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Activity Report 2011

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 CENTER
Rennes - Bretagne-Atlantique

THEME
Robotics

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Project-Team LAGADIC

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2. Overall Objectives

2.1. Introduction

Research activities of the Lagadic team are concerned with visual servoing and active vision. Visual servoing consists in using the information provided by a vision sensor to control the movements of a dynamic system. This system can be real within the framework of robotics, or virtual within the framework of computer animation or augmented reality. 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.

This set of themes of visual servoing is the central scientific topic of the Lagadic group. More generally, our objective is 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. 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, structure and motion) through the visual servoing approach.

2.2. Highlights

Amaury Dame received a runner-up award from the GdR Robotique for the best 2010 Ph.D. thesis in robotics.

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][2]. 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 to 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. To consider visual servoing within large scale applications, it is mandatory to handle natural scenes without any fiducial markers but with complex objects in various illumination conditions. If fiducial markers may still be useful to validate theoretical aspects of visual servoing in modeling and control, non cooperative objects have to be considered to address 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.

4. Application Domains

4.1. Panorama

The natural applications of our research are obviously in robotics. In the past, we mainly worked in the following fields:

- grasping and manipulating tools in hostile environments such as nuclear environment typically;
- underwater robotics for the stabilization of images and the positioning of uninstrumented robot arm;
- agro-industry for the positioning of a vision sensor in order to ensure an improvement of the quality controls of agro-alimentary products; and
- video surveillance by the control of the movements of a pan-tilt camera to track mobile natural objects.

More recently, we addressed the field of mobile robotics through activities around the Cycab vehicle (see Section 5.4): detection and tracking of mobile objects (pedestrians, other vehicles), control by visual servoing of the movements of the vehicle.

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 interested in using visual servoing for robot arms in space, micromanipulation, autonomous vehicle navigation in large urban environments, and underactuated flying robots such as miniature helicopters and aircrafts.

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, active perception for the optimal generation of 3D echographic images, 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 realization 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.

Lastly, our work in visual servoing and active perception could be related with those carried out in cognitive science, in particular in the field of psychovision (for example on the study of eye motion in the animal and human visual system, on the study of the representation of perception, or on the study of the links between action and perception).

5. Software

5.1. ViSP: a visual servoing platform

Participants: Fabien Spindler [correspondant], Filip Novotny, 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 basic visual features (points, straight lines, circles, spheres, cylinders, frames, image moments...) that can be combined together, and image processing algorithms that allows tracking of visual cues (dots, segments, ellipses,...) or tracking of 3D model-based objects. Simulation capabilities are also available. ViSP and its full functionalities are presented in Fig. 1 and described in [7].

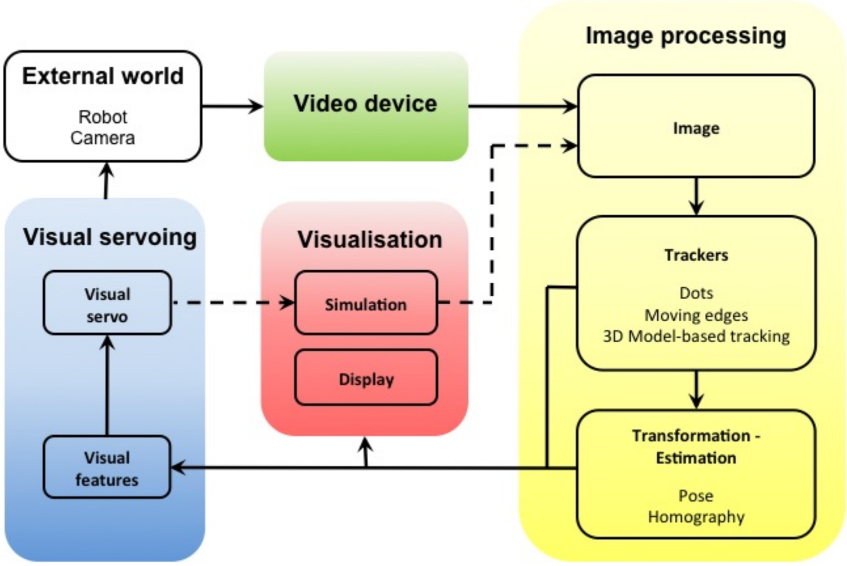


Figure 1. ViSP software architecture.

This year, we continued to improve the software and documentation quality. A new version available at http://www.irisa.fr/lagadic/visp/visp.html was released in October 2011. To ease ViSP installation, we provide also precompiled ViSP SDK including pre-built ViSP library and headers.

This last release code has been downloaded 400 times during the first month of 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 a ROS stack and ViSP 3D model-based tracker has been proposed by the community as a ROS package (see http://www.ros.org/wiki/vision_visp).

5.2. Development work: Robot vision platforms

Participants: Fabien Spindler [correspondant], Romain Tallonneau.

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.

This platform is by far the most-used one by Lagadic members (9 papers published by Lagadic in 2011 enclose results validated on it or data acquired on it). Note that this platform is also open to researcher from other labs. For example, the work done in [24] was validated on the Gantry robot.

These equipments require specific hardware, but also software maintenance actions and new developments in order to make them evolve. Training and assistance of the users, presentation of demonstrations also form part of the daily activities.

To improve the panel of demonstrations and to highlight our research activities, we have developed a new demonstration that combines 3D model-based visual tracking and visual servoing techniques provided in ViSP (see Section 5.1) to pick up cubes in order to build a tower. One of the challenges was to automate the initial object localization requested to initialize the tracker. At this end we have developed a generic template pose estimation algorithm based on Surf points of interest matched with the corresponding points provided in a database computed offline during a learning step.

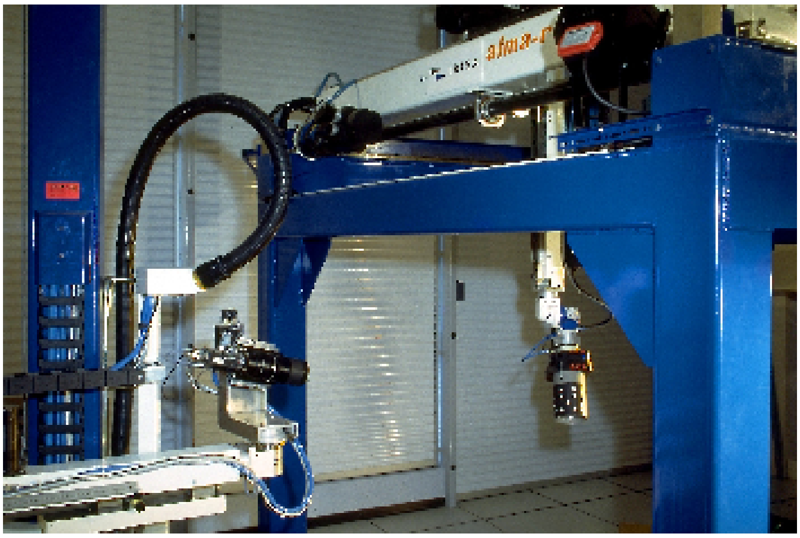


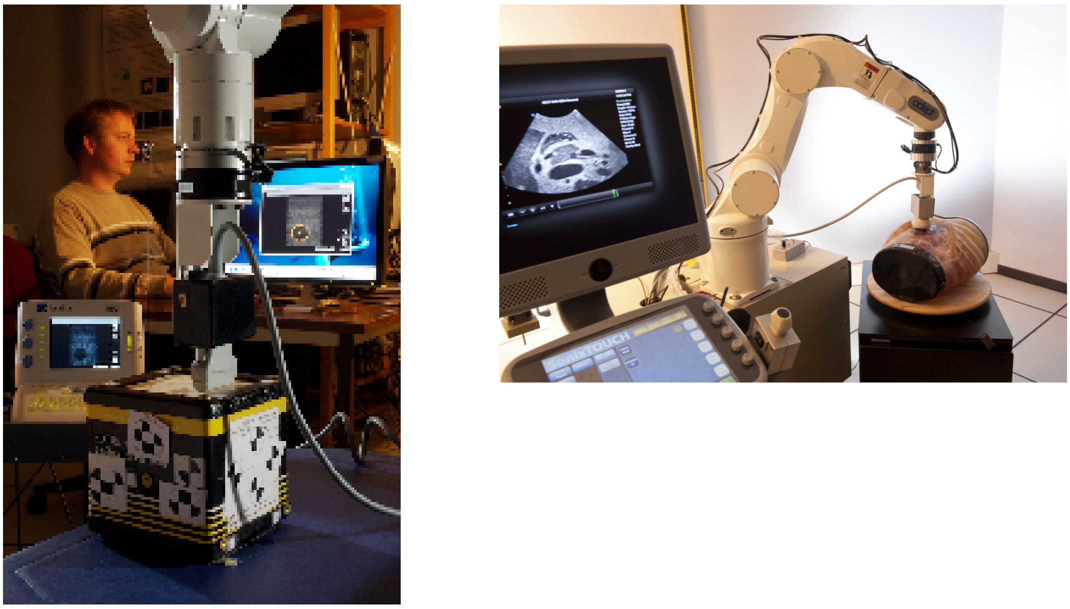
Figure 2. Lagadic robotics platforms for vision-based manipulation

5.3. Development work: Medical robotics platforms

Participants: Fabien Spindler [correspondant], Alexandre Krupa.

This platform is composed by two robots, a six degrees of freedom Hippocrate medical arm designed by the Sinters company (see Fig. 3.a) and an Adept Viper S850 arm (see Fig. 3.b). 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 the robot end-effector.

The research and experiments concerning ultrasound visual servoing applied to positioning or tracking tasks conducted with this medical robotics platforms are described in Section 6.3. Note that 4 papers published in 2011 by Lagadic enclose results validated on it.



(a) (b)

Figure 3. Lagadic medical robotics platforms: a) Hippocrate medical robot, b) Viper robot arm equiped with a SonixTouch 3D ultrasound probe.

5.4. Development work: Cycab

Participants: Fabien Spindler [correspondant], Andrea Cherubini.

The Cycab is a four wheel drive autonomous electric car dedicated to vision-based autonomous navigation (see Fig. 4). A pan-tilt head (Biclops PTM) equipped with a firewire Marlin camera with about 70 degrees field of view is mounted on the front bumper, as well as a Sick LDMRS laser rangefinder. Concerning the computer units, the Cycab is equipped with two microprocessors dedicated to the low level control of the vehicle actuators and a laptop dedicated to high level visual navigation. They are connected through an internal CAN bus. The camera, the pan-tilt head and the laser rangefinder are connected to the laptop. The research and experiments conducted with the Cycab are described in Section 6.2.3. Note that 4 papers published by Lagadic in 2011 enclose experimental results obtained with the Cycab.

6. New Results

6.1. Visual tracking

6.1.1. 3D model-based tracking

Participants: Antoine Petit, Eric Marchand.

Figure 4. Lagadic Cycab vehicle

Our 3D model-based tracking algorithm [3] was used in various contexts. First, it has been studied and tested on a mock-up of a telecommunication satellite using a 6-DOF robotic arm, with satisfactory results in terms of accuracy of the pose estimation and computational costs [41], [42]. A potential application would be the final phase of space rendezvous mission using visual navigation. Then, it has been considered for designing a visual servoing scheme able to control the walking of a humanoid robot [29].

6.1.2. Omnidirectional stereovision

Participants: Guillaume Caron, El Mustapha Mouaddib, Eric Marchand.

Omnidirectional cameras allow direct tracking and motion estimation of planar regions in images during a long period of time. However, using only one sensor leads to plane and trajectory reconstruction up to a scale factor. We proposed to develop dense plane tracking based on omnidirectional stereovision to answer this issue. The method estimates simultaneously the parameters of several 3D planes along with the camera motion using a spherical projection model formulation [20].

6.1.3. Motion estimation using mutual information

Participant: Eric Marchand.

Our work with Amaury Dame related to template tracking using mutual information as registration criterion has been extended to motion estimation applications. It has been applied to mosaicing from an image sequence [28]. The main advantage is that this approach is robust to noise, lighting variations and does not require a statistically robust estimation process.

6.1.4. Augmented reality

Participants: Pierre Martin, Hideaki Uchiyama, Eric Marchand.

We developed an approach for detecting and tracking various types of planar objects with geometrical features[45]. We combine traditional keypoint detectors with Locally Likely Arrangement Hashing (LLAH) for keypoint matching. In order to produce robustness to scale changes, we build a non-uniform image pyramid according to keypoint distribution at each scale. It demonstrates that it is possible to detect and track different types of textures including colorful pictures, binary fiducial markers and handwritings. This approach was extended to consider non-rigidly deformable markers [46].

6.2. Visual servoing

6.2.1. Micro-manipulation

Participant: Eric Marchand.

We developed an accurate nanopositioning system based on direct visual servoing [43],[17]. 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.

6.2.2. Multi sensor-based control

Participants: Olivier Kermorgant, François Chaumette.

We have designed a generic sensor-based control approach to automatically tune the weights related to the features involved as inputs of a control scheme, allowing to take constraints into account. This scheme has been applied to several confugirations, such as fusing the data provided by an eye-in-hand camera and an eye-to-hand camera, ensuring the visibility constraint, and avoiding the robot joint limits [30], [31], [32], [11].

6.2.3. Visual navigation of mobile robots

Participants: Eric Marchand, Andrea Cherubini, Fabien Spindler, François Chaumette.

We have developed a visual servoing 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 [27]. We have also fused the data provided by a pan-tilt camera and a laser range sensor for the autonomous navigation of a mobile vehicle while avoiding obstacles [23], [22]. Real experiments with our Cycab (see Section 5.4) have been conducted on Place de Jaude in Clermont-Ferrand in the scope of the ANR Tosa CityVIP project (See Section 8.2.1).

6.2.4. Visual servoing for aircrafts

Participants: Céline Teulière, Eric Marchand, Laurent Coutard, François Chaumette.

A dynamic controller has been designed for the homing of a quadri-rotor aerial vehicle [39]. A color-based tracking algorithm has also been designed and combined with an image-based visual servoing for chasing a moving target from a a flying UAV [44]. Finally, a method has been developed to detect and localize an aircrat carrier in an image sequence, from which visual servoing control laws have been designed for the automatic landing [25], [26].

6.3. Medical robotics

6.3.1. Visual servoing based on ultrasound images

Participants: Caroline Nadeau, Alexandre Krupa.

We developed a new approach of ultrasound image based visual servoing that directly uses the intensities of the ultrasound image pixels as visual features. This method that spares any segmentation or image processing time consuming step was initially proposed to control the 6 DOF of a conventional 2D probe for positioning and tracking tasks [38], [48]. To increase the tracking performance we also adapted this method by considering a predictive control law based on the periodicity of physiological motions [36]. Rigid motion compensation experiments were conducted in the context of the ANR USComp project (See Section 8.2.3). The method was also improved by estimating on-line the image 3D gradient required for the positioning task and extended for the use of a bi-plane ultrasound probe [37]. Finally, the use of a 3D motorized probe was also considered to compute directly the image 3D gradient and a comparison of the results obtained with the different probes (2D, bi-plan, 3D) was performed [12].

6.3.2. Autonomous control modes for ultrasound probe guidance

Participants: Tao Li, Alexandre Krupa.

In the context of the ANR Prosit (See Section 8.2.2), we developed several autonomous control modes in order to assist a doctor during a robotized and teleoperated ultrasound examination (tele-echography). The robotic tasks we proposed concern: an automatic scanning of the patient by a 2D probe, a shared control mode that maintains the visibility of an anatomic element of interest while the doctor teleoperates the slave robot holding the 2D probe, an automatic positioning task that allows the doctor to retrieve a desired anatomic section that was previously captured by the doctor. The two latter modes are based on visual servoing schemes that use as input image moments extracted from the observed 2D ultrasound image. This extraction is performed thanks to an active contour (snake) based on Fourier descriptors that we developed and implemented on GPU in order to provide real-time performance [34], [47]. The proposed autonomous control modes were experimentally validated on the Lagadic medical robotics platform (see Section 5.3) and are now in the process of being integrated on the Prosit robot platform.

6.3.3. Real-time 3D ultrasound image reconstruction and 3D deformation tracking

Participants: Deukhee Lee, Alexandre Krupa.

We developed and implemented on GPU an algorithm that reconstructs in real-time a sequence of dense ultrasound volumes from a set of pre-scan 2D ultrasound images provided online by a motorized ultrasound probe [33]. Then 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 the sequence of reconstructed ultrasound volumes [33]. The algorithm consists in estimating in real-time, from intensity-value changes between successive 3D ultrasound images, motions of a set of 3D control points that describe the evolution of 3D Thin-Plate Splines (TPS) modeling the deformation. The estimated rigid motion was then used in a pose-based control scheme to automatically displace the probe held by a robot for soft tissue motion compensation. These works were conducted in the context of the ANR USComp project (See Section 8.2.3).

7. Contracts and Grants with Industry

7.1. Dassault Aviation

Participants: Laurent Coutard, François Chaumette.

no. Inria 5140, duration : 36 months.

This contract supports Laurent Coutard's Ph.D. about automatic aircraft landing on carrier by visual servoing (see Section 6.2.4).

7.2. Fondation EADS

Participants: Antoine Petit, Eric Marchand.

no. Inria 5605, duration : 36 months.

This contract supports Antoine Petit's Ph.D. about 3D model-based tracking of satellites (see Section 6.1.1).

7.3. Orange Labs

Participants: Pierre Martin, Eric Marchand.

duration : 36 months.

This contract is devoted to support the Cifre convention between Orange Labs and Université de Rennes 1 regarding Pierre Martin's Ph.D. (see Section 6.1.4).

8. Partnerships and Cooperations

8.1. Regional Initiatives

8.1.1. FUI Rev-TV project

Participants: Guillaume Caron, Manikandan Bakthavatchalam, Céline Teulière, François Chapeau, Eric Marchand.

no. Inria 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 focus 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.

8.2. National Initiatives

8.2.1. ANR Tosa CityVIP

Participants: Andrea Cherubini, Fabien Spindler, Eric Marchand, François Chaumette.

no. Inria 3208, duration: 42 months.

This project, managed by Lasmea, started in June 2008. It involves eight partners, including Lagadic. The project consists of enhancing the autonomy of urban vehicles by integrating sensor-based techniques with a geographical database. The work that we have realized within this project is described in Section 6.2.3.

8.2.2. ANR Contint Prosit

Participants: Tao Li, Alexandre Krupa, François Chaumette.

no. Inria 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 6.3.2.

8.2.3. ANR Contint US-Comp

Participants: Caroline Nadeau, Deukhee Lee, Alexandre Krupa, François Chaumette.

no. Inria 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 6.3.1 and 6.3.3.

8.2.4. ANR P2N Nanorobust

Participant: Eric Marchand.

duration: 48 months.

This project started in November 2011. It is composed of a consortium managed by Femto-ST with LPN, Isir, 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: Eric Marchand, François Chaumette.

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.

8.3. 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. Visits of International Scientists

Chuanto Zang, a Ph.D. student from Koichi Hashimoto's lab at Tohoku University in Sendai, Japan, spent a two-month visit from January till March 2011.

8.4.2. Participation In International Programs

8.4.2.1. STIC AmSud

Participants: Eric Marchand, François Chaumette.

This project aims to handle the problem of monocular real-time 3D object tracking targeting augmented reality and visual servoing applications. This is a collaboration with the computer science center of Federal University of Pernambuco in Recife, Brazil and with the Robotics and automation division, Mining technology center at the Universidad de Chile in Santiago, Chile.

Joao Paulo Lima and Francisco Simoes from the Federal University of Pernambuco had a one-month visit in Rennes in November 2011. François Chaumette had a one-week visit at the Universidad de Chile in Santiago in December 2011.

9. Dissemination

9.1. Animation of the scientific community

- *Editorial boards of journals*
  - Eric Marchand is Associate Editor of the IEEE Trans. on Robotics
  - François Chaumette is in the Editorial Board of the Int. Journal of Robotics Research. He is also Associate Editor of the Int. Journal of Optomechatronics.
- *Technical program committees of conferences*
  - François Chaumette: ICRA'11, IROS'11, ICRA'12.
  - Eric Marchand: CVPR'11, Orasis'11, IROS'11, RFIA'12, ICRA'12
  - Alexandre Krupa: Orasis'11
- *Selection committees*
  - François Chaumette was in the selection committee for a Professor position at Ecole Centrale de Nantes, for an Assistant Prof. position at University of Cergy-Pontoise ("Chaire CNRS"), and for an Assistant Prof. position at University of Amiens.
  - Eric Marchand was in the selection committee for an Assistant Prof. position at Insa Lyon ("Chaire CNRS"), and for an Assistant Prof. position at Université de Rennes 1.
- *Ph.D. and HdR jury*
  - François Chaumette: Hector Becerra (Ph.D., reviewer, University of Zaragosa, Spain), Paolo Salaris (Ph.D., University of Pisa, Italy), Felipe Belo (Ph.D., University of Pisa, Italy), Viviane Cadenat (HdR, Laas, reviewer)
- François Chaumette is a member of the Scientific Council of the GdR on Robotics.
- Eric Marchand was elected in the board of the "Images et réseaux" cluster.
- Eric Marchand was elected in the scientic commission of the École supérieure d'ingénieurs de Rennes.
- Alexandre Krupa is a member of the Inria Cost-GTAI in charge of the evaluation of the ARC and ADT from October 2011.
- François Chaumette is a member of the executive board of the project committee of Inria Rennes-Bretagne Atlantique.
- François Chaumette is a member of the animation committee of Inria's thematic domain "Perception, cognition, interaction".
- Fabien Spindler is a member of the "Comité de centre" and of the "Commission développement durable" of Inria Rennes-Bretagne Atlantique.
- Alexandre Krupa is a member of the CUMIR of Inria Rennes-Bretagne Atlantique (*Commission des Utilisateurs des Moyens Informatiques*).

9.2. Teaching

François Chaumette:

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

Master Erasmus Mundus : “Visual servoing”, 3 hours, M2, Ecole Centrale de Nantes

5^th IEEE Latin American Summer School on Robotics: “Visual servoing”, 3 hours, M2, Universidad de Chile, Santiago.

Alexandre Krupa:

Master SIBM (Signals and Images in Biology and Medicine): “Medical robotics guided from images”, 3 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: geometry”, 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 Erasmus Mundus : “computer vision”, 12 hours, M1, Ecole Centrale de Nantes

PhD & HdR:

Ph.D.: Caroline Nadeau, “Asservissement visuel échographique : application au positionnement et au suivi de coupes anatomiques”, Université de Rennes 1, defense in November 2011, supervised by Alexandre Krupa [12]

Ph.D.: Olivier Kermorgant, “Fusion d’informations multi-capteurs en asservissement visuel”, Université de Rennes 1, defense in November 2011, supervised by François Chaumette [11]

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: Laurent Coutard, “Appontage pas asservissement visuel”, started in November 2009, supervised by François Chaumette

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

Ph.D. in progress: Antoine Petit, “3D model-based tracking of complex object in a spatial context”, started in December 2011, 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

10. Bibliography

Major publications by the team in recent years

[1] F. CHAUMETTE, S. HUTCHINSON. *Visual servo control, Part I: Basic approaches*, in "IEEE Robotics and Automation Magazine", December 2006, vol. 13, n^o 4, p. 82-90, http://www.irisa.fr/lagadic/pdf/2006_ieee_ram_chaumette.pdf.

[2] F. CHAUMETTE, S. HUTCHINSON. *Visual servo control, Part II: Advanced approaches*, in "IEEE Robotics and Automation Magazine", March 2007, vol. 14, n^{o} 1, p. 109-118, http://www.irisa.fr/lagadic/pdf/2007_ieee_ram_chaumette.pdf.

[3] A. COMPORT, E. MARCHAND, M. PRESSIGOUT, F. CHAUMETTE. *Real-time markerless tracking for augmented reality: the virtual visual servoing framework*, in "IEEE Trans. on Visualization and Computer Graphics", July 2006, vol. 12, n^{o} 4, p. 615–628, http://www.irisa.fr/lagadic/pdf/2006_ieee_tvcg_comport.pdf.

[4] A. KRUPA, G. FICHTINGER, G. HAGER. *Real-time motion stabilization with B-mode ultrasound using image speckle information and visual servoing*, in "Int. Journal of Robotics Research, IJRR, Special Issue on Medical Robotics, N. Ayache and J. Desai (Eds.)", October 2009, vol. 28, n^{o} 10, p. 1334-1354, http://www.irisa.fr/lagadic/pdf/2009_ijrr_krupa.pdf.

[5] N. MANSARD, F. CHAUMETTE. *Task sequencing for sensor-based control*, in "IEEE Trans. on Robotics", February 2007, vol. 23, n^{o} 1, p. 60-72, http://www.irisa.fr/lagadic/pdf/2007_itro_mansard.pdf.

[6] E. MARCHAND, F. CHAUMETTE. *Feature tracking for visual servoing purposes*, in "Robotics and Autonomous Systems, Special Issue on “Advances in Robot Vision”, D. Kragic, H. Christensen (Eds.)", July 2005, vol. 52, n^{o} 1, p. 53–70, http://www.irisa.fr/lagadic/pdf/2005_ras_marchand.pdf.

[7] E. MARCHAND, F. SPINDLER, F. CHAUMETTE. *ViSP for visual servoing: a generic software platform with a wide class of robot control skills*, in "IEEE Robotics and Automation Magazine", December 2005, vol. 12, n^{o} 4, p. 40-52, http://www.irisa.fr/lagadic/pdf/2005_ieee_ram_marchand.pdf.

[8] R. MEBARKI, A. KRUPA, F. CHAUMETTE. *2D ultrasound probe complete guidance by visual servoing using image moments.*, in "IEEE Trans. on Robotics", April 2010, vol. 26, n^{o} 2, p. 296-306, http://www.irisa.fr/lagadic/pdf/2010_tro_mebarki.pdf.

[9] M. PRESSIGOUT, E. MARCHAND. *Real-Time Hybrid Tracking using Edge and Texture Information*, in "Int. Journal of Robotics Research, IJRR", July 2007, vol. 26, n^{o} 7, p. 689-713, special joint issue IJCV/IJRR on robot and vision, http://www.irisa.fr/lagadic/pdf/2007_ijrr_pressigout.pdf.

[10] S. SEGVIC, A. REMAZEILLES, A. DIOSI, F. CHAUMETTE. *A mapping and localization framework for scalable appearance-based navigation*, in "Computer Vision and Image Understanding", February 2009, vol. 113, n^{o} 2, p. 172-187, http://www.irisa.fr/lagadic/pdf/2009_cviu_segvic1.pdf.

Publications of the year

Doctoral Dissertations and Habilitation Theses

[11] O. KERMORGANT. *Fusion d’informations multi-capteurs en asservissement visuel*, Université de Rennes 1, Mention Traitement du Signal, November 2011, http://www.irisa.fr/lagadic/pdf/2011_thesis_kermorgant.pdf.

[12] C. NADEAU. *Asservissement visuel échographique : application au positionnement et au suivi de coupes anatomiques*, Université de Rennes 1, Mention Traitement du Signal, November 2011, http://www.irisa.fr/lagadic/pdf/2011_thesis_nadeau.pdf.

Articles in International Peer-Reviewed Journal

[13] A. CHERUBINI, F. CHAUMETTE, G. ORIOLO. *Visual servoing for path reaching with nonholonomic robots*, in "Robotica", 2011, vol. 29, n^{o} 7, p. 1037-1048, http://hal.inria.fr/hal-00639659/en.

[14] C. COLLEWET, E. MARCHAND. *Photometric visual servoing*, in "IEEE Trans. on Robotics", 2011, vol. 27, n^{o} 4, p. 828-834, http://hal.inria.fr/inria-00629834/en.

[15] A. DAME, E. MARCHAND. *Mutual information-based visual servoing*, in "IEEE Trans. on Robotics", 2011, vol. 27, n^{o} 5, p. 958-969, http://hal.inria.fr/hal-00639674/en.

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

[17] B. TAMADAZTE, N. LE FORT - PIAT, E. MARCHAND. *A direct visual servoing scheme for automatic nanopositioning.*, in "IEEE-ASME Transactions on Mechatronics.", 2011, p. 1-10, http://hal.inria.fr/hal-00574748/en.

[18] R. TATSAMBON FOMENA, O. TAHRI, F. CHAUMETTE. *Distance-based and Orientation-based Visual Servoing from Three Points*, in "IEEE Trans. on Robotics", 2011, vol. 27, n^{o} 2, p. 256-267, http://hal.inria.fr/hal-00639701/en.

International Peer-Reviewed Conference/Proceedings

[19] J. ARDOUIN, A. LÉCUYER, M. MARCHAL, E. MARCHAND. *Design and Evaluation of Methods to Prevent Frame Cancellation in Real-Time Stereoscopic Rendering*, in "IEEE Symposium on 3D User Interfaces, 3DUI 2011", Singapore, 2011, p. 95-98, http://hal.inria.fr/hal-00639649/en.

[20] G. CARON, E. MARCHAND, E. MOUADDIB. *Tracking planes in omnidirectional stereovision*, in "IEEE Int. Conf. on Robotics and Automation, ICRA'11", Shanghai, China, 2011, p. 6306-6311, http://hal.inria.fr/hal-00639646/en.

[21] F. CHAUMETTE. *Recent results in visual control of mobile robots*, in "IROS Workshop on Visual Control of Mobile Robots, Vicomor", Sans Francisco, USA, 2011, http://hal.inria.fr/hal-00639655/en.

[22] A. CHERUBINI, F. CHAUMETTE. *Visual Navigation With Obstacle Avoidance*, in "IEEE/RSJ Int. Conf. on Intelligent Robots and Systems, IROS'11", San Francisco, USA, 2011, p. 1593-1598, http://hal.inria.fr/hal-00639660/en.

[23] A. CHERUBINI, F. SPINDLER, F. CHAUMETTE. *A Redundancy-Based Approach for Visual Navigation with Collision Avoidance*, in "IEEE Symp. on Computational Intelligence in Vehicles and Transportation Systems, CIVTS'11", Paris, France, 2011, http://hal.inria.fr/hal-00639658/en.

[24] A. COMPORT, R. MAHONY, F. SPINDLER. *A Visual Servoing Model for Generalised Cameras: Case study of non-overlapping cameras*, in "IEEE Int. Conf. on Robotics and Automation, ICRA'11", Shanghai, China, 2011, p. 5683-5688, http://hal.inria.fr/hal-00639670/en.

[25] L. COUTARD, F. CHAUMETTE. *Visual detection and 3D model-based tracking for landing on aircraft carrier*, in "IEEE Int. Conf. on Robotics and Automation, ICRA'11", Shanghai, China, 2011, p. 1746-1751, http://hal.inria.fr/hal-00639672/en.

[26] L. COUTARD, F. CHAUMETTE, J.-M. PFLIMLIN. *Automatic landing on aircraft carrier by visual servoing*, in "IEEE/RSJ Int. Conf. on Intelligent Robots and Systems, IROS'11", San Francisco, USA, 2011, p. 2843-2848, http://hal.inria.fr/hal-00639673/en.

[27] A. DAME, E. MARCHAND. *A new information theoretic approach for appearance-based navigation of non-holonomic vehicle*, in "IEEE Int. Conf. on Robotics and Automation, ICRA'11", Shanghai, China, 2011, p. 2459-2464, http://hal.inria.fr/hal-00639679/en.

[28] A. DAME, E. MARCHAND. *Video mosaicing using a Mutual Information-based Motion Estimation Process*, in "IEEE Int. Conf. on Image Processing, ICIP'11", Brussels, Belgium, 2011, p. 1525-1528, http://hal.inria.fr/hal-00639686/en.

[29] C. DUNE, A. HERDT, E. MARCHAND, O. STASSE, P.-B. WIEBER, E. YOSHIDA. *Vision based control for Humanoid robots*, in "IROS Workshop on Visual Control of Mobile Robots (ViCoMoR)", San Francisco, USA, 2011, p. 19-26, http://hal.inria.fr/hal-00639681/en.

[30] O. KERMORGANT, F. CHAUMETTE. *Avoiding joint limits with a low-level fusion scheme*, in "IEEE/RSJ Int. Conf. on Intelligent Robots and Systems, IROS'11", San Francisco, USA, 2011, p. 768-773, http://hal.inria.fr/hal-00639684/en.

[31] O. KERMORGANT, F. CHAUMETTE. *Combining IBVS and PBVS to ensure the visibility constraint*, in "IEEE/RSJ Int. Conf. on Intelligent Robots and Systems, IROS'11", San Francisco, USA, 2011, p. 2849-2854, http://hal.inria.fr/hal-00639683/en.

[32] O. KERMORGANT, F. CHAUMETTE. *Multi-sensor data fusion in sensor-based control: application to multi-camera visual servoing*, in "IEEE Int. Conf. on Robotics and Automation, ICRA'11", Shanghai, China, 2011, p. 4518-4523, http://hal.inria.fr/hal-00639682/en.

[33] D. LEE, A. KRUPA. *Intensity-based visual servoing for non-rigid motion compensation of soft tissue structures due to physiological motion using 4D ultrasound*, in "IEEE/RSJ Int. Conf. on Intelligent Robots and Systems, IROS'11", San Francisco, USA, 2011, p. 2831-2836, http://hal.inria.fr/hal-00639687/en.

[34] T. LI, A. KRUPA, C. COLLEWET. *A robust parametric active contour based on Fourier descriptors*, in "IEEE Int. Conf. on Image Processing, ICIP'11", Bruxelles, Belgium, September 2011, http://hal.inria.fr/hal-00645326/en.

[35] E. MARCHAND. *Model based tracking for catadioptric cameras*, in "IROS Workshop on Visual Tracking and Omnidirectional Vision, VTOV", Sans Francisco, USA, 2011, http://hal.inria.fr/hal-00639688/en.

[36] C. NADEAU, A. KRUPA, J. GANGLOFF. *Automatic Tracking of an Organ Section with an Ultrasound Probe: Compensation of Respiratory Motion*, in "Int. Conf. on Medical Image Computing and Computer Assisted Intervention, MICCAI'11", Toronto, Canada, 2011, http://hal.inria.fr/hal-00639691/en.

[37] C. NADEAU, A. KRUPA. *Improving ultrasound intensity-based visual servoing: tracking and positioning tasks with 2D and bi-plane probes*, in "IEEE/RSJ Int. Conf. on Intelligent Robots and Systems, IROS'11", San Francisco, USA, 2011, p. 2837-2842, http://hal.inria.fr/hal-00639692/en.

[38] C. Nadeau, A. Krupa. *Intensity-based direct visual servoing of an ultrasound probe*, in "IEEE Int. Conf. on Robotics and Automation, ICRA'11", Shanghai, China, 2011, p. 5677-5682, http://hal.inria.fr/hal-00639689/en.

[39] R. Ozawa, F. Chaumette. *Dynamic Visual Servoing with Image Moments for a Quadrotor Using a Virtual Spring Approach*, in "IEEE Int. Conf. on Robotics and Automation, ICRA'11", Shanghai, China, 2011, p. 5670-5676, http://hal.inria.fr/hal-00640876/en.

[40] A. Petit, G. Caron, H. Uchiyama, E. Marchand. *Evaluation of Model based Tracking with TrakMark Dataset*, in "2nd Int. Workshop on AR/MR Registration, Tracking and Benchmarking", Basel, Switzerland, 2011, http://hal.inria.fr/hal-00639700/en.

[41] A. Petit, N. Despre, E. Marchand, K. Kanani, F. Chaumette, S. Provost, G. Flandin. *3D Model-based Visual tracking for Space Autonomous Rendezvous*, in "8th Int. ESA Conf. on Guidance and Navigation Control Systems, GNC'11", Carlsbad, Czech Republic, 2011, http://hal.inria.fr/hal-00639698/en.

[42] A. Petit, E. Marchand, K. Kanani. *Vision-based Space Autonomous Rendezvous : A Case Study*, in "IEEE/RSJ Int. Conf. on Intelligent Robots and Systems, IROS'11", San Francisco, USA, 2011, p. 619-624, http://hal.inria.fr/hal-00639699/en.

[43] B. Tamadazte, G. Duceux, N. Le Fort-Piat, E. Marchand. *Highly precise micropositioning task using a direct visual servoing scheme.*, in "IEEE internatioanal Conference on Robotics and Automation, ICRA'11.", Shangai, China, 2011, vol. sur CD ROM, 6 pages, http://hal.inria.fr/hal-00554841/en.

[44] C. Teulière, L. Eck, E. Marchand. *Chasing a moving target from a flying UAV*, in "IEEE/RSJ Int. Conf. on Intelligent Robots and Systems, IROS'11", San Francisco, USA, 2011, http://hal.inria.fr/hal-00639702/en.

[45] H. Uchiyama, E. Marchand. *Deformable Random Dot Markers*, in "IEEE Int. Symp. on Mixed and Augmented Reality, ISMAR'11", Basel, Switzeland, 2011, p. 237-238, http://hal.inria.fr/hal-00639703/en.

[46] H. Uchiyama, E. Marchand. *Toward Augmenting Everything: Detecting and Tracking Geometrical Features on Planar Objects*, in "IEEE Int. Symp. on Mixed and Augmented Reality, ISMAR'11", Basel, Switzeland, 2011, p. 17-25, http://hal.inria.fr/hal-00639704/en.

National Peer-Reviewed Conference/Proceedings

[47] T. Li, A. Krupa, C. Collewet. *Un contour actif robuste basé sur les descripteurs de Fourier*, in "ORASIS - Congrès des jeunes chercheurs en vision par ordinateur", Praz-sur-Arly, France, INRIA Grenoble Rhône-Alpes, 2011, http://hal.inria.fr/inria-00595287/en.

[48] C. Nadeau, A. Krupa. *Asservissement visuel direct d'une sonde échographique*, in "Recherche en Imagerie et Technologies pour la Santé, RITS'11", Rennes, France, 2011, http://hal.inria.fr/hal-00639690/en.