.com/watch?v=QRBofzL4MDY).

6.7. WarpDriver

KEYWORDS: Crowd Simulation - Pedestrian Simulation - Collision Avoidance - Reactive Navigation

FUNCTIONAL DESCRIPTION

WarpDriver is a microscopic crowd simulation software, which simulates the collision-free locomotion of many individual agents among the obstacles of a given environment. The originality of the algorithm relies on motion prediction mechanism which allows each agent to predict the probability of colliding other agents with respect to their current motion, their past motion, and the presence of obstacles forcing agents to follow some paths in the environment. Agents then move to their goal whilst they minimize their probability of colliding obstacles.

- Participants: David Wolinski and Julien Pettré
- Contact: Julien Pettré
- URL: http://team.inria.fr/lagadic

6.8. bib2html

FUNCTIONAL DESCRIPTION

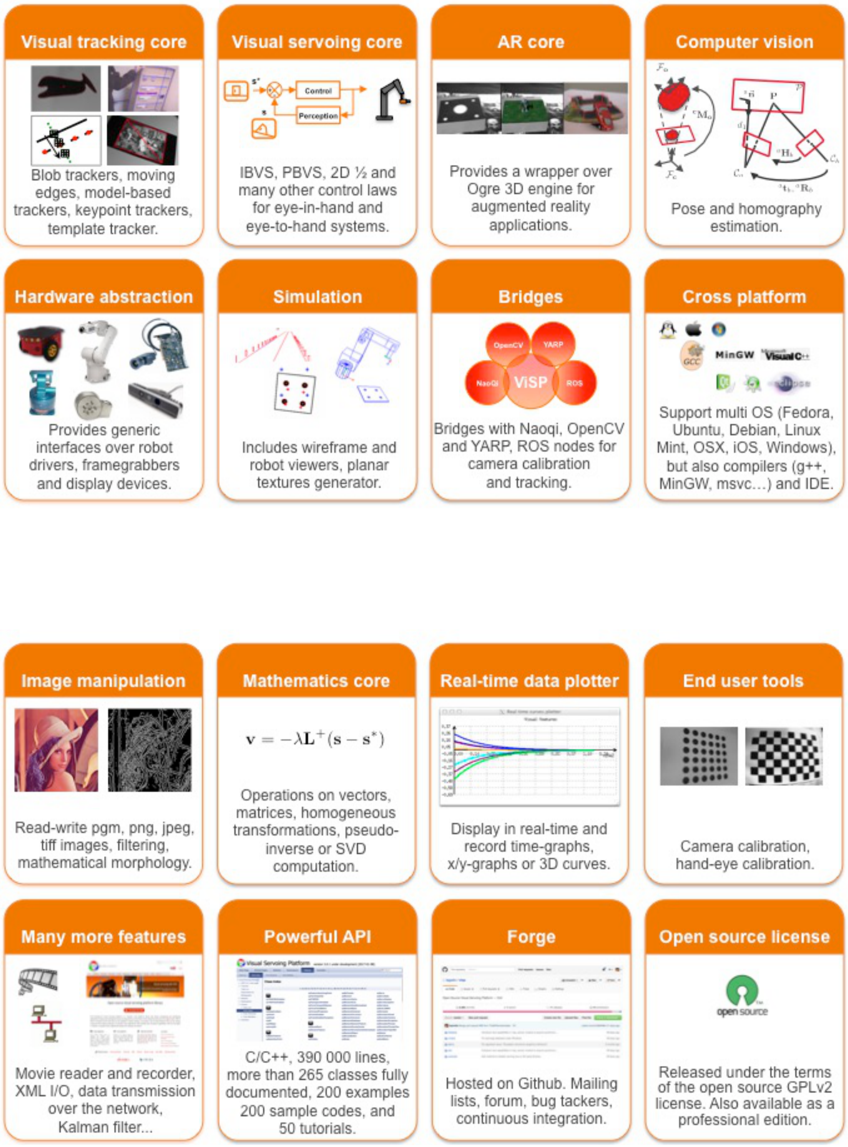


Figure 1. This figure highlights ViSP main capabilities for visual tracking, visual servoing, and augmented reality that may benefit from computer vision algorithms. ViSP allows controlling specific platforms through hardware abstraction or in simulation. ViSP provides also bridges over other frameworks 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 Github 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: Eric Marchand
- URL: http://www.irisa.fr/lagadic/soft/bib2html/bib2html.html

6.9. Platforms

6.9.1. Robot vision platform

Participant: Fabien Spindler [contact].

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.a). These robots are equipped with cameras. The Gantry robot also allows embedding grippers on its end-effector.

This year we completed the platform with a haptic Virtuose 6D device from Haption company (see Fig. 2.b). This device is used for visual-based shared control (see Section 9.3.1.3).

Note that 3 papers published by Lagadic in 2016 enclose results validated on this platform [21][48][46].

(a) (b)

Figure 2. a) Lagadic robotics platform for vision-based manipulation, b) Virtuose 6D haptic device

6.9.2. Mobile robots

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

6.9.2.1. 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 Pioneer 3DX from Adept (see Fig. 3.b). 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 Section 7.4.5), we have three electric wheelchairs in Rennes, one from Permobil, one from Sunrise and the last from YouQ (see Fig. 3.c). 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 ultrasound sensors to perform the required servoing for assisting handicapped people.

Note that 11 papers exploiting the indoors mobile robots were published this year [67][26][61][37][62][30] [55][38][71][64][66].

6.9.2.2. Outdoor vehicles

A camera rig has been developed in Sophia Antipolis. It can 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 shown in the video http://www-sop.inria.fr/members/Renato-Jose.Martins/iros15.html.

Paper [68] contains experimental results obtained with this camera rig.

6.9.3. Medical robots

Participants: Fabien Spindler [contact], 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 (see Section 7.3).

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.

This year we replaced the F/T sensor attached to one of the Viper robot in order to use a DAQ acquisition board able to provide measures at a higher frame rate (up to 1 kHz). This feature is especially useful for flexible needle steering by ultrasound visual servoing (see Fig. 5.b).

Notice that 10 papers published this year include experimental results obtained with this platform [40][31][34][58][57][70][52][59] [50][51].

6.9.4. Humanoid robots

Participants: Giovanni Claudio, Fabien Spindler [contact].

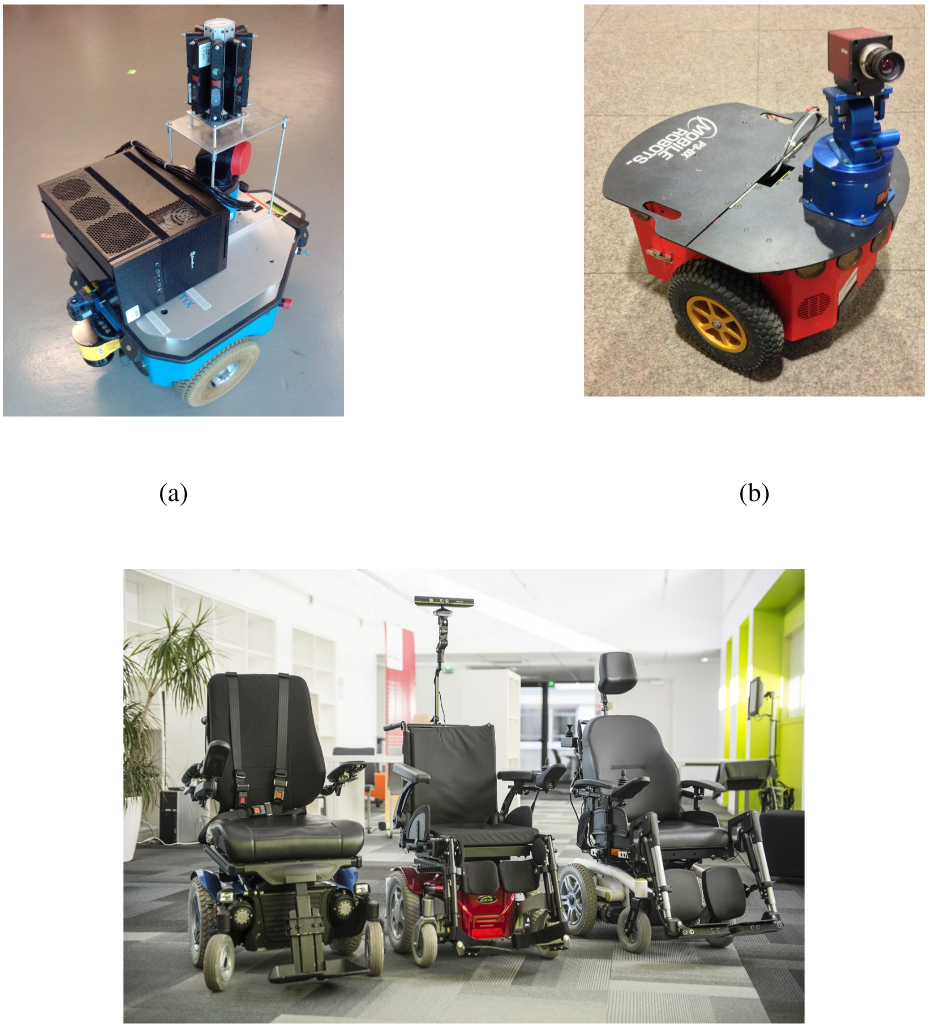
Romeo is a humanoid robot from SoftBank Robotics which is intended to be a genuine personal assistant and companion. For the moment only the upper part of the body (trunk, arms, neck, head, eyes) is working. This research platform is used to validate our researches in visual servoing and visual tracking for object manipulation (see Fig. 6.a).

In July, this platform was extended with Pepper, another human-shaped robot designed by SoftBank Robotics to be a genuine day-to-day companion (see Fig. 6.b). It has 17 degrees of freedom mounted on a wheeled holonomic base and a set of sensors (cameras, laser, ultrasound, inertial) that makes this platform interesting for researches in vision-based manipulation and navigation. Our first developments were devoted to visual servoing for controlling the gaze of the robot exploiting the redundancy of the head and mobile base and adding the capability to follow a person.

Note that 4 papers published this year include experimental results obtained with these platforms [53][81][65][20].

6.9.5. Unmanned Aerial Vehicles (UAVs)

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

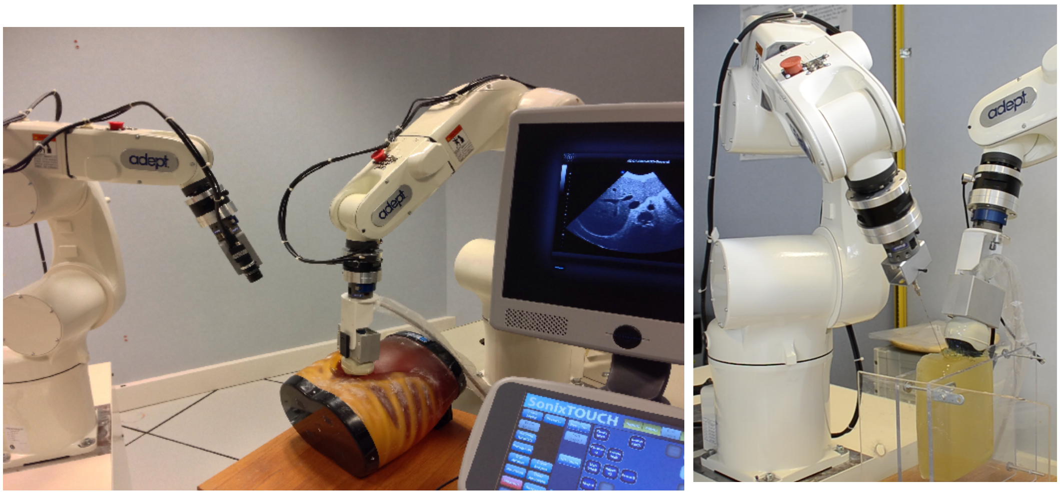


(a) (b)

(c)

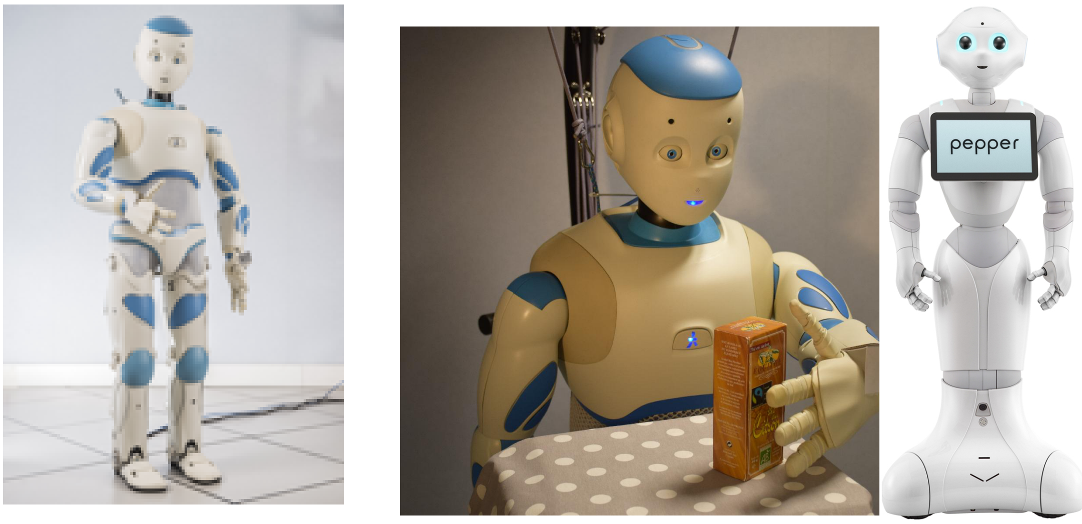
Figure 3. a) Hannibal platform, b) Pioneer P3-DX robot, c) wheelchairs from Permobil, Sunrise and YouQ.

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.



(a) (b)

Figure 6. a) Romeo experimental platform, b) Pepper human-shaped robot

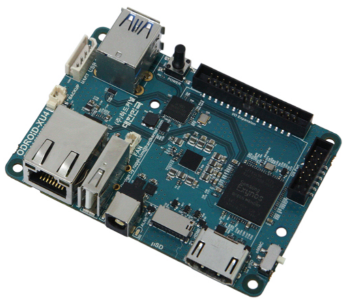
From 2014, Lagadic also started some activities involving perception and control for single and multiple quadrotor UAVs, especially thanks to a grant from “Rennes Métropole” (see Section 9.1.5) and the ANR project “SenseFly” (see Section 9.2.5). To this end, we purchased four quadrotors from Mikrokopter Gmbh, Germany (see Fig. 7.a), and one quadrotor from 3DRobotics, USA (see 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 (see 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 (see Fig. 7.c). The quadrotor group is 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.

Two papers published this year enclose experimental results obtained with this platform [72][64].

(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 Perception

7.1.1. Micro/nano Manipulation

Participants: Le Cui, Eric Marchand.

Le Cui's Ph.D. [15] ended with a contribution related to visual tracking and estimation of the 3D pose of a micro/nano-object. It is indeed a key issue in the development of automated manipulation tasks using visual feedback. The 3D pose of the micro object can be estimated based on a template matching algorithm. Nevertheless, a key challenge for visual tracking in a scanning electron microscope (SEM) was the difficulty to observe the motion along the depth direction. We then proposed a template-based hybrid visual tracking scheme that uses luminance information to estimate the object displacement on x-y plane and uses defocus information to estimate object depth [54].

7.1.2. 3D Localization for Space Debris Removal

Participants: Aurélien Yol, Eric Marchand, François Chaumette.

This study is realized in the scope of the FP7 Removedebris project (see Section 9.3.1.1) [27]. We compared two vision-based navigation methods for tracking space debris in a low Earth orbit environment. The proposed approaches rely on a frame to frame model-based tracking in order to obtain the complete 3D pose of the camera with respect to the target [2]. The proposed algorithms robustly combine points of interest and edge features, as well as color-based features if needed. Experimental results have been obtained demonstrating the robustness of the approaches on synthetic image sequences simulating a CubeSat satellite orbiting the Earth [75].

7.1.3. 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 are now considering to perform this localization from a set of keyframe images corresponding to the landing trajectory.

7.1.4. Scene Registration based on Planar Patches

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

Image registration has been a major problem in computer vision over the past decades. It implies searching an image in a database of previously acquired images to find one (or several) that fulfill some degree of similarity, e.g. an image of the same scene from a similar viewpoint. This problem is interesting in mobile robotics for topological mapping, re-localization, loop closure and object identification. Scene registration can be seen as a generalization of the above problem where the representation to match is not necessarily defined by a single image (i.e. the information may come from different images and/or sensors), attempting to exploit all information available to pursue higher performance and flexibility. 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 [26].

7.1.5. Direct RGB-D Registration

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

Dense direct RGB-D registration methods are widely used in tasks ranging from localisation and tracking to 3D scene reconstruction [7]. This work addresses a peculiar aspect which drastically limits the applicability of direct registration, namely the weakness of the convergence domain. In general, registration is performed only between close frames (small displacements), since dense registration tasks are particularly sensible to the local convexity of the cost error function. The main contribution of this work is an adaptive RGB-D error cost function that has a larger convergence domain and a faster convergence in both simulated and real data

[67], [68]. This formulation employs the relative condition number metric to update the weighting of the RGB and depth costs. This approach is performed within a multi-resolution framework, where an efficient pixel selection for both RGB and ICP costs reduces the computational cost whilst preserving the precision. The formulation results in a larger region of attraction and faster convergence than classical RGB, ICP and RGB-D costs. Experiments was conducted using real sequences of indoor and outdoor images using perspective and spherical RGB-D sensors. Significant improvements was denoted in terms of the convergence stability and the speed of convergence in comparison with state-of-the-art methods.

7.1.6. Online localization and mapping for UAVs

Participants: Muhammad Usman, Paolo Robuffo Giordano, Eric Marchand.

Localization and mapping in unknown environments is still an open problem, in particular for what concerns UAVs because of the typical limited memory and processing power available onboard. In order to provide our quadrotor UAVs with high autonomy, we started studying how to exploit onboard cameras for an accurate (but fast) localization and mapping in unknown indoor environments. We chose to base both processes on the newly available Semi-Direct Visual Odometry (SVO) library (http://rpg.ifi.uzh.ch/software) which has gained considerable attention over the last years in the robotics community. The idea is to exploit dense images (i.e., with little image pre-processing) for obtaining an incremental update of the camera pose which, when integrated over time, can provide the camera localization (pose) w.r.t. the initial frame. In order to reduce drifts during motion, a concurrent mapping thread is also used for comparing the current view with a set of keyframes (taken at regular steps during motion) which constitute a “map” of the environment. We have started porting the SVO library to our UAVs and the preliminary results showed good performance of the localization accuracy against the Vicon ground truth. We are now planning to close the loop and base the UAV flight on the reconstructed pose from the SVO algorithm.

7.1.7. Reflectance and Illumination Estimation for Realistic Augmented Reality

Participants: Salma Jiddi, Eric Marchand.

The acquisition of surface material properties and lighting conditions is a fundamental step for photo-realistic Augmented Reality. Human visual cues remain sensitive to the global coherence within a computer-generated image. Absence or bad rendered virtual shadows, unconsidered specular reflections and/or occlusions, confused color perception such as an exuberantly bright virtual object are all elements which may not help an AR user interact and commit to a target application. In this work, we studied a new method for the estimation of the diffuse and specular reflectance properties of an indoor real static scene. Using an RGB-D sensor, we further estimate the 3D position of light sources responsible for specular phenomena and propose a novel photometry-based classification for all the 3D points. The resulting algorithm allows convincing AR results such as realistic virtual shadows as well as proper illumination and specularity occlusions [60].

7.1.8. Optimal Active Sensing Control

Participants: Paolo Salaris, Riccardo Spica, Paolo Robuffo Giordano.

This study concerns the problem of active sensing control. The objective is to improve the estimation accuracy of an observer by determining the inputs of the system that maximize the amount of information gathered by the outputs. In [9] this problem has been solved within the Structure from Motion (SfM) framework for 3D structure estimation problems, i.e. a point, a sphere and a cylinder, in the particular case where the observability property is instantaneously guaranteed. The optimal estimation strategy is hence given in terms of the instantaneous velocity direction of the camera velocities.

Recently, we have extended the optimal active sensing control to the case where the observability property is not instantaneously guaranteed. To simplify the analysis, we considered nonlinear differentially flat systems. Moreover, to quantify the richness of the acquired information the Observability Gramian (OG) has been used. We have hence defined a trajectory for the flat outputs of the system by using B-Spline curves and then, we have exploited an online gradient descent strategy to move the control points of such B-Spline in order to actively maximise the smallest eigenvalue of the OG over the whole fixed planning time horizon. While the system travels along its planned (optimized) trajectory, an Extended Kalman Filter (EKF) is used to estimate the system state. In order to keep memory of the past acquired sensory data for online re-planning, the OG is also computed on the past estimated state trajectories. This is then used for an online replanning of the optimal trajectory during the robot motion which is continuously refined by exploiting the estimated system state by the EKF. In order to show the effectiveness of our method we have considered a simple but significant case of a planar robot with a single range measurement. The simulation results show that, along the optimal path, the EKF converges faster and provides a more accurate estimate than along any other possible (non-optimal) paths. These results have been submitted to ICRA'2017.

7.2. Sensor-based Robot Control

7.2.1. Determining Singularity Configurations in IBVS

Participant: François Chaumette.

This theoretical study has been achieved through an informal collaboration with Sébastien Briot and Philippe Martinet from IRCCyN in Nantes, France. It concerns the determination of the singularity configurations of image-based visual servoing using tools from the mechanical engineering community and the concept of "hidden" robot. In a first step, we have revisited the welknown case of using three image points as visual feature, and then solved the general case of n image points [22]. The case of three image straight lines has also been solved for the first time [23].

7.2.2. Interval-based IBVS convergence domain computation

Participant: Vincent Drevelle.

This work aims to compute the set of camera poses from which IBVS will converge to the desired pose (that corresponds to the reference image). Starting from a (small) initial attraction domain of the desired pose (obtained using Lyapunov theory), we employ subpavings and guaranteed integration to iteratively increase the proven convergence domain, using a viability-based approach. Image-domain and pose-domain constraints are also enforced, like feature points visibility or workspace boundaries. First results have been obtained for a 3DOF line-scan camera IBVS case [56].

7.2.3. Visual Servoing of Humanoid Robots

Participants: Giovanni Claudio, Don Joven Agravante, Fabien Spindler, François Chaumette.

This study is realized in the scope of the BPI Romeo 2 and H2020 Comanoid projects (see Sections 9.2.7 and 9.3.1.2).

In a first step, we have considered classical kinematic visual servoing schemes for gaze control and manipulation tasks, such as can or box grasping. Two-hand manipulation has also been achieved using a master/slave approach [53], [81]. In a second step, we have designed the modeling of the visual features at the acceleration level to embed visual tasks and visual constraints in an existing QP controller [20][80]. Experimental results have been obtained on Romeo (see Section 6.9.4).

7.2.4. Model Predictive Visual Servoing

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

This study is realized in collaboration with Pierre-Brice Wieber, from Bipop group at Inria Rhône Alpes.

Model Predictive Control (MPC) is a powerful control framework able to take explicitly into account the presence of constraints in the controlled system (e.g., actuator saturations, sensor limitations, and so on). In this research activity, we studied the possibility of using MPC for tackling one of the most classical constraints of visual servoing applications, that is, the possibility to lose tracking of features because of occlusions, limited camera field of view, or imperfect image processing/tracking. The MPC framework depends upon the possibility to predict the future evolution of the controlled system over some time horizon, for correcting the current state of the modeled system whenever new information (e.g., new measurements) become available. We have also explored the possibility of applying these ideas in a multi-robot collaboration scenario where a UAV with a downfacing camera (with limited field of view) needs to provide localization services to a team of ground robots [13].

7.2.5. Model Predictive Control for Visual Servoing of a UAV

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

Visual servoing is a welknown class of techniques meant to control the pose of a robot from visual input by considering an error function directly defined in the image (sensor) space. These techniques are particularly appealing since they do not require, in general, a full state reconstruction, thus granting more robustness and lower computational loads. However, because of the quadrotor underaction and inherent sensor limitations (mainly limited camera field of view), extending the classical visual servoing framework to the quadrotor flight control is not straightforward. For instance, for realizing a horizontal displacement the quadrotor needs to tilt in the desired direction. This tilting, however, will cause any downlooking camera to point in the opposite direction with, e.g., possible loss of feature tracking because of the limited camera field of view.

In order to cope with these difficulties and achieve a high-performance visual servoing of quadrotor UAVs, we are exploring the possibility of using techniques borrowed from Model-Predictive Control (MPC) for explicitly dealing with this kind of constraints during flight. Indeed, MPC is a class of (numerical) optimal control techniques able to explicitly take into account state and input constraints, as well as complex (and underactuated) nonlinear dynamics of the controlled system. In particular, the ability to predict, over some future time window, the behavior of the visual features on the image plane will allow the quadrotor to fly “blindly” for some limited phases, for then regaining tracking of any lost feature. This possibility will be crucial for allowing quick maneuvering guided by a direct visual feedback. We have started addressing the case of a simulated planar UAV as a representative case study, and we are now working towards an experimental validation with a real quadrotor UAV equipped with an onboard camera.

7.2.6. Visual-based shared control

Participants: Firas Abi Farraj, Nicolò Pedemonte, Paolo Robuffo Giordano.

This work concerns our activities in the context of the RoMaNS H2020 project (see Section 9.3.1.3. Our main goal is to allow a human operator to be interfaced in an intuitive way with a two-arm system, one arm carrying a gripper (for grasping an object), and the other one carrying a camera for looking at the scene (gripper + object) and providing the needed visual feedback. The operator should be allowed to control the two-arm system in an easy way for letting the gripper approaching the target object, and she/he should also receive force cues informative of how feasible her/his commands are w.r.t. the constraints of the system (e.g., joint limits, singularities, limited camera fov, and so on).

We have started working on this topic by proposing a shared control architecture in which the operator could provide instantaneous velocity commands along four suitable task-space directions not interfering with the main task of keeping the gripper aligned towards the target object (this main task was automatically regulated). The operator was also receiving force cues informative of how much her/his commands were conflicting with the system constraints, in our case joint limits of both manipulators. Finally, the camera was always moving so as to keep both the gripper and the target object at two fixed locations on the image plane [46].

We have then extended this framework in two directions: first, by allowing the possibility of controlling a whole future trajectory for both arms (gripper+camera) while coping with the system constraints. The operator was then receiving an ‘integral’ force feedback along the whole planned trajectory: in this way, the operator’s actions and the corresponding force cues were function of a planned trajectory (thus, carrying information over a future time window) that could be manipulated at runtime. Second, we studied how to integrate learning from demonstration into our framework by first using learning techniques for extracting statistical regularities of ‘expert users’ executing successful trajectories for the gripper towards the target object. Then, these learned trajectories were used for generating force cues able to guide novice users during their teleoperation task by the ‘hands’ of the expert users who demonstrated the trajectories in the first place. Both works have been submitted to ICRA’2017.

7.2.7. Direct Visual Servoing

Participants: Quentin Bateux, Eric Marchand.

In the direct visual servoing methods such as photometric framework, the images as a whole are used to define the control law. This can be opposed to the classical visual servoing approaches that relies on geometric features and where image processing algorithms that extract and track visual features are necessary. In [21], we proposed a generic framework to consider histograms as visual features. A histogram is an estimate of the probability distribution of a variable (for example the probability of occurrence in an intensity, color, or gradient orientation in an image). We demonstrated that the framework we proposed applies, but is not limited to, a wide set of histograms and allows the definition of efficient control laws.

Nevertheless, the main drawback for the direct visual servoing class of methods comparing to the classical geometric visual servoing methods is their comparatively limited convergence range. We then proposed in [48] a new direct visual servoing control law that relies on a particle filter to perform non-local and non-linear optimization in order to increase the convergence domain. To each particle considered we associate a virtual camera that predicts the image it should capture by using image transfer techniques. This new control law has been validated on a 6 DOF positioning task performed on our Gantry robot (see Section 6.9.1).

7.2.8. Audio-based Control

Participants: Aly Magassouba, François Chaumette.

This study is concerned with the application of sensor-based control approach to audio sensors. It is made in collaboration with Nancy Bertin from Panama group at Irisa and Inria Rennes-Bretagne Atlantique. Auditory features such as Interaural Time Difference (ITD), Interaural Level Difference (ILD), and sound energy have been modeled and integrated in various control schemes to control the motion of a mobile robot with two microphones onboard [66], [64]. Experiments with Romeo and Pepper (see Section 6.9.4) have also been achieved [65]. They show the robustness of closed loop sensor-based control with respect to coarse modeling and that explicit sound source localization is not a mandatory step for aural servoing.

7.3. Medical Robotics

7.3.1. Non-rigid Target Tracking in Ultrasound Images

Participants: Lucas Royer, Alexandre Krupa.

We pursued our work concerning the development of a real-time approach that allows tracking deformable soft tissue structures in 3D ultrasound sequences. In previous work we proposed a method which consists in estimating the target deformation by combining robust dense motion estimation and mechanical model simulation. This year we improved the robustness of our method to several image artefacts as the presence of large shadows, local illumination changes and image occlusions that occur due to the modification of the imaging gain and re-orientation of the ultrasound beam induced by probe motion. To achieve this, we proposed a new dissimilarity criterion between the current and reference images based on the Sum of Conditional Variance (SCV). Our new criterion, that we named Sum of Confident Conditional Variance (SCCV), consists in discriminating unconfident voxels thanks to the use of a pixel-wise quality measurement of the ultrasound images. This improved approach was experimentally validated on organic soft tissues and the obtained results were published in [40].

7.3.2. Optimization of Ultrasound Image Quality by Visual Servoing

Participants: Pierre Chatelain, Alexandre Krupa.

This study is realized in collaboration with Prof. Nassir Navab from the Technical University of Munich (TUM).

In previous work, we have developed ultrasound-based visual servoing methods to fulfill various tasks, such as compensating for physiological motion, maintaining the visibility of an anatomic target during ultrasound probe teleoperation, or tracking a surgical instrument. However, due to the specific nature of ultrasound images, guaranteeing a good image quality during the procedure remains a challenge. Therefore we pursued our study on the use of ultrasound confidence maps as a new modality for automatically positioning an ultrasound probe in order to improve the image quality. In addition to our visual servoing approach that optimizes the global quality of the image, this year we proposed a control fusion to optimize the acoustic window for a specific anatomical target which is tracked in the ultrasound images [50]. Recently, we extended our confidence-driven control to the out-of-plane motion of a 3D ultrasound probe and experimentally validated it on a human volunteer at TUM [14].

7.3.3. Visual Servoing using Shearlet Transform

Participants: Lesley-Ann Duflot, Alexandre Krupa.

In collaboration with the Femto-ST lab in Besançon, we proposed in a first-hand a solution to reduce the acquisition time of an Optical Coherence Tomography (OCT) 3D imaging scanner. This latter consists in sweeping a laser beam on a tissue sample of interest. To increase the frame rate of this imaging device we proposed to apply an optimal trajectory to the laser that covers entirely the image but without performing all the OCT measurements. The reconstruction of the missing data is then achieved by applying an updated Fast Iterative Soft-Thresholding Algorithm (FISTA) on a sparse representation of the image that is based on the shearlet transform [57]. In a second hand, we studied the feasibility of using the subsampled shearlet coefficients of an ultrasound image as the visual features of an image-based visual servoing. In a preliminary study we estimated numerically the interaction matrix that links the variation of the shearlet coarsest coefficients to the 6 degrees of freedom motion of the ultrasound probe and uses it in the visual servoing framework. The results obtained in cases of automatic probe positioning and phantom motion compensation demonstrated the efficiency of the shearlet-based features in terms of accuracy, repeatability, robustness and convergence behavior [59]. Then we proposed to consider a more efficient and adequate shearlet implementation that consists in a non-subsampled representation of the image. In this case the shearlet coefficients represent different images, focused on different singularities of the initial image, and we consider directly their pixel intensity values in the visual feature vector similarly to the photometry-based visual servoing approach. The modeling of the interaction matrix was analytically derived and experimental results demonstrated the reliability of the new method and its robustness to speckle noise [58].

7.3.4. 3D Steering of Flexible Needle by Ultrasound Visual Servoing

Participants: 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 the past we only considered the control of the insertion and needle rotation along and around its main axis by the use of a duty-cycling control strategy. This latter consists in adapting online from visual feedback the orientation of a beveled-tip flexible needle during its insertion for controlling the needle curvature in 3D space that is induced by asymmetrical forces exerted on the bevel. However, such strategy limits the workspace of the needle tip. Therefore we proposed a new control method for flexible needle steering that combines direct base manipulation and needle tip based control. The direct base manipulation control is generated thanks to the use of a 3D model of a flexible beveled tip needle that gives the adequate motion of the needle base to obtain a given motion of the needle tip. This 3D model is based on virtual springs that characterize the needle mechanical interaction with soft tissue and is adapted online from visual tracking of the needle shape. 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 [51]. Preliminary results of an automatic needle tip positioning in a translucent gelatine phantom, observed by 2 orthogonal cameras, demonstrated the feasibility of the combination between direct base manipulation and needle tip control for reaching a desired target. This hybrid control allows better targeting capabilities in terms of larger needle workspace and reduced needle bending. In order to predict the trajectory of a needle during insertion under lateral motion of the tissue, we also improved our 3D model of the flexible needle to take into account the effect of the motion of the tissues on the needle shape. This was achieved thanks to the design of an algorithm based on an unscented Kalman filter that estimates the tissue motion. Results obtained from several needle insertions in a moving soft tissue phantom showed that our model gives good performance in terms of needle trajectory prediction. This model was also considered in a closed-loop control approach to allow automatic reaching of a target in case of tissue lateral displacement [52]. Future work will address the consideration of 3D ultrasound as visual feedback.

7.3.5. Enhancement of Ultrasound Elastography by Visual Servoing and Force Control

Participants: Pedro Alfonso Patlan Rosales, Alexandre Krupa.

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 an user-dependent quality of the elastography image. To improve the ultrasound elastography imaging and provide quantitative measurement, we developed an assistant robotic palpation system that automatically moves a 2D ultrasound probe for optimizing ultrasound elastography [70]. The main originality of this work is the use of the elastography modality directly as input of the robot controller. Force measures are also considered in the probe control in order to automatically induce soft tissue deformation needed for real-time elastography imaging process.

7.4. Navigation of Mobile Robots

7.4.1. Visual Navigation from an Image Memory

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 localization as well as for the visual servoing are not composed of points of interest, but either on mutual information [71] following the idea proposed in [3], or straight lines that are more common indoors [38], or finally on a combination of points of interest and straight lines [11]. Satisfactory experimental results have been obtained using the Pioneer mobile robot (see Section 6.9.2).

7.4.2. Robot-Human Interactions during Locomotion

Participant: Julien Pettré.

In collaboration with the Gepetto team of Laas in Toulouse and the Mimetic group in Rennes, we have studied how humans avoid collision with a robot. Understanding how humans achieve such avoidance is crucial to better anticipate humans' reactions to the presence of a robot and to control the robot to adapt its trajectory accordingly. It is generally assumed that humans avoid a robot just like they avoid another human. In this work, we bring the empirical demonstration that humans actually set a specific strategy to avoid robots, and that, more precisely, they show a preference to give way to a robot which is on a collision course with them [41]. This results brings useful insight about human-robot interactions during locomotion, and provides useful guidelines to design reactive navigation techniques for mobile robots aimed at moving among humans.

7.4.3. Scene Mapping based on Intelligent Human/Robot Interactions

Participant: Patrick Rives.

For mobile robots to operate in compliance with human presence, interpreting the impact of human activities and responding constructively is a challenging goal. Towards this objective, mapping an environment allows robots to be deployed in diverse workspaces, marking this skill as a primary element in the integration of robots into human-populated environments. We proposed an effective approach for using human activity cues in order to enhance robot mapping and navigation and in particular in filtering noisy human detections, detecting passages, inferring space occupancy and allowing navigation within unexplored areas. Our contributions [36] are based on the development of intelligent interactions among conceptually different mapping levels, namely, the metric, social and semantic levels. Experiments, using the Hannibal platform (see Section 6.9.2), highlighted a number of strong dependences among these levels and the way in which they can be used to enhance individual performances and in turn the global robot operation.

7.4.4. Autonomous Social Navigation of a Wheelchair

Participants: Vishnu Karakkat Narayanan, Marie Babel.

This work is realized in collaboration with Anne Spalanzani (Chroma team - Inria Grenoble).

A key issue that hinders the adoption of assistive robotic technologies such as robotized wheelchair, in the real world, is that they need to operate in mostly human environments and among human crowds. Indeed intelligent wheelchairs need to be deployed in a human environment thereby making it essential for such robots to incorporate a sense of human-awareness. Simply put, humans are special objects that have to be perceived and acted on in a special manner by robots that interact with us humans. Thus one can define Human-aware Navigation as an intersection between human-robot interaction and robotic motion planning.

In this context we introduced a low-level velocity controller that could be employed by a social robot like a robotic wheelchair for approaching a group of interacting humans, in order to become a part of the interaction. Taking into account an interaction space that is created when at least two humans interact, a meeting point can be calculated where the robot should reach in order to equitably share space among the interacting group. We then proposed a sensor-based control law which uses the position and orientation of the humans with respect to the sensor as inputs, to reach the meeting point while respecting spatial social constraints [61]. Experiments using a mobile robot equipped with a single laser scanner, realized in collaboration with Ren Luo (Taiwan) within the Sampen Inria associated team, also proved the success of the algorithm in a noisy real world scenario [62].

In addition, a semi-autonomous framework for human-aware navigation in an intelligent wheelchair has been designed. A generalized linear control sharing framework was proposed that was able to progressively correct the user teleoperation in order to avoid obstacles and in order to avoid disturbance to humans. Meanwhile, we also proposed a Bayesian approach for user intention estimation. The formulation was partly inferred from the design of the controller for assisted doorway passing, wherein we hypothesized that predicting short term goals is sufficient for eliminating user intention uncertainty [16].

7.4.5. Semi-autonomous Control of a Wheelchair for Navigation Assistance

Participants: Louise Devigne, Vishnu Karakkat Narayanan, Marie Babel.

To address the wheelchair driving assistance issue, we proposed a unified shared control framework able to smoothly correct the trajectory of the electrical wheelchair [16]. 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 [55]. The robotic solution is currently under validation process with volunteering patients of Pôle Saint Hélier (France) who present different disabling neuro-pathologies preventing them to drive non-assisted wheelchairs.

Within the frame of ISI4NAVE associated team (see Section 9.4.1.2), this shared-control solution has been then coupled with first experimental biofeedback devices such as haptic devices. Preliminary tests have been conducted within the PAMELA facility at University College of London and within the rehabilitation center of Pôle Saint Hélier in Rennes (see Section 8.1.3). They involved regular wheelchair users as well as medical staff. We have demonstrated the ability of the framework to provide relevant assistance and now need to focus on methods to fine-tune parameters and customize/calibrate to the individual and evolving needs of each user.

7.5. Multi-robot and Crowd Motion Control

7.5.1. Advanced multi-robot control and estimation

Participant: 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 fulfillment 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. We gave two contributions in this field: in the first one [35], we proposed a decentralized exploration strategy for a team of 3D agents able to guarantee exploration of a finite space in a finite amount of time while coping with the constraints of a connected sensing/communication graph for the robot group against sensing/communication constraints (limited range, occluded line-of-sight), and of obstacle and inter-robot collision avoidance. The strategy exploits a suitable state machine for assigning dynamic roles to the agents in the group for allowing completion of the exploration in finite time. Second, in [28] we studied how the choice of a leader agent in a leader-follower scenario could affect the performance of the group when tracking a desired formation (shape and gross motion). The proposed strategy allows selecting the “best leader” online as a function of the current group state (relative positions and velocities) and of the group topology (assumed connected). By cycling among several connected topologies during motion, we could show that our proposed leader selection algorithm provides the best performance among other possible choices (including the random one) while coping with the constraint of a connected (but possibly time-varying) topology.

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

7.5.2. Rigidity-based methods for formation control

Participants: Fabrizio Schiano, Riccardo Spica, Andrea Peruffo, Paolo Robuffo Giordano.

Most multi-robot applications must rely on *relative sensing* among the robot pairs (rather than absolute/external sensing such as, e.g., GPS). 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 the recent past, we have proposed a decentralized gradient-based rigidity maintenance action for a group of quadrotor UAVs [10]. By starting in a rigid configuration, the group of UAVs was 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. This (rigidity-based) control/estimation framework has now been extended to the case of *bearing rigidity* for directed graphs: here, rather than distances the measurements are the 3D bearing vectors expressed in the local body-frame of each agent. The theory has been extended to the case of 3D agents evolving in $\mathbb{R}^3 \times \mathbb{S}^1$ by proposing a decentralized bearing controller/localization algorithm that only requires one single distance measurement (among an arbitrary pair of agents) for a correct convergence [72]. The proposed algorithm ensures stabilization towards a desired bearing formation, and allows for the possibility of actuating the motion directions in the null-space of the bearing constraints (that is, collective translations in 3D, expansion/retraction, and coordinated rotation about a vertical axis).

The need of a single distance measurement (for fixing the formation scale) has also been relaxed in [73] where an *active* scale estimation scheme has been proposed for allowing the (distributed) estimation of the various inter-agent distances online by processing the measured bearings and the known agent ego-motion (body-frame linear and angular velocities). Finally, we have also proposed an extension of the "distance" rigidity maintenance controller proposed in [10] to the case of bearing measurements (and bearing rigidity), by considering the typical sensing constraints of onboard cameras, that is, limited range, limited field of view, of possible mutual occlusions when two or more agents lie on the same line-of-sight. This work has been experimentally validated with 5 quadrotor UAVs, and has been submitted to ICRA'2017.

These works were realized in collaboration with the RIS group at Laas, Toulouse, and with Technion, Israel.

7.5.3. Cooperative localization using interval analysis

Participants: Ide Flore Kenmogne Fokam, Vincent Drevelle.

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 bounded-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. Ongoing work focuses on position uncertainty domain computation in image-based UAV localization [63], and its extension to cooperative localization in a multi-UAV fleet.

7.5.4. Numerical Models of Local Interactions during Locomotion

Participants: Julien Bruneau, Panayiotis Charalambous, David Wolinski, Julien Pettré.

The numerical models of local interactions are core components of reactive navigation techniques (which allows a robot to avoid dynamic obstacles) and of microscopic crowd simulation algorithms (which allows to simulate a crowd motion as a collection of agent trajectories). We have pursued our efforts to design local models of interactions which capture humans pedestrian behavior, to simulate how they adapt their trajectory so as to perform interactions with their neighbors [12]. This year, our efforts were focused on the simulation of grouping behaviors [39], and mid-term strategies human set to perform energy-efficient sequences of successive avoidance adaptations [24]. These two situations deal with complex situations of interactions, where several interactions of different kinds need to be combined to compute agents trajectories. For example, when moving in groups, agents have to keep close to the other members of their group while they should not collide with them, as well as they should avoid collision with any other agent or obstacle out of this group.

We also revisited the foundation of velocity-based models of local interaction for collision avoidance. Using a velocity-based model, a collision-free motion is computed for one agent by extrapolating the future motion of neighbor agents with respect to their current position and velocity. From this information, each agent can deduce the set of velocities (called admissible velocities) that lead to a collision-free motion in the near future. The extrapolation is generally simply based on a linear extrapolation of the future position along the current velocity vector. This is simplistic as it assumes that the current velocity vector is representative of the future motion, while it is often false when, for instance, the agent is currently performing adaptations due to ongoing collision avoidance, or when the agent is following a curvy path. To improve the accuracy of motion prediction and the resulting simulation, we have introduced a probabilistic representation of future position, that can be computed from a set of context elements such as the layout of the environment or the agents past motion [42]. We demonstrate in this work the high impact on the level of realism of resulting simulations. This work is implemented in the WarpDriver software (see Section 6.7).

Finally, we address applications of our simulators to the Computer Animation. Crowd simulation agents generally have a simplistic geometrical and kinematics models, typically, an oriented 2D circle moving on a flat surface. In Computer Animation, an animation of a crowd of 3D realistic characters can be computed on top of the agents simulation by computing their internal joints trajectories so as to perform walking motion along computed agents trajectories. However, the discrepancies between the 2D model of agents and 3D full body characters may result into residual collisions between character shapes. In this collaboration with the Mimetic team, we demonstrate that simple secondary animations for characters, such as local shoulder motions, can be efficiently triggered to camouflage those artefacts, with a very low computational overhead [29].

7.5.5. *Motion Planning for Digital Characters*

Participant: Julien Pettré.

Motion planning is an important component for agents and robot navigation and control, providing them the ability to perform geometrical reasoning over their environment to transform a high-level distant goal in their environment into a sequence of local motions and sub-goals to reach. This year, we have been involved into two collaborations dealing with motion planning. First collaboration was with the University of Utrecht in the Netherlands. We have proposed a method to evaluate and compare various environment decomposition techniques [74]. Environment decomposition is an important step to perform navigation planning in large static environments. Second collaboration was with the University of North Carolina in Chapel Hill (see Section 9.4.1.1). We have coupled a contact planner for virtual characters with ITOMP, a motion optimization technique to achieve complex motion in cluttered environment [69].

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Grants with Industry

8.1.1. *Technicolor*

Participants: Salma Jiddi, Eric Marchand.

no Univ. Rennes 1 15CC310-02D, duration: 36 months.

This project funded by Technicolor started in October 2015. It supports Salma Jiddi's Ph.D. about augmented reality (see Section 7.1.7).

8.1.2. *Realyz*

Participant: Eric Marchand.

no Inria Rennes 10822, duration: 36 months.

This project funded by Realiz started in October 2015. It is realized in cooperation with Anatole Lecuyer, Hybrid group at Irisa and Inria Rennes-Bretagne Atlantique to support Guillaume Cortes Ph.D. about motion capture.

8.1.3. *Pôle Saint Hélier*

Participants: Louise Devigne, Marie Babel.

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

This project started in November 2015. It addresses 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.

8.1.4. Axyn

Participants: Dayana Hassan, Paolo Salaris, Patrick Rives.

no Inria Sophia 10874-1, duration: 36 months.

The objective of this project that started in November 2016 is to explore new methodologies for the interaction between humans and robots, autonomous navigation and mapping and to transfer the results obtained on the robotic platform developed by AXYN for assisting disabled/elderly people at home or in hospital structures. Cost limits, good accessibility to aged people, robustness and safety related to the applications are at the heart of the project. This contract (ANRT-CIFRE) support Dayana Hassan's Ph.D.

9. Partnerships and Cooperations

9.1. Regional Initiatives

9.1.1. 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 ended in October 2016. It supported in part Suman Raj Bista's Ph.D. about visual navigation (see Section 7.4.1).

9.1.2. 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 the shearlet transform (see Section 7.3.3).

9.1.3. 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).

9.1.4. ARED Mod4Nav

Participants: Aline Baudry, Marie Babel.

no INSA Rennes 2016/01, duration: 36 months.

This project funded by the Brittany council started in October 2016. It supports in part Aline Baudry's Ph.D. about wheelchair modeling.

9.1.5. "Equipement mi-lourd Rennes Métropole"

Participant: Paolo Robuffo Giordano.

no 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 6.9.5 has been purchased in part thanks to this grant.

9.1.6. IRT Jules Verne Mascot

Participant: François Chaumette.

no Inria Rennes 10361, duration: 36 months.

This project started in October 2015. It is managed by IRT Jules Verne in Nantes and realized in cooperation with IRCCyN, Airbus, Renault, Faurecia and Alsthom. Its goal is to perform screwing for various industrial applications.

9.1.7. IRT b<>com NeedleWare

Participants: Hadrien Gurnel, Alexandre Krupa.

no Inria Rennes 9072, duration: 36 months.

This project started in October 2016. It supports Hadrien Gurnel's Ph.D. about the study of a shared control strategy fusing haptic and ultrasound visual control for assisting manual steering of needles for biopsies or therapy purposes in a synergetic way.

9.2. National Initiatives

9.2.1. France Life Imaging WP3-FLI ANFEET

Participant: Alexandre Krupa.

duration: 24 months.

This project started in January 2016. Its objective is to initiate collaborative research with the ICube laboratory (Strasbourg) on the control and supervision of flexible endoscopes in the digestive tube using ultrasound images.

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 7.1.3).

9.2.3. ANR Contint Entracte

Participant: Julien Pettré.

no Inria Rennes 8013, duration: 42 months.

This project started in November 2013. It is realized in collaboration with the Gepetto group at Laas, Toulouse, and the Mimetic group at Irisa and Inria Rennes Bretagne Atlantique. It addresses the problem of motion planning for anthropomorphic systems, and more generally, the problem of manipulation path planning. ENTRACTE proposes to study in parallel both the mathematical foundation of artificial motion and the neurocognitive structures used by humans to quickly solve motion problems.

9.2.4. ANR JCJC Percolation

Participant: Julien Pettré.

no Inria Rennes 7991, duration: 42 months.

The ANR "Jeune Chercheur" Percolation project started on January 2014. It aims at designing perception-based crowd simulation algorithms. We develop agents which are capable of perceiving their virtual environment through virtual sensors, and which are able to navigate in it, as well as to interact with the other agents.

9.2.5. ANR JCJC SenseFly

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

no Irisa CNRS 50476, duration: 36 months.

The ANR "Jeune Chercheur" SenseFly project 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 6.9.5 has been purchased thanks to this grant.

9.2.6. ANR PLaTINUM

Participants: Eduardo Fernandez Moral, Vincent Drevelle, Patrick Rives.

no Inria Sophia 10204, 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. It aims at proposing novel solutions to robust long-term mapping of urban environments.

9.2.7. BPI Romeo 2

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

no Inria Rennes 7114, duration: 60 months.

This project started in November 2012. It is composed of a large consortium managed by Softbank Robotics (ex Aldebaran Robotics) with Laas in Toulouse, Isir in Paris, Lirmm in Montpellier, Inria groups Lagadic, Bipop (Pierre-Brice Wieber), Flowers (Pierre-Yves Oudeyer), and many other partners. It aims at developing advanced control and perception functionalities to a humanoid robot. In this project, we are in charge of visual manipulation and navigation with Romeo and Pepper. It supports in part Suman Raj Bista's Ph.D. about visual navigation (see Section 7.4.1), as well as Nicolas Cazy's Ph.D. about model-based predictive control for visual servoing (see Section 7.2.4).

9.2.8. Equipex Robotex

Participants: Fabien Spindler, François Chaumette.

no Inria Rennes 6388, duration: 9 years.

Lagadic is one of the 15 French academic partners involved in the Equipex Robotex network thats started in February 2011. It is devoted to get and manage significative equipment in the main robotics labs in France. In the scope of this project, we have got the humanoid robot Romeo (see Section 6.9.4).

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 2017

Coordinator: University of Surrey (United Kingdom)

Partners: Surrey Satellite Technology (United Kingdom), Airbus (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 (see Section 7.1.2).

9.3.1.2. H2020 Comanoid

Participants: Don Joven Agravante, Giovanni Claudio, Souriya Trinh, Fabien Spindler, François Chaumette.

Title: Multi-contact Collaborative Humanoids in Aircraft Manufacturing

Programm: H2020

Duration: January 2015 - December 2018

Coordinator: CNRS (Lirmm)

Partners: Airbus Group (France), DLR (Germany), Università Degli Studi di Roma La Sapienza (Italy), CNRS (I3S)

Inria contact: Francois 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. H2020 Romans

Participants: Nicolò Pedemonte, Firas Abi Farraj, Fabien Spindler, François Chaumette, Paolo Robuffo Giordano.

Title: Robotic Manipulation for Nuclear Sort and Segregation

Programm: H2020

Duration: May 2015 - April 2018

Coordinator: University of Birmingham

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

CNRS contact: Paolo Robuffo Giordano

The RoMaNS (Robotic Manipulation for Nuclear Sort and Segregation) project will advance the state of the art in mixed autonomy for tele-manipulation, to solve a challenging and safety-critical "sort and segregate" industrial problem, driven by urgent market and societal needs. Cleaning up the past half century of nuclear waste, in the UK alone (mostly at the Sellafield site), represents the largest environmental remediation project in the whole of Europe. Most EU countries face related challenges. Nuclear waste must be "sorted and segregated", so that low-level waste is placed in low-level storage containers, rather than occupying extremely expensive and resource intensive high-level storage containers and facilities. Many older nuclear sites (>60 years in UK) contain large numbers of legacy storage containers, some of which have contents of mixed contamination levels, and sometimes unknown contents. Several million of these legacy waste containers must now be cut open, investigated, and their contents sorted. This can only be done remotely using robots, because of the high levels of radioactive material. Current state-of-the-art practice in the industry, consists of simple tele-operation (e.g. by joystick or teach-pendant). Such an approach is not viable in the long-term, because it is prohibitively slow for processing the vast quantity of material required. The project will: 1) Develop novel hardware and software solutions for advanced bi-lateral master-slave tele-operation. 2) Develop advanced autonomy methods for highly adaptive automatic grasping and manipulation actions. 3) Combine autonomy and tele-operation methods using state-of-the-art understanding of mixed initiative planning, variable autonomy and shared control approaches. 4) Deliver a TRL 6 demonstration in an industrial plant-representative environment at the UK National Nuclear Lab Workington test facility.

9.3.2. Collaborations with European Partners

Participants: Fabien Spindler, Alexandre Krupa, François Chaumette.

Project acronym: i-Process

Project title: Innovative and Flexible Food Processing Technology in Norway

Duration: January 2016 - December 2019

Coordinator: Sintef (Norway)

Other partners: Nofima, Univ. of Stavanger, NMBU, NTNU (Norway), DTU (Denmark), KU Leuven (Belgium), and about 10 Norwegian companies.

Abstract: This project is granted by the Norwegian Government. Its main objective is to develop novel concepts and methods for flexible and sustainable food processing in Norway. In the scope of this project, the Lagadic group is involved for visual tracking and visual servoing of generic and potentially deformable objects. Prof. Pal Johan from the Norwegian University of Life Sciences (NMBU), and Ekrem Misimi from Sintef spent a short visit in June and October respectively.

9.4. International Initiatives

9.4.1. Inria Associate Teams

9.4.1.1. SIMS

Title: Realistic and Efficient Simulation of Complex Systems

International Partners:

University of North Carolina at Chapel Hill (USA) - GAMMA Group - Ming C. Lin, Dinesh Manocha

University of Minnesota (USA) - Motion Lab - Stephen Guy

Brown University (USA) - VenLab - William Warren

Start year: 2012

See http://people.rennes.inria.fr/Julien.Pettre/EASIMS/easims.html

The general goal of SIMS is to make significant progress toward realistic and efficient simulation of highly complex systems, which raise combinatory explosive problems. This proposal is focused on human motion and interaction, and covers 3 active topics with wide application range:

1. Crowd simulation: virtual human interacting with other virtual humans,
2. Autonomous virtual humans interacting with their environment,
3. Physical simulation: real humans interacting with virtual environments.

SIMS is orthogonally structured by transversal questions: the evaluation of the level of realism reached by a simulation (which is a problem by itself in the considered topics), considering complex systems at various scales (micro, meso and macroscopic ones), and facing combinatory explosion of simulation algorithms.

9.4.1.2. ISI4NAVE

Title: Innovative Sensors and adapted Interfaces for assistive NAVigation and pathology Evaluation

International Partner:

University College London (United Kingdom) - Aspire CREATe - Tom Carlson

Start year: 2016

See http://www.irisa.fr/lagadic/team/MarieBabel/ISI4NAVE/ISI4NAVE.html

The global ageing population, along with disability compensation constitute major challenging societal and economic issues. In particular, achieving autonomy remains a fundamental need that contributes to the individual's wellness and well-being. In this context, innovative and smart technologies are designed to achieve independence while matching user's individual needs and desires.

Hence, designing a robotic assistive solution related to wheelchair navigation remains of major importance as soon as it compensates partial incapacities. This project will then address the following two issues. First, the idea is to design an 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. Indeed, adapted interfaces should improve the understanding of people that suffer from cognitive and/or visual impairments.

The originality of the project is to continuously integrate medical validation as well as clinical trials during the scientific research work in order to match user needs and acceptation.

9.4.2. Inria International Partners

9.4.2.1. Informal International Partners

- Alexandre Krupa has a collaboration with Prof. Nassir Navab from the Technical University of Munich concerning the joint supervision of Pierre Chatelain's Ph.D. (see Section 7.3.2).

9.4.3. Participation in International Programs

The Lagadic group is one of the few external partners of the Australian Center for Robotic Vision (see http://roboticvision.org). It groups QUT in Brisbane, ANU in Canberra, Monash University and Adelaide University. In the scope of this project, Peter Corke and Ben Upcroft spent a short visit in May 2016 while Jurgen Leitner spent a 1-month visit in October 2016.

9.5. International Research Visitors

9.5.1. Visits of International Scientists

- Nicolas Alt, senior researcher at Technical University of Munich (TUM) was a visiting scientist at Sophia Antipolis from Jan until Feb 2016. He worked on visuo-haptic environment perception.
- Alejandro Perez Yus, Ph.D. student at Universidad de Zaragoza, spent a 3-month visit in Sophia Antipolis from Sep until Nov 2016. He worked on the calibration of multi-camera RGB-D systems.
- Prof. Denis Wolf, associate professor at Univ. Sao Paulo, Brasil, spends a sabbatical year in Sophia Antipolis from Jul 2016 to Aug 2017. He works on semantic learning applied to intelligent vehicles.
- Nicola Battilani, Ph.D. student at University of Modena and Reggio Emilia, spent a 6-month visit in Rennes from May until Oct 2016. He worked on shared control algorithms for optimal 3D reconstruction from vision.

- Prof. Volkan Isler from University of Minnesota, Phillip Schmidt, Ph.D. student from DLR, Prof. Ivan Petrovic from Univ. of Zagreb, Prof. Purang Abolmaesumi from Univ. of British Columbia, Prof. Nassir Navab from Technical University of Munich, and Prof. Russ Taylor from John Hopkins University spent a short visit in the group in 2016.

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific Events Organization

10.1.1.1. General Chair, Scientific Chair

- Marie Babel was the Scientific Chair of the workshop "Innovation Robotique et Santé : Assistance à la conduite de fauteuil roulant" organized in Inria Rennes on December 2016 (150 participants).

10.1.1.2. Member of the Organizing Committees

- François Chaumette was in charge of organizing a Tutorial on Vision for Robotics at ICRA'2016: http://www.icra2016.org/conference/tutorials. The plenary speakers were Peter Corke (QUT, Australia), Jana Kosecka (George Mason University, US), Eric Marchand [45] and François Chaumette [44]. Around 200 participants attended this tutorial.
- Patrick Rives was in charge of co-organizing the "Journée Transports Intelligents " on behalf of the RFIA'2016 conference in Clermont-Ferrand: http://rfia2016.iut-auvergne.com/index.php/rfp-ia
- Paolo Robuffo Giordano has co-organized the Invited Session "Rigidity Theory for Problems in Multi-Agent Coordination" at the 54^{th} IEEE Conf. on Decision and Control (CDC 2015), together by D. Zelazo (Technion, Israel) and A. Franchi (LAAS, France).

10.1.2. Scientific Events Selection

10.1.2.1. Chair of Conference Program Committees

- Paolo Robuffo Giordano: Workshop/Tutorial Session Chair for IROS 2016, Daejeon, Korea

10.1.2.2. Member of the Conference Program Committees

- François Chaumette: ICRA'2016
- Eric Marchand: ICRA 2016
- Patrick Rives: ICRA'2016, CVPR'2016
- Paolo Robuffo Giordano: ICRA'2016

10.1.2.3. Reviewer

- Marie Babel: IROS'2016 (2), ICIP'2016 (4)
- François Chaumette: IROS'2016 (1), ICRA'2017 (1)
- Vincent Drevelle: IFAC 2017 World Congress (1).
- Alexandre Krupa: IROS'2016 (1), ICRA'2017 (1)
- Eric Marchand: IROS 2016, ICRA 2017 (1), RFIA 2016 (2)
- Julien Pettré: SIGGRAPH 2016 (3), Collective Dynamics (1), CASA 2016 (3), IROS 2016 (3), ALIFE 2016 (2), ACM SCA 2016 (1), ACM CIE (1), TVCG (1), SIGGRAPH ASIA 2016 (1), Elsevier CAG (1), Pacific Graphics 2016 (1), Plos ONE (1), ACM MIG 2016 (2), IEEE VR 2017 (1), IEEE TBME (1), Taylor and Francis JMB (1), Eurographics 2017 (4), Elsevier TRB (1).
- Patrick Rives: ICRA'2016, ITSC'2016, CVPR'2016, ECCV'2016, IV'2016, ICINCO'2016, RFIA'2016, ICRA'2017

- Paolo Robuffo Giordano: ACC'2017 (1), DARS'2016 (2), ICRA'2017(2), IROS'2016 (3), RSS'2016 (1)

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, Editorial Board of the Springer Tracts in Advanced Robotics, Board Member of the Springer Encyclopedia of Robotics.
- Alexandre Krupa: Associate Editor of the IEEE Robotics and Automation Letters
- Eric Marchand: Associate Editor of the IEEE Robotics and Automation Letters
- Julien Pettré: Associate Editor for Computer Animation and Virtual Worlds, Associate Editor for Collective Dynamics
- Paolo Robuffo Giordano: Associate Editor of the IEEE Transactions on Robotics

10.1.3.2. Reviewer - Reviewing Activities

- Marie Babel: IEEE Trans. on Human-Machine Systems (1)
- François Chaumette: IEEE Trans. on Robotics (2), IEEE/ASME Trans. on Mechatronics (1), Robotics and Autonomous Systems (1), Journal of Intelligent and Robotic Systems (1), Control Engineering Practice (1)
- Vincent Drevelle: Transportation Research Part C (1)
- Eric Marchand : Int. Journal of robotics Research (1), Software, Practice and Experience (1), IEEE Trans. on Visualization and Computer Graphics (1), Visual Computer (1)
- Patrick Rives: IEEE Robotics and Automation Letters (1), Robotics and Autonomous Systems (1)
- Paolo Robuffo Giordano: IEEE Robotics and Automation letters (2), IEEE Trans. on Control of Network Systems (1), IEEE Trans. on Haptics (1)

10.1.4. Invited Talks

- François Chaumette: Plenary talk at RCAR'2016, Angkor Wat, Cambodia [43].
- Paolo Robuffo Giordano. Invited Talk: Collective Control, State Estimation and Human Interaction for Quadrotors in Unstructured Environments. 2016 GIS Micro-Drones Day, ENAC, Toulouse, France, October 2016
- Paolo Robuffo Giordano. Invited Seminar: Estimation and Control for Multi-Robot Systems. 2016 IEEE RAS Summer School on Multi-Robot Systems, Singapore, June 2016

10.1.5. Leadership within the Scientific Community

- François Chaumette is a 2016-2019 elected member of the Administrative Committee of the IEEE Robotics and Automation Society. He is also a member of the Scientific Council of the CNRS INS2I.
- François Chaumette and Patrick Rives are members of the scientific council of the "GdR Robotique".

10.1.6. Scientific Expertise

- François Chaumette is vice-president of the ANR Tremplin-ERC program (in charge of providing grants to recipients of non-funded A and B Starting and Consolidator ERC proposals). He was also a member of the "Institut Universitaire de France (IUF)" selection committee in charge of evaluating senior proposals, and served in the jury to select an Irstea senior researcher (DR2).
- Julien Pettré is project proposal reviewer for the Netherlands Organisation for Scientific Research.
- Paolo Robuffo Giordano is a reviewer for EU FP7 projects, for the ANR (French National Research Agency) ASTRID 2016 Program, for the "Comité ECOS Nord" of the "Ministère des affaires étrangères et du développement international" and the "Ministère de l'Enseignement supérieur et de la Recherche", and for the DGA as expert on algorithms and sensors for drones.

10.1.7. Research Administration

- 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.
- Alexandre Krupa and Julien Pettré are members of the CUMIR ("Commission des Utilisateurs des Moyens Informatiques pour la Recherche") 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 is also 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. He is in the board of the "Pôle Images et Réseaux" and in the board of "Ecole doctorale Matisse".
- Julien Pettré is an elected member of the "Comité de Centre" at Inria Rennes-Bretagne Atlantique.
- Patrick Rives is a member of the "Comité des projets" and "Comité de Centre" at Inria Sophia Antipolis-Méditerranée.

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

Marie Babel:

Master INSA2: "Robotics", 26 hours, M1, 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 ESIR2: "Real-time systems and RTOS", 24 hours, M1, Esir Rennes

Master GLA: "Terrain information systems", 14 hours, M2, Université de Rennes 1

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

Licence Info: "Computer systems architecture", 20 hours, L1, Université de Rennes 1

Licence Miage: "Computer programming", 78 hours, M1, Université de Rennes 1

Master CTS: "Instrumentation, localization, GPS", 4 hours, M2, Université de Rennes 1

Licence and Master ET: "Electronics project", 23 hours, L3 and 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

Julien Pettré:

Licence Info : “Programmation Informatique”, 40, LI1, Université de Rennes 1, Rennes

INSA1: “Programmation Informatique”, 40 hours, INSA Rennes

10.2.2. Supervision

- Ph.D.: Le Cui, “Robust micro/nano-positioning by visual servoing”, defended on January 2016, supervised by Eric Marchand [15]
- Ph.D.: Vishnu Karakkat Narayanan, “Semi-autonomous navigation of a wheelchair by visual servoing and user intention analysis”, defended in November 2016, supervised by Marie Babel and Anne Spalanzani (Chroma group at Inria Rhône-Alpes) [16]
- Ph.D.: Nicolas Cazy, “Commande prédictive pour la réalisation de tâches d’asservissement visuel successives”, defended in November 2016, supervised by Paolo Robuffo Giordano, François Chaumette and Pierre-Brice Wieber (Bipop group at Inria Rhône-Alpes) [13]
- Ph.D.: Julien Bruneau, “Studying and modeling complex interactions for crowd simulation”, defended in November 2016, supervised by Julien Pettré and Anne-Hélène Olivier (Mimetic group at Inria Rennes-Bretagne Atlantique and Irisa) [12]
- Ph.D.: Aly Magassouba, “Aural servo: towards an alternative approach to sound localization for robot motion control”, defended in December 2016, supervised by François Chaumette and Nancy Bertin (Panama group at Inria Rennes-Bretagne Atlantique and Irisa)
- Ph.D.: Lucas Royer, “Real-time tracking of deformable targets in 3D ultrasound sequences”, defended in December 2016, supervised by Alexandre Krupa, Maud Marchal (Hybrid group at Inria Rennes-Bretagne Atlantique and Irisa) and Guillaume Dardenne (IRT b<>com)
- Ph.D.: Pierre Chatelain, “Quality-driven control of a robotized ultrasound probe”, defended in December 2016, supervised by Alexandre Krupa and Nassir Navab (Technische Universität München) [14]
- Ph.D.: Suman Raj Bista, “Indoor Navigation of Mobile Robots based on Visual Memory and Image-Based Visual Servoing”, defended in December 2016, supervised by Paolo Robuffo Giordano and François Chaumette [11]
- 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: 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, “Enhancement of ultrasound elastography by visual servoing and force control”, 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, “Visual servoing using shearlet transform”, 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: Guillaume Cortes, “Motion Capture”, started in October 2015, supervised Eric Marchand and Anatole Lecuyer.
- 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)
- Ph.D. in progress: Quentin Delamare, “Algorithmes d’estimation et de commande pour des quadrirotors en interaction physique avec l’environnement”, started in September 2016, supervised by Paolo Robuffo Giordano
- Ph.D. in progress: Axel Lopes, “Data assimilation for synthetic vision-based crowd simulation algorithms”, started in October 2016, supervised by Julien Pettré and François Chaumette
- Ph.D. in progress: Aline Baudry, “Contribution à la modélisation des fauteuils roulants pour l’amélioration de leur navigation en mode semi-autonome”, started in October 2016, supervised by Marie Babel and Sylvain Guégan (Mechanical Engineering Dpt/LGCGM at Insa Rennes)
- Ph.D. in progress: Hadrien Gurnel, “Shared control of a biopsie needle from haptic and ultrasound visual feedback”, started in October 2016, supervised by Alexandre Krupa and Maud Marchal (Hybrid group at Inria Rennes-Bretagne Atlantique and Irisa)
- Ph.D. in progress: Dayana Hassan, “Plate-forme robotisée d’assistance aux personnes à mobilité réduite”, started in November 2016, supervised by Paolo Salaris, Patrick Rives and Frank Anjeaux (Axyn robotique)
- Internship: Valentin Bureau from May 2016 until Sep 2016 (2 months in mobility in University College of London within ISI4NAVE associated team), M1/Second year of Computer Science department, INSA Rennes, supervised by Marie Babel
- Internship: Timothée Collard “Adapting a localization application to ROS and MAV navigation” from Jun 2016 until Aug 2016, M1, Université de Rennes 1, supervised by Vincent Drevelle
- Internship: Benjamin Fasquelle from May 2016 until Aug 2016, M1, ENS Rennes, supervised by Eric Marchand
- Benoit Heintz from Mar 2016 until Jul 2016, L2 level, ENSIL Limoges, supervised by Fabien Spindler and Giovanni Claudio
- Internship: Manutea Huang from Jun 2016 until Sep 2016, L3/First year of Computer Science department, INSA Rennes, supervised by Marie Babel
- Internship: Daniel Huc from May 2016 until Sep 2016, M2, IM2AG Grenoble, supervised by Julien Pettré

- Internship: Valentin Limantour from Sep 2016 until December 2016, M1, ENIB Brest, supervised by Paolo Robuffo Giordano
- Internship: Etienne Moisdon from May 2016 until Jun 2016, M, Univ. Rennes 1, supervised by Julien Pettré

10.2.3. External Ph.D. and HdR Juries

- François Chaumette: Julien Bruneau (Ph.D., president, Inria Rennes), Andrea Cherubini (HdR, president, Lirmm, Montpellier)
- Alexandre Krupa: Laure-Anais Chanel (Ph.D., reviewer, ICube, Strasbourg), Mouloud Ourak (Ph.D., reviewer, FEMTO-ST, Besançon), Paul Mignon (Ph.D., reviewer, TIMC-IMAG, Grenoble)
- Eric Marchand: Vishnu Karakkat Narayanan (Ph.D., president, Inria Rennes), Suman Raj Bista (Ph.D., president, Inria Rennes), Limming Yang (Ph.D., reviewer, EC Nantes), Tu-Hoa Pham (Ph.D., reviewer, Lirmm, Montpellier).
- Julien Pettré: Christian Vassallo (Ph.D., Laas, Toulouse), Fabien Cissé (Ph.D., UPMC, Paris), Thomas Pitiot (PH.D., ICube, Strasbourg)
- Patrick Rives: Zui Tao (Ph.D., president, UTC, Compiègne), Bruno Ricaud (Ph.D., reviewer, Ecole des Mines, Paris), Victor Gibert (Ph.D., member, IRCCyN, Nantes), Yue Kang (Ph.D., reviewer, UTC, Compiègne), Abdelhamid Dine (Ph.D., president, ENS-Cachan, Paris-Saclay), Pierre Merriaux (Ph.D., reviewer, Esigelec, Rouen), Fabrice Mayran de Chamiso (Ph.D., member, CEA-LIST, Paris-Saclay), Bruno Vallet (HdR, member, IGN, Paris).
- Paolo Robuffo Giordano: Osamah Saif (Ph.D., UTC, Compiègne, France), Marco Aggravi (Ph.D., University of Siena, Italy), Leonardo Meli (Ph.D., University of Siena, Italy).

10.3. Popularization

- Due to the visibility of our experimental platforms, the team is often requested 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, grasping and dual arm manipulation by Romeo, vision-based shared control using our haptic device for object manipulation, the control of a fleet of quadrotors, vision-based detection and tracking for space navigation in a rendezvous context, the semi-autonomous navigation of a wheelchair, and augmented reality applications. Some of these demonstrations are available as videos on VispTeam YouTube channel (https://www.youtube.com/user/VispTeam/videos). This year there were among others, demonstrations organized for the HCERES expert committee that evaluated IRISA, about twenty people affiliated to the CNRS electronics network, students of the “Innovation et entreprenariat” Master, those of the L3 R&I at ENS Rennes, about twenty students from the “Ecole des Mines de Nancy”, several classes of high school students around Rennes, without forgetting the members of the Ph.D. thesis juries.
- Fabien Spindler and Giovanni Claudio were interviewed by TV Rennes about Pepper robot (https://www.facebook.com/166100743494694/videos/vb.166100743494694/959489554155805/?type=2&theater).
- Marie Babel participated to “15^{e} Journée nationale des pôles de compétitivité” in March 2016 (Paris): HandiViz project was selected by the French Ministry of Finance
- Marie Babel participated to the Science Festival in October 2016 with an interview at “Village des Sciences” and a workshop for general public organized in Acigné near Rennes.
- Marie Babel participated to the “Convention Nationale des SATT” (October 2016, Paris).
- Marie Babel gave a talk on "HandiViz: a new driving experience" in October 2016, during the “Semaine des Technologies - Robotique et santé” organized at Insa Rennes.

- Vincent Drevelle participated to the “Journée science et musique” in Rennes, with an interactive demonstration of sound-based tracking of a micro aerial vehicle with a beam projector (in cooperation with the Panama team).
- An article related to the research activity of Alexandre Krupa on robotic needle steering entitled “Un robot qui apprend à viser” has been published in March 2016 in the general-audience magazine “Sciences Ouest”: http://www.espace-sciences.org/sciences-ouest/340/dossier/un-robot-qui-apprend-a-viser.
- Paolo Robuffo Giordano has given press releases on the activities involving formation control for multiple quadrotor UAVs to Émergences Inria, Sciences Ouest, and “Industrie & Technologies”.

11. Bibliography

Major publications by the team in recent years

[1] F. CHAUMETTE, S. HUTCHINSON. *Visual servoing and visual tracking*, in "Handbook of Robotics", B. SICILIANO, O. KHATIB (editors), Springer, 2008, chap. 24, pp. 563-583, http://hal.inria.fr/hal-00920414/en

[2] A. COMPORT, E. MARCHAND, M. PRESSIGOUT, F. CHAUMETTE. *Real-time markerless tracking for augmented reality: the virtual visual servoing framework*, in "IEEE Trans. on Visualization and Computer Graphics", July 2006, vol. 12, n^{o} 4, pp. 615–628, https://hal.inria.fr/inria-00161250

[3] A. DAME, E. MARCHAND. *Second order optimization of mutual information for real-time image registration*, in "IEEE Trans. on Image Processing", 2012, vol. 21, n^{o} 9, pp. 4190-4203, http://hal.inria.fr/hal-00750528/en

[4] A. DIOSI, S. SEGVIC, A. REMAZEILLES, F. CHAUMETTE. *Experimental Evaluation of Autonomous Driving Based on Visual Memory and Image Based Visual Servoing*, in "IEEE Trans. on Intelligent Transportation Systems", September 2011, vol. 12, n^{o} 3, pp. 870–883, http://hal.inria.fr/hal-00639680/en

[5] E. MARCHAND, F. SPINDLER, F. CHAUMETTE. *ViSP for visual servoing: a generic software platform with a wide class of robot control skills*, in "IEEE Robotics and Automation Magazine", December 2005, vol. 12, n^{o} 4, pp. 40-52, https://hal.inria.fr/inria-00351899

[6] R. MEBARKI, A. KRUPA, F. CHAUMETTE. *2D ultrasound probe complete guidance by visual servoing using image moments*, in "IEEE Trans. on Robotics", April 2010, vol. 26, n^{o} 2, pp. 296-306, https://hal.inria.fr/inria-00544791

[7] M. MEILLAND, A. COMPORT, P. RIVES. *Dense omnidirectional RGB-D mapping of large scale outdoor environments for real-time localisation and autonomous navigation*, in "Journal of Field Robotics, Special Issue on Ground Robots Operating in dynamic, unstructured and large-scale outdoor environments", June 2015, vol. 32, n^{o} 4, pp. 474-503, http://hal.inria.fr/hal-01010429

[8] C. NADEAU, A. KRUPA. *Intensity-based ultrasound visual servoing: modeling and validation with 2D and 3D probes*, in "IEEE. Trans. on Robotics", August 2013, vol. 29, n^{o} 4, pp. 1003-1015 [*DOI :* 10.1109/TRO.2013.2256690], http://hal.inria.fr/hal-00854100

[9] R. SPICA, P. ROBUFFO GIORDANO, F. CHAUMETTE. *Active Structure from Motion: Application to Point, Sphere and Cylinde*, in "IEEE Trans. on Robotics", December 2015, vol. 30, n^{o} 6, pp. 1499-1513, http://hal.inria.fr/hal-01010429

[10] D. ZELAZO, A. FRANCHI, H. H. BÜLTHOFF, P. ROBUFFO GIORDANO. *Decentralized rigidity maintenance control with range measurements for multi-robot systems*, in "The Int. Journal of Robotics Research", January 2015, vol. 34, n^{o} 1, pp. 105-128, http://hal.inria.fr/hal-01076423

Publications of the year

Doctoral Dissertations and Habilitation Theses

[11] S. R. BISTA. *Indoor Navigation of Mobile Robots based on Visual Memory and Image-Based Visual Servoing*, Universite de Rennes 1 ; Inria Rennes Bretagne Atlantique, December 2016, https://tel.archives-ouvertes.fr/tel-01426763

[12] J. BRUNEAU. *Studying and modeling complex interactions for crowd simulation*, Université de Rennes 1 [UR1], November 2016, https://hal.inria.fr/tel-01425268

[13] N. CAZY. *Predictive control for the achievement of successive visual servoing tasks*, Université Rennes 1, November 2016, https://tel.archives-ouvertes.fr/tel-01421363

[14] P. CHATELAIN. *Quality-Driven Control of a Robotized Ultrasound Probe*, Université de Rennes 1 ; Technische Universität München, December 2016, https://tel.archives-ouvertes.fr/tel-01426511

[15] L. CUI. *Robust micro/nano-positioning by visual servoing*, Université Rennes 1, January 2016, https://tel.archives-ouvertes.fr/tel-01267585

[16] V. KARAKKAT NARAYANAN. *Characterizing assistive shared control through vision-based and human-aware designs for wheelchair mobility assistance* , Inria Rennes - Bretagne Atlantique ; INSA Rennes, November 2016, https://tel.archives-ouvertes.fr/tel-01426748

[17] A. MAGASSOUBA. *Aural servo: towards an alternative approach to sound localization for robot motion control*, Université Rennes 1, December 2016, https://tel.archives-ouvertes.fr/tel-01426710

[18] P. ROBUFFO GIORDANO. *Contributions to shared control and coordination of single and multiple robots*, Université de Rennes 1, January 2016, Habilitation à diriger des recherches, https://tel.archives-ouvertes.fr/tel-01301644

[19] L. ROYER. *Real-time Tracking of Deformable Targets in 3D Ultrasound Sequences*, INSA de Rennes, December 2016, https://tel.archives-ouvertes.fr/tel-01426711

Articles in International Peer-Reviewed Journals

[20] D. J. AGRAVANTE, G. CLAUDIO, F. SPINDLER, F. CHAUMETTE. *Visual servoing in an optimization framework for the whole-body control of humanoid robots*, in "IEEE Robotics and Automation Letters", 2017, https://hal.inria.fr/hal-01421734

[21] Q. BATEUX, É. MARCHAND. *Histograms-based Visual Servoing*, in "IEEE Robotics and Automation Letters", January 2017, vol. 2, n^{o} 1, pp. 80-87, https://hal.inria.fr/hal-01265560

[22] S. BRIOT, F. CHAUMETTE, P. MARTINET. *Revisiting the determination of the singularity cases in the visual servoing of image points through the concept of hidden robot*, in "IEEE Transactions on Robotics", January 2017, vol. 33, n^o 2, https://hal.archives-ouvertes.fr/hal-01399774

[23] S. BRIOT, P. MARTINET, F. CHAUMETTE. *Determining the Singularities for the Observation of Three Image Lines*, in "IEEE Robotics and Automation Letters", April 2017, vol. 2, n^o 2, pp. 412-419, https://hal.archives-ouvertes.fr/hal-01398925

[24] J. BRUNEAU, J. PETTRÉ. *EACS: Effective Avoidance Combination Strategy*, in "Computer Graphics Forum", September 2016 [*DOI :* 10.1111/CGF.13066], https://hal.inria.fr/hal-01392248

[25] V. DREVELLE, P. BONNIFAIT. *Interval-based fast fault detection and identification applied to radio-navigation multipath*, in "International Journal of Adaptive Control and Signal Processing", January 2016, vol. 30, pp. 154–172 [*DOI :* 10.1002/ACS.2535], https://hal.inria.fr/hal-01258946

[26] E. FERNÁNDEZ-MORAL, P. RIVES, V. ARÉVALO, J. GONZÁLEZ-JIMÉNEZ. *Scene structure registration for localization and mapping*, in "Robotics and Autonomous Systems", January 2016, vol. 75, n^o B, pp. 649-660 [*DOI :* 10.1016/J.ROBOT.2015.09.009], https://hal.inria.fr/hal-01237845

[27] J. FORSHAW, G. AGLIETTI, N. NAVARATHINAM, H. KADHEM, T. SALMON, A. PISSELOUP, E. JOFFRE, T. CHABOT, I. RETAT, R. AXTHELM, S. BARRACLOUGH, A. RATCLIFFE, C. BERNAL, F. CHAUMETTE, A. POLLINI, W. STEYN. *REMOVEDEBRIS: An In-Orbit Active Debris Removal Demonstration Mission*, in "Acta Astronautica", October 2016, vol. 127, pp. 448-463 [*DOI :* 10.1016/J.ACTAASTRO.2016.06.018], https://hal.inria.fr/hal-01342268

[28] A. FRANCHI, P. ROBUFFO GIORDANO. *Online Leader Selection for Improved Collective Tracking and Formation Maintenance*, in "IEEE Transactions on Control of Network Systems", 2016 [*DOI :* 10.1109/TCNS.2016.2567222], https://hal.archives-ouvertes.fr/hal-01315463

[29] L. HOYET, A.-H. OLIVIER, R. KULPA, J. PETTRÉ. *Perceptual Effect of Shoulder Motions on Crowd Animations*, in "ACM Transactions on Graphics", July 2016 [*DOI :* 10.1145/2897824.2925931], https://hal.inria.fr/hal-01357713

[30] V. KARAKKAT NARAYANAN, F. PASTEAU, M. MARCHAL, A. KRUPA, M. BABEL. *Vision-based adaptive assistance and haptic guidance for safe wheelchair corridor following*, in "Computer Vision and Image Understanding", August 2016, vol. 179, pp. 171-185, https://hal.inria.fr/hal-01277585

[31] A. KRUPA, D. FOLIO, C. NOVALES, P. VIEYRES, T. LI. *Robotized Tele-Echography: an Assisting Visibility Tool to Support Expert Diagnostic*, in "IEEE Systems Journal", September 2016, vol. 10, n^o 3, pp. 974-983 [*DOI :* 10.1109/JSYST.2014.2314773], https://hal.archives-ouvertes.fr/hal-00986875

[32] J. LIMA, F. SIMÕES, H. UCHIYAMA, V. TEICHRIEB, E. MARCHAND. *Depth-Assisted Rectification for Real-Time Object Detection and Pose Estimation*, in "Machine Vision and Applications", February 2016, vol. 27, n^o 2, pp. 193-219, https://hal.inria.fr/hal-01233046

[33] É. MARCHAND, H. UCHIYAMA, F. SPINDLER. *Pose Estimation for Augmented Reality: A Hands-On Survey*, in "IEEE Transactions on Visualization and Computer Graphics", December 2016, vol. 22, n^o 12, pp. 2633 - 2651 [*DOI :* 10.1109/TVCG.2015.2513408], https://hal.inria.fr/hal-01246370

[34] C. NADEAU, A. KRUPA, J. PETR, C. BARILLOT. *Moments-Based Ultrasound Visual Servoing: From Mono to Multi-plane Approach*, in "IEEE Transactions on Robotics", 2017 [*DOI :* 10.1109/TRO.2016.2604482], https://hal.inria.fr/hal-01385661

[35] T. NESTMEYER, P. ROBUFFO GIORDANO, H. H. BÜLTHOFF, A. FRANCHI. *Decentralized Simultaneous Multi-target Exploration using a Connected Network of Multiple Robots*, in "Autonomous Robots", 2016 [*DOI :* 10.1007/S10514-016-9578-9], https://hal.inria.fr/hal-01332937

[36] P. PAPADAKIS, P. RIVES. *Binding human spatial interactions with mapping for enhanced mobility in dynamic environments*, in "Autonomous Robots", 2016 [*DOI :* 10.1007/S10514-016-9581-1], https://hal.inria.fr/hal-01342255

[37] F. PASTEAU, V. KARAKKAT NARAYANAN, M. BABEL, F. CHAUMETTE. *A visual servoing approach for autonomous corridor following and doorway passing in a wheelchair*, in "Robotics and Autonomous Systems", January 2016, vol. 75, part A, pp. 28-40 [*DOI :* 10.1016/J.ROBOT.2014.10.017], https://hal.inria.fr/hal-01068163

[38] S. RAJ BISTA, P. ROBUFFO GIORDANO, F. CHAUMETTE. *Appearance-based Indoor Navigation by IBVS using Line Segments*, in "IEEE Robotics and Automation Letters", January 2016, vol. 1, n° 1, pp. 423-430, Also presented in IEEE Int. Conf. on Robotics and Automation, Stockolm, Sweden, https://hal.inria.fr/hal-01259750

[39] Z. REN, P. CHARALAMBOUS, J. BRUNEAU, Q. PENG, J. PETTRÉ. *Group Modeling: A Unified Velocity-Based Approach*, in "Computer Graphics Forum", 2016 [*DOI :* 10.1111/CGF.12993], https://hal.inria.fr/hal-01372766

[40] L. ROYER, A. KRUPA, G. DARDENNE, A. LE BRAS, É. MARCHAND, M. MARCHAL. *Real-time Target Tracking of Soft Tissues in 3D Ultrasound Images Based on Robust Visual Information and Mechanical Simulation*, in "Medical Image Analysis", January 2017, vol. 35, pp. 582 - 598 [*DOI :* 10.1016/J.MEDIA.2016.09.004], https://hal.inria.fr/hal-01374589

[41] C. VASSALLO, A.-H. OLIVIER, P. SOUÈRES, A. CRÉTUAL, O. STASSE, J. PETTRÉ. *How do walkers avoid a mobile robot crossing their way?*, in "Gait and Posture", January 2017, vol. 51, pp. 97-103, https://hal.archives-ouvertes.fr/hal-01371202

[42] D. WOLINSKI, M. C. LIN, J. PETTRÉ. *WarpDriver: Context-Aware Probabilistic Motion Prediction for Crowd Simulation*, in "ACM Transactions on Graphics", November 2016, vol. 35, n° 6 [*DOI :* 10.1145/2980179.2982442], https://hal.inria.fr/hal-01411087

Invited Conferences

[43] F. CHAUMETTE. *Visual servoing with and without image processing*, in "Plenary talk, IEEE International Conference on Real-time Computing and Robotics, RCAR'2016", Angkor Wat, Cambodia, June 2016, https://hal.inria.fr/hal-01385400

[44] F. CHAUMETTE. *Visual servoing*, in "Tutorial on Vision for Robotics, IEEE Int. Conf. on Robotics and Automation", Stockholm, Sweden, May 2016, https://hal.inria.fr/hal-01385401

[45] E. MARCHAND. *Visual tracking*, in "Tutorial on Vision for Robotics, IEEE Int. Conf. on Robotics and Automation", Stockholm, Sweden, May 2016, https://hal.inria.fr/hal-01385405

International Conferences with Proceedings

[46] F. ABI-FARRAJ, N. PEDEMONTE, P. ROBUFFO GIORDANO. *A Visual-Based Shared Control Architecture for Remote Telemanipulation*, in "IEEE/RSJ Int. Conf. on Intelligent Robots and Systems, IROS'16", Daejeon, South Korea, October 2016, pp. 4266-4273, https://hal.inria.fr/hal-01355785

[47] G. ANDRADE, F. NOUVIALE, J. ARDOUIN, É. MARCHAND, M. MARCHAL, A. LÉCUYER. *Enjoy 360° Vision with the FlyVIZ*, in "SIGGRAPH 2016 Emerging Technologies", Anaheim, United States, July 2016 [*DOI :* 10.1145/2929464.2929471], https://hal.inria.fr/hal-01387573

[48] Q. BATEUX, E. MARCHAND. *Particle Filter-based Direct Visual Servoing*, in "IEEE/RSJ Int. Conf. on Intelligent Robots and Systems, IROS'16", Daejeon, South Korea, October 2016, pp. 4180-4186, https://hal.inria.fr/hal-01355396

[49] S. BRIOT, P. MARTINET, F. CHAUMETTE. *Singularity Cases in the Visual Servoing of Three Image Lines*, in "2017 IEEE International Conference on Robotics and Automation (ICRA 2017)", Singapour, Singapore, Proceedings of 2017 IEEE International Conference on Robotics and Automation (ICRA 2017), May 2017, https://hal.archives-ouvertes.fr/hal-01435811

[50] P. CHATELAIN, A. KRUPA, N. NAVAB. *Confidence-Driven Control of an Ultrasound Probe: Target-Specific Acoustic Window Optimization*, in "IEEE Int. Conf. on Robotics and Automation, ICRA'16", Stockholm, Sweden, May 2016, https://hal.inria.fr/hal-01274748

[51] J. CHEVRIE, A. KRUPA, M. BABEL. *Needle Steering Fusing Direct Base Manipulation and Tip-based Control*, in "IEEE Int. Conf. on Robotics and Automation, ICRA'16", Stockholm, Sweden, May 2016, https://hal.inria.fr/hal-01304860

[52] J. CHEVRIE, A. KRUPA, M. BABEL. *Online prediction of needle shape deformation in moving soft tissues from visual feedback*, in "IEEE/RSJ Int. Conf. on Intelligent Robots and Systems, IROS'16", Daejeon, South Korea, October 2016, pp. 2357-2362, https://hal.inria.fr/hal-01355484

[53] G. CLAUDIO, F. SPINDLER, F. CHAUMETTE. *Vision-based manipulation with the humanoid robot Romeo*, in "IEEE-RAS International Conference on Humanoid Robotics, Humanoids 2016", Cancun, Mexico, November 2016, https://hal.inria.fr/hal-01385408

[54] L. CUI, E. MARCHAND, S. HALIYO, S. RÉGNIER. *Three-Dimensional Visual Tracking and Pose Estimation in Scanning Electron Microscopes*, in "IEEE/RSJ Int. Conf. on Intelligent Robots and Systems, IROS'16", Daejeon, South Korea, October 2016, pp. 5210-5215, https://hal.inria.fr/hal-01355393

[55] L. DEVIGNE, V. KARAKKAT NARAYANAN, F. PASTEAU, M. BABEL. *Low complex sensor-based shared control for power wheelchair navigation*, in "IROS2016 - IEEE/RSJ International Conference on Intelligent Robots and Systems", Daejeon, South Korea, October 2016, pp. 5434-5439, https://hal.inria.fr/hal-01355410

[56] V. DREVELLE. *Convergence domain of image-based visual servoing with a line-scan camera*, in "Summer Workshop on Interval Methods, SWIM 2016", Lyon, France, June 2016, https://hal.inria.fr/hal-01415435

[57] L.-A. DUFLOT, A. KRUPA, B. TAMADAZTE, N. ANDREFF. *Shearlet Transform: a Good Candidate for Compressed Sensing in Optical Coherence Tomography*, in "IEEE Int. Conf. on Engineering in Medicine and Biology Society, EMBC'16", Orlando, United States, August 2016, pp. 435-438, https://hal.inria.fr/hal-01355488

[58] L.-A. DUFLOT, A. KRUPA, B. TAMADAZTE, N. ANDREFF. *Shearlet-based vs. Photometric-based Visual Servoing for Robot-assisted Medical Applications*, in "IEEE/RSJ Int. Conf. on Intelligent Robots and Systems, IROS'16", Daejeon, South Korea, October 2016, pp. 4099-4104, https://hal.inria.fr/hal-01355414

[59] L.-A. DUFLOT, A. KRUPA, B. TAMADAZTE, N. ANDREFF. *Toward Ultrasound-based Visual Servoing using Shearlet Coefficients*, in "IEEE Int. Conf. on Robotics and Automation, ICRA'16", Stockholm, Sweden, May 2016, https://hal.inria.fr/hal-01304753

[60] S. JIDDI, P. ROBERT, E. MARCHAND. *Reflectance and Illumination Estimation for Realistic Augmentations of Real Scenes*, in "IEEE Int. Symp. on Mixed and Augmented Reality, ISMAR'16 (poster session)", Merida, Mexico, September 2016, Poster, https://hal.inria.fr/hal-01355581

[61] V. KARAKKAT NARAYANAN, A. SPALANZANI, M. BABEL. *A semi-autonomous framework for human-aware and user intention driven wheelchair mobility assistance*, in "IEEE/RSJ Int. Conf. on Intelligent Robots and Systems, IROS'16", Daejeon, South Korea, October 2016, pp. 4700-4707, https://hal.inria.fr/hal-01355481

[62] V. KARAKKAT NARAYANAN, A. SPALANZANI, R. C. LUO, M. BABEL. *Analysis of an adaptive strategy for equitably approaching and joining human interactions*, in "IEEE Int. Symp. on Robot and Human Interactive Communication, RO-MAN", New-York, United States, IEEE Int. Symp. on Robot and Human Interactive Communication, RO-MAN, August 2016, https://hal.inria.fr/hal-01330889

[63] I.-F. KENMOGNE, V. DREVELLE. *Image-based Mobile Robot localization using Interval Methods*, in "Summer Workshop on Interval Methods, SWIM 2016", Lyon, France, June 2016, https://hal.inria.fr/hal-01415432

[64] A. MAGASSOUBA, N. BERTIN, F. CHAUMETTE. *Audio-based robot controlfrom interchannel level difference and absolute sound energy*, in "IEEE/RSJ Int. Conf. on Intelligent Robots and Systems, IROS'16", Daejeon, South Korea, October 2016, pp. 1992-1999, https://hal.inria.fr/hal-01355394

[65] A. MAGASSOUBA, N. BERTIN, F. CHAUMETTE. *Binaural auditory interaction without HRTF for humanoid robots: A sensor-based control approach*, in "Workshop on Multimodal Sensor-based Control for HRI and soft manipulation, IROS'2016", Daejeon, South Korea, October 2016, https://hal.inria.fr/hal-01408422

[66] A. MAGASSOUBA, N. BERTIN, F. CHAUMETTE. *First applications of sound-based control on a mobile robot equipped with two microphones*, in "IEEE Int. Conf. on Robotics and Automation, ICRA'16", Stockholm, Sweden, May 2016, https://hal.inria.fr/hal-01277589

[67] R. MARTINS, E. FERNANDEZ-MORAL, P. RIVES. *Adaptive Direct RGB-D Registration and Mapping for Large Motions*, in "Asian Conference on Computer Vision, ACCV 2016", Taipei, Taiwan, November 2016, https://hal.inria.fr/hal-01403953

[68] R. MARTINS, P. RIVES. *Increasing the Convergence Domain of RGB-D Direct Registration Methods for Vision-based Localization in Large Scale Environments*, in "Workshop on Planning, Perception and Navigation

for Intelligent Vehicles – IEEE Intelligent Transportation Systems Conference, ITSC PPNIV", Rio de Janeiro, Brazil, November 2016, https://hal.inria.fr/hal-01403961

[69] C. PARK, J. S. PARK, S. TONNEAU, N. MANSARD, F. MULTON, J. PETTRÉ, D. MANOCHA. *Dynamically balanced and plausible trajectory planning for human-like characters*, in "20th ACM SIGGRAPH Symposium on Interactive 3D Graphics and Games", Redmond, United States, ACM, February 2016, pp. 39-48 [*DOI :* 10.1145/2856400.2856405], https://hal.inria.fr/hal-01290368

[70] P. PATLAN-ROSALES, A. KRUPA. *Automatic palpation for quantitative ultrasound elastography by visual servoing and force control*, in "IEEE/RSJ Int. Conf. on Intelligent Robots and Systems, IROS'16", Daejeon, South Korea, October 2016, pp. 2357-2362, https://hal.inria.fr/hal-01355406

[71] S. RAJ BISTA, P. ROBUFFO GIORDANO, F. CHAUMETTE. *Appearance-based Indoor Navigation by IBVS using Mutual Information*, in "IEEE Int. Conf. on Control, Automation, Robotics and Vision, ICARCV 2016", Phuket, Thailand, November 2016, https://hal.inria.fr/hal-01355382

[72] F. SCHIANO, A. FRANCHI, D. ZELAZO, P. ROBUFFO GIORDANO. *A Rigidity-Based Decentralized Bearing Formation Controller for Groups of Quadrotor UAVs*, in "IEEE/RSJ International Conference on Intelligent Robots and Systems, IROS 2016", Daejeon, South Korea, October 2016, pp. 5099-5106, https://hal.archives-ouvertes.fr/hal-01348543

[73] R. SPICA, P. ROBUFFO GIORDANO. *Active Decentralized Scale Estimation for Bearing-Based Localization*, in "IEEE/RSJ Int. Conf. on Intelligent Robots and Systems, IROS'16", Daejeon, South Korea, October 2016, https://hal.inria.fr/hal-01355789

[74] W. VAN TOLL, R. TRIESSCHEIJN, M. KALLMANN, R. OLIVA, N. PELECHANO, J. PETTRÉ, R. GERAERTS. *A comparative study of navigation meshes*, in "MIG '16 - 9th International Conference on Motion in Games", San Francisco, United States, ACM, October 2016, pp. 91 - 100 [*DOI :* 10.1145/2994258.2994262], https://hal.inria.fr/hal-01392267

[75] A. YOL, E. MARCHAND, F. CHAUMETTE, K. KANANI, T. CHABOT. *Vision-based navigation in low earth orbit*, in "Int. Symp. on Artificial Intelligence, Robotics and Automation in Space, i-SAIRAS'16", Beijing, China, June 2016, https://hal.inria.fr/hal-01304728

Conferences without Proceedings

[76] S. BRIOT, F. CHAUMETTE, P. MARTINET. *Revisiting the determination of the singularity cases in the visual servoing of image points through the concept of "hidden robot"*, in "2017 IEEE International Conference on Robotics and Automation (ICRA 2017)", Singapour, Singapore, May 2017, https://hal.archives-ouvertes.fr/hal-01435810

Scientific Books (or Scientific Book chapters)

[77] F. CHAUMETTE, S. HUTCHINSON, P. CORKE. *Visual Servoing*, in "Handbook of Robotics, 2nd edition", B. SICILIANO, O. KHATIB (editors), Springer, 2016, pp. 841-866, https://hal.inria.fr/hal-01355384

[78] M. OURAK, B. TAMADAZTE, N. ANDREFF, É. MARCHAND. *Multimodal Image Registration and Visual Servoing*, in "Lecture Notes in Electrical Engineering", Springer, July 2016, vol. 383, pp. 157 - 175 [*DOI :* 10.1007/978-3-319-31898-1_9], https://hal.inria.fr/hal-01433996

Research Reports

[79] S. BRIOT, P. MARTINET, F. CHAUMETTE. *Technical Report associated with the Paper: "Determining the Singularities for the Observation of Three Image Lines"*, IRCCyN ; IRISA, November 2016, https://hal.archives-ouvertes.fr/hal-01400575

Other Publications

[80] D. J. AGRAVANTE, F. CHAUMETTE. *Combining visual servoing and walking in an acceleration resolved whole-body control framework*, June 2016, Journées Nationales de la Recherche Humanoïde, Toulouse, France, https://hal.inria.fr/hal-01358639

[81] G. CLAUDIO, D. J. AGRAVANTE, F. SPINDLER, F. CHAUMETTE. *Dual arm manipulation and whole body control with the humanoid robot Romeo by visual servoing*, June 2016, Journées Nationales de la Recherche Humanoïde, Toulouse, France, https://hal.inria.fr/hal-01358124