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Activity Report 2012

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

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Project-Team LAGADIC

Keywords: Visual Servoing, Tracking, Slam, Computer Vision, Robotics, Intelligent Transportation System, Augmented Reality

Since April 2012, the Lagadic group is localized both in Rennes and Sophia Antipolis. The Lagadic part in Rennes is also an Irisa group.

Creation of the Project-Team: December 06, 2004 .

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2. Overall Objectives

2.1. Introduction

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 traditionaly 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.

2.2. Highlights of the Year

- Marie Babel and Alexandre Krupa have defended their HdR in June 2012 [10] and December 2012 [13] respectively.
- Our paper [38] related to visual servoing based on dense ultrasound images (see Section 6.4.1) has been selected as one of the three finalists for the Best Oral Presentation in the Hamlyn Symposium on Medical Robotics'2012.

3. Scientific Foundations

3.1. Visual servoing

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

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

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

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

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

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

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

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

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

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

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

3.2. Visual tracking

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

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

3.3. Slam

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

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

4. Application Domains

4.1. Overview

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

5.1. ViSP: a visual servoing platform

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

Since 2005, we develop and release under the terms of the GPLv2 licence, ViSP, an open source library that 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 and documentation quality. A new version available at http://www.irisa.fr/lagadic/visp/visp.html was released in July 2012. To ease ViSP installation, we provide also precompiled ViSP SDK including pre-built ViSP library and headers.

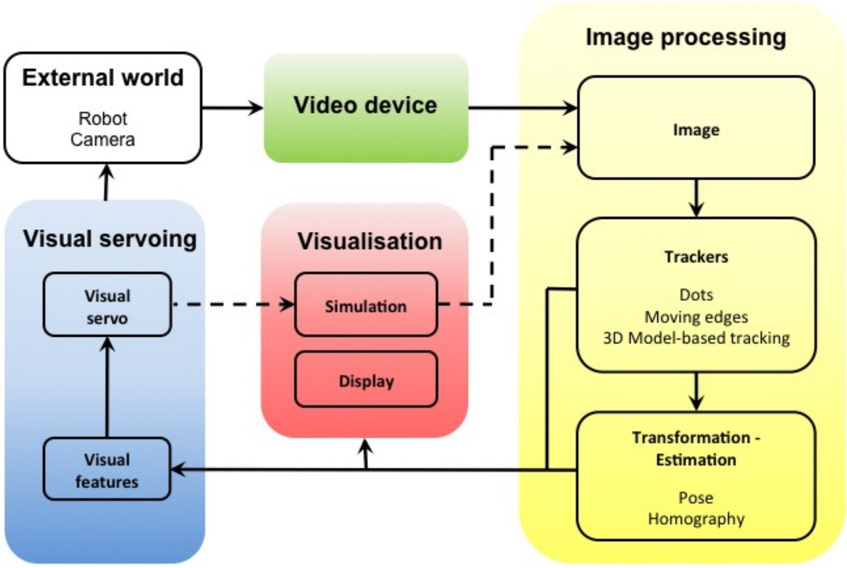


Figure 1. ViSP software architecture.

This last release under deposit to the APP ("Agence de Protection des Programmes") has been downloaded 887 times since its availability. It 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 a graduate course delivered at MIT, at IFMA Clermont-Ferrand and ESIR Rennes engineer schools. ViSP is now also part of "`vision_visp`" ROS stack (see http://www.ros.org/wiki/vision_visp) and ViSP 3D model-based tracker has been proposed by colleagues from Laas in Toulouse as a ROS package. This encouraged us to enhance "`vision_visp`" stack by proposing new ROS packages to calibrate intrinsic and extrinsic camera parameters, and a new 3D model-based tracker with automatic initialisation and reinitialisation after tracking loss (with help of specific textured patterns on the object).

5.2. DESlam

Participants: Patrick Rives [correspondant], Maxime Meilland.

The DESlam (Dense Egocentric Slam) software developed in collaboration with Andrew Comport from I3S in Sophia Antipolis was deposited 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. Development work: 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.

Two papers published by Lagadic in 2012 enclose results validated on this platform. Note that it is also opened to researcher from other labs. For example, this year an associate professor from LSIIT in Strasbourg did experiments on the Gantry robot.

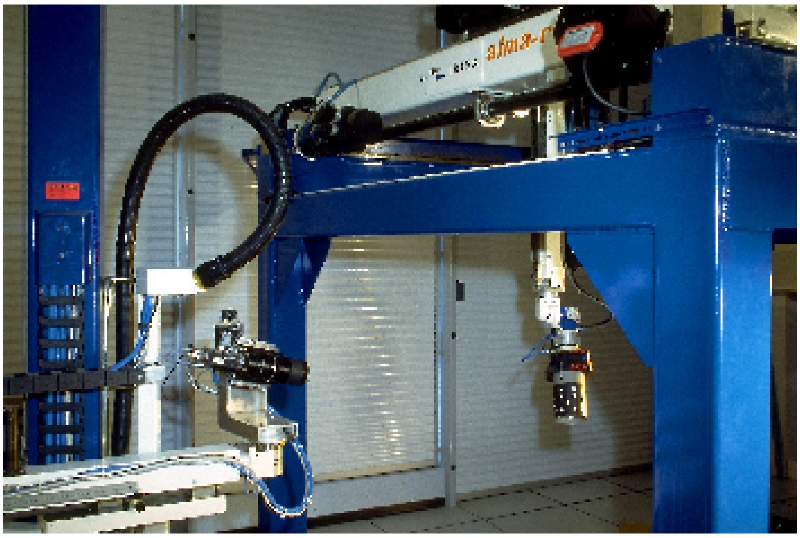


Figure 2. Lagadic robotics platforms for vision-based manipulation

5.4. Development work: Medical robotics platforms

Participants: Fabien Spindler [correspondant], Alexandre Krupa.

This tesbed 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 a six degrees of freedom Adept Viper S850 arm (see Fig. 3). This year we bought a new Adept Viper S650 arm to replace our eight year old Hippocrate medical arm designed by the Sinters company. 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 plan to exploit the two Viper robots for demonstrating needle insersion under ultrasound imaging to precisely guide the needle toward a target while optimizing its visibility (see Section 6.4.4).

Note that four papers published by Lagadic in 2012 enclose experimental results obtained with this platform.

5.5. Development work: Mobile robotics platforms

Participants: Fabien Spindler [correspondant], 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.

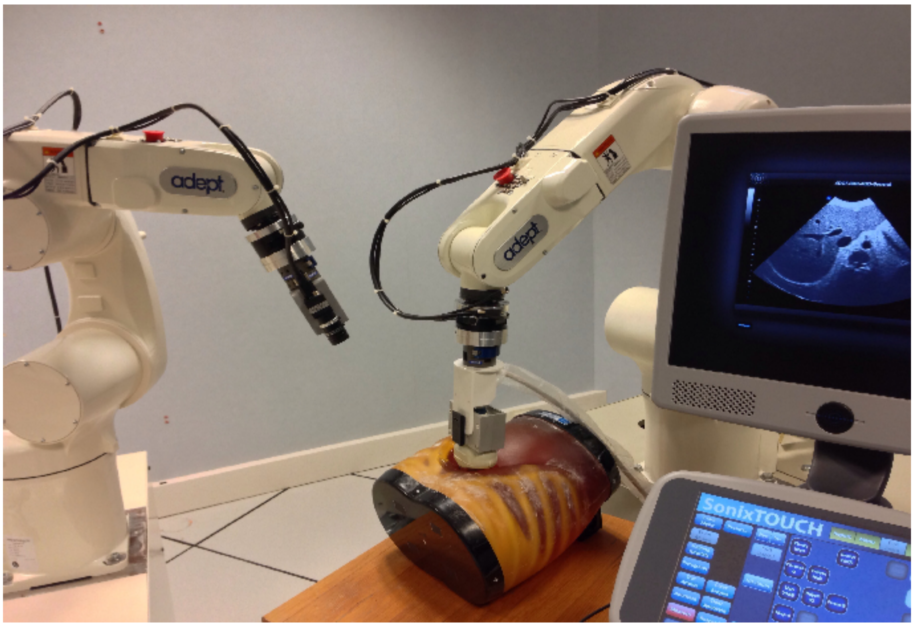


Figure 3. Lagadic medical robotics platforms. On the right Viper S850 robot arm equiped with a SonixTouch 3D ultrasound probe. On the left Viper S650 equipped with a tool changer that allows to attach a classical camera.

Moreover, to validate the researches in personally assisted living topic (see 6.3.6), 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 three cameras to perform the required servoing for assisting handicaped people. Moreover, to ensure the direct security of the user, seven infrared proximity sensors have been installed all around the wheelchair.

5.5.2. Outdoors mobile robots

The team exploit 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.

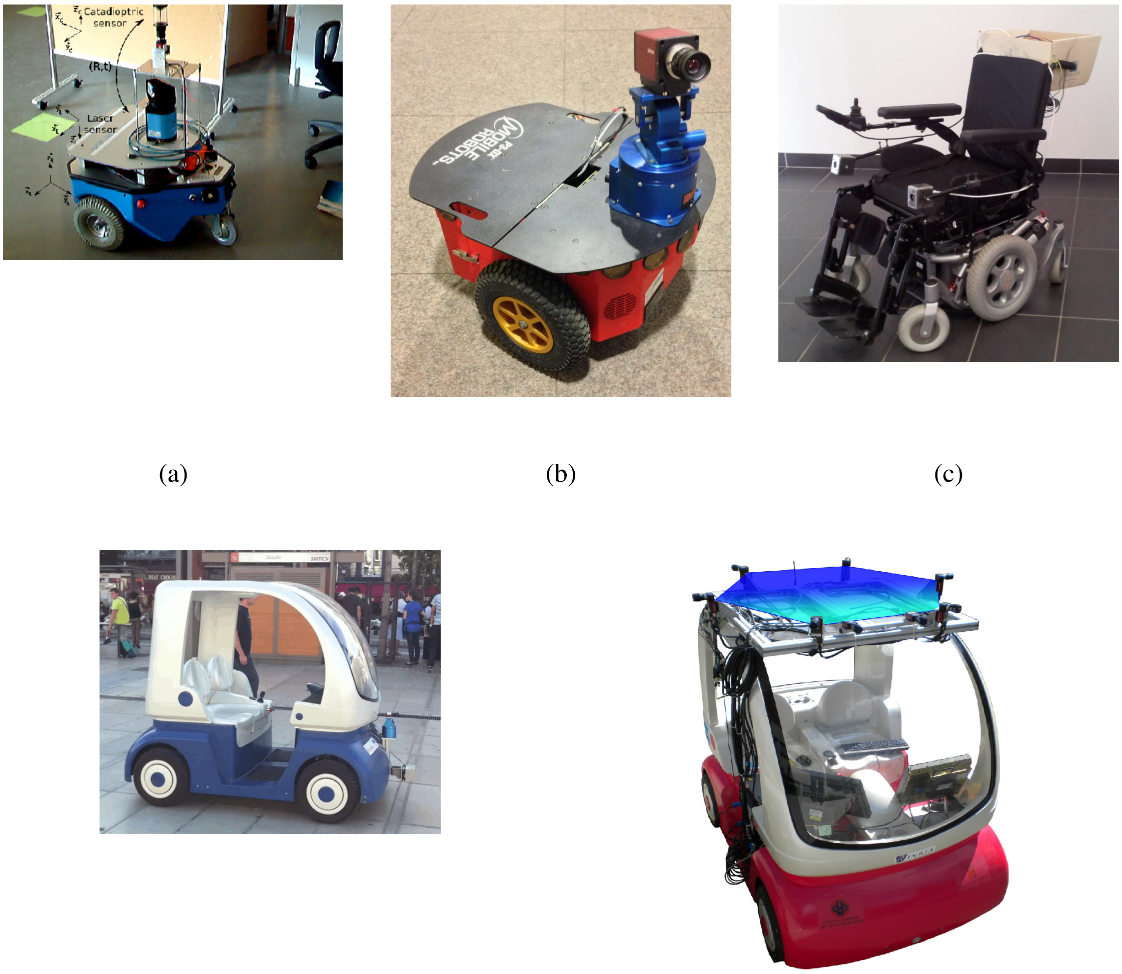
Note that 5 papers published by Lagadic in 2012 enclose experimental results obtained with these mobile robotics platforms.

6. New Results

6.1. Visual tracking

6.1.1. 3D model-based tracking

Participants: Antoine Petit, Eric Marchand.



(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.

Our 3D model-based tracking algorithm [2] was used in various contexts. We began a collaboration with Astrium EADS in 2010 in order to build a more versatile algorithm able to consider complex objects. The main principle is to align the projection of the 3D model of the object with observations made in the image for providing the relative pose between the camera and the object using a non-linear iterative optimization method. The approach proposed takes advantage of GPU acceleration and 3D rendering. From the rendered model, visible edges are extracted, from both depth and texture discontinuities. Potential applications would be the final phase of space rendezvous mission, in-orbit servicing, large debris removal using visual navigation, or airborne refuelling [41], [40], [32].

6.1.2. Omnidirectional vision system

Participant: Eric Marchand.

In this study performed in collaboration with Guillaume Caron and El Mustapha Mouaddib from Mis in Amiens, we have been interested by the redundancy brought by stereovision in omnidirectional vision sensors. This has been obtained by combining a single camera and multiple mirrors. Within this framework, we proposed to extend the 3D model-based tracking algorithm [2] for such system [15].

Thanks to a collaboration with Esiea in Laval, France, and the Inria and Irisa Hybrid team, we developed a system named Flyviz that has been patented. It is composed of a helmet mounted catadioptric camera coupled with an immersive display. The image acquired by the sensor is processed to give the user a full 360-degree panoramic view [27].

6.1.3. Pose estimation using mutual information

Participant: Eric Marchand.

Our work with Amaury Dame related to template tracking using mutual information [17] as registration criterion has been extended to 3D pose estimation using a 3D model. Since a homography was estimated, the tracking approach presented in [17] was usable for planar scenes. The new approach [45] can be considered for any scene or camera motion. Considering mutual information as similarity criterion, this approach is robust to noise, lighting variations and does not require a statistically robust estimation process. It has been used for visual odometry in large scale environment.

6.1.4. Pseudo-semantic segmentation

Participants: Rafik Sekkal, François Pasteau, Marie Babel.

To address the challenge of tracking initialization issues, we investigate joint segmentation and tracking approaches characterized by resolution and hierarchy scalability as well as a low computational complexity. Through an original scalable Region Adjacency Graph (RAG), regions can be adaptively processed at different scale representations according to the target application [42]. The results of this pseudo-semantic segmentation process are further used to initialize the object tracker (patch, visual objects, planes...) on several scales of resolutions.

6.1.5. Augmented reality using RGB-D camera

Participants: Hideaki Uchiyama, Eric Marchand.

We consider detection and pose estimation methods of texture-less planar objects using RGB-D cameras. It consists in transforming features extracted from the color image to a canonical view using depth data in order to obtain a representation invariant to rotation, scale, and perspective deformations. The approach does not require to generate warped versions of the templates, which is commonly needed by existing object detection techniques [35].

We also investigate the use of RGB-D sensors for object detection and pose estimation from natural features. The proposed method exploits depth information to improve keypoint matching of perspectively distorted images. This is achieved by generating a projective rectification of a patch around the keypoint, which is normalized with respect to perspective distortions and scale [34].

6.2. Visual servoing

6.2.1. Visual servoing using the sum of conditional variance

Participants: Bertrand Delabarre, Eric Marchand.

Within our study of direct visual servoing, we propose a new similarity function: the use of the sum of conditional variance [31] that replace SSD or mutual information [3]. It has been shown to be invariant to non-linear illumination variations and inexpensive to compute. Compared to other direct approaches of visual servoing, it is a good trade off between techniques using the pixels luminanc,e which are computationally inexpensive but non robust to illumination variations, and other approaches using the mutual information, which are more complicated to compute but offer more robustness towards the variations of the scene.

6.2.2. Photometric moment-based visual servoing

Participants: Manikandan Bakthavatchalam, Eric Marchand, François Chaumette.

The direct visual servoing approaches that have been developed in the group in the recent years, either using the luminance of each pixel, or the mutual information [3], or the sum of conditional variance described just above, allows reaching an excellent positioning accuracy. This good property is however counterbalanced by a small convergence domain due to the strong non linearities involved in the control scheme. To remedy to these problems, we started a study on using photometric moments as inputs of visual servoing. We expect to find again the nice decoupling and large convergence domain that we obtained for binary moments, without the need of any object segmentation.

6.2.3. Visual servoing using RGB-D sensors

Participants: Céline Teulière, Eric Marchand.

We propose a novel 3D servoing approach [43] that uses dense depth maps to perform robotic tasks. With respect to pose-based approaches, our method does not require the estimation of the 3D pose, nor the extraction and matching of 3D features. It only requires dense depth maps provided by 3D sensors. Our approach has been validated in servoing experiments using the depth information from a low cost RGB-D sensor. Thanks to the introduction of M-estimator in the control law, positioning tasks are properly achieved despite the noisy measurements, even when partial occlusions or scene modifications occur.

6.2.4. Visual servoing of cable-driven parallel robot

Participant: François Chaumette.

This study is realized in collaboration with Rémy Ramadour and Jean-Pierre Merlet from EPI Coprin at Inria Sophia Antipolis. Its goal is to adapt visual servoing techniques for cable-driven parallel robot in order to achieve acurate manipulation tasks. This study is in the scope of the Inria large-scale initiative action Pal (see Section 8.2.7).

6.2.5. Micro-Nanomanipulation

Participants: Eric Marchand, Le Cui.

In collaboration with Femto-ST in Besançon, we developed an accurate nanopositioning system based on direct visual servoing [20]. This technique relies only on the pure image signal to design the control law, by using the pixel intensity of each pixel as visual features. The proposed approach has been tested in terms of accuracy and robustness in several experimental conditions. The obtained results have demonstrated a good behavior of the control law and very good positioning accuracy: 89 nm, 14 nm, and 0.001 degrees in the x, y and θ_z axes of a positioning platform, respectively.

We begin a work, within the ANR P2N Nanorobust project (see Section 8.2.4), 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.

6.2.6. Autonomous landing by visual servoing

Participants: Laurent Coutard, François Chaumette.

This study was realized in collaboration with Dassault Aviation with the financial support of DGA. It was concerned with the autonomous landing of fixed wing aircrafts on carrier by visual servoing. A complete system has been developed [12]. The vision part consists in detecting the carrier in the image sequence and then tracking it using either dense template tracking or our 3D model-based tracker [2]. The visual servoing part consists in computing particular visual features able to correctly handle the aircraft degrees of freedom. Perturbations due to the wind and carrier motions have also been considered. The complete system has been validated in simulation using synthetic images provided by Xplane simulator and a dynamic model of the aircraft provided by Dassault Aviation.

6.3. Visual navigation of mobile robots

6.3.1. Visual navigation using mutual information

Participants: Eric Marchand, Bertrand Delabarre.

We have developed a visual navigation scheme based on the mutual information between the images acquired by an onboard camera and a visual memory to control the orientation of a vehicle during its navigation [18].

We also proposed to extend this approach to visual servoing with vision systems that consider the unified sphere model for central cameras using a normalized version of the mutual information. This permitted to apply the technique to large fields of view with a more reliable similarity function [30].

6.3.2. 3D Mapping and real time navigation

Participants: Maxime Meilland, Patrick Rives.

This study was realized in collaboration with Andrew Comport from I3S in Sophia Antipolis. Our approach relies on a monocular camera on board the vehicle and the use of a database of spherical images of the scene acquired during an offline step [14]. This geo-referenced database allows us to obtain a robust **drift free** localization. Basically, the database is composed of spherical images augmented by depth that are positioned in a GIS (Geographic information system). This spherical robot centered representation accurately represents all necessary information for vision-based navigation and mapping [37]. During the online navigation, the vehicle pose is computed by aligning the current image acquired by the camera with the closest reference sphere extracted from the database [26].

6.3.3. Indoors Slam

Participants: Cyril Joly, Patrick Rives, Pierre Martin, Eric Marchand.

We developed in Sophia Antipolis a new Slam method fusing laser scan data with the spherical images provided by an omnidirectional camera. Thanks to the trace of the laser scan projected onto the spherical view, we are able to compute a RGB-D model of the environment by using a dense visual Slam approach.

In Rennes and in collaboration with Orange Labs, we considered the development of a visual Slam algorithm. Since the targeted platforms in this this study are Android Smartphone, sequential Slam approaches have been studied.

6.3.4. Topological navigation

Participants: Alexandre Chapoulie, Patrick Rives.

This study is realized in collaboration with David Filliat from Ensta in Paris. Navigation algorithms are often sensitive to the robot orientation involving an impossibility to detect a place already visited from a different point of view. In order to alleviate this drawback, panoramic or omnidirectional cameras are often used. We have developed a loop closure detection algorithm based on an ego-centric spherical view that satisfies, in addition to other properties, a robot orientation independence [11].

A topological model captures the accessibility of the different places in the environment and allows a coarse localization. From a sequence of spherical views, we have developed a context-based segmentation algorithm. We hence define a topological place as having a structure which does not change, variation leading to a place change. The structure variations are detected with an efficient change-point detection algorithm [28].

6.3.5. Development of an autonomous shopping cart

Participants: Luca Marchetti, Patrick Rives.

This work is realized in collaboration with Pascal Morin from Isir in Paris. It consists in developing a shopping cart with autonomy capabilities (automatic user following, obstacle avoidance, etc), as part of the Inria Large-scale initiative action Pal, which aims at developing robotic tools for disabled persons or elderlies (see Section 8.2.7). Experiments have been successfully conducted both on the mobile robot Hannibal and on the wheeled walking aid ANG (Assistive Navigation Guide) developed by the EPI Coprin in Sophia Antipolis [36].

6.3.6. Automous navigation of wheelchairs

Participants: Rafik Sekkal, François Pasteau, Marie Babel.

This study is aimed at designing a robotic vision-based system dedicated to assisted navigation of electrical wheelchair in an unkown environment. In particular, going through doors, taking the elevator in a secure way without risking collision because of hazardous wheelchair motions remain a relevant issue. The idea is here to provide an embedded and flexible system able to ensure the immediate compatibility of the proposed system with existing electrical wheelchairs. From the platform described in Section 5.5, we first addressed the door detection issue for automatically initializing the tracking process that is required for localisation and navigation purposes. We then defined a low complex solution of automatic door recognition that can be decomposed into three successive steps: line extraction (LSD-based algorithm), vanishing point estimation and door recognition itself by using geometrical cues. As soon as a door is detected and tracked through model-based trackers, the idea is to take into account the position of the wheelchair joystick in order to interpret the intention of the user. First experiments have shown the validity of the proposed approach. This study is conducted in conjunction with the scope of the Inria large-scale initiative action Pal (see Section 8.2.7).

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 [16].

6.4. Medical robotics

6.4.1. Visual servoing based on dense ultrasound information

Participants: Caroline Nadeau, Alexandre Krupa.

In the context of the ANR USComp project (see Section 8.2.3), we pursued our works on the development of ultrasound image-based visual servoing methods that directly use pixel intensities of the ultrasound image as control inputs. In opposite with methods based on geometrical visual features, this new approach does not require any image segmentation step that is difficult to robustly perform on ultrasound images. By coupling our method with a predictive control law based on the periodicity of physiological motion, we propose a solution to stabilize the ultrasound image by actively compensating the physiological motions of the patient. The principle consists in automatically synchronizing the 6 DOF motion of a 2D or 3D probe with the rigid motion of a soft tissue target. First ex-vivo results obtained on animal tissues demonstrated the validity of the concept [39].

In collaboration with Prof. Pierre Dupont from Harvard University at Boston, we also addressed the motion tracking of a target that can consist of either the tip of a robot inserted on a beating heart or cardiac tissues. Unlike the previous work, where the motion compensation task was realized physically by moving the probe attached to a robotic arm, we propose here to track the motion of the target using a 3D region of interest (ROI) which is automatically moved within the whole volume observed by a 3D probe thanks to our intensity-based ultrasound visual servoing method. In vivo animal experiments were conducted in Children's Hospital at Boston and validated this tracking approach [38].

6.4.2. Autonomous control modes for ultrasound probe guidance

Participants: Tao Li, Alexandre Krupa.

In the context of the ANR Prosit project (see Section 8.2.2), we proposed several autonomous control modes in order to assist a doctor during a robotized and teleoperated ultrasound examination (tele-echography). This year we developed an assistance functionality that automatically maintains the visibility of an anatomic element of interest while the doctor teleoperates the 2D ultrasound probe held by the medical robot. The method is based on a multi-task controller that gradually activates an ultrasound visual servoing in case some geometrical features leave a pre-defined safe area of the image in order to bring them back inside the view [33]. With this approach the DOFs of the robotized probe are not exclusively constrained by the visibility task but also available for the tele-operation. This new assistance functionality was implemented on the ANR Prosit robotic platform and first in vivo results obtained on a human volunteer validated the concept.

6.4.3. Real-time soft-tissue deformation tracking in 3D ultrasound

Participant: Alexandre Krupa.

We proposed a dense ultrasound tracking algorithm that estimates in real time both rigid and non-rigid motions of a region of interest observed in a sequence of 3D ultrasound images. The deformation is modeled by 3D thin-plate splines (TPS) whose parameters are estimated online from intensity difference measured in successive volumes. To increase the robustness of this approach to image noise, we proposed two solutions to mechanically constrain the deformable model. The first is based on the addition of a regularization term in the TPS model and the second consists in coupling the TPS with a mass-spring system. These methods were validated on simulated sequences of deformed 3D ultrasound images.

6.4.4. Needle detection and tracking in 3D ultrasound

Participant: Alexandre Krupa.

We designed an algorithm able to detect a needle inserted manually in a 3D ultrasound volume from an arbitrary point, and able to robustly track this needle in real-time. We also experimentally demonstrated the possibility to guide the ultrasound probe to keep the needle visible and aligned, using visual servoing. Such a system could assist an operator during manual insertions, which are currently performed under free-hand ultrasound monitoring. In addition, we plan in future works to combine this method to a needle steering robotic system for guiding accurately the needle toward a target while optimizing its visibility.

7. Bilateral Contracts and Grants with Industry

7.1. Bilateral Grants with Industry

7.1.1. Dassault Aviation

Participants: Laurent Coutard, François Chaumette.

no. Inria Rennes 5140, duration : 36 months.

This contract that started in 2009 supported Laurent Coutard's Ph.D. about automatic aircraft landing on carrier by visual servoing (see Section 6.2.6).

7.1.2. Fondation EADS

Participants: Antoine Petit, Eric Marchand.

no. Inria Rennes 5605, duration : 36 months.

This contract that started in March 2011 supports Antoine Petit's Ph.D. about 3D model-based tracking for applications in space (see Section 6.1.1).

7.1.3. Orange Labs

Participants: Pierre Martin, Eric Marchand.

no UR1 10CC310-03, duration : 36 months.

This contract started in February 2010. It is devoted to support the Cifre convention between Orange Labs and Université de Rennes 1 regarding Pierre Martin's Ph.D (see Section 6.3.3).

7.1.4. 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.

7.1.5. ECA Robotics

Participants: Romain Drouilly, Patrick Rives.

no. Inria Sophia 7030, duration : 36 months.

This project that started in May 2012 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. FUI Rev-TV project

Participants: Céline Teulière, François Chapeau, Eric Marchand.

no. Inria Rennes 4549, duration: 36 months.

This project started in January 2010. It is composed of a consortium managed by Technicolor with Artefacto, Istia, Telecom Bretagne, Soniris, Bilboquet and Inria Lagadic and Metiss groups. The goal of this project is to provide tools to develop new TV programs allowing the final user to interact within an immersive and convivial interface. Within this project, we focused on the development of tracking algorithms (3D localization) and on visual servoing techniques for camera localization.

8.1.2. 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 is to develop an augmented reality library for smartphones.

8.1.3. Apash project

Participants: Rafik Sekkal, 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 6.3.6.

8.2. National Initiatives

8.2.1. DGA/DGCIS Rapid Canari

Participants: Patrick Rives, Cyril Joly.

no. Inria Sophia 4979, duration : 36 months.

This project started in July 2010. It aims at developing a full autonomous indoor mobile robot dedicated to survey missions. The partners are Robopec and ECA companies. We are in charge of the development of Slam aspects. The contract supported Cyril Joly's engineer grant (see Section 6.3.3).

8.2.2. ANR Contint Prosit

Participants: Tao Li, Alexandre Krupa.

no. Inria Rennes 3585, duration: 46 months.

This project is led by the Prisme lab in Bourges. It started in December 2008 in collaboration with LIRMM in Montpellier, LMS in Poitiers, CHU of Tours, and the Robosoft company. Its goal is to develop an interactive master-slave robotic platform for medical diagnosis applications (tele-echography) with assistance functionalities. The work that we have realized within this project is described in Section 6.4.2.

8.2.3. ANR Contint US-Comp

Participants: Caroline Nadeau, Alexandre Krupa.

no. Inria Rennes 3560, duration: 42 months.

This project, led by Alexandre Krupa, started in December 2008. It involves a collaboration with the Visages team in Rennes, LSIIT in Strasbourg and Lirmm in Montpellier. Its goal is to provide methodological solutions for real-time compensation of soft tissues motion during ultrasound imaging. The approach consists in synchronizing the displacement of a 2D or 3D ultrasound probe to stabilize the observed image by the use of a robotic arm. The work that we have realized within this project is described in Sections 6.4.1 and 6.4.3.

8.2.4. ANR P2N Nanorobust

Participants: Le Cui, Eric Marchand.

no. UR1 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.

8.2.5. PEA Decsa

Participants: Aurélien Yol, Eric Marchand, François Chaumette.

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.

8.2.6. Equipex Robotex

Participants: Aurélien Yol, 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. This year, it allowed us to buy the Viper S650 arm and the Pioneer 3DX described in Sections 5.4 and 5.5. In a near future, we plan to buy a humanoid robot, Romeo, by Aldebaran Robotics.

8.2.7. Inria Large Scale Initiative Action Pal

Participants: Patrick Rives, Marie Babel, François Chaumette, Luca Marchetti, Cyril Joly, Rafik Sekkal, François Pasteau.

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 6.3.6, 6.2.4 and 6.3.5.

8.3. European Initiatives

8.3.1. FP7 Regpot Across

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 (Austrtia), Politecnico di Milano (Italy), University of Sevilla (Spain), Eindhoven University of Technology (The Netherlands), University of Athens (Greece), etc.

8.4. International Initiatives

8.4.1. Participation in International Programs

8.4.1.1. Inria/CNPq MuNave

The project MuNave (2010 - 2012) funded through the Inria/CNPq collaboration framework, succeeds to a long time collaboration between Patrick Rives and the CTI in Campinas (Brazil). This project aims at investigating new research themes in perception and control for autonomous mobile robots.

8.5. International Research Visitors

8.5.1. Visits of International Scientists

- Shogo Arai, Assistant Prof. at the University of Tohoku in Sendai, Japan, spent a two-month visit in our group in Rennes in March and April 2012 to work on visual servoing.
- Nicolas Alt, Ph.D. student at the Technische Universität München, Germany, visited our group in Sophia Antipolis from July 2 to September 26. He worked on the detection and modeling of transparent objects using a Kinect.
- Rogelio Esteller Curto, Assistant Prof. at the University of Jaume-I in Castillon, Spain, has spent a one-month visit in our group in Rennes in November 2012 to work on visual servoing.

8.5.2. Internships

Thanks to the FP7 Regpot project (see Section 8.3.1), we have got three internships from University of Zagreb from March to June 2012:

- Ante Trbojevic
- Petra Bosilj
- Petar Palasek.

Two internships from the University of Guanajuato started in December 2012:

- Raul Orlando Alvarado Lara
- Francisco Javier Rangel Butanda.

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.
  - François Chaumette is in the Editorial Board of the Int. Journal of Robotics Research. He has also been Associate Editor of the Int. Journal of Optomechatronics from its creation in 2007 till September 2012.
- *Technical program committees of conferences*
  - François Chaumette: ICRA'12, RSS'12, ISPRS'12, IROS'12, SYROCO'12, ISOT'12, WRV'13, ICRA'13
  - Eric Marchand: RFIA'12, Coresa'12, ICRA'12, RSS'12, ICRA'13
  - Patrick Rives: ICRA'12, RFIA'12, Innorobo'12, Vicomor'12
- *Selection committees*
  - François Chaumette was in the selection committee for a Professor position at the "Université de Strasbourg" and at the "Université Paul Sabatier" in Toulouse.
  - Alexandre Krupa was in the selection committee for an Assistant Professor position at the "Université de Strasbourg" and at the "Université de Franche-Comté".
  - Eric Marchand was in the selection committee for an Assistant Professor position at the "Université de Strasbourg" and at "Ensicaen" in Caen. He was in the selection committee for a Professor position at the "Université de Rennes 1".
  - Patrick Rives was in the selection committee of Starting and Advanced Research positions at Inria.

- *Participation in seminars, invitation*
  - François Chaumette has been invited to give a talk at the 4th Cimat Robotics Workshop in Guanajuato, Mexico [21] and to the 3rd French-Sino Symposium on Virtual Reality in Qingdao, China [22].
  - Eric Marchand has been invited to give a talk at the Workshop on Fundamental and Applied 3D Computer Vision in honor of Richard Hartley in Clermont Ferrand [23].
  - Patrick Rives has been invited to give a talk at the RFIA Atelier Monument 3D (Lyon, France, January 2012) [24], Innorobo Conference on Service Robotics (Lyon, France, March 2012) [25], and IROS Workshop Vicomor (Vilamoura, Portugal, October 2012) [26].
- *Animation at the international level*
  - François Chaumette has been elevated to IEEE Fellow in November 2012. He served as expert for the ERC Starting Grants and has been appointed to be a panel member of the ERC Consolidator Grants. He was in the 2012 and 2013 IEEE RAS chapter of the year award nomination committee.
- *Animation at the national level*
  - François Chaumette and Patrick Rives are members of the scientific council of the "GdR Robotique" and JNRR.
  - François Chaumette served for the ANR Contint monitoring committee.
  - Patrick Rives is an expert for Oseo (Agence Nationale pour la Valorisation), Agence Nationale de la Recherche (ANR) and the Swiss National Science Foundation.
  - 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 développments technologiques").
  - François Chaumette is a member of the animation committee of Inria's thematic domain "Perception, cognition, interaction".
- *Animation at the regional and local levels*
  - Eric Marchand is in the board of the "Images et réseaux" competitivity cluster.
  - 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 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 and Fabien Spindler are members 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, Institut National des Sciences Appliquées de Rennes

Master INSA1: “Assembler”, 30 hours, L3, Institut National des Sciences Appliquées de Rennes

Master INSA2: “Computer science project”, 30 hours, M1, Institut National des Sciences Appliquées de Rennes

Master INSA2: “Image analysis”, 18 hours, M1, Institut National des Sciences Appliquées de Rennes

Master INSA1: “Remedial math courses”, 24 hours, L3, Institut National des Sciences Appliquées de Rennes

Master INSA1: “Risk Management for Information Systems”, 8 hours, L3, Institut National des Sciences Appliquées de Rennes

François Chaumette:

Master ESIR3: “Visual servoing”, 12 hours, M2, Ecole supérieure d’ingénieurs de Rennes

Ph.D.: IEEE RAS Summer School on Robot Vision and Applications: “Visual servoing”, 4.5 hours, Universidad de Chile, Santiago.

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

Eric Marchand:

Master ESIR2: “Colorimetry”, 24 hours, M1, Ecole supérieure d’ingénieurs de Rennes

Master ESIR2: “Computer vision”, 24 hours, M1, Ecole supérieure d’ingénieurs de Rennes

Master ESIR3: “Special effects”, 24 hours, M2, Ecole supérieure d’ingénieurs de Rennes

Master ESIR3: “Computer vision: tracking and recognition”, 24 hours, M2, Ecole supérieure d’ingénieurs de Rennes

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

9.2.2. Supervision

HdR: Marie Babel, “From image coding and representation to robotic vision”, Université de Rennes 1, defense in June 2012 [10]

HdR: Alexandre Krupa, “Contributions à l’asservissement visuel échographique”, Université de Rennes 1, defense in December 2012 [13]

Ph.D.: Maxime Meilland, “Cartographie RGB-D dense pour la localisation visuelle temps-réel et la navigation autonome”, Ecole des Mines de Paris, defense in March 2012, supervised by Patrick Rives and Andrew Comport (I3S/CNRS) [14]

Ph.D.: Alexandre Chapoulie, “Contributions aux méthodes de détection visuelle de fermeture de boucle et de segmentation topologique de l’environnement”, Université de Nice-Sophia Antipolis, defense in December 2012, supervised by Patrick Rives and David Filliat (ENSTA) [11]

Ph.D.: Laurent Coutard, “Apportage automatique d’avions par asservissement visuel”, Université de Rennes 1, defense in December 2012, supervised by François Chaumette [12]

Ph.D. in progress: Tao Li, “Commande d’un robot de télé-échographie par asservissement visuel échographique”, started in October 2009, supervised by Alexandre Krupa

Ph.D. in progress: Pierre Martin, “Augmented reality on smartphones”, started in February 2010, supervised by Eric Marchand

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: Antoine Petit, “3D model-based tracking of complex objects in a spatial context”, started in December 2010, supervised by Eric Marchand

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

9.2.3. Juries

- François Chaumette: Pierre Lebraly (Ph.D., president, Institut Pascal, Clermont-Ferrand), Adrien Durand Petiteville (Ph.D., reviewer, Laas, Toulouse), Pierre Rouanet (Ph.D., president, Inria Bordeaux), Moslem Kazemi (Ph.D., reviewer, Simon-Fraser University, Vancouver), Baptiste Charmette (Ph.D., reviewer, Institut Pascal, Clermont-Ferrand)
- Eric Marchand: Maxime Meilland (Ph.D., reviewer, Inria Sophia Antipolis), Pauline Merveilleux (Ph.D., reviewer, Mis, Amiens), Cédric Demonceaux (HDR, reviewer, Université de Bourgogne, Le Creusot)
- Patrick Rives: Mohamed Marouf (Ph.D., Ecole des Mines de Paris), Alessandro Victorino (HdR, Heudiasyc, Compiègne), Pauline Merveilleux (Ph.D., reviewer, Mis, Amiens), Cédric Demonceaux (HdR, reviewer, Université de Bourgogne, Le Creusot), Baptiste Charmette (Ph.D., reviewer, Institut Pascal, Clermont-Ferrand)

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, and vision-based detection and tracking for space navigation in a rendezvous context.
- Fabien Spindler is a member of the editorial board of “Ouest Inria”, the internal journal at Inria Rennes Bretagne Atlantique.
- Eric Marchand was co-author of an article entitled "FlyVIZ : un casque qui permet de voir dans toutes les directions" in Interstice, which is an online French popularization magazine for research in computer science.

10. Bibliography

Major publications by the team in recent years

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