IN PARTNERSHIP WITH:
CNRS

Institut national des sciences appliquées de Rennes

Université Rennes 1

Activity Report 2017

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, end of the Project-Team: 2017 December 31

Keywords:

Computer Science and Digital Science:

A5.4. - Computer vision
A5.4.4. - 3D and spatio-temporal reconstruction
A5.4.5. - Object tracking and motion analysis
A5.4.6. - Object localization
A5.4.7. - Visual servoing
A5.6. - Virtual reality, augmented reality
A5.10. - Robotics
A5.10.2. - Perception
A5.10.4. - Robot control
A5.10.5. - Robot interaction (with the environment, humans, other robots)
A5.10.6. - Swarm robotics

Other Research Topics and Application Domains:

B2.4.3. - Surgery
B2.5. - Handicap and personal assistances
B5.1. - Factory of the future
B5.6. - Robotic systems
B7.2.1. - Smart vehicles
B8.4. - Security and personal assistance

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2. Overall Objectives

2.1. Overall Objectives

Historically, research activities of the Lagadic team are concerned with visual servoing, visual tracking, and active vision. Visual servoing consists in using the information provided by a vision sensor to control the movements of a dynamic system. This research topic is at the intersection of the fields of robotics, automatic control, and computer vision. These fields are the subject of profitable research since many years and are particularly interesting by their very broad scientific and application spectrum. Within this spectrum, we focus on the interaction between visual perception and action. This topic is important 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 traditionally 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 (DoF) 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 DoF. 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:

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

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:

$$\dot{\mathbf{s}} = \frac{\partial \mathbf{s}}{\partial \mathbf{p}}\, \dot{\mathbf{p}} = \mathbf{L}_{\mathbf{s}}\, \mathbf{v} \qquad (2)$$

where $\mathbf{L}_{\mathbf{s}}$ 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:

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

where λ is a proportional gain that has to be tuned to minimize the time-to-convergence, $\widehat{\mathbf{L}_{\mathbf{s}}}^{+}$ 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 DoF 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

- Claudio Pacchierotti has been elected Chair of the IEEE Technical Committee on Haptics for the term 2018-2020. He also published a review paper on the topic of wearable haptic devices for the hand [29].
- Julien Pettré will coordinate the H2020 ICT 25 EUropean Project CrowdBot starting from January 2018. The project gathers 5 academic partners - UCL (UK), EPFL and ETHZ (Switzerland), RWTH (Germany) and Inria (France) - as well as 2 industrial partners - Locomotec GmbH (Germany) and SoftBank Robotics (France). The project will address the navigation of robots in crowded environment. While having robot moving in crowds can be of crucial importance (e.g., semi-autonomous wheelchairs), the project will design new robot navigation techniques that minimize the risk of negative impact raised by the presence of the robot (traffic perturbation, collision, etc.).

5.1.1. Awards

- Lagadic was 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 was to address search and rescue operations in regions which are difficult to access or dangerous following disasters. For this, the team explored 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 demonstrated live at the Hannover fair in April 2017.

6. New Software and Platforms

6.1. bib2html

Latex bibliography generator

KEYWORDS: LaTeX - Bibliography

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

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

6.2. DESlam

Dense Egocentric SLAM

KEYWORDS: Deph Perception - Robotics - Localisation

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

- Participants: Andrew Ian Comport, Maxime Meilland and Patrick Rives
- Contact: Patrick Rives

6.3. HandiViz

Driving assistance of a wheelchair

KEYWORDS: Health - Persons attendant - Handicap
FUNCTIONAL DESCRIPTION: The HandiViz software proposes a semi-autonomous navigation framework of a wheelchair relying on visual servoing.

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

- Participants: François Pasteau and Marie Babel
- Contact: Marie Babel

6.4. Perception360

Robot vision and 3D mapping with omnidirectional RGB-D sensors.
KEYWORDS: Depth Perception - Localization - 3D reconstruction - Realistic rendering - Sensors - Image registration - Robotics - Computer vision - 3D rendering
FUNCTIONAL DESCRIPTION: This software is a collection of libraries and applications for robot vision and 3D mapping with omnidirectional RGB-D sensors or standard perspective cameras. This project provides the functionality to do image acquisition, semantic annotation, dense registration, localization and 3D mapping. The omnidirectional RGB-D sensors used within this project have been developed in Inria Sophia-Antipolis by the team LAGADIC.

- Contact: Patrick Rives

6.5. SINATRACK

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

- Participants: Antoine Guillaume Petit, Éric Marchand and François Chaumette
- Contact: Éric Marchand

6.6. UsTk

Ultrasound toolkit for medical robotics applications guided from ultrasound images
KEYWORDS: Echographic imagery - Image reconstruction - Medical robotics - Visual tracking - Visual servoing (VS)
FUNCTIONAL DESCRIPTION: UsTk, standing for Ultrasound Toolkit, is a cross-platform extension of ViSP software dedicated to two- and three-dimensional ultrasound image processing and visual servoing based on ultrasound images. Written in C++, UsTk architecture provides a core module that implements all the data structures at the heart of UsTk, a grabber module that allows to acquire ultrasound images from an Ultrasonix or a Sonosite device, a GUI module to display data, an IO module for providing functionalities to read/write data from a storage device, and a set of image processing modules to compute the confidence map, to track a needle, and to track an image template. All these modules could be used to control the motion of an ultrasound probe by ultrasound visual servoing.

- Participants: Alexandre Krupa, Marc Pouliquen, Fabien Spindler and Pierre Chatelain
- Partners: Université de Rennes 1 - IRSTEA
- Contact: Alexandre Krupa
- URL: https://team.inria.fr/lagadic/

6.7. ViSP

Visual servoing platform

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

SCIENTIFIC DESCRIPTION: Since 2005, we develop and release ViSP [1], an open source library available from https://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.

[1] E. Marchand, F. Spindler, F. Chaumette. ViSP for visual servoing: a generic software platform with a wide class of robot control skills. IEEE Robotics and Automation Magazine, Special Issue on "Software Packages for Vision-Based Control of Motion", P. Oh, D. Burschka (Eds.), 12(4):40-52, December 2005.

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, iOS, Windows and Linux. ViSP online documentation allows to ease learning. More than 280 fully documented classes organized in 17 different modules, with more than 300 examples and 64 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: Aurélien Yol, Éric Marchand, Fabien Spindler, François Chaumette and Souriya Trinh
- Partner: Université de Rennes 1
- Contact: Fabien Spindler
- URL: http://visp.inria.fr

6.8. Platforms

6.8.1. 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 6 DoF Gantry robot, the other one is a 4 DoF cylindrical robot (see Fig. 2.a). These robots are equipped with cameras. The Gantry robot also allows embedding grippers on its end-effector.

We are also using a haptic Virtuose 6D device from Haption company (see Fig. 2.b). This device is used as master device in many of our shared control activities (see Sections 9.3.1.3, 7.3.3, and 7.3.4).

Note that eight papers published by Lagadic in 2017 enclose results validated on this platform [35], [37], [15], [63], [58], [48], [51], [52].

6.8.2. Mobile Robots

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

6.8.2.1. 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.

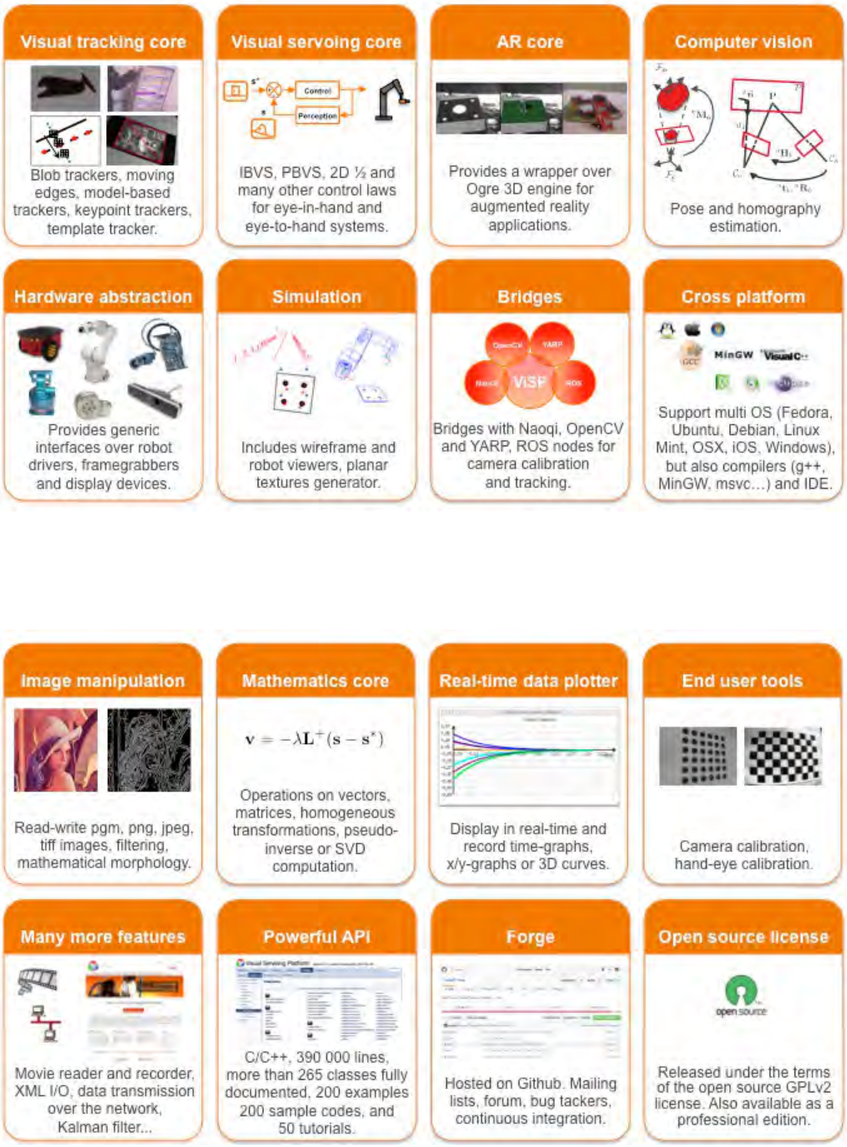


Figure 1. This figure highlights ViSP main capabilities for visual tracking, visual servoing, and augmented reality that may benefit from computer vision algorithms. ViSP allows controlling specific platforms through hardware abstraction or in simulation. ViSP provides also bridges over other frameworks 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.

(a) (b)

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

Moreover, to validate the researches in personally assisted living topic (see Section 7.5.3), 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 five papers exploiting the indoors mobile robots were published this year [15], [30], [31], [53], [60].

6.8.2.2. 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 speed of 30 km/h and a maximum speed of 80 km/h. The sequences are recorded at a frame rate of 20 Hz, whith a synchronization of the six global shutter cameras of the stereo system, producing spherical images with a resolution of 2048x665 pixels (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.

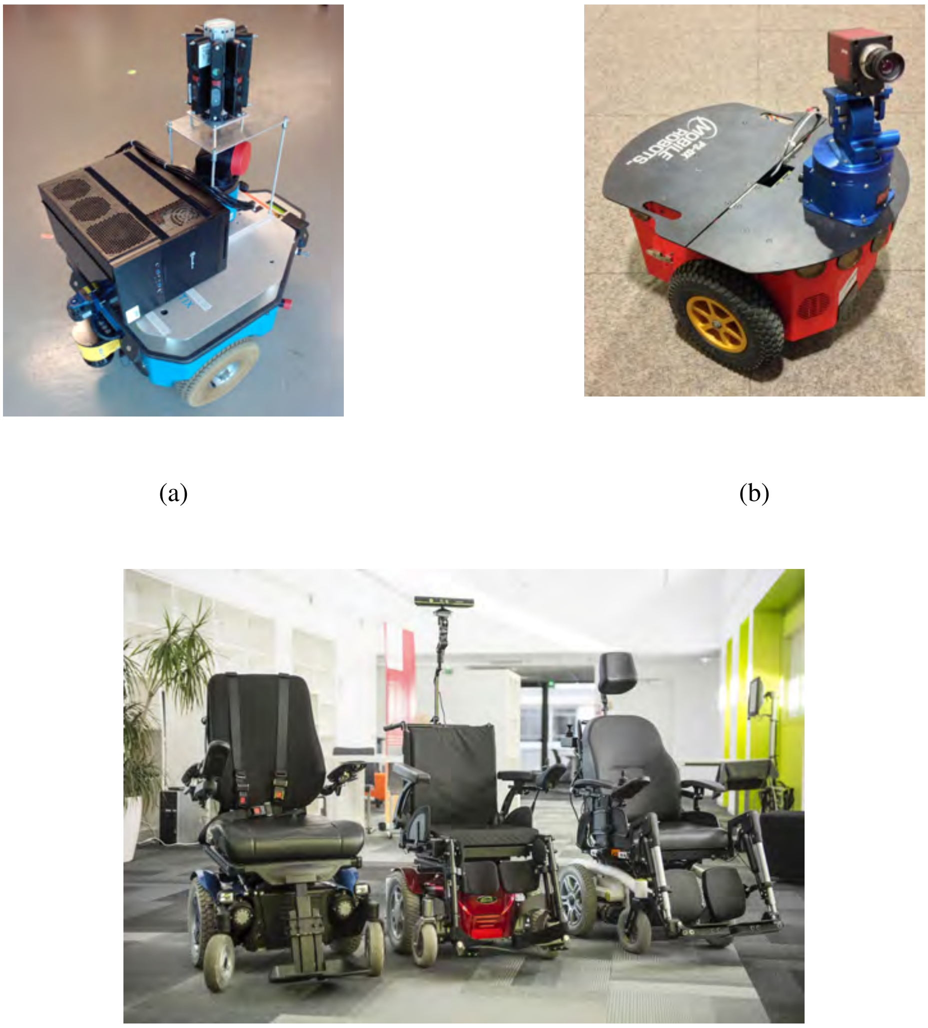
6.8.3. Medical Robotic Platform

Participants: Marc Pouliquen, Fabien Spindler [contact], Alexandre Krupa.

This platform is composed by two 6 DoF Adept Viper 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. The haptic Virtuose 6D device (see Fig. 2.b) can also be used within this platform.

This testbed is of primary interest for researches and experiments concerning ultrasound visual servoing applied to probe positioning, soft tissue tracking, elastography or robotic needle insertion tasks (see Section 7.3).

Note that seven papers published this year include experimental results obtained with this platform [56], [57], [72], [33], [19], [48], [37]

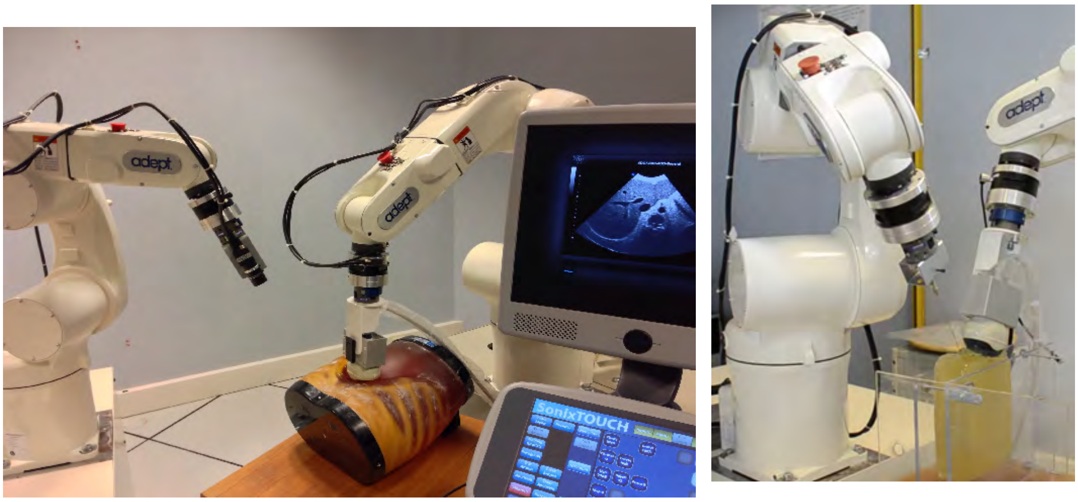


(a) (b)

(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 robotic 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.

6.8.4. 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. 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).

Last year, 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 DoF mounted on a wheeled holonomic base and a set of sensors (cameras, laser, ultrasound, inertial, microphone) that makes this platform interesting for researches in vision-based manipulation, and visual navigation (see Section 7.5.1).

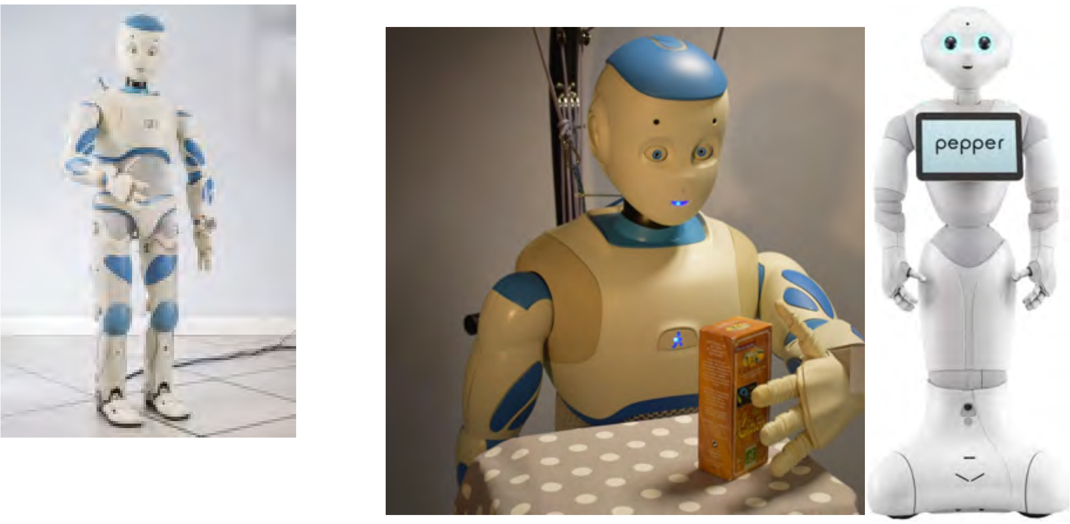
Note that two papers published this year include experimental results obtained with these platforms [13], [60].

6.8.5. Unmanned Aerial Vehicles (UAVs)

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

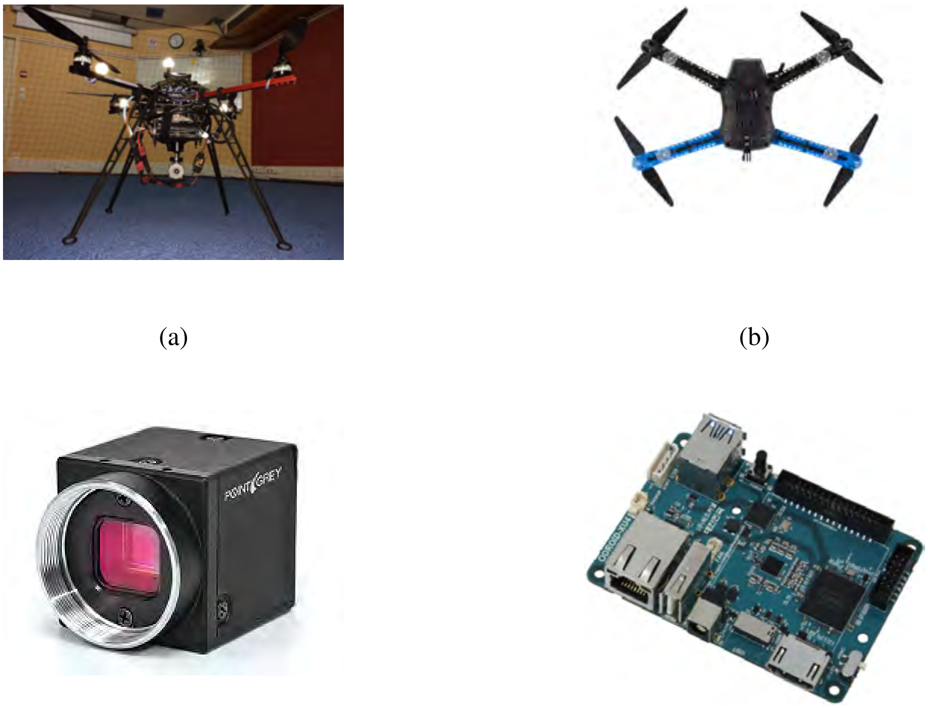
From 2014, Lagadic also started some activities involving perception and control for single and multiple quadrotor UAVs, especially thanks to a grant from “Rennes Métropole” (see Section 9.1.4) and the ANR project “SenseFly” (see Section 9.2.5). To this end, we purchased four quadrotors from Mikrokopter 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.

This year four papers published enclose experimental results obtained with this platform [49], [50], [42], [62].



(a) (b)

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



(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. Visual Tracking for Motion Capture

Participant: Eric Marchand.

This work is achieved in collaboration with Anatole Lécuyer (Inria Hybrid group) through the co-supervision of Guillaume Cortes Ph.D.

In the context of the development of new optical tracking devices, we propose an approach to greatly increase the tracking workspace of VR applications without adding new sensors [69]. Our approach relies on controlled cameras able to follow the tracked markers all around the VR workspace providing 6 DoF tracking data. We designed the proof-of-concept of such approach based on two consumer-grade cameras and a pan-tilt head. This approach has also been extended for the tracking of a drone in GPS denied environment [42].

We also achieved a short study related to the analysis of the 3D motion of head and hand in CAVE-based applications with the goal to optimize optical tracking sensors placement [43].

7.1.2. Object 3D Tracking based on Depth Information and CAD Model

Participants: Agniva Sengupta, Eric Marchand, Alexandre Krupa.

In the context of the iProcess project (see Section 9.3.3.2), we started this year a new study related to pose estimation and tracking of a rigid object observed by a RGB-D camera. We developed a pose estimation approach based on depth information measurement and the use of a CAD model represented by a 3D tetrahedral mesh. The pose parameters are estimated through an iterative optimization process that minimizes the point-to-plane Euclidean distance between the point cloud observed by the RGB-D camera and the surface of the 3D mesh. Preliminary results obtained with simple objects constituted by a set of orthogonal planes showed good performance of this approach. However, the method failed for the case of complex objects that exhibit important curvature surfaces. In order to address this issue we are currently extending the approach to take into account also the RGB information in the optimization criterion.

7.1.3. General Model-based Tracker

Participants: Souriya Trinh, Fabien Spindler, François Chaumette.

We have generalized the model-based tracker [2] available in ViSP [5] to integrate the depth information provided by a RGB-D sensor using the method described in the previous paragraph. It is now possible to fuse in the same optimization scheme measurements such as points of interest, edges, and depth, which allows to improve the robustness and accuracy of the tracker.

7.1.4. 3D Localization for Airplane Landing

Participants: Noël Mériaux, Pierre-Marie Kerzerho, Patrick Rives, Eric Marchand, François Chaumette.

This study was 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 implemented a direct registration method based on dense vision-based tracking that allows localizing the on-board camera from a set of keyframe images corresponding to the landing trajectory. First experiments with simulated and real images have been carried on with promising results. This approach is particularly interesting at the beginning of the descent when the landing track is far away and not very observable in the image. In that sense, the direct registration method is strongly complementary with the model-based approach studied before.

7.1.5. Extrinsic Calibration of Multiple RGB-D Cameras

Participants: Eduardo Fernandez Moral, Patrick Rives.

In collaboration with Alejandro Perez-Yus from the University of Zaragoza, we developed a novel method to estimate the relative poses between RGB and depth cameras without the requirement of an overlapping field of view, thus providing flexibility to calibrate a variety of sensor configurations. This calibration problem is relevant to robotic applications which can benefit of using several cameras to increase the field of view. In our approach, we extract and match lines of the scene in the RGB and depth cameras, and impose geometric constraints to find the relative poses between the sensors. In [31], an analysis of the observability properties of the problem is presented. We have validated our method in both synthetic and real scenarios with different camera configurations, demonstrating that our approach achieves good accuracy and is very simple to apply, in contrast with previous methods based on trajectory matching using visual odometry or SLAM.

7.1.6. Scene Registration with Large Convergence Domain

Participants: Renato José Martins, 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 [12]. The main idea is to explore the properties given by planar surfaces with co-visibility and their normals from two distinct viewpoints. We estimate, in two decoupled stages, the rotation and then the translation, both based on the normal vectors orientation and on the depth. These two stages are efficiently computed by using low resolution depth images and without any feature extraction/matching. In [53], we also analyze the limitations and observabilty of this approach, and its relationship to ICP point-to-plane. Notably, if the rotation is observable, at least five DoF can be estimated in the worst case. To demonstrate the effectiveness of the method, we evaluate the initialization technique in a set of challenging scenarios, comprising simulated spherical images from the Sponza Atrium model benchmark and real spherical indoor sequences.

7.1.7. Scene Semantization based on Deep Learning Approach

Participants: Eduardo Fernandez Moral, Patrick Rives.

Semantic segmentation of images is an important problem for mobile robotics and autonomous driving because it offers basic information which can be used for complex reasoning and safe navigation. This problem constitutes a very active field of research, where the state-of-the-art evolves continuously with new strategies based on different kinds of deep neural networks for image segmentation and classification. RGB-D images are starting to be employed as well for the same purpose to exploit complimentary information from color and geometry. The team LAGADIC has explored several strategies to increase the performance and the accuracy of semantic segmentation from RGB-D images. We propose a multi-pipeline architecture to exploit effectively the complimentary information from RGB-D images and thus to improve the semantic segmentation results. The multi-pipeline architecture processes the color and depth layers in parallel, before concatenating their feature maps to produce the final semantic prediction. Our results are evaluated on public benchmark datasets to show the improved accuracy of the proposed architecture. [46] Though we address this problem in the context of urban images segmentation, our results can also be extended to other contexts, like indoor scenarios and domestic robotics.

Our research is partly motivated by the need of semantic segmentation solutions with better segmentation around contours. Besides, we note that one of the main issues when comparing different neural networks architectures is how to select an appropriate metric to evaluate their accuracy. We have studied several metrics for multi-class classification, and we propose a new metric which accounts for both global and contour accuracy in a simple formulation to overcome the weaknesses of previous metrics. This metric is based on the Jaccard index, and takes explicitly into account the distance to the border regions of the different classes, to encode jointly the rate of correctly labeled pixels and how homeomorphic is the segmentation to the real object boundaries. We also present a comparative analysis of our proposed metric and several commonly used metrics for semantic segmentation together with a statistical analysis of their correlation.

7.1.8. Online Localization and Mapping for UAVs

Participants: Muhammad Usman, Paolo Robuffo Giordano.

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.

7.1.9. Reflectance and Illumination Estimation for Realistic Augmented Reality

Participants: Salma Jiddi, Eric Marchand.

A key factor for realistic Augmented Reality is a correct illumination simulation. This consists in estimating the characteristics of real light sources and use them to model virtual lighting. This year, we studied a novel method for recovering both 3D position and intensity of multiple light sources using detected cast shadows. Our algorithm has been successfully tested on a set of real scenes where virtual objects have visually coherent shadows [70].

7.1.10. Optimal Active Sensing Control

Participants: Marco Cognetti, Paolo Salaris, Paolo Robuffo Giordano.

This study concerns the problem of active sensing control whose objective is to reduce the estimation uncertainty of an observer as much as possible by determining the inputs of the system that maximize the amount of information gathered by the few noisy outputs while at the same time reduce the negative effects of the process/actuation noise. The latter is far from being negligible for several robotic applications (a prominent example being aerial vehicles).

Last year, we extended a previous work [9] to the case where the observability property is not instantaneously guaranteed, and hence the optimal estimation strategy cannot be given in terms of the instantaneous velocity direction of the robot and consequently of the onboard sensors. These outcomes of this research have been presented in [61] for nonlinear differentially flat systems. This year, we have moved some steps forward in order to improve and generalize the work in [61]: first of all, we have replaced the Observability Gramian (OG) with the Constructibility Gramian (CG). Despite their similar form, they differ from the fact that the OG measures the information collected along the path about the initial state of the nonlinear system while the CG measures the one about the current/final state with which most robotics applications are more concerned. Second, we have overcome the limit of previous work [61] that only deals with the case where the OG and the CG are known in closed-form. We have also applied our method to the unicycle vehicle which is a more complex dynamic system than the one used in [61] and tested our machinery to the cases of self-calibration and environment reconstruction. Moreover, thanks to the arrival of Marco Cognetti in our group as Post-doc, we are currently working on the application of our method to a quadrotor UAV, which is a much more complex dynamic system, for which the CG is not known in closed-form. The ultimate goal is to test our new machinery in a real experiment with a quadrotor UAV. Finally, we have also worked on the problem of considering the process/actuation noise in the optimization algorithm. As the CG (or the OG) does not take into account the degrading effects on the information collected through the outputs of the process/actuation noise, we have proposed to directly maximize the smallest eigenvalue of the covariance matrix given by the Riccati differential equation of the EKF, used as estimation algorithm. The results of this approach have been submitted to ICRA 2018.

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 LS2N in Nantes, France. It concerned 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 well-known case of using three image points as visual feature, and then solved the general case of n image points [16]. The case of three image straight lines has also been solved for the first time [17].

We have also designed a control scheme in order to avoid these singularities during the execution of a visual servoing scheme [38].

7.2.2. Visual Servoing through Mirror Reflection

Participants: François Chaumette, Eric Marchand.

Apart the use of catadioptric cameras, only few visual servoing works exploit the use of mirror. Such a configuration is however interesting since it allows overpassing the limited camera field of view. Based on the known projection equations involved in such a system, we studied the theoretical background that allows the control of planar mirror for visual servoing in different configurations. Limitations intrinsic to such systems, such as the number of DoF actually controllable, have been studied. The case of point feature was considered in [51] and this has been extended to line in [52].

7.2.3. Visual Servoing of Humanoid Robots

Participants: Giovanni Claudio, 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).

We have designed the modeling of the visual features at the acceleration level to embed visual tasks and visual constraints in an existing Quadratic Programming controller [13]. Experimental results have been obtained on Romeo (see Section 6.8.4).

7.2.4. Model Predictive Visual Servoing

Participants: Paolo Robuffo Giordano, François Chaumette.

This study was realized in collaboration with Pierre-Brice Wieber, from Bipop group at Inria Rhône Alpes, through the co-supervision of Nicolas Cazy's Ph.D.

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 study, 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 [41].

7.2.5. *Model Predictive Control for Visual Servoing of a UAV*

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

Visual servoing is a well-known 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 underactuation 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 chose to rely on MPC for explicitly dealing with this kind of constraints during flight. We have recently considered the problem of controlling in minimum-time a quadrotor UAV equipped with a downlooking camera that needs to reach a desired pose w.r.t. a target on the ground from visual input. The control problem is solved by an online replanning strategy that is able to generate (at camera rate) minimum-time trajectories towards the final pose while coping with actuation constraints (limited propeller thrusts) and sensing constraints (target always in the camera fov). By exploiting the camera images during motion, the replanning strategy is able to adjust online the optimal trajectory and, thus, be robust against unmodeled effects and other disturbances (which can be typically expected on a quadrotor flying aggressively). The approach has been validated via numerical simulations in [59]. We are now working towards an experimental validation, as well as novel algorithmic extensions allowing for the possibility of temporarily losing sight of the target object for relaxing the visibility constraint (and, thus, gain in maneuverability).

7.2.6. *UAVs in Physical Interaction with the Environment*

Participants: Quentin Delamare, Paolo Robuffo Giordano.

Most research in UAVs deals with either contact-free cases (the UAVs must avoid any contact with the environment), or in “static” contact cases (the UAVs need to exert some forces on the environment in quasi-static conditions, reminiscent of what has been done with manipulator arms). Inspired by the vast literature on robot locomotion (from, e.g., the humanoid community), in this research topic we aim at exploiting the contact with the environment for *helping* a UAV maneuvering in the environment, in the same spirit in which we humans (and, supposedly, humanoid robots) use our legs and arms when navigating in cluttered environments for helping in keeping balance, or perform maneuvers that would be, otherwise, impossible.

As an initial case study, we have considered a planar UAV equipped with a 1 DoF actuated arm capable of hooking at some pivots in the environment. This UAV (named MonkeyRotor) needs to “jump” from one pivot to the next one by exploiting the forces exchanged with the environment (the pivot) and its own actuation system (the propellers). This study considers the full dynamics in both cases (hooked, free-flying), proposes an optimization problem for finding optimal trajectories from an initial hooked configuration to the next one, and validates the approach in simulation. We are now working towards a physical realization of a first prototype. This activity is done in cooperation with LAAS-CNRS (Dr. Antonio Franchi who is co-supervising Quentin Delamare).

7.2.7. *Visual Servoing for Steering Simulation Agents*

Participants: Axel Lopez Gandia, Eric Marchand, François Chaumette, Julien Pettré.

Steering is one of the basic functionality of any character animation system. It provides characters with the ability to locally move in the environment so as to achieve basic navigation tasks, such as reaching a goal, avoiding a collision with an obstacles, etc. This problem has been explored in various contexts (e.g., motion planning, autonomous characters or crowd simulation). It turned out that this component plays an important role on the quality of character animation and received a lot of attention. Many important steps have been taken to improve steering techniques: potential fields, sets of attractive and repulsive forces, linear programming in the velocity space, local optimization of navigation functions, etc. Each new category of approach leads to characters close to forming realistic trajectories when achieving navigation.

Nevertheless, all these techniques remain quite far from the way real humans form their locomotion trajectory, because they are all based on kinematics and geometry. Humans obviously do not solve geometrical problems of this nature while moving in their environment but control their motion from perceptual features, and more especially visual features they perceive from the environment. For simulating more accurately the perception-action loop used by humans to navigate in their environment, we developed a technique which provides characters with vision capabilities, by equipping them with a virtual retina on which we project information about their surroundings. In a first version, we projected information about the relative motion of objects around them, allowing characters to estimate the risk of collision they face, and to move so as to minimize this risk [21]. More recently, we projected a purely visual information, and we established the relations that exist between the visual features characters perceive and the motion they perform. This way, we are able to steer characters so as their visual flow satisfies some conditions, allowing them for example to reach a goal while avoiding surrounding obstacles, could they be static or moving.

7.2.8. Direct Visual Servoing

Participants: Quentin Bateux, Eric Marchand.

We have proposed a deep neural network-based method to perform high-precision, robust and real-time 6 DoF visual servoing [63]. We studied how to create a dataset simulating various perturbations (occlusions and lighting conditions) from a single real-world image of the scene. A convolutional neural network is fine-tuned using this dataset to estimate the relative pose between two images of the same scene. The output of the network is then employed in a visual servoing control scheme. The method converges robustly even in difficult real-world settings with strong lighting variations and occlusions.

7.3. Medical Robotics

7.3.1. Visual Servoing using Wavelet and Shearlet Transforms

Participants: Lesley-Ann Duflot, Alexandre Krupa.

In collaboration with Femto-ST lab in Besançon and the Research Group on Computational Data Analysis at Universitat Bremen, we developed a new generation of direct visual servoing methods in which the signal control inputs are the coefficients of a multiscale image representation. In particular, we considered the use of multiscale image representations that are based on discrete wavelet and shearlet transforms. We succeeded to derive an analytical formulation of the interaction matrix related to the wavelet and shearlet coefficients and experimentally demonstrated the performances of the proposed visual servoing approaches. We also considered this control framework in the design of a medical application which consists in automatically moving a biological sample carried by a parallel micro-robotic platform using Optical Coherence Tomography (OCT) as visual feedback. The objective is to automatically retrieve the region of the sample that corresponds to an initial optical biopsy for diagnosis purpose. First results obtained with a 3 DoF eye-to-hand visual servoing demonstrated the feasibility to use the wavelet coefficients of the OCT image as input of the control law.

7.3.2. 3D Steering of Flexible Needle by Ultrasound Visual Servoing

Participants: Jason Chevrie, Marie Babel, Alexandre Krupa.

We pursued our work on 3D steering of a flexible needle using ultrasound visual servoing [11]. This year, in collaboration with the Surgical Robotics Laboratory of the University of Twente, we developed a method to control a 2 DoF needle insertion device attached to the end-effector of a 6-DoF robotic arm in order to automatically insert a flexible needle toward a spherical target embedded in a moving biological tissue (bovine liver). We proposed a method that uses both base manipulation control and tip-based control while compensating the tissue motion to avoid lateral tearing. The visual feedback provided by the ultrasound probe was used to track the target and an electromagnetic tracker attached inside the needle was used to locate its tip. In this study, the motion compensation of the moving tissue was performed by minimizing the interaction force measured at the base of the needle insertion device. In our approach we used the generic task control framework to fuse the needle targeting and motion compensation tasks into a single control law. First experimental ex-vivo results demonstrated the efficiency of the proposed control to reach a target in moving biological tissue.

7.3.3. Robotic Assistance for Ultrasound Elastography by Visual Servoing, Force Control and Teleoperation

Participants: Pedro Alfonso Patlan Rosales, Alexandre Krupa.

This work concerns the development of a robotic assistant system for quantitative ultrasound elastography. This imaging modality provides the elastic parameters of a tissue which are commonly related with a certain pathology. It is performed by applying continuous stress variation on the tissue in order to estimate a strain map. Usually, this stress variation is performed manually by the user through the manipulation of the ultrasound probe and it results therefore in an user-dependent quality of the strain map. 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 [72]. This year we extended our previous robotic palpation system in order to perform 3D elastography and allow the user to teleoperate the probe orientation through a haptic device [56]. This extension is based on the use of a 3D ultrasound probe held by a 6 DoF robotic arm and the design of a new control law based on the task control framework that simultaneously performs three tasks: i) autonomous palpation by force control of the tissue required for the strain map estimation, ii) probe lateral alignment on a stiff target of interest for optimizing its visibility by visual servoing and iii) teleoperation of the probe orientation by the user for exploration purpose. Recently, we also proposed a solution that allows the estimation of the strain map of a moving tissue that is subject to physiological motion [57]. It is based on the combination of a non-rigid motion tracking of the tissue of interest in the ultrasound image and an automatic 6 DoF compensation of the perturbation motion by visual servoing using dense ultrasound information.

7.3.4. Haptic Guidance of a Biopsy Needle

Participants: Hadrien Gurnel, Alexandre Krupa.

We started a new study in collaboration with Maud Marchal (Inria Hybrid group) related to the assistance of manual needle steering for biopsies or therapy purposes (see Section 9.1.7). Instead of automatically inserting the needle by a robotic arm as we did in other works, our objective is to develop a solution that provides haptic cue feedback to the clinician that helps him during its manual gesture. The haptic cue feedback will be provided by a haptic device holding the needle. This year we developed a software tool that simulates and visualizes the interaction of a virtual needle with a deformable virtual organ. This organ is represented by a 3D mesh and a mass-spring-damper model was considered to simulate its deformation due to the needle insertion motion. The development of this software was based on our libraries UsTk and ViSP and the external library VTK (Visualization Toolkit). We also interfaced to this simulator our Haption Virtuose 6D haptic device to allow the user to teleoperate the virtual needle and to feel the force applied by the needle on the virtual tissue. This simulator will constitute an important tool for our future development of dynamic haptic guides before testing them in a real experimental setup.

7.4. Teleoperation

7.4.1. Shared Control for Remote Manipulation

Participants: Firas Abi Farraj, 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. Recently, we have extended this framework in several directions:

1. in a first extension, the existing instantaneous interface has been improved towards an "integral" approach in which the user can command parts of the future manipulator trajectory, while the autonomy makes sure that no constraint is violated (in this case we considered, again, joint limits and singularities, as well as a more realistic vision constraint for keeping the gripper and the object always in visibility and not overlapping). This shared control algorithm was validated in simulation in [58]. We are currently completing a full implementation on our dual-arm system (the two Viper robots);
2. second, we have 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 [37];
3. third, we have considered a grasping scenario in which a post-grasp task is specified (e.g., the grasped object needs to follow a predefined trajectory): in this scenario, the operator (supported by the robot autonomy) needs to decide where to best grasp in order to then execute the desired post-grasp action. However, different grasping poses will result in easier/harder execution by the robot because of any possible constraint (e.g., joint limits and singularities). Since awareness of these constraints is hard for any operator, in this case the autonomy component cues the operator with a force feedback indicating the best grasp pose w.r.t. the existing constraints and post-grasp task. The operator has still control over where to grasp, but she/he is guided by the force feedback into more feasible grasp poses than what she/he could have guessed without any feedback [48];
4. finally, we have considered the task of assisting an operator in control of a UAV which is mapping a remote environment with an onboard camera. In this scenario the operator can control the UAV motion during the mapping task. However, as in any estimation problem, different motions will result less/more optimal w.r.t. the scene estimation task: therefore, a force feedback is produced in order to assist the operator in selecting the UAV motion (in particular, its linear velocity) that also results optimal for the sake of facilitating the scene estimation process. The results have been validated with numerical simulations in a realistic environment [39].

7.4.2. Wearable haptics

Participants: Marco Aggravi, Claudio Pacchierotti.

Kinesthetic haptic feedback is used in robotic teleoperation to provide the human operator with force information about the status of the slave robots and their interaction with the remote environment. Although kineshetic feedback has been proven to enhance the performance of teleoperation systems, it still shows several limitations, including its negative effect on the safety and stability of such systems, or the limited workspace, available DoF, high cost, and complexity of kinesthetic interfaces. In this respect, wearable haptics is gaining great attention. Safe, compact, unobtrusive, inexpensive, easy-to-wear, and lightweight haptic devices enable researchers to provide compelling touch sensations to multiple parts of the body, significantly increasing the applicability of haptics in many fields, such as robotics, rehabilitation, gaming, and immersive systems.

In this respect, our objective has been to study, design, and evaluate novel wearable haptic interfaces for the control of remote robotic systems as well as interacting with virtual immersive environments.

We have started by working on a multi-point wearable feedback solution for robotic manipulators operating in a cluttered environment [40]. The slave system is composed of an anthropomorphic soft robotic hand attached to a 6-axis force-torque sensor, which is in turn fixed to a 6-DoF robotic arm. The master system is composed of a Leap Motion controller and two wearable vibrotactile armbands, worn on the forearm and upper arm. The Leap Motion tracks the user's hand pose to control the pose of the manipulator and the grasping configuration of the robotic hand. The armband on the forearm conveys information about collisions of the slave hand/wrist system (green patch to green armband, see Fig. 8), whereas the armband on the upper arm conveys information about collisions of the slave arm (orange patch to orange armband). The amplitude of the vibrotactile feedback relayed by the armbands is proportional to the interaction force of the collision. A camera mounted near the manipulator's end-effector enables the operator to see the environment in front of the robotic hand. To validate our system, we carried out a human subjects telemanipulation experiment in a cluttered scenario. Twelve participants were asked to control the motion of the robotic manipulator to grasp an object hidden between debris of various shapes and stiffnesses. Haptic feedback provided by our wearable devices significantly improved the performance of the considered telemanipulation tasks. Finally, all subjects but one preferred conditions with wearable haptic feedback.

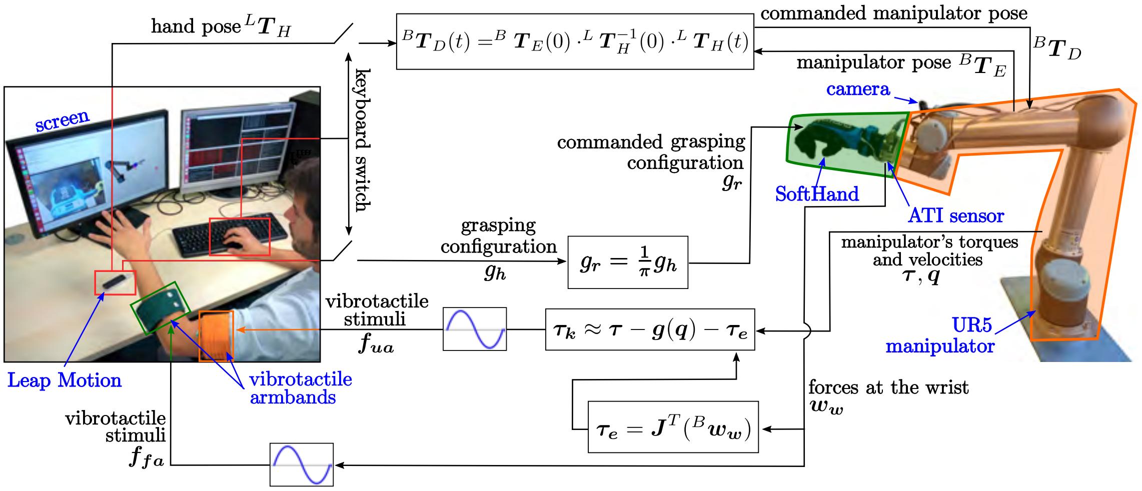


Figure 8. Haptic-enabled teleoperation system. We used two vibrotactile wearable devices to provide multi-point haptic feedback about collisions of the slave robot with the remote environment [40].

We have also used wearable haptics for guidance [20]. In this context, haptic feedback is not used to provide information about a force exerted by the salve robot in the remote environment, but it provides guidance cues about a predetermined trajectory to follow. Toward this, we developed a novel wearable device for the forearm. Four cylindrical rotating end effectors, located on the user's forearm, can generate skin stretch at the ulnar, radial, palmar, and dorsal sides of the arm. When all the end effectors rotate in the same direction, the cutaneous device is able to provide cues about a desired pronation/supination of the forearm. On the other hand, when two opposite end effectors rotate in opposite directions, the device is able to provide cutaneous cues about a desired translation of the forearm. Combining these two stimuli, we can provide both rotation and translation guidance. To evaluate the effectiveness of our device in providing navigation information, we carried out two experiments of haptic navigation. In the first one, subjects were asked to translate and rotate the forearm toward a target position and orientation, respectively. In the second experiment, subjects were asked to control a 6-DoF robotic manipulator to grasp and lift a target object. Haptic feedback provided by our wearable device improved the performance of both experiments with respect to providing no haptic feedback.

Moreover, it showed similar performance with respect to sensory substitution via visual feedback, without overloading the visual channel.

Finally, we also used wearable haptics for immersive virtual and augmented reality experiences, mainly addressing tasks related to entertainment and industrial training. In these case, we used wearable devices for the fingertips able to provide pressure and skin stretch sensations [24]. This article has also been featured in the News section of Science Magazine.

We also presented a review paper on the topic of wearable haptic devices for the hand [29].

7.5. Navigation of Mobile Robots

7.5.1. Visual Navigation from an Image Memory

Participants: Paolo Robuffo Giordano, François Chaumette.

This study achieved during Suman Raj Bista's Ph.D. was 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 only, but on a combination of points of interest and straight lines since they are more common indoors [60]. Satisfactory experimental results have been obtained using the Pioneer mobile robot (see Section 6.8.2) and Pepper (See Section 6.8.4).

7.5.2. 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. Last year, we brought the empirical evidence that humans actually set a specific strategy to avoid robots: they showed a preference to give way to a robot [36]. However, the robot was passive, i.e., not reacting to the presence of participants. This year, we studied interactions between humans and reactive robot, performing avoidance maneuvers to avoid collisions. Our conclusions are that, in such situations of human-robot interactions, human behave again as during human-human avoidance interactions. Again, this study provides useful guidelines about the design of robot control techniques.

7.5.3. Semi-Autonomous Control of a Wheelchair for Navigation Assistance

Participants: Louise Devigne, Marie Babel.

In order to improve the access to mobility for people with disabilities, we have previously designed a semi-autonomous assistive wheelchair system which progressively corrects the trajectory as the user manually drives the wheelchair and smoothly avoids obstacles. Within the frame of ISI4NAVE associated team (see Section 9.4.1.2), we investigated probabilistic blending approaches which take into account uncertainty in the interaction [45]. We also designed a shared-control curb-following solution for outdoor assisted power wheelchair navigation. Once a curb is detected, user input is blended with constraints deduced from the distance from sensors to the detected curb. This provides an intuitive shared control scheme capable of assisting the user while needed i.e. while approaching a curb. Preliminary validation tests of the robotic system were conducted within the PAMELA facility.

Developing and testing such systems for wheelchair driving assistance requires a significant amount of material resources and clinician time. With Virtual Reality technology, prototypes can be developed and tested in a risk-free and highly flexible Virtual Environment before equipping and testing a physical prototype. Additionally, users can "virtually" test and train more easily during the development process. We then designed a power wheelchair driving simulator allowing the user to navigate with a standard wheelchair in an immersive 3D Virtual Environment. In order to validate the framework including the driving assistance solution, we performed tests on the Immersia platform (Inria Hybrid team) with able-bodied participants and we have shown that the simulator it generates a good sense of presence and requires rather low cognitive effort from users [44].

7.5.4. Wheelchair Kinematics and Dynamics Modeling for Shared Control

Participants: Aline Baudry, Marie Babel.

The driving experience of an electric powered wheelchair can be disturbed by unpleasant dynamic effects of the caster wheels, particularly during maneuvers in narrow rooms and direction changes. In order to prevent their nasty behaviour, we propose to model caster wheel kinematics and dynamics in order to implement a control law for a semi-autonomous assistance to maneuver in narrow environments. We conducted a preliminary study that has been achieved for our three types of wheelchair, each presenting different kinematic behaviors: front caster type, rear caster type and mid-wheel drive (see Figure 3.c). Transfer functions for each of these configurations have been identified. We achieved to design a parametric transfer function of the caster's behavior regarding to the initial orientation, wheelchair's velocity and user mass, in order to develop a sensorless maneuver control law.

7.5.5. Wheelchair Autonomous Navigation for Fall Prevention

Participants: Solenne Fortun, Marie Babel.

The Prisme project (see Section 9.1.8) is devoted to fall prevention and detection of inpatients with disabilities. For wheelchair users, falls typically occur during transfer between the bed and the wheelchair and are mainly due to a bad positioning of the wheelchair. In this context, the Prisme project addresses both fall prevention and detection issues by means of a collaborative sensing framework. Ultrasonic sensors are embedded onto both a robotized wheelchair and a medical bed. The measured signals are used to detect fall and to automatically drive the wheelchair near the bed at an optimal position determined by occupational therapists. We first designed a detection solution based on a multiple echoes technique that enhances the system perception abilities. This augmented perception system is planned to be used for wheelchair navigation as well as fall detection.

7.5.6. Robotic Platform for Assistance to People with Reduce Mobility

Participants: Dayana Hassan, Paolo Salaris, Patrick Rives.

The main objective of this work is to develop, in collaboration with AXYN Robotics (see Section 8.2.4), an intelligent vehicle to help elderly or persons with reduced mobility to move safely within a retirement home, an hospital or other much more crowded and dynamic environments. First of all, the vehicle has to be able to move within the environment while at the same time update the current map as accurately as possible. Once the map of the environment is available, the robot has to be able to plan the trajectory and reach a given destination. The robot should also follow a person taking into account social behaviors or bring towards a given destination, e.g. the canteen, making sure that an elderly person, affected e.g. by Alzheimer's disease, follows the robot. The robot should also work as an intelligent walker and help people in case of falling. In all these cases, it is very important to include humans (i.e. his/her model, his/her behaviors, his/her intentions etc.) within the study in order to develop adaptable human-aware path planning and control strategies. During this first year, the problem of following a person has been studied, starting from the literature, in order to find a suitable control scheme that merges feedback control laws, aimed at reactively cope with neighborhood environment events and feedforward ones, mainly intended to take into account the intentions of the person to follow, also including social behaviors.

7.6. Multi-robot and Crowd Motion Control

7.6.1. Rigidity-based Methods for Formation Control

Participants: Fabrizio Schiano, 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 our previous works we have addressed the problem of coordinating a team of quadrotor UAVs equipped with onboard cameras from which one could extract “relative bearings” (unit vectors in 3D) w.r.t. the neighboring UAVs in visibility. This problem is known as bearing-based formation control and localization. The basic assumption, however, was to always have a bearing rigid graph which may easily conflict with any sensing/communication constraint (measurements/edges can be lost whenever, e.g., a UAV leaves the camera fov, or it is occluded by another UAV/obstacle). In [62] we have then tackled the problem of “bearing rigidity maintenance” by studying how to formalize the problem of maintaining bearing rigidity over time despite possible sensing/communication constraints (min/max range, limited camera fov and occlusions in the reported work). Thanks to a suitable weighing machinery, we could define a “bearing rigidity eigenvalue” as a suitable metric for quantifying the degree of rigidity in the interaction graph, and then we could propose a gradient-based controller able to maintain the rigidity eigenvalue always positive (and, thus, guarantee bearing rigidity maintenance). The approach has been validated by experiments run on 5 quadrotor UAVs.

7.6.2. 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. Results have been obtained for image-based localization of a single UAV, enabling to characterize the pose uncertainty domain from measurements uncertainties [50], and also fusion with onboard proprioceptive sensors [49]. Extension to cooperative localization in a multi-UAV fleet has been studied in the two-robot case and continues as an ongoing work.

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

8.1.1. Robocortex

Participants: Souriya Trinh, Fabien Spindler, François Chaumette.

no Inria Rennes 11369, duration: 20 months.

This contract with the Inria Robocortex start up in Sophia-Antipolis started in September 2016. It is devoted to provide our expertise in visual tracking for an application specified by Dassault Aviation.

8.1.2. ABB

Participants: Souriya Trinh, Fabien Spindler, François Chaumette.

no Inria Rennes 12597, duration: 8 months.

This contract with ABB in Barcelona started in September 2017. It is devoted to provide our expertise in visual tracking and visual servoing for an industrial application.

8.1.3. IRT b<>com

Participants: Hadrien Gurnel, Fabien Spindler, Alexandre Krupa.

no Inria Rennes 11774, duration: 36 months.

This contract started in October 2016 and concerns the leasing to IRT b<>com of two modules of the Lagadic medical robotic platform. Each module is rent 40 days during a 3-year period in the context of the IRT b<>com NeedleWare project (see Section 9.1.7).

8.2. Bilateral Grants with Industry

8.2.1. 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 7.1.9).

8.2.2. Realyz

Participant: Eric Marchand.

no Inria Rennes 10822, duration: 36 months.

This project funded by Realyz started in October 2015. It is achieved in cooperation with Anatole Lécuyer from Hybrid group at Irisa and Inria Rennes-Bretagne Atlantique to support Guillaume Cortes Ph.D. about motion tracking in virtual reality.

8.2.3. 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.

8.2.4. 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 (see Section 7.5.6).

9. Partnerships and Cooperations

9.1. Regional Initiatives

9.1.1. 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 7.3.1).

9.1.2. 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 7.6.2).

9.1.3. 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.

9.1.4. "Equipement mi-lourd Rennes Métropole"

Participant: Paolo Robuffo Giordano.

no CNRS Rennes 14C0481, duration: 36 months.

This grant from "Rennes Métropole" has been obtained in June 2014 and supported the activities related to the use of drones (quadrotor UAVs). The platform described in Section 6.8.5 has been purchased in part thanks to this grant.

9.1.5. "Allocation d'installation scientifique"

Participant: Claudio Pacchierotti.

no CNRS Rennes 17C0487, duration: 36 months.

This grant from "Rennes Métropole" has been obtained in July 2017 and supported the activities related to the teleoperation of drones (quadrotor UAVs) using wearable haptics interfaces.

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 achieved in cooperation with LS2N, 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 biopsy or therapy purposes in a synergetic way (see Section 7.3.4).

9.1.8. Prisme

Participants: Solenne Fortun, Marie Babel.

no Insa Rennes 9072, duration: 24 months.

This project started in January 2017 and is supported by Brittany region/BPI. This project aims at designing a fall prevention strategy based on the sensing collaboration of a smart wheelchair and a smart medical bed. Fall detection and automatic positioning of the wheelchair next to the bed issues are planned to be addressed (see Section 7.5.5).

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, Pierre-Marie Kerzerho, Patrick Rives, François Chaumette.

no Inria Rennes 8304, duration: 48 months.

This project ended in October 2017. It involved a consortium managed by Onera in Toulouse with Airbus, Spikenet Technology, LS2N, and Lagadic. Its aim was to develop vision-based localization and navigation techniques for autonomous landing on a runway (see Section 7.1.4).

9.2.3. ANR Contint Entracte

Participant: Julien Pettré.

no Inria Rennes 8013, duration: 42 months.

This project ended in April 2017. It was realized in collaboration with the Gepetto group at Laas, Toulouse, and the Mimetic group at Irisa and Inria Rennes Bretagne Atlantique. It addressed the problem of motion planning for anthropomorphic systems, and more generally, the problem of manipulation path planning. Entracte proposed to study in parallel both the mathematical foundations 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 ended on June 2017. It aimed at designing perception-based crowd simulation algorithms. We developed agents able of perceiving their virtual environment through virtual sensors, and 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, 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 are studied in the project. Part of the platforms described in Section 6.8.5 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 involves 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, Fabien Spindler, François Chaumette.

no Inria Rennes 7114, duration: 60 months.

This project ended in October 2017. It involved 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), etc. It aimed at developing advanced control and perception functionalities to a humanoid robot. In this project, we developed visual manipulation and navigation tasks with Romeo and Pepper.

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 that started in February 2011. It is devoted to get and manage significant equipment in the main robotics labs in France. In the scope of this project, we have got the humanoid robot Romeo (see Section 6.8.4).

9.3. European Initiatives

9.3.1. FP7 & H2020 Projects

9.3.1.1. FP7 Space RemoveDEBRIS

Participants: Eric Marchand, François Chaumette.

Instrument: Specific Targeted Research Project

Duration: October 2013 - September 2018

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 [22], [47].

9.3.1.2. H2020 ICT Comanoid

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

Title: Multi-contact Collaborative Humanoids in Aircraft Manufacturing

Programme: 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 are 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 ICT Romans

Participants: Firas Abi Farraj, Fabien Spindler, François Chaumette, Claudio Pacchierotti, Paolo Robuffo Giordano.

Title: Robotic Manipulation for Nuclear Sort and Segregation

Programme: 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 aims at: 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 in European Programs, Except FP7 & H2020

9.3.2.1. Interreg Adapt

Participants: Nicolas Le Borgne, Marie Babel.

Programme: Interreg VA France (Channel) England

Project acronym: Adapt

Project title: Assistive Devices for empowering disAbled People through robotic Technologies

Duration: 01/2017 - 06/2021

Coordinator: ESIGELEC/IRSEEM Rouen

Other partners: INSA Rennes - IRISA, LGCGM, IETR (France), Université de Picardie Jules Verne - MIS (France), Pôle Saint Hélier (France), CHU Rouen (France), Réseau Breizh PC (France), Ergovie (France), Pôle TES (France), University College of London - Aspire CREATE (UK), University of Kent (UK), East Kent Hospitals Univ NHS Found. Trust (UK), Health and Europe Centre (UK), Plymouth Hospitals NHS Trust (UK), Canterbury Christ Church University (UK), Kent Surrey Sussex Academic Health Science Network (UK), Cornwall Mobility Center (UK).

Abstract: This project aims to develop innovative assistive technologies in order to support the autonomy and to enhance the mobility of power wheelchair users with severe physical/cognitive disabilities. In particular, the objective is to design and evaluate a power wheelchair simulator as well as to design a multi-layer driving assistance system.

9.3.3. Collaborations with European Partners

9.3.3.1. ANR Opmops

Participants: Florian Berton, Julien Pettré.

Programme: ANR

Project acronym: Opmops

Project title: Organized Pedestrian Movement in Public Spaces: Preparation and Crisis Management of Urban Parades and Demonstration Marches with High Conflict Potential

Duration: June 2017 - June 2020

Coordinator: Université de Haute Alsace (for France), Technische Universität Kaiserslautern (for Germany)

Other partners: Gendarmerie Nationale, Hochschule München, ONHYS S.A.S, Polizei Rheinland-Pfalz, Universität Koblenz-Landau, VdS GmbH

Abstract: This project is about parades of highly controversial groups or of political demonstration marches are considered as a major threat to urban security. Due to the movement of the urban parades and demonstration marches (in the following abbreviated by UPM) through large parts of cities and the resulting space and time dynamics, it is particularly difficult for forces of civil security (abbreviated in the following by FCS) to guarantee safety at these types of urban events without endangering one of the most important indicators of a free society. In this proposal, partners representing the FCS (police and industry) will cooperate with researchers from academic institutions to develop a decision support tool which can help them both in the preparation phase and crisis management situations of UPMs. Specific technical issues which the French-German consortium will have to tackle include the following: Optimization methods to plan UPM routes, transportation to and from the UPM, location and personnel planning of FCS, control of UPMs using stationary and moving cameras, and simulation methods, including their visualization, with specific emphasis on social behavior.

9.3.3.2. iProcess

Participants: Agniva Sengupta, Fabien Spindler, Eric Marchand, 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 (see Section 7.1.2). Prof. Ekrem Misimi from Sintef spent a 4-month visit from May 2017 and a 1-week visit in November 2017. François Chaumette and Alexandre Krupa spent a short period at Sintef in Trondheim in February and June 2017 respectively.

9.4. International Initiatives

9.4.1. Inria Associate Teams Not Involved in an Inria International Labs

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 (Institution - Laboratory - Researcher):

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

Start year: 2016

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

The global ageing population, along with disability compensation constitutes 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 then addresses 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. Participation in International Programs

9.4.2.1. ACRV

The Lagadic group is one of the five external partners of the Australian Center for Robotic Vision (see http://roboticvision.org). This center groups QUT in Brisbane, ANU in Canberra, Monash University and Adelaide University. In the scope of this project, Quentin Bateux received a grant to participate to the 2017 Robotic Vision Summer School in Kioloa (New South Wales) and spent a 1-week visit at QUT in March 2017.

9.5. International Research Visitors

9.5.1. Visits of International Scientists

- Prof. Denis Wolf, Associate Professor at Univ. Sao Paulo, Brazil, spent a sabbatical year in Sophia Antipolis from July 2016 to August 2017. He worked on semantic learning applied to intelligent vehicles.
- Prof. Dan Zelazo (Technion) and Prof. Antonio Bicchi (Univ. Pisa) spent a short visit in the group in Rennes in 2017.

9.5.1.1. Internships

- Giuseppe Sirignano (Univ. Salerno), from October 2017 to March 2018
- Mario Selvaggio (Univ. Naples), from November 2017 till end of December 2017

9.5.2. Visits to International Teams

9.5.2.1. Research Stays Abroad

- Jason Chevrie spent a 3-month visit in Sarthak Misra's lab at the Surgical Robotics Laboratory (SRL) of University of Twente (Netherlands) where he performed robotic experiments in the scope of his Ph.D (see Section 7.3.2).
- François Chaumette was invited for a 1-week visit at Zhejiang University in November 2017.

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific Events Organisation

10.1.1.1. General Chair, Scientific Chair

- Marie Babel was the Scientific Chair of the workshop "Serious game et réalité virtuelle : de la conception à l'utilisation" organized in Inria Rennes on December 15th 2017.

10.1.1.2. Member of the Organizing Committees

- Marie Babel and Patrick Rives were in the Organizing Committee of JNRR 2017 ("Journées Nationales de la Recherche en Robotique") held in Biarritz in November 2017
- Alexandre Krupa co-organized with Christoph Hennersperger (Technical University of Munich) and Danail Stoyanov (University College London) the Workshop on "Medical Imaging Robotics" at IROS 2017, Vancouver, Canada (http://robotic-imaging.com)
- Claudio Pacchierotti was the Publicity Chair of the 2017 IEEE World Haptics conference held in Münich, Germany. He also co-organized the workshop on "Wearable haptic systems: design, applications, and perspectives," at this conference.
- Paolo Robuffo Giordano was Editor-in-Chief of the IEEE Int. Symposium on Multi-Robot and Multi-Agent Systems (MRS 2017)

10.1.1.3. Chair of Conference Program Committees

- Julien Pettré was Program Chair for the 2017 ACM Motion in Games Conference, Barcelona, 8-10 November 2017

10.1.1.4. Member of the Conference Program Committees

- François Chaumette: ICRA 2018 (Associate Editor)
- Claudio Pacchierotti: WHC 2017 (Associate Editor)
- Julien Pettré: Eurographics 2017, ACM SCA 2017
- Patrick Rives: ICINCO 2017 (Program Committee Membership)
- Paolo Robuffo Giordano: IROS 2018 (Associate Editor), ICRA 2018 (Associate Editor), RSS 2018, ISRR 2017

10.1.1.5. Reviewer

- Marie Babel: ICRA 2017 (1)
- François Chaumette: CDC 2017 (1)
- Vincent Drevelle: IROS 2017 (1)
- Alexandre Krupa: IROS 2017 (1), Surgetica 2017 (1), ICRA 2018 (1)
- Eric Marchand: IROS 2017 (3), ICRA 2018 (2)
- Claudio Pacchierotti: WHC 2017, ICRA 2017, IROS 2017, Haptics 2018, also Senior Reviewer for IEEE Robotics & Automation Society Young Reviewers Program (from 2016)
- Julien Pettré: ACM SIGGRAPH (2), ACM SIGGRAPH Asia 2017 (2), Eurographics 2018 (1), IEEE VR 2018 (1), ACM SCA 2017 (2)

- Patrick Rives: ICRA 2017 (3), CVPR 2017 (2), ICCV 2017, Icinco 2017 (3), IV 2017 (1), PPINV 2017 (3)
- Paolo Robuffo Giordano: ACC 2017 (1), HFR 2017(2), ICRA 2018(2), IROS 2017(2)
- Paolo Salaris: ACC 2017 (1), RSS 2017 (2), IROS 2017 (1)
- Fabien Spindler: IROS 2017 (1)

10.1.2. Journal

10.1.2.1. Member of the Editorial Boards

- François Chaumette: Editorial Board of the Int. Journal of Robotics Research, Funding 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, Senior Editor of the IEEE Trans. on Robotics (from December 2017).
- Alexandre Krupa and Eric Marchand are Associate Editors of the IEEE Robotics and Automation Letters.
- Julien Pettré: Editorial board of Collective Dynamics, Associate Editor for Computer Animation and Virtual Worlds

10.1.2.2. Reviewer - Reviewing Activities

- Marie Babel: IEEE RAL (1), IEEE THMS (1)
- François Chaumette: Journal of Intelligent & Robotics Systems (1), Int. Journal of Robotics Research (1)
- Alexandre Krupa: Int. Journal of Robotics Research (1)
- Eric Marchand: Int. Journal of Robotics Research (1)
- Claudio Pacchierotti: TOH (5), RAL (8), TBME (1), TMECH(1), IJMRCAS(1), Plos One (1)
- Julien Pettré: Plos One (1), Wiley's Computer Animation and Virtual Worlds (1), Current Directions in Psychological Science (1), Elsevier's Computer and Graphics (1), IEEE TVCG (1), Journal of Motor Behavior (1).
- Patrick Rives: IEEE-Robotics and Automation Letters (1)
- Paolo Robuffo Giordano: L-CSS(1), RAL (1), TRO (1), TSMC (1)
- Paolo Salaris: IEEE-Robotics and Automation Letters (1), IEEE Trans. on Control, Systems Technology (1), Int. Journal of Robotics Research (1), Int. Journal of Control, Automation and Systems IJCAS (1)

10.1.3. Invited Talks

- Marie Babel:
  - "Assistance and Service Robotics in a Human Environment Workshop" at IEEE IROS 2017 workshop about "Smart wheelchairs: the tomorrow's vehicles?".
  - "Navigation en milieu humain : comprendre pour mieux assister" at JNRR 2017
- François Chaumette: "Visual servoing with and without image processing", University of Zhejiang, December 2017.
- Vincent Drevelle: "Set-membership interval methods for observation robotics", ENSTA Bretagne, Brest, France, October 2017.
- Eric Marchand: "The dense approach for visual servoing", "Journées scientifiques" Inria, Sophia Antipolis, June 2017.
- Claudio Pacchierotti: "Wearable haptics for VR and AR". Max-Planck Institute for Intelligent Systems, Stuttgart, Germany, 2017.
- Julien Pettré:

  - “Microscopic crowd modeling and simulation: an holistic approach”, Univ. Pompeu Fabra (Barcelona), May 2017
  - “Pedestrian Dynamics: Modeling, Validation and Calibration”, Brown University ICERM workshop, August 2017
  - “Velocity-based algorithms for crowd simulation”, workshop “Piétons et foules”, Univ. Orsay, December 2017
- Paolo Robuffo Giordano:
  - “A New Look at Shared Control for Complex Robotics Systems”. Ecole Normale Supérieure (ENS), Rennes, France, December 2017
  - “Blending Human Assistance and Local Autonomy for Advanced Telemanipulation”. Humanoids 2017 Workshop on Towards Robust Grasping And Manipulation Skills For Humanoids, November 2017
  - “Recent Results on Shared Control for Human- assisted Telemanipulation”. IROS 2017 Workshop on Human in-the-loop robotic manipulation: on the influence of the human role, September 2017
  - “Shared Control Architectures for Single and Multiple Robots”. LS2N, Nantes, France, July 2017
  - “Graph-Theoretical Tools for Sensor-based Multi-Robot Applications”. Robolog 2017 workshop, IRISA, France, June 2017
  - “Collective Control, State Estimation and Human Interaction for Quadrotors in Unstructured Environments”. ICRA 2017 Workshop on Human Multi-Robot System Interaction, June 2017
  - “Recent results in Collective Control, State Estimation and Human Interaction for Quadrotors in Unstructured Environments”. Aerial Robotics workshop, Paris, France, March 2017
- Fabien Spindler: “ViSP integration in ROS ecosystem”, “Journée technique : retour d’expériences autour de ROS” organized by “Réseau métier des roboticiens et mécatroniciens”, Cité Scientifique de l’Université de Lille, August 2017.

10.1.4. 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 and vice-president of the Tremplin-ERC ANR program.
- Claudio Pacchierotti is the Chair of the IEEE Technical Committee on Haptics.
- Philippe Martinet is vice-president of the “GdR Robotique”. François Chaumette and Patrick Rives are members of its scientific council.

10.1.5. Scientific Expertise

- Marie Babel served as an expert for the International Mission of the French Research Ministry (MEIRIES).
- François Chaumette served as a Panel member for the ERC PE7 consolidator grants. He also served in the selection committee for a Professor position at UTC (Compiègne). He was also involved in the evaluation of a research proposal submitted to the Research Foundation of Flanders, and for an Associate Prof. position at the City University of Hong Kong.
- Claudio Pacchierotti was a member of the jury for the EuroHaptics Best PhD thesis award, for the Robotics Made in Italy Video Contest, and served for Hans Fischer Senior Fellowship at the Institute for Advanced Study of the Technical University of Munich (TUM-IAS).
- Paolo Robuffo Giordano was reviewer of ERC Starting Grants and Consolidator Grants for the EU, of ANR projects, and of NWO projects (Dutch funding agency).

- Patrick Rives served as member of the “Comité d’Evaluation” of the ANR Challenge “Malin” and of the ANR Challenge “Rose”.

10.1.6. 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.
- 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”.
- Alexandre Krupa is a member of the CUMIR (“Commission des Utilisateurs des Moyens Informatiques pour la Recherche”) of Inria Rennes-Bretagne Atlantique.
- Paolo Salaris is member of the “Comité de Suivi Doctoral (CSD)” of Inria Sophia Antipolis.

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”, 24 hours, M1, Université de Rennes 1

Master Elec: “Connected and geolocalized embedded applications”, 24 hours, M2, Université de Rennes 1

Licence Info: “Computer systems architecture”, 24 hours, L1, Université de Rennes 1

Licence and Master Elec: “Electronics project”,38 hours, L3 and M1, Université de Rennes 1

Portail Info-Elec: “Discovering programming and electronics”, 14 hours, L1, Université de Rennes 1

LabFab School Mobility: “Build your robot”, 30 hours, DU

Licence Miage: “Computer programming”, 78 hours, L3, Université de Rennes 1

Master Elec: “Instrumentation, localization, GPS”, 4 hours, M2, Université de Rennes 1

Master Elec: “Data fusion”, 20 hours, M2, 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:

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

10.2.2. Supervision

- Ph.D.: Renato José Martins, “Robust navigation and control of an autonomous vehicle”, defended in October 2017, supervised by Patrick Rives and Samuel Siqueira Bueno (CTI) [12]
- Ph.D.: Jason Chevrie, “Flexible needle steering using ultrasound visual servoing”, defended in December 2017, supervised by Alexandre Krupa and Marie Babel [11]
- Ph.D. in progress: Fabrizio Schiano, “Collective control with onboard sensors for multiple quadrotor UAVs”, to be defended in January 2018, supervised by Paolo Robuffo Giordano
- Ph.D. in progress: Pedro Patlan-Rosales, “A robotic control framework for quantitative ultrasound elastography”, to be defended in January 2018, supervised by Alexandre Krupa
- Ph.D. in progress: Quentin Bateux, “Visual servoing from global descriptors”, started in October 2014, supervised by Eric Marchand
- 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 Lécuyer (Hybrid group).
- 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 and Antonio Franchi (LAAS)
- Ph.D. in progress: Axel Lopez Gandia, “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 biopsy needle from haptic and ultrasound visual feedback”, started in October 2016, supervised by Alexandre Krupa, Maud Marchal (Hybrid group at Inria Rennes-Bretagne Atlantique and Irisa) and Laurent Launay (IRT b<>com)
- 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)
- Ph.D. in progress: Agniva Sengupta, “Localization and characterization of objects with unknown shapes”, started in January 2017, supervised by Alexandre Krupa and Eric Marchand
- Ph.D. in progress: Xavier De Tinguy de la Giroulière, “Conception de techniques d’interaction multi-sensorielles pour la manipulation dextre d’objets en réalité virtuelle”, started in September 2017, supervised by Maud Marchal, Anatole Lécuyer (Hybrid group) and Claudio Pacchierotti
- Ph.D. in progress: Rahaf Rahal, “Mixed tactile-force feedback for safe and intuitive robotic teleoperation”, started in October 2017, supervised by Paolo Robuffo Giordano and Claudio Pacchierotti
- Ph.D. in progress: Nicolas Le Borgne, “Contrôle partagé et navigation assistée d’un fauteuil roulant en extérieur”, started in October 2017, supervised by Marie Babel
- Ph.D. in progress: Florian Berton, “Design of a virtual reality platform for studying immersion and behaviours in aggressive crowds”, started in November 2017, supervised by Julien Pettré

10.2.3. External Ph.D. and HdR Juries

- François Chaumette: Abed Malti (HdR, reviewer, Tlecem University, Algeria), Guillaume Laurent (HdR, reviewer, Femto ST, Besançon), Sylvain Lanneau (Ph.D., member, LS2N, Nantes)
- Eric Marchand: Angélique Loesch (Ph.D., reviewer, Univ. Clermont Auvergne, CEA), Pierre Rolin (Ph.D., reviewer, Univ. de Nancy), Hristina Hristova (Ph.D., president, Univ. de Rennes 1)
- Paolo Robuffo Giordano: Alexandre Boeuf (Ph.D., reviewer, LAAS, Toulouse), Valerio Modugno (Ph.D., reviewer, University of Rome La Sapienza, Italy), Mohamed Sorour (Ph.D., reviewer, LIRMM, Montpellier)

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 new year’s lab greetings, for the Inria industry journey focused on data and applications in Paris, for the “Semaine de l’Informatique Graphique et de la Réalité virtuelle”, and for the Science and music journey.
- Marie Babel participated as a member in a panel discussion during the Digital Tech Conference organized in Rennes in December 2017.
- Julien Pettré wrote a vulgarization paper [68], explaining how crowd simulation is used in the field of visual effects for the movie and the video-game industries. The crowd simulation topic was presented during the “Pint of Science FR 2017” event, which organizes mini conferences animated by researchers in public places such as cafes and bars.

11. Bibliography

Major publications by the team in recent years

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[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

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