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Activity Report 2013

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
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THEME
Robotcs and Intelligent environ-
ments

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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 ourselves on the interaction between visual perception and action. This topic is significant because it provides an alternative to the traditional Perception-Decision-Action cycle. It is indeed possible to link more closely the perception and action aspects, by directly integrating the measurements provided by a vision sensor in closed loop control laws. Our objective is thus to design strategies of coupling perception and action from images for applications in robotics, computer vision, virtual reality and augmented reality.

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

Thanks to the recent arrival of Patrick Rives and his students in the group, which makes Lagadic now localized both in Rennes and Sophia Antipolis, the group now also focus 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 also the construction of the representations which are used at the task level. Simultaneous Localization and Mapping (Slam) is thus now one of our research area.

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

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

3. Research Program

3.1. Visual servoing

Basically, visual servoing techniques consist in using the data provided by one or several cameras in order to control the motions of a dynamic system [1]. Such systems are usually robot arms, or mobile robots, but can also be virtual robots, or even a virtual camera. A large variety of positioning tasks, or mobile target tracking, can be implemented by controlling from one to all the degrees of freedom of the system. Whatever the sensor

configuration, which can vary from one on-board camera on the robot end-effector to several free-standing cameras, a set of visual features has to be selected at best from the image measurements available, allowing to control the desired degrees of freedom. A control law has also to be designed so that these visual features $\mathbf{s}(t)$ reach a desired value \mathbf{s}^* , defining a correct realization of the task. A desired planned trajectory $\mathbf{s}^*(t)$ can also be tracked. The control principle is thus to regulate to zero the error vector $\mathbf{s}(t) - \mathbf{s}^*(t)$. With a vision sensor providing 2D measurements, potential visual features are numerous, since 2D data (coordinates of feature points in the image, moments, ...) as well as 3D data provided by a localization algorithm exploiting the extracted 2D features can be considered. It is also possible to combine 2D and 3D visual features to take the advantages of each approach while avoiding their respective drawbacks.

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

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

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

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

$$\dot{\mathbf{s}} = \frac{\partial \mathbf{s}}{\partial \mathbf{p}} \dot{\mathbf{p}} = \mathbf{L}_s \mathbf{v} \quad (2)$$

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

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

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

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

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

3.2. Visual tracking

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

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

3.3. Slam

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

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

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 motions, 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. Software and Platforms

5.1. ViSP: a visual servoing and tracking software library

Participants: Fabien Spindler [correspondant], Aurélien Yol, Eric Marchand, François Chaumette.

Since 2005, we develop and release under the terms of the GPLv2 licence, ViSP, an open source library available from <http://team.inria.fr/lagadic/visp/visp.html>. It allows fast prototyping of visual tracking and visual servoing tasks. ViSP was designed to be independent with 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 allows tracking of visual cues (dots, segments, ellipses,...) or 3D model-based tracking of known objects. Simulation capabilities are also available. ViSP and its full functionalities are presented in Fig. 1 and described in [6].

This year, we continued our efforts to improve the software by increasing the compatibility with exotic platforms, fixing issues, and by introducing an hybrid scheme in the model-based tracker to take advantage of texture. We also improved the documentation by providing tutorials covering the main capabilities of the software. Two releases were produced, one in February downloaded 1000 times and the other in July downloaded 730 times. With the help of the community, the last release was also packaged for Ubuntu 13.10. A new template tracker developed during A. Dame's Ph.D. was recently introduced and will be available in the next release.

Concerning ROS community, all the existing packages in "vision_visp" ROS stack (see http://www.ros.org/wiki/vision_visp) were updated and ported to catkin build system. To ease ViSP usage in the ROS framework, the last release was packaged for ROS.

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

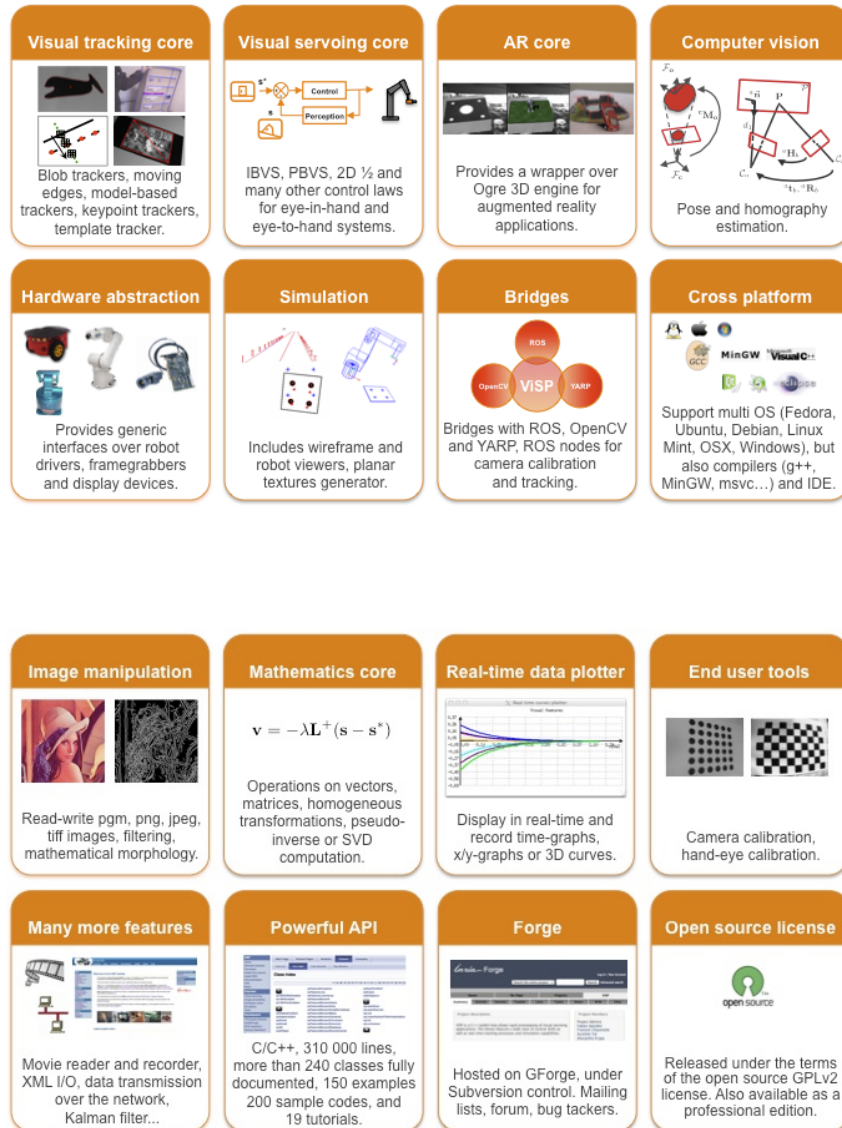


Figure 1. This figure highlights ViSP main capabilities for visual tracking, visual servoing, and augmented reality that may benefit from computer vision algorithms. ViSP allows controlling specific platforms through hardware abstraction or in simulation. ViSP provides also bridges over other frameworks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

5.2. DESlam software

Participant: Patrick Rives [correspondant].

The DESlam (Dense Egocentric Slam) software developed in collaboration with Andrew Comport from I3S in Sophia Antipolis was registered to the APP (“Agence de Protection des Programmes”) (IDDN.FR.001.320001.000.S.P.2012.000.21000). 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 indoors or outdoors environments and it allows to localize in real time (45Hz) a robot or a person carrying out a mobile camera.

5.3. Robot vision platforms

Participant: Fabien Spindler [correspondant].

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

Three papers published by Lagadic in 2013 enclose results validated on this platform.

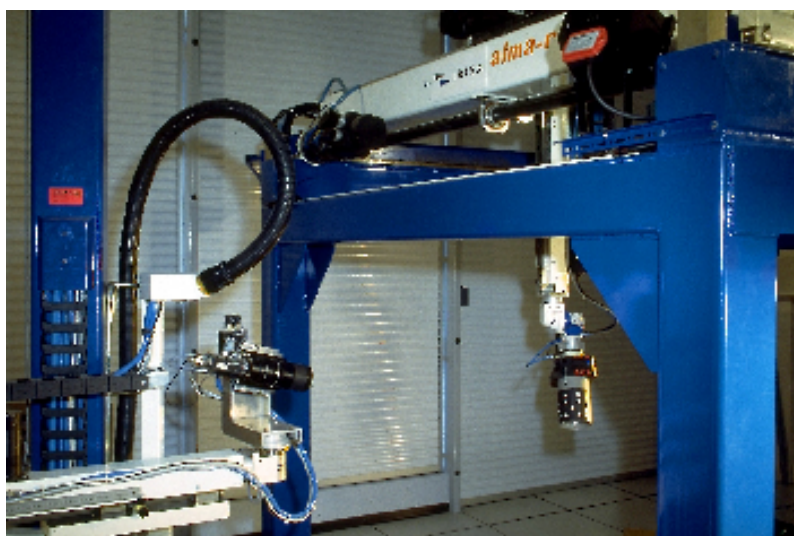


Figure 2. Lagadic robotics platforms for vision-based manipulation

5.4. Medical robotics platforms

Participants: Fabien Spindler [correspondant], Alexandre Krupa.

This testbed is of primary interest for researches and experiments concerning ultrasound visual servoing applied to positioning or tracking tasks described in Section 6.4.

This platform is composed by two Adept Viper six degrees of freedom arms (see Fig. 3). Ultrasound probes connected either to a SonoSite 180 Plus or an Ultrasonix SonixTouch imaging system can be mounted on a force torque sensor attached to each robot end-effector.

We started experimentation to validate needle detection and tracking under ultrasound imaging (see Section 6.4.1).

This year, two papers enclose experimental results obtained with this platform.

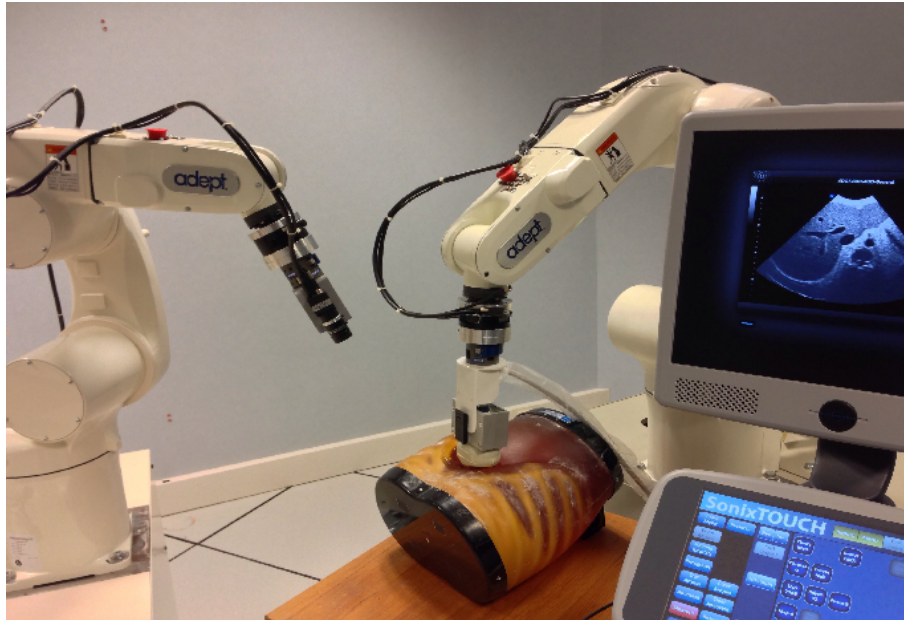


Figure 3. Lagadic medical robotics platforms. On the right Viper S850 robot arm equipped with a SonixTouch 3D ultrasound probe. On the left Viper S650 equipped with a tool changer that allows to attach a classical camera.

5.5. Mobile robotics platforms

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

5.5.1. Indoors 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. 4.a), and a Pioneer 3DX from Adept in Rennes (see Fig. 4.b) as well as a Robotino from Festo. These platforms are equipped with various sensors needed for Slam purposes, autonomous navigation and sensor-based control.

Moreover, to validate the researches in personally assisted living topic (see 6.3.4), we bought in Rennes a six wheel electric wheelchair from Penny and Giles Drives Technology (see Fig. 4.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 let us acquire the user intention through the joystick position and control the wheelchair by applying corrections to its motion. The wheelchair has been fitted with cameras to perform the required servoing for assisting handicapped people. Moreover, to ensure the direct security of the user, seven infrared proximity sensors have been installed all around the wheelchair.

Note that three papers exploiting the indoors mobile robots were published this year.

5.5.2. *Outdoors mobile robots*

The team exploits also Cycab urban electrical cars (see Figs. 4.d and 4.e). Two vehicles in Sophia Antipolis and one in Rennes are instrumented with cameras and range finders to validate researches in the domain of intelligent urban vehicle. Cycabs were used as experimental testbeds in several national projects.

Three papers published by Lagadic in 2013 enclose experimental results obtained with these outdoors mobile robots.

5.5.3. *Technological Development Action (ADT) P2N*

The ADT P2N aims at sharing existing and in development codes between the Lagadic and E-Motion teams in the field of autonomous navigation of indoors robots. These codes are also used in the platforms involved in the large-scale initiative action PAL (Personnally Assisted Living, see Section 8.2.6). This year, the most notable activities for this ADT have been to:

- adapt a navigation module developed by E-Motion to the mobile platform used at Sophia-Antipolis;
- make the SLAM module developed by Lagadic usable by the E-Motion navigation module;
- port the code on the wheelchairs used in PAL;
- develop the core architecture running under ROS supporting the different sensors and platforms available in Sophia-Antipolis.

6. New Results

6.1. Visual tracking

6.1.1. *3D model-based tracking*

Participants: Antoine Petit, Eric Marchand.

This study focused on the issue of estimating the complete 3D pose of the camera with respect to a potentially textureless object, through model-based tracking. We proposed to robustly combine complementary geometrical and color edge-based features in the minimization process, and to integrate a multiple-hypotheses framework in the geometrical edge-based registration phase [49], [48], [58], [11].

6.1.2. *Pose estimation through multi-planes tracking*

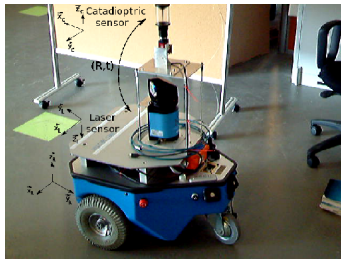
Participants: Bertrand Delabarre, Eric Marchand.

This study dealt with dense visual tracking robust towards scene perturbations using 3D information to provide a space-time coherency. The proposed method is based on a piecewise-planar scenes visual tracking algorithm which aims at minimizing an error between an observed image and reference templates by estimating the parameters of a rigid 3D transformation taking into account the relative positions of the planes in the scene. Both the sum of conditional variance and mutual information have been considered [39] [57].

6.1.3. *Pose estimation from spherical moments*

Participant: François Chaumette.

This study has been realized in collaboration with Omar Tahri from ISR in Coimbra (Portugal) and Youcef Mezouar from Institut Pascal in Clermont-Ferrand. It was devoted to the classical PnP (Perspective-from-N-Points) problem whose goal is to estimate the pose between a camera and a set of known points from the image measurement of these points. We have developed a new method based on invariant properties of the spherical projection model, allowing us to decouple the pose estimation in two steps: the first one provides the translation by minimizing a criterium using an iterative Newton-like method, the second one directly provides the rotation by solving a Procrustes problem [56], [26].



(a)



(b)



(c)



(d)



(e)

Figure 4. a) Hannibal platform, b) Pioneer P3-DX robot, c) six wheel electric wheelchair, d) Cycab available in Rennes, e) one of the Cycabs available in Sophia Antipolis.

6.1.4. Structure from motion

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

Structure from motion (SfM) is a classical and well-studied problem in computer and robot vision, and many solutions have been proposed to treat it as a recursive filtering/estimation task. However, the issue of *actively* optimizing the transient response of the SfM estimation error has not received a comparable attention. In the work [55], we studied the problem of designing an online active SfM scheme characterized by an error transient response equivalent to that of a reference linear second-order system with desired poles. Indeed, in a nonlinear context, the observability properties of the states under consideration are not (in general) time-invariant but may depend on the current state and on the current inputs applied to the system. It is then possible to simultaneously act on the estimation gains and system inputs (i.e., the camera velocity for SfM) in order to optimize the observation process and impose a desired transient response to the estimation error. The theory developed in [55] has a general validity and can be applied to many different contexts: in [55] it is shown how to tailor the proposed machinery to two concrete SfM problems involving structure estimation for point features and for planar regions from measured image moments.

6.1.5. 3D reconstruction of transparent objects

Participant: Patrick Rives.

This work has been realized in collaboration with Nicolas Alt, Ph.D. student at the “Technische Universität München” (TUM).

Visual geometry reconstruction of unstructured domestic or industrial scenes is an important problem for applications in virtual reality, 3D video or robotics. With the advent of Kinect sensor, accurate and fast methods for 3D reconstruction have been proposed. However, transparent objects cannot be reconstructed with methods that assume a consistent appearance of the observed 3D structure for different viewpoints. We proposed an algorithm that searches the depth map acquired by a depth camera for inconsistency effects caused by transparent objects. Consistent scene parts are filtered out. The result of our method hence complements existing approaches for 3D reconstruction of Lambertian objects [30].

6.1.6. Pseudo-semantic segmentation

Participants: Rafik Sekkal, Marie Babel.

This study has been realized in collaboration with Ferran Marques from Image Processing Group of the Technical University of Catalonia (Barcelona). We designed a video segmentation framework based on contour projections. This 2D+t technique provides a joint hierarchical and multiresolution solution. Results obtained on state-of-the-art benchmarks have demonstrated the ability of our framework to insure the spatio-temporal consistency of the regions along the sequence.

6.1.7. Augmented reality

Participants: Pierre Martin, Eric Marchand.

Using Simultaneous Localization And Mapping (SLAM) methods becomes more and more common in Augmented Reality (AR). To achieve real-time requirement and to cope with scale factor and the lack of absolute positioning issue, we proposed to decouple the localization and the mapping step. This approach has been validated on an Android Smartphone through a collaboration with Orange Labs [44].

Dealing with AR, we have proposed a method named Depth-Assisted Rectification of Patches (DARP), which exploits depth information available in RGB-D consumer devices to improve keypoint matching of perspective distorted images [43].

6.2. Visual servoing

6.2.1. Photometric moment-based visual servoing

Participants: Manikandan Bakthavatchalam, François Chaumette.

This goal of this work is to use a set of photometric moments as visual features for visual servoing. We first determined the analytical form of the interaction matrix related to these moments. From the results obtained in the past from binary moments, we then selected a set of four features to control four degrees of freedom (dof) with excellent decoupling and stability properties [35]. More recently, thanks to a collaboration with Omar Tahri from ISR Coimbra in Portugal, these results have been extended to the full six dof case.

6.2.2. *Visual servoing of humanoid robot*

Participant: François Chaumette.

This study has been realized in collaboration with the Pal robotics company located in Barcelona, Spain. It was devoted to the control of the arm of a humanoid robot by visual servoing for manipulation tasks [29].

6.2.3. *Visual servoing of cable-driven parallel robot*

Participant: François Chaumette.

This study is realized in collaboration with Rémy Ramadour and Jean-Pierre Merlet from Coprin group at Inria Sophia Antipolis. Its goal is to adapt visual servoing techniques for cable-driven parallel robot in order to achieve accurate manipulation tasks. This study is in the scope of the Inria large-scale initiative action PAL (see Section 8.2.6).

6.2.4. *Nanomanipulation*

Participants: Le Cui, Eric Marchand.

We began a work, within the ANR P2N Nanorobust project (see Section 8.2.1), on the development of micro- and nano-manipulation within SEM (Scanning Electron Microscope). Our goal is to provide visual servoing techniques for positioning and manipulation tasks with a nanometer precision. This year, we focused on the characterisation of the projection model of a SEM along with the approach required for its calibration.

6.3. *Visual navigation of mobile robots*

6.3.1. *New RGB-D sensor design for indoor 3D mapping*

Participants: Eduardo Fernandez Moral, Patrick Rives.

A multi-sensor device has been developed for omnidirectional RGB-D (color+depth) image acquisition (see Figure 5.a). This device allows acquiring such omnidirectional images at high frame rate (30 Hz). This approach has advantages over other alternatives used nowadays in terms of accuracy and real-time spherical image construction of indoor environments, which are of particular interest for mobile robotics. This device has important prospective applications, such as fast 3D-reconstruction or simultaneous localization and mapping (SLAM). A novel calibration method for such device has been developed. It does not require any specific calibration pattern, taking into account the planar structure of the scene to cope with the fact that there is no overlapping between sensors. A method to perform image registration and visual odometry has also been developed. This method relies in the matching of planar primitives that can be efficiently obtained from the depth images. This technique performs considerably faster than previous registration approaches based on ICP.

6.3.2. *Long term mapping*

Participants: Tawsif Gokhool, Patrick Rives.

This work inscribes in the context of lifelong navigation and map building. The kind of representation that we focus on is made up of a topometric map consisting of a graph of spherical RGB-D views. Thanks to the use of a saliency map built from the photometric and geometric data, we are able to characterize the conditioning of the pose estimation algorithm and to keep as keyframes only a subset of the spherical RGB-D views acquired on the fly. Subsequently, a study on the spread of keyframes was made. The aim was to investigate ways of covering completely and optimally the explored environment in a pose graph representation. Again, over here, the benefits are twofold. Firstly, data acquisition at a throttle of 30 Hz induces many redundant information in the database, which may not necessarily contribute much to the registration phase. Therefore, intelligent selection of keyframes helped in the reduction of data redundancy. Furthermore, as pointed out in the literature, frame to keyframe alignment has the advantage of reducing trajectory drift since the propagation error is diminished as well (see Figure 5.b)

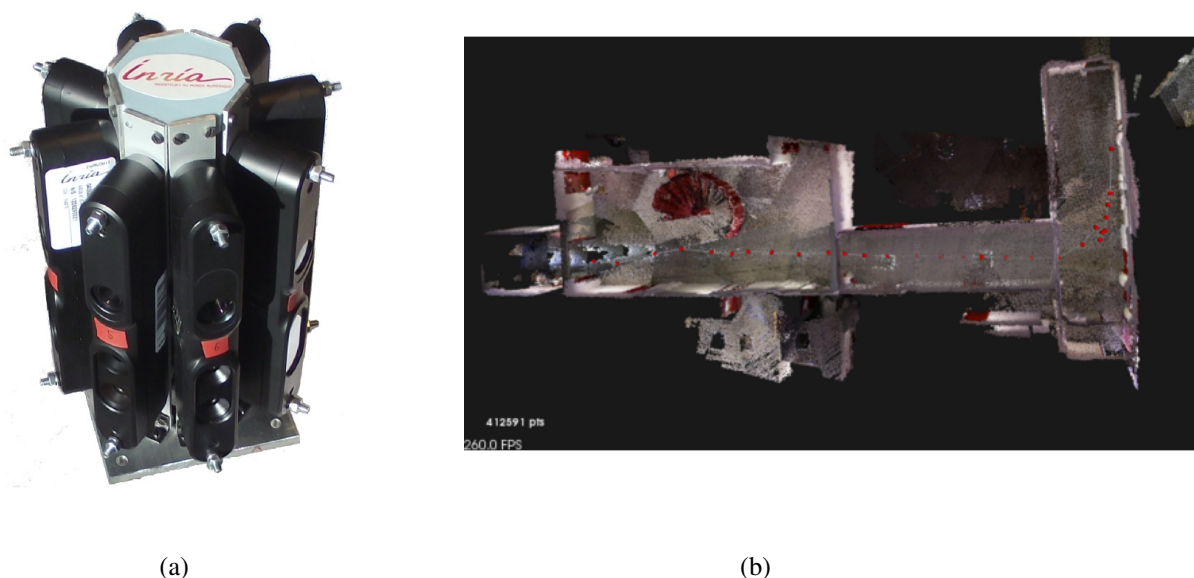


Figure 5. a) Omnidirectional RGB-D sensor, b) Top view of dense visual SLAM with fusion of intensity and depth

6.3.3. Semantic mapping

Participants: Romain Drouilly, Patrick Rives.

Semantic mapping aims at building rich cognitive representations of the world in addition to classical topometric maps. A dense labeling has been achieved from high resolution outdoor images using an approach combining Random Forest (RF) and Conditional Random Field (CRF). A second development dealt with the use of semantic information for localization in indoor scenes. For this kind of scenes dense labeling is more difficult due to the large number of potential classes. Therefore algorithms developed for this task rely on a sparse representation of indoor environments called “pbmap”. It consists of a graph whose nodes are the planes present in a given scene. These planes are the only parts of the scene that are labeled. Very high labeling rates of planes has been reached (more than 90%) and it has been shown that these labeled planes could be useful for localization and navigation tasks.

6.3.4. Autonomous navigation of wheelchairs

Participants: Rafik Sekkal, François Pasteau, Marie Babel.

The goal of this work is to design an autonomous navigation framework of a wheelchair by means of a single camera and visual servoing. We focused on a corridor following task where no prior knowledge of the environment is required. The servoing process matches the non-holonomic constraints of the wheelchair and relies on two visual features, namely the vanishing point location and the orientation of the median line formed by the straight lines related to the bottom of the walls [53]. This overcomes the initialization issue typically raised in the literature. The control scheme has been implemented onto a robotized wheelchair and results show that it can follow a corridor with an accuracy of ± 3 cm [47]. This study is in the scope of the Inria large-scale initiative action PAL (see Section 8.2.6) as well as of the Apash project (see Section 8.1.2).

6.3.5. Semi-autonomous control of a wheelchair for navigation assistance along corridors

Participants: Marie Babel, François Pasteau, Alexandre Krupa.

This study concerns a semi-autonomous control approach that we designed for safe wheelchair navigation along corridors. The control relies on the combination of a primary task of wall avoidance performed by a dedicated visual servoing framework and a manual steering task. A smooth transition from manual driving to assisted navigation is obtained thanks to a gradual visual servoing activation method that guarantees the continuity of the control law. Experimental results clearly show the ability of the approach to provide an efficient solution for wall avoiding purposes. This study is in the scope of the Inria large-scale initiative action PAL (see Section 8.2.6) as well as of the Apash project (see Section 8.1.2).

6.3.6. Target tracking

Participants: Ivan Markovic, François Chaumette.

This study was realized in the scope of the FP7 Regpot Across project (see Section 8.3.1.2) during the three-month visit of Ivan Markovic, Ph.D. student at the University of Zagreb. It consisted in developing a pedestrian visual tracking from an omni-directional fish-eye camera and a visual servoing control scheme so that a mobile robot is able to follow the pedestrian. This study has been validated on our Pioneer robot (see Section 5.5).

6.3.7. Obstacle avoidance

Participants: Fabien Spindler, François Chaumette.

This study was realized in collaboration with Andrea Cherubini who is now Assistant Prof. at Université de Montpellier. It is concerned with our long term researches about visual navigation from a visual memory without any accurate 3D localization [9]. In order to deal with obstacle avoidance while preserving the visibility in the visual memory, we have proposed a control scheme based on tentacles for fusing the data provided by a pan-tilt camera and a laser range sensor [14]. Recent progresses have been obtained by considering moving obstacles [38].

6.4. Medical robotics

6.4.1. Needle detection and tracking in 3D ultrasound

Participants: Pierre Chatelain, Alexandre Krupa.

We developed an algorithm for detecting and tracking a flexible needle in a sequence of 3D ultrasound volumes when it is manually inserted, without any a priori information on the insertion direction. Our approach is based on the combination of a RANSAC algorithm with Kalman filtering in a closed loop fashion and allows real-time tracking of the needle. In addition, a pose-based visual servoing was developed for automatically moving a robotized 3D ultrasound probe in order to keep the needle tip centered in the volume and to align its main axis with the central plane of the volume. This needle detection algorithm and probe automatic guidance were experimentally validated during the insertion of a needle in a gelatin phantom [37].

6.4.2. Non-rigid target tracking in ultrasound images

Participants: Marie Babel, Alexandre Krupa.

In order to robustly track the motion of a tumour or cyst during needle insertion, we developed a new approach to track a deformable target within a sequence of 2D ultrasound images. It is based on a dedicated hierarchical grid interpolation algorithm (HGI) that is typically used for real-time video compression purposes. This approach provides a continuous motion representation of the target by using a grid of control points that models both their global displacement and local deformations. The motion of each control point is estimated by a hierarchical and multi-resolution local search method in order to minimize the sum of squared difference of the target pixel intensity between successive images. This new approach was validated from 2D ultrasound images of real human tissues undergoing rigid and non-rigid deformations.

6.4.3. Adaptive arc-based path planning for robot-assisted needle 3D steering using duty-cycling control technique

Participant: Alexandre Krupa.

This study concerned the development of a method for three dimensional steering of a beveled-tip flexible needle that can be used in medical robotics for percutaneous assistance procedures. The proposed solution is the extension of an adaptive arc-based 2D planar approach. It combines the Rapidly-Exploring Random Tree (RRT) algorithm, the duty-cycling needle control technique and stop and turn phases to reorientate the needle in a new working plane each time it is necessary. Simulation results demonstrate the feasibility of this approach to reach a 3D target while avoiding obstacles and its robustness to needle kinematic model errors.

6.4.4. Gait analysis

Participants: Cyril Joly, Patrick Rives.

Clinical evaluation of frailty in the elderly is the first step to decide the degree of assistance they require. Advances in robotics make it possible to turn a standard assistance device into an augmented device that may enrich the existing tests with new sets of daily measured criteria. We designed an augmented 4-wheeled rollator, equipped with a Kinect and odometers, for daily biomechanical gait analysis. It allows to estimate on line legs and feet configurations during the walk. Preliminary results [42] obtained on four healthy persons show that relevant data can be extracted for gait analysis (e.g. foot orientation and tibia-foot angle, feet position) during an assisted walk.

This work has been realized in collaboration with Claire Dune from the University of Toulon and in the scope of the Inria large-scale initiative action PAL (see Section 8.2.6).

6.5. Control of single and multiple UAVs

6.5.1. State estimation and flight control of quadrotor UAVs

Participants: Riccardo Spica, Paolo Robuffo Giordano.

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

Key components for the successful deployment of such systems are (i) a reliable state estimation module able to deal with highly unstructured and/or GPS-denied indoor environments, and (ii) a robust flight control algorithm able to cope with model uncertainties and external disturbances (e.g., adverse atmospheric conditions). The difficulty of these estimation and control problems is also increased by the limited amount of sensing and processing capabilities onboard standard quadrotors: this clearly imposes additional strict requirements on the complexity of the employed algorithms.

In the context of robust flight control of standard quadrotors, the works [31], [32] addressed the theoretical developments and experimental validation of a novel nonlinear adaptive flight controller able to estimate online the UAV dynamic parameters (such as the position of the center of mass when carrying unmodeled payloads), and to compensate for external wind gusts. In parallel, we also developed in [54] a high performance and open-source hardware/software control architecture for flight control of quadrotor UAVs made available to the general public on a open repository. This was achieved by combining state-of-the-art filtering and control techniques with a careful customization and calibration of a commercially available and low-cost quadrotor platform. Finally, still in the context of flight control, the work [51] reported a successful experimental validation of several flight tests for a novel overactuated quadrotor design with tilting propellers behaving as a fully-actuated rigid body in 3D space (thus, able to control its position and orientation in a fully decoupled way).

As for state estimation, the work [40] introduces a novel nonlinear estimation filter meant to obtain a metric measurement of the body-frame linear velocity from optical flow decomposition (thus, visual input) and concurrent fusion of the accelerometer/gyro readings from the onboard IMU. The peculiarity of this filtering technique is the possibility to both explicitly characterize and impose the transient response of the estimation error (thus, the filter performance) by acting on the estimation gains and UAV motion (acceleration). This is in contrast with the consolidated use of EKF schemes which, because of their inherent linearization of the system dynamics, do not typically allow to draw any conclusions about the stability/transient response of the estimation error.

These works were realized in collaboration with the robotics groups at the University of Cassino, Italy, and at the Max Planck Institute for Biological Cybernetics, Tübingen, Germany.

6.5.2. *Collective control of multiple UAVs*

Participant: Paolo Robuffo Giordano.

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

In the context of multi-robot (and multi-UAV) coordinated control, *connectivity* of the underlying graph is perhaps the most fundamental requirement in order to allow a group of robots accomplishing common goals by means of *decentralized* solutions. In fact, graph connectivity ensures the needed continuity in the data flow among all the robots in the group which, over time, makes it possible to share and distribute the needed information. In this respect, in [23] a fully decentralized strategy for continuous connectivity maintenance for a group of UAVs has been theoretically developed and experimentally validated on a team of 4 quadrotor UAVs. An extension for allowing an external planner (e.g., a human user) to vary online the minimum degree of connectivity of the group was also proposed in [52]. Finally, [45] dealt with the issue of coupling the purely reactive strategy for connectivity maintenance with an autonomous exploration algorithm in a cluttered 3D environment (still experimentally tested on a team of quadrotor UAVs). The complete software architecture developed for performing these and similar multi-UAV experiments was also published in [41].

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

7. Bilateral Contracts and Grants with Industry

7.1. Bilateral Contracts with Industry

7.1.1. *Foundation EADS*

Participants: Antoine Petit, Eric Marchand.

no. Inria Rennes 5605, duration: 36 months.

This contract ended in December 2013. It supported Antoine Petit's Ph.D. about 3D model-based tracking for applications in space (see Section 6.1.1).

7.1.2. *Astrium EADS*

Participants: Tawsif Gokhool, Patrick Rives.

no. Inria Sophia 7128, duration: 36 months.

The objective of this project that started in February 2012 is to investigate the general problem of visual mapping of complex 3D environments that evolve over time. This contract supports Tawsif Gokhool's Ph.D. (see Section 6.3.2).

7.1.3. ECA Robotics

Participants: Romain Drouilly, Patrick Rives.

no. Inria Sophia 7030, duration: 36 months.

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

8. Partnerships and Cooperations

8.1. Regional Initiatives

8.1.1. i-Lab ExtAR

Participants: Clément Samson, Eric Marchand.

duration: 24 months.

ExtAR is an Inria i-Lab with Artefacto that started in March 2011. Its goal was to develop an augmented reality library for smartphones.

8.1.2. Oseo Apash project

Participants: François Pasteau, Marie Babel.

no Insa Rennes 2012-230, duration: 24 months.

Started in September 2012, the Apash project is supported by the Images & Réseaux cluster. It involves three laboratories connected to INSA Rennes, namely Irisa/Inria, IETR and LGCGM. Two industrial partners take part into this project: AdvanSEE and Ergovie. It aims at designing a driving assistance for electrical wheelchair towards the autonomy and security of disabled people. The work realized within this project is described in Section 6.3.4.

8.1.3. ARED NavRob

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

no Inria Rennes 8033, duration: 36 months.

This project funded by the Brittany council started in October 2013. It supports in part Suman Bista's Ph.D. about visual navigation of a humanoid robot (see Section 8.2.4).

8.2. National Initiatives

8.2.1. ANR P2N Nanorobust

Participants: Le Cui, Eric Marchand.

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

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

8.2.2. ANR Contint Visioland

Participants: Patrick Rives, François Chaumette.

duration: 48 months.

This project started in November 2013. It is composed of a consortium managed by Onera in Toulouse with Airbus, Spikenet Technology, Ircsyn, and Lagadic. It aims to develop vision-based localization and navigation techniques for an autonomous landing on a runway.

8.2.3. PEA Decsa

Participants: Aurélien Yol, Eric Marchand.

no Inria Rennes 6630, duration: 36 months.

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

8.2.4. Oseo Romeo 2

Participants: Nicolas Cazy, Suman Bista, Fabien Spindler, Paolo Robuffo Giordano, François Chaumette.

no Inria Rennes 7114, duration: 48 months.

This project started in November 2012. It is composed of a large consortium managed by Aldebaran Robotics. It aims to develop advanced control and perception functionalities to a humanoid robot. It supports in part Suman Bista's Ph.D. about visual navigation of a humanoid robot (see Section 8.2.4), as well as Nicolas Cazy's Ph.D. about model-based predictive control for visual servoing.

8.2.5. Equipex Robotex

Participants: Fabien Spindler, François Chaumette.

no Inria Rennes 6388, duration: 10 years.

Lagadic is one of the 15 French partners involved in the Equipex Robotex network. It is devoted to get significative equipments in the main robotics labs in France. In a near future, we plan to buy a humanoid robot, Romeo, by Aldebaran Robotics.

8.2.6. Inria large scale initiative action PAL

Participants: François Pasteau, Vishnu Narayanan, Cyril Joly, Marie Babel, Patrick Rives, François Chaumette.

Lagadic participates in the large-scale initiative action PAL (Personally Assisted Living) to develop technologies and services to improve the autonomy and quality of life for elderly and fragile persons. The purpose of PAL is to provide an experimental infrastructure, in order to facilitate the development of models, tools, technologies and concept demonstrations. Using the skills and objectives of the involved teams, four research themes have been defined: a) assessing the degree of frailty of the elderly, b) mobility of people, c) rehabilitation, transfer and assistance in walking, and d) social interaction. Lagadic is currently involved in the themes "mobility of people" and "assistance in walking" through collaborations with the EPI e-Motion (Grenoble), EPI Coprin (Sophia-Antipolis), and Handibio (Toulon). See Sections 6.2.3, 6.3.4, 6.3.5 and 6.4.4.

Furthermore, the annual three-day PAL workshop has been organized in Rennes by François Pasteau, Marie Babel and Céline Gharsalli in July 2013.

8.3. European Initiatives

8.3.1. FP7 Projects

8.3.1.1. FP7 Space RemoveDEBRIS

Participants: Eric Marchand, Fabien Spindler, François Chaumette.

Instrument: Specific Targeted Research Project

Duration: from October 2013 till September 2016

Coordinator: University of Surrey (United Kingdom)

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

Inria contact: François Chaumette

Abstract: The goal of this project is to validate the model-based tracking algorithms developed during Antoine Petit's Ph.D. (see Section 6.1.1) on images acquired during an actual space debris removal mission.

8.3.1.2. FP7 Regpot Across

Participant: François Chaumette.

Program: Regpot

Project acronym: Across

Project title: Center of Research Excellence for Advanced Cooperative Systems

Duration: from September 2011 till March 2015

Coordinator: Prof. Ivan Petrovic from University of Zagreb (Croatia)

Other partners: KTH (Sweden), ETHZ (Switzerland), TUM (Germany), University of Manchester (UK), Vienna University of Technology (Austria), Politecnico di Milano (Italy), University of Sevilla (Spain), Eindhoven University of Technology (The Netherlands), University of Athens (Greece), etc.

Abstract: the goal of this project is to enhance collaborations with the University of Zagreb.

8.4. International Initiatives

8.4.1. Participation In other International Programs

- As a follow up to the long term collaboration with the “Centro de Tecnologia da Informação Renato Archer” (CTI) in Campinas (Brazil), a new Ph.D. student, Renato José Martins, joined the team in Sophia Antipolis thanks to a grant from the CNPq (2013-2017). He is co-directed by Patrick Rives and Samuel Siqueira Bueno from “Divisão de Robótica e Visão Computacional” at CTI. In the context of the project MuNave, funded by the Inria/CNPq Collaboration framework (2010-2012), Geraldo Silveira, researcher at CTI, has spent a one-week visit in Sophia Antipolis in May 2013.
- Alexandre Krupa started a collaboration with Nassir Navab from the Technische Universität München by beginning since September 2013 the joint supervision of Pierre Chatelain's Ph.D.

8.5. International Research Visitors

8.5.1. Visits of International Scientists

8.5.1.1. Internships

- Raul Orlando Alvarado Lara and Francisco-Javier Rangel Butanda from the University of Guanajuato in Mexico did a 4-month master internship in Rennes. It was granted by Conacyt and their work was about visual servoing and 3D localization respectively.

- Ivan Markovic, Ph.D. student at the University of Zagreb, spent a three-month visit in Rennes in the scope of the FP7 Regpot Across project (see Section 8.3.1.2 and 6.3.6).
- Eduardo Moral-Fernandez, Ph.D. student at the Universidad de Malaga, Spain, visited our group in Sophia Antipolis from March to December 2013. He worked on dense SLAM using omnidirectional RGB-D sensors.

8.5.2. Visits to International Teams

- Manikandan Bakthavatchalam spent a three-month visit at ISR in Coimbra, Portugal, for collaborating with Omar Tahri about visual servoing based on photometric moments (see Section 6.2.1).
- Rafiq Sekkal spent a two-month visit at UPC in Barcelona, Spain, to collaborate with Ferran Marques on contour-based spatio-temporal segmentation (see Section 6.1.6).
- Pierre Chatelain spent a four-month visit in Nassir Navab's lab at TUM, Germany, in the scope of his Ph.D.

9. Dissemination

9.1. Scientific Animation

- *Editorial boards of journals*
 - Eric Marchand and Paolo Robuffo Giordano are Associate Editors of the IEEE Trans. on Robotics.
 - Eric Marchand is a Guest Editor (with Peter Corke and Jana Kosecka) of a Special Issue of the Int. Journal of Robotics Research on Robot Vision.
 - François Chaumette is in the Editorial Board of the Int. Journal of Robotics Research.
- *Technical program committees of conferences*
 - François Chaumette: WRV'13, ICRA'13, RSS'13, ICRA'14
 - Eric Marchand: ICRA'13, IROS'13, ISMAR'13 (area chair), RSS'13, ORASIS'13, ICRA'14, RFIA'14 (area chair)
 - Patrick Rives: RFIA'14
 - Paolo Robuffo Giordano: ICRA'13, RSS'13, IJCAI'13, ICRA'14
 - Alexandre Krupa: Orasis'13
 - Marie Babel: ACIVS'13
- *Selection committees*
 - Patrick Rives participated to the selection committees of research scientists (CR2) at Inria Nancy-Grand Est, Inria senior researchers (DR2), and Inria Starting and Advanced Research positions. .
 - François Chaumette was in the selection committee for an Assistant Professor position at the "Université Blaise Pascal" in Clermont-Ferrand. He also served in the jury for the selection of research scientists (CR2) at Inria Rhône-Alpes.
 - Eric Marchand was in the selection committee for an Assistant Professor position at INSA Rennes.
 - Alexandre Krupa was in the selection committee for an Assistant Professor position at the "Université de Montpellier 2".
- *Participation in seminars, invitation*
 - Alexandre Krupa was invited by Nassir Navab to give a talk at the Chair for Computer Aided Medical Procedures (CAMP) from the Technische Universität München in May 2013.

- François Chaumette was invited to give a seminar at the University of Zagreb during a one-week visit in July 2013 in the scope of the FP7 Across Regpot project (see Section 8.3.1.2). He also gave a talk at DGA-MI in Bruz during a workshop about visual localization.
- Paolo Robuffo Giordano was invited to give talks at I3S in Sophia-Antipolis, Inria Grenoble, Isir in Paris, Ensam in Paris in the scope of the “GdR Robotique”, and University of Rome “La Sapienza”. He also presented an invited talk at the IEEE/RSJ IROS Workshop on Vision-based Closed-Loop Control and Navigation of Micro Helicopters in GPS-denied Environments [28].
- Fabien Spindler was invited to present the ViSP software at the “Journées technologiques Robotex” in Toulouse in June 2013.
- *Animation at the international level*
 - François Chaumette served as a panel member of the ERC Consolidator Grants (PE7). He also served in the 2013 IEEE RAS Fellow Nomination Committee.
 - Paolo Robuffo Giordano served as external reviewer for evaluating research proposals of the Swiss National Science Foundation (SNSF).
 - Paolo Robuffo Giordano co-organized the ICRA’13 workshop “Towards Fully Decentralized Multi-Robot Systems: Hardware, Software and Integratio”, Karlsruhe, Germany and the “Sixth Workshop on Human-Friendly Robotics” at the University of Rome “La Sapienza”, Italy.
- *Animation at the national level*
 - François Chaumette and Patrick Rives are members of the scientific council of the “GdR Robotique” and JNRR.
 - Eric Marchand was a member of the AERES evaluation panel for U2IS lab at ENSTA Paristech.
 - Patrick Rives is a member of the Inria evaluation committee.
 - Alexandre Krupa is a member of the Inria Cost-GTAI in charge of the evaluation of the ADTs (“Actions de développements technologiques”).
- *Animation at the regional and local levels*
 - Eric Marchand is in the board of the “Images et réseaux” competitiveness cluster.
 - Alexandre Krupa is a member of the GestChir project at the IRT B-Com in Rennes.
 - Eric Marchand is a member of the scientific council of the “École supérieure d’ingénieurs de Rennes” (ESIR).
 - François Chaumette is 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 is a member of the committee in charge of all the temporary recruitments (“Commission Personnel”) at Inria Rennes-Bretagne Atlantique and Irisa. He is particularly in charge of Irisa Ph.D. students.
 - Marie Babel is a member of the “Comité de centre” of Inria Rennes-Bretagne Atlantique.
 - Fabien Spindler is a member of the “Commission développement durable” of Inria Rennes-Bretagne Atlantique.
 - Alexandre Krupa is a member of the CUMIR (“Commission des Utilisateurs des Moyens Informatiques”) of Inria Rennes-Bretagne Atlantique.

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

Marie Babel:

Master INSA3: “Statistical Signal Processing”, 24 hours, M2, INSA Rennes
 Master INSA1: “Assembler”, 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”, 24 hours, L3, INSA Rennes
 Master INSA1: “Risk Management for Information Systems”, 8 hours, L3, INSA Rennes

François Chaumette:

Master ESIR3: “Visual servoing”, 10 hours, M2, Ecole supérieure d’ingénieurs de Rennes

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

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

Paolo Robuffo Giordano

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

9.2.2. Supervision

9.2.2.1. Ph.D.

Ph.D.: Tao Li, “Commande d’un robot de télé-échographie par asservissement visuel échographique”, Université de Rennes 1, defense in February 2013, supervised by Alexandre Krupa [10]

Ph.D.: Antoine Petit, “3D model-based tracking of complex objects in a spatial context”, Université de Rennes 1, defense in December 2013, supervised by Eric Marchand [11]

Ph.D. in progress: Rafik Sekkal, “Features extraction and robust tracking of objects for video representation”, started in October 2010, supervised by Marie Babel

Ph.D. in progress: Manikandan Bakthavatchalam, “Utilisation des moments photométriques en asservissement visuel”, started in October 2011, supervised by François Chaumette

Ph.D. in progress: Bertrand Delabarre, “An information theoretic approach for navigation in robotics”, started in October 2011, supervised by Eric Marchand

Ph.D. in progress: Tawsif Gokhool, “Représentations valides à long terme pour la navigation et l’apprentissage des modèles 3D”, started in February 2012, supervised by Patrick Rives

Ph.D. in progress: Romain Drouilly, “Représentation hybride métrique, topologique et sémantique d’environnement 3D pour la localisation temps réel”, started in May 2012, supervised by Patrick Rives

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

Ph.D. in progress: Riccardo Spica, “Autonomous vision-based two-hand manipulation strategies for humanoid robots”, started in December 2012, supervised by Paolo Robuffo Giordano and François Chaumette

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

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

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

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

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

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

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

9.2.2.2. Internships

- Antoine Berlon, Master in computer science, Univ. de Rennes 1
- Grégoire Boizante, Master at INSA Rennes
- Baptiste Brun, Master in computer science, Univ. de Rennes 1
- Sylvain Devie, Graduate student, ENS Cachan Bretagne
- Corentin Hardy, Graduate student, ENS Cachan Bretagne
- Lucas Royer, Master at INSA Rennes

9.2.3. Juries

- François Chaumette: Hugues Sert (Ph.D., reviewer, Inria Lille), Soukalo Dembele (HdR, reviewer, Femto, Besançon), Olivier Stasse (HdR, Laas, Toulouse), Nicolas Mansard (HdR, Laas, Toulouse), Fabien Expert (Ph.D, ISM, Marseille)
- Patrick Rives: Hugues Sert (Ph.D., Inria Lille), Benjamin Lefaudeux (Ph.D., Inria Rocquencourt)
- Eric Marchand: Cyril Roussillon (Ph.D., reviewer, LAAS, Toulouse), Joao Paulo Silva do Monte Lima (Ph.D., reviewer, Federal University of Pernambuco, Recife, Brazil), Tomy Tikkaälä (Ph.D., reviewer, I3S, Sophia-Antipolis), Jeff Delaune (Ph.D., reviewer, Onera, Toulouse), Mohamed Tamaazousti (Ph.D., reviewer, CEA, Fontenay-aux-Roses), Glauco Garcia Scandaroli (Ph.D., ISIR, Paris), Ricardo Marquès (Ph.D, president, Rennes), Pascal Lino (Ph.D, president, Rennes).
- Alexandre Krupa: Naresh Marturi (Ph.D., reviewer, Femto, Besançon)

9.3. Popularization

- Due to the visibility of our experimental platforms, the team is often asked to present its research activities to students, researchers or industry. Our panel of demonstrations allows us to highlight recent results concerning the positioning of an ultrasound probe by visual servoing, the construction of a tower by combining 3D model-based visual tracking and visual servoing techniques to pick up cubes that are assembled, the navigation of a mobile robot in urban environments, vision-based detection and tracking for space navigation in a rendezvous context, the semi-autonomous navigation of a wheelchair, and augmented reality applications.

- Fabien Spindler is a member of the editorial board of “Ouest Inria”, the internal journal at Inria Rennes-Bretagne Atlantique.
- Alexandre Krupa co-authored an article titled “Au coeur des hommes” in the journal DocSciences that is intended for general public. This article is about medical robotics guided from images [27]. An article entitled “L’asservissement visuel au service de la robotique médicale” has also been published in May 2013 in the “Emergences” general-public magazine of Inria Rennes-Bretagne Atlantique <http://emergences.inria.fr/lettres2013/newslettern26/126asservissementvisuel>.
- Paolo Robuffo Giordano participated to the “Café des sciences Drones” at the “Espace des sciences” in Rennes in November 2013 to illustrate his activities on quadrotor UAVs to the general public.
- Marie Babel and François Chaumette participated to the “Science Festival” in October 2013 with a debate after the projection of the film “Vivre avec des robots” in Brécé near Rennes.
- Marie Babel and François Pasteau gave a 1-hour lecture on “Assistance to the mobility: the place of the robotics” on December 13th, during the “Conf’Lunch” monthly seminar organised by Inria in Rennes. Furthermore, two articles related to wheelchair navigation have been published in general-public magazines, namely “Des yeux pour les fauteuils roulants” in “Emergences” in July 2013 (http://emergences.inria.fr/lettres2013/newsletter_n27/L27-FAUTEUIL) and “Un fauteuil qui a les yeux en face des roues” in “Sciences Ouest” (the magazine of the “Espace des sciences” in Rennes) in November 2013 (<http://www.espace-sciences.org/sciences-ouest/314/actualite/un-fauteuil-qui-a-les-yeux-en-face-des-roues>).

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Major publications by the team in recent years

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- [10] T. LI. *Commande d'un robot de télé-échographie par asservissement visuel*, Université Rennes 1, February 2013., <http://hal.inria.fr/tel-00803767>
- [11] A. PETIT. *Robust visual detection and tracking of complex objects: applications to space autonomous rendezvous and proximity operations*, Université Rennes 1, December 2013., <http://hal.inria.fr/tel-00931604>

Articles in International Peer-Reviewed Journals

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- [28] P. ROBUFFO GIORDANO. *Vision-Based Bilateral Shared Control and Autonomous Flight for Single and Multiple Quadrotor UAVs*, in "IEEE/RSJ IROS Int. Work. on Vision-based Closed-Loop Control and Navigation of Micro Helicopters in GPS-denied Environments", Tokyo, Japan, November 2013., <http://hal.inria.fr/hal-00923376>

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