INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Team LAGADIC

Visual servoing in robotics, computer vision, and computer animation

Rennes

THEME COG

Activity Report

2004

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Head of project-team
François Chaumette [DR Inria]

Administrative assistant
Stéphanie Lemaile [TR Inria, shared with Temics, Vista and Visages teams]

Inria research scientists
Éric Marchand [CR]
Alexandre Krupa [CR, from 01/10/2004]

Inria technical staff
Fabien Spindler [IR]

Inria project technical staff
Cédric Riou [Sora project]

Inria junior technical staff
Anne-Sophie Tranchant [shared with Visages team]

Inria Post-doctoral fellows
Peihua Li [until 31/08/2004]

Teaching assistants
Anthony Remazeilles [Insa, University of Rennes 1, from 01/09/2004]

Ph-D students
Odile Bourquardez [DGA/CNRS grant from 01/10/2004]
Andrew Comport [Inria grant, Sora project]
Nicolas Mansard [ENS Cachan-Bretagne member]
Muriel Pressigout [Research Ministry grant]
Anthony Remazeilles [Research Ministry grant until 31/08/2004, shared with Texmex team]
Omar Tahri [Inria - Brittany Region grant until 31/03/2004]

2. Overall Objectives

Keywords: *active vision*, *augmented reality*, *computer vision*, *image sequence*, *robot vision*, *tracking*, *visual servoing*.

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 which 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 the potential applications to which can lead our work. 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 those resulting from an omnidirectional vision sensor or echographic probes. We are finlly interested in revisiting traditional problems in computer vision (3D localization, structure and motion) through the visual servoing approach.

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 [31] [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 n 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 k measurements has to be selected at best, allowing to control the m degrees of freedom desired. A control law has also to be designed so that these measurements $\mathbf{s}(t)$ reach a desired value $\mathbf{s}^*$, defining a correct realization of the task. A desired 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 as well 2D data (coordinates of feature points in the image, moments, ...) 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 [3].

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:

$$\mathbf{s} = \mathbf{s}(\mathbf{r}(t)) \tag{1}$$

where $\mathbf{r}(t)$ describes the pose at the instant t between the camera frame and the target frame. The variation of $\mathbf{s}$ can be linked to the relative kinematic motion $\mathbf{v}$ between the camera and the scene:

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

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:

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

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

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 highly non linear and does not present any decoupling properties. In some cases, it may lead to inadequate robot trajectories or even motions impossible to realize, local minima, tasks singularities, etc. [1]. It is thus extremely important to choose 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.

Furthermore, embedding visual servoing in the task function approach [32] allows to solve 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.

4. Application Domains

Keywords: *augmented reality*, *image-guided neuro-surgery*, *robot vision*, *underwater robotics*, *vehicle navigation*.

The natural applications of our research are obviously in robotics. In the past, we mainly worked in the field of the grasping and of the manipulation of tools, in the field of underwater robotics for the stabilization of images, and the positioning of uninstrumented robot arms, in the field of agro-industry for the positioning of a vision sensor in order to ensure an improvement of the quality controls of agro-alimentary products, as well as in the field of the video surveillance (control of the movements of a pan-tilt camera to track mobile natural objects). More recently, we addressed the field of mobile robotics via the activities undertaken around the Cycab vehicle: detection and tracking of mobile objects (pedestrians, other vehicles), control by visual servoing of the movements of the vehicle.

In fact, researches which we undertake 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 robot system considered (the robot and the vision sensor can even be virtual as we will see it in the continuation).

Currently, we are interested in using visual servoing for the control of the movements of miniature helicopters and aircrafts. We are also interested in the navigation of a mobile robot using an omnidirectional vision sensor. In collaboration with the Visages team, we also address the field of medical robotics. The applications under consideration for the moment 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, coupling between an off-set vision of the field of examination and a force sensor for tele-operated examinations, etc.

Robotics is not the only possible applicability to our research tasks. Recently, we were interested in collaboration with the Siames project to apply the techniques of visual servoing in the field of computer animation. It can be a question either of controlling the movement of virtual humanoids according to their pseudo-perception, or to control 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.

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 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 can be related with those carried out in cogniscience, in particular in the field of psychovision (for example on the study of eye motion in the animal and human visual system, or 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: Éric Marchand, Fabien Spindler.

Visual servoing is a very active research area in vision-based robotics. A software environment that allows fast prototyping of visual servoing tasks is then of prime interest. The main reason is certainly that it usually requires specific hardware (the robot and, most of the time, dedicated image processing boards). The consequence is that the resulting applications are often not portable and cannot be easily adapted to other environments. Today's software design allows one to propose elementary components that can be combined to build portable high-level applications. Furthermore, the increasing speed of micro-processors allows the development of real-time image processing algorithms on a usual workstation. We have developed a library of canonical vision-based tasks for eye-in-hand visual servoing that contains the most classical linkages that are used in practice. The ViSP software environment features all the following capabilities : independence with respect to the hardware, simplicity, extendibility, portability. Moreover, ViSP involves a large library of elementary positioning tasks w.r.t. various basic control features (points, lines, circles, spheres, cylinders,...) that can be combined together, and an image processing library that allows the tracking of visual cues (dot, segment, ellipse, spline,...). This modular platform has been primarily developed in C++ on Unix workstations and is now available on Linux and Windows XP.

5.2. Marker software : Marker-based augmented reality kernel

Participant: Éric Marchand.

The Marker software implements an algorithm supplying the computation of camera pose, the calibration of the cameras using fiducial markers. Pose computation is handled using virtual visual servoing. The principle consists in considering the pose and the calibration as a dual problem of visual servoing. This method presents many advantages : similar accuracy as for the usual non-linear minimization methods, simplicity, effectiveness. A licence of this software was yielded to the Total Immersion company.

5.3. MarkerLess : MarkerLess-based augmented reality kernel

Participants: Cédric Riou, Andrew Comport, Éric Marchand.

Markerless is an upgrade of the Marker software with additional features developed within the SORA Riam Project. It allows the computation of camera pose with no fiducial marker. It also relies on virtual visual servoing. See paragraph 6.3.1 for more details.

5.4. Development work : Robot vision platforms

Participant: Fabien Spindler.

We exploit several experimental platforms to validate our research work in robot vision, in visual servoing and in active vision. More precisely, we have two robotic systems built by Afma Robots : the first one is a cartesian robot with six degrees of freedom, the other one is a cylindrical robot with four degrees of freedom. Each robot is equipped with a CCD camera mounted on the effector and an Imaging Technology framegrabber. A PC on Linux communicates with the robot using a SBS Technologies bus adapter. 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.

5.5. Development work : Medical robot

Participants: Anne-Sophie Tranchant, Fabien Spindler.

In 2003, we have acquired a new robotic system with an ultrasound probe dedicated to medical applications, specifically to 3D remote echography. Because of technical problems, the project was delayed. Fall 2004, the material was declared opened to service by the Sinters company. The end of the year will be devoted to the complete test of the system. Therefore, to anticipate the future vision-based developments we have made new API to control the specific framegrabber or cameras attached to the robot.

5.6. Development work : Cycab

Participants: Fabien Spindler, Eric Marchand.

The Cycab is a small autonomous electric car equipped with a pan-tilt camera located behind its front windshield. Two Linux computers are onboard. One is used for the visual tracking and the control computation, while the other one is devoted to the low-level control of the car's velocity and wheel steering. An other external pan-tilt camera is mounted on top of a building in order to have an overlook of the area where the Cycab experiments are performed. On this research platform, we have developed vision-based mobile robot applications in a real outdoor environment.

The first one consists in positioning the mobile robot by visual servoing relatively to a simple target. The control scheme tries to keep constant the distance between the onboard camera and the target. The second one consists in detecting and tracking a mobile object from one of the pan-tilt cameras. Dealing with the onboard camera, an objet of interest could be a pedestrian crossing the Cycab trajectory, while with the external camera it could be the Cycab itself. Based on pose estimation using the external camera, we try to increase the precision of the position of the mobile object and to determine its trajectory.

6. New Results

6.1. Visual servoing

6.1.1. Visual servoing using image moments

Participants: Omar Tahri, François Chaumette.

This year, we have ended our study on the use of image moments in visual servoing. We first remind that we have determined the analytical form of the interaction matrix related to any image moment, either using the classical perspective projection model [9], or using a spherical projection model [8]. Objects defined by closed edges or by a set of discrete points have been considered. Thanks to the moment invariants theory, we have also determined optimal combinations of moments so that the corresponding interaction matrix is as much decoupled and linear as possible. This result was valid only when the object is parallel to the image plane. This year we have extended this previous result to the more general case where the desired object position may have any orientation with respect to the camera. We have also developed a new method to estimate the pose of an object from its image moments. This method is composed of two successive steps: the first one provides an initialization of the pose by computing a cost function in a two-dimensional space; the second one consists in improving the estimation of the pose using a virtual visual servoing scheme. Satisfactory experimental results have been obtained on a six degrees of freedom robotics system.

6.1.2. Vision-based tasks sequencing

Participants: Nicolas Mansard, François Chaumette.

The aim of this study is to realize global and high level robotics tasks by an adequate sequencing of local vision-based tasks. Classical visual servoing approaches tend to constrain all the degrees of freedom (dofs) of the robot during the execution of a task. The key idea is to control the robot with a very under-constrained task when it is far from the desired position, and to incrementally constrain the global task by adding further tasks as the robot moves closer to the goal. We have used the redundancy formalism of the task function approach for such a purpose [20]. As long as they are sufficient, the remaining dofs are used to avoid the robot joint limits. Closer from the goal, when not enough dofs remain available for the avoidance, an execution controller selects a task to be temporary removed from the applied tasks. The released dofs can then be used for the joint limits avoidance. A complete solution to implement this general idea has been proposed. Experiments have proven the validity of the approach. Other constraints (such as obstacles avoidance, visibility preserving, occlusion avoidance, etc.) will be considered in a near future.

6.1.3. Navigation from a visual memory

Participants: Anthony Remazeilles, François Chaumette.

This research study is carried out in collaboration with P. Gros (Texmex team). We are working on automatic robot motion control, using visual information provided by an on-board camera and an image data base of the navigation space. The image base describes the environment in which the robotic system moves. Thanks to this base, the robot localization is nothing but a k nearest-neighbor search of the initial image given by the camera before the motion. The localization stage therefore avoids reconstructing the entire 3D scene, which is a time consuming and complex process.

The definition of the path that the robot has to follow is also defined in terms of images: the desired position corresponds to the image that the camera should obtain at the end of the motion. The same image retrieval method presented before enables to localize the desired position. By translating the image base into a valuated graph (corresponding to the feasibility to go from an image to an other), and using graph theory, the shortest image path can be easily found between the initial image and the desired one. Those images, extracted from the database, describe in a continuous way the space the robot has to pass through in order to reach the desired position.

Our navigation scheme is based on the potential field approach. The robot moves in order to make visible visual features defined on the image path and initially out of the camera field of view. The control law is computed online, by using suitable potential functions, depending on the feature projections on the current image plane, and the image path. Once again, explicit $3D$ reconstruction is not necessary.

During this year, we have extended our method in order to be able to deal with general motions and $3D$ environments. We have defined new potential functions which give the robotic system the ability to control the translational motions along the camera optical axis, and the rotational motions around objects of the environment. Some simulations have been performed and confirm that the control law gives adequate results for a six degrees of freedom robot. In the future, obstacles will however have to be taken into account in the navigation scheme.

As long as the displacement to realize is large, landmarks that belong to the initial camera field of view are likely to disappear during the navigation. Visual landmarks update is therefore a key problem that has to be considered. This year, we have proposed an automatic update of visible points, based on the image transfer theory. Once again, the $3D$ model is not used; epipolar geometry, computed between the current view and the image path is a sufficient information for making points projection. However, even if we have obtained some promising results on image sequences, this method should be improved to be used for the on-line control of a real robotic system.

At last, we have proposed during this year a new method for improving the image data base structure. The graph structure has been changed in order to take directly into account motions that a mobile robotic system can perform. The idea is that the image path provided by the graph corresponds to motions that are easy to perform by a non-holonomic system.

6.1.4. Control of aircrafts by visual servoing

Participants: Odile Bourquardez, François Chaumette.

We have started in October 2004 a study to develop visual servoing techniques in order to control aircrafts during landing, take off, and in-flight refueling. First, we will have to model the visual features to realize these tasks from the available measurements in the images. Then, we will have to design control schemes in order to deal with such under actuated systems.

6.2. Medical robotics

6.2.1. Visual servoing based on 2D ultrasound images

Participants: Alexandre Krupa, François Chaumette.

This work is just starting and consists in studying and elaborating new visual servoing methods based on 2D ultrasound images. The issue of this study is to directly control the motion of a medical robot from visual features extracted from ultrasound images. The modeling aspects involved in this study differ from the one of classical visual servoing because an ultrasound probe does not act like a standard camera. In fact, an ultrasound probe provides information only in its observation plane whereas a standard camera provides a projection of the 3D scene to a 2D image. We start our study in modeling the ultrasound probe and its interaction with the 3D scene. In a first stage, we investigate the choice of relevant visual features that allow to realize some robotic tasks. Since ultrasound images are very noisy, we have to take into account constraints such as real time extraction and robust features detection. On the other hand, we work on the modeling of the interaction matrix related to the chosen visual features. Based on the future results of this work, we plan to use the formalism of the task function approach to move automatically an ultrasonic probe by using an ultrasound image-based control scheme.

6.3. Tracking

Elaboration of objects tracking algorithms in image sequences is an important issue for research and application related to visual servoing and more generally for robot vision. A robust extraction and real-time spatio-temporal tracking process of visual cue is indeed one of the keys to success a visual servoing task. Fiducial markers have been used for a long time since they ensure a reliable and fast tracking. However, since such features are not present in realistic environments, it is no longer possible to be limited to such techniques.

6.3.1. 3D model-based tracking by virtual visual servoing

Participants: Andrew Comport, Cédric Riou, Éric Marchand, François Chaumette.

A real-time, robust and efficient 3D model-based tracking algorithm for a monocular vision system has been developed. Tracking objects in the scene amounts to compute the pose between the camera and the objects. Non-linear pose computation is formulated by means of a virtual visual servoing approach. In this context, the derivation of point-to-curves interaction matrices are given for different features including lines, circles, cylinders and spheres. A local moving-edge tracker is used in order to provide a real-time estimation of the displacements normal to the object contours. A method is proposed for combining local position uncertainty and global pose uncertainty in an efficient and accurate way by propagating uncertainty. Robustness is obtained by integrating an M-estimator into the visual control law via an iteratively re-weighted least squares implementation. The proposed method has been validated on several complex image sequences including outdoor environments. Application for this tracker is robotics and visual servoing as well as augmented reality applications. More recently, we have considered sensors fusion algorithm for both image-based tracking algorithm and magnetic sensor tracking.

6.3.2. 3D model-based tracking of articulated objects

Participants: Andrew Comport, Éric Marchand, François Chaumette.

We have extended the model-based tracking algorithm (see Section 6.3.1) and proposed a new approach for real-time visual tracking of the articulated class of non-rigid objects in 3D. The main idea consists in symmetrically modeling the motion and velocity of an articulated object via an intuitive kinematic set approach which is linked to a Lagrange-d'Alembert formulation. Firstly, a joint configuration is modeled by using Pfaffian velocity constraints. The configuration and location of a joint is then used to build a general Jacobian Matrix which relates individual rigid body velocities(twists) to an underlying minimal subspace. An iterative non-linear control law is then derived in order to minimize a set of distance errors in the image and estimate the system parameters. By doing this, the tracking techniques are efficient and precise leading to real-time performance and accurate measurements. Experimental results considering prismatic, rotational and helical type links and up to eight general parameters have been exhibited.

6.3.3. Tracking for visual servoing

Participants: Peihua Li, François Chaumette.

This year, we have developed an object tracking method based on the fusion of image cues and particle filtering [19]. The cues that have been considered are color likelihood, edge likelihood, and structure likelihood. This method has been used for tracking human faces. It gives good qualitative results and can be used in visual servoing to control the pan, tilt and zoom of a camera. The accuracy of the results are however insufficient to control the six degrees of freedom of a robot.

To overcome this problem, we then have developed an accurate and robust shape tracking algorithm. Two steps are involved in the algorithm. Firstly, the object shape is assumed to vary under an affine model, the edge detection is performed along the normal lines to the contour, and we have used a Kalman filter to perform efficient tracking. The second step concerns image matching based on a full perspective model, which is achieved iteratively by searching locally along the normal lines also. The experiments we have realized demonstrate that the tracking algorithm is accurate and robust enough to be used in a six dof visual servoing.

6.3.4. 3D model-free multimodal tracking

Participants: Muriel Pressigout, Éric Marchand.

For the time-being, most of the available tracking techniques can be divided into two main classes: edge-based and texture-based tracking. The former approach focuses on tracking 2D or 3D features such as geometrical primitives (points, segments, circles,...), object contours, 3D object, etc. The latter explicitly uses a texture or the luminance information that represents the tracked objects. These two classes of approaches have complementary advantages and drawbacks, so it is quite natural to use both of them. Therefore, the proposed method however integrates simultaneously both approaches. Since both edge and tracking algorithms can be seen as optimization algorithms, our goal was to define a unique state vector that describes both the appearance of the template as well as its edge boundaries modeled using Nurbs. Considering this vector state, we are able to compute the parameters of a 2D transformation that minimize the error between this current multi-cues template and the displaced reference one. The multimodal tracking algorithm combines the motion estimation of contour points and of texture points in an unique non-linear minimization process. Since data are likely to be corrupted with noise, a robust minimization is required. Robustness is obtained by considering robust M-estimation into the minimization process through an iteratively re-weighted least squares implementation. Since this tracker is precise and fast enough, it has been used successfully in visual servoing experiments whereas single cue trackers have failed or were not accurate enough. The considered 2D transformation is valid only for planar object. There does not exist any 2D transformation that accounts for a generic 3D object motion. Therefore to handle such cases, we are now interested in multimodal 3D tracking, by combining pose computation and motion estimation. Such a tracker should be more robust and smoother than traditional 3D trackers.

7. Contracts and Grants with Industry

7.1. Cemagref-Ofival contract : Quality evaluation of pork meat

Participants: Eric Marchand, François Chaumette.

no. Inria 1 00 C 0494, duration : 36 months.

This study deals with the evaluation of the quality of pork meat by active vision and MRI measurements. It results from a joint proposal made by Cemagref Rennes, Olympig company and Vista team to Ofival which agreed to financially support this project. Our task was to develop a vision-based estimation of the volume of ham pieces. We have designed algorithms for 3D reconstruction and exploration of an unknown object using a mobile and controlled camera. We use a space carving algorithm to obtain a precise and robust reconstruction of the 3D structure of the object. To ensure the completeness of the reconstruction, we have defined a gaze planning strategy that mainly uses a representation of known and unknown areas as a basis for selecting new viewpoints. The trajectory that realizes this exploration is performed using a visual servoing approach. The software developed at Irisa has been transferred this year at Cemagref for their experiments

7.2. Edixia contract: Localization from several cameras

Participant: François Chaumette.

no. Inria 104C050600, duration : 12 months.

The aim of this contract with the Edixia company is to develop a method to localize the 3D pose between a car mounted on an assembly process and a robot arm using four off-board cameras, each of them observing only one hole on the bottom of the car.

7.3. French national programme Riam

7.3.1. Sora project

Participants: Cédric Riou, Andrew Comport, Éric Marchand.

no. Inria 2 03 C 1428, duration : 24 months.

The goal of the Sora project (Objects tracking for augmented reality) is to develop a tracking algorithm for augmented reality applications. Our partners are Total-Immersion and VideoMage companies. Augmented reality has now progressed to the point where real-time applications are being considered and needed. On the other hand, it is important that synthetic elements are rendered and aligned in the scene in an accurate and visually acceptable way. In order to address these issues in real-time, a robust and efficient 3D model-based tracking algorithm is proposed for a "video see through" monocular vision system. Virtual objects can then be projected into the scene from the camera pose computed using our algorithm. The tracking rate is 50Hz.

7.4. French national programme Predit

7.4.1. Mobivip project

Participants: Anthony Remazeilles, François Chaumette.

no. Inria 2 03 A 2005, duration : 36 months.

This project, started in December 2003, is a large project headed by Inria Sophia Antipolis. It is concerned with the navigation of mobile vehicles in urban environments. Within this project, our work consists in designing autonomous vision-based navigation techniques using an image database of the environment. This work is closely related to the Robea Bodega project and to Anthony's Remazeilles's PhD.

8. Other Grants and Activities

8.1. Regional initiatives

8.1.1. CPER initiative : 3D echography capture by a robotics system

Participants: Anne-Sophie Tranchant, Fabien Spindler, Alexandre Krupa, François Chaumette.

In November 2003, the Lagadic and Visages teams have jointly acquired a new robotics system marketed by Sinters company and dedicated to medical applications, specifically to the remote control of medical ultrasound probes. This system is based on a six degrees-of-freedom intrinsically safe robot. It is equipped with a force/torque sensor mounted at the tip of the robot arm which can move an ultrasonic or Doppler probe on the patient's skin while applying a programmable and constant force. To prove the interest of robotics approaches for medical applications, we will pursue three objectives. Firstly, using ultrasound (US) images recorded over the probe trajectory and the corresponding robot positions, we will work on the 3D ultrasound image volume reconstruction. Secondly, using an external camera, we will develop visual servoing tasks to achieve an automatic probe positioning, or to control that the probe follows a planned trajectory in order to increase the 3D US reconstruction accuracy. Finally, we will work on the modeling of the US images in order to exploit them directly in a visual servoing scheme.

8.2. National initiatives

8.2.1. Initiatives supported by CNRS

8.2.2. Robea Robotics research programme

- *Omnibot project*
  Participants: François Chaumette, Éric Marchand.

This two-years project, started in October 2002, aims at developing robot navigation schemes using a panoramic vision sensor. It involves a collaboration between several academic labs, Lasmea in Clermont-Ferrand, Lirmm in Montpellier, Crea in Amiens and our team. This year, we have determined the analytical form of the interaction matrix related to image moments using the specific geometrical models of panoramic sensors. A visual servoing control law has then been derived from this modeling step. A circle tracker has been developed at Irisa to validate visual servoing experiment at Lasmea.

- *Complex dynamic scene interpretation and reactive motion planning.*
  Participants: Eric Marchand, Fabien Spindler.
  This three-years project, started in October 2002, is a collaboration between Inria Rhône-Alpes (Sharp, Movi and Prima teams), the Laas (Ria group) and Inria Rennes (Vista team). The objective of this project is the automatic control of a vehicle in road environment. For this year, we have focused on the detection and tracking of mobile obstacles by a moving camera. To this end, we have used motion analysis algorithms (motion detection and tracking) previously developed in the Vista team. One of the originality of our approach is that we do not extract geometrical information from images (no spatial image segmentation) but we directly exploit the intensity image sequence. In addition, we consider a visual servoing module in order to maintain the tracked object of interest in the camera field of view.
- *Egocentre project*
  Participants: Nicolas Mansard, François Chaumette.
  This three-years project, started in September 2003, aims at developing task sequencing schemes to realize high level robotics tasks from local sensor-based control techniques. Comparison between vision-based control and human beings for gaze control is also considered. It involves a collaboration between Laas, Cerco and Enit, all located in Toulouse, and our team.
- *Bodega project*
  Participants: Anthony Remazeilles, François Chaumette.
  This two-years project, started in November 2003, aims at designing vision-based and sensor-based methods for the autonomous navigation of mobile vehicles moving around an urban environment. It involves a collaboration between Ensil in Limoges, UTC in Compiègne, Lasmea in Clermont-Ferrand, the Icare team of Inria Sophia-Antipolis, and our team.
- *Robvolint project*
  Participants: Odile Bourquardez, François Chaumette.
  This two-years project, started in November 2003, aims at developing vision-based localization techniques and visual servoing schemes for small helicopters moving around an indoor environment. It involves a collaboration between I3S in Nice, CEA in Fontenay-aux-Roses, Ircynn in Nantes, and our team.

8.3. Bilateral international co-operation

8.3.1. Inria-Grices project, France-Portugal

Participants: François Chaumette, Fabien Spindler, Muriel Pressigout.

This collaboration with IST Lisbon, Portugal (Prof. J. Santos-Victor and Prof. R. Caldas Pinto) is concerned with visual servoing and image sequence analysis for robotics applications. F. Spindler and M. Pressigout have spent a three days visit at IST in November 2004 and Prof. J. Santos-Victor and Prof. R. Caldas Pinto have come for a short visit in our team in November and December 2004.

8.3.2. Visiting scientists

- Danica Kragic, Associate Professor at KTH, Stockhölm, did a one-month visit in March 2004.
- Rob Mahony, Associate Professor at ANU, Canberra, did a one-month visit in November 2004.
- Short visits by Greg Hager (John Hopkins University), Seth Hutchinson (Beckmann Institute, Urbana Champaign), Nassir Navab (Munchen University)

8.3.3. Project reviewing

- F. Spindler is member of the engineers reviewing committee of the french institute for agronomy research (Inra).

9. Dissemination

9.1. Leadership within scientific community

- F. Chaumette participates in the Scientific Committee of the CNRS Autonomous and Communicating Robotics program (RTP 17).
- *Editorial boards of journals*
  - F. Chaumette is Associate Editor of IEEE Trans. on Robotics.
- *Conference organization*
  - Éric Marchand was in the Local Organizing Committee of the MICCAI'04 conference (Medical Image Computing, Computer-Assisted Intervention and medical robotics). He was in charge of the local organization of the Miccai satellite workshop AMI-ARCS "Augmented Reality in Computer Assisted Intervention".
  - F. Chaumette and D. Duhaut (UBS Lorient) are the General Chairs of JNRR'05 ("Journées Nationales de la Recherche en Robotique") which we co-organize and will be held in October 2005 in Guidel (Morbihan). All the members of the Lagadic group are in the Local Organizing Committee.
- *Technical program committees of conferences*
  - F. Chaumette : ECCV'2004, member of the Editorial Committee of RFIA'2004, MICCAI'2004, ICRA'2005, CVPR'2005.

9.2. Teaching

- Master M2RI of Computer Science, Ifsic, University of Rennes 1 (E. Marchand) : 3D Computer vision.
- Diic INC, Ifsic, University of Rennes 1 (E. Marchand, F. Chaumette, N. Mansard: 3D vision, visual servoing; E. Marchand, F. Spindler : programming tools for image processing).
- Insa Rennes, Electrical Engineering Dpt (F. Chaumette, F. Spindler, N. Mansard, O. Bourquardez : computer vision).
- Master I2S, University of Montpellier (F. Chaumette: visual servoing)
- Graduate student interns : O. Bourquardez (Master LSIIT, Strasbourg), A. Samia (Master Lab, Besançon), F. Lotte (Insa Rennes)
- External thesis supervision :
  - A. Alhaj (Cemagref, Rennes) supervised by F. Chaumette;
  - J. Pages (University of Girona, Spain and Cemagref Rennes) supervised by F. Chaumette.

9.3. Participation in seminars, invitations, awards

- A. Remazeilles, F. Chaumette and P. Gros (Texmex group) received the RFIA'2004 best paper award [27].
- A. Comport, E. Marchand, F. Chaumette received the AMDO'2004 third best paper award [12].
- F. Chaumette was invited for a three-day visit at the University of Alicante, Spain in July 2004, and at KTH in Stockhölm in December 2004.
- F. Chaumette gave an invited talk at Lab Besançon in May 2004 on recent advances in visual servoing.
- E. Marchand and F. Chaumette have been invited to participate to a Workshop on "Advances in Robot Vision - From Domestic Environments to Medical Applications", during IROS'2004, Sendai, Japan in September 2004 [21].
- F. Chaumette has been invited to participate to a Tutorial on "Advanced Visual Servoing" during IROS'2004, Sendai, Japan in September 2004.

10. Bibliography

Major publications by the team in recent years

[1] F. CHAUMETTE. *Potential problems of stability and convergence in image-based and position-based visual servoing*, in "The Confluence of Vision and Control, LNCIS Series, No 237, Springer-Verlag", 1998.

[2] B. ESPIAU, F. CHAUMETTE, P. RIVES. *A new approach to visual servoing in robotics*, in "IEEE Transactions on Robotics and Automation", vol. 8, n° 6, June 1992, p. 313-326.

[3] E. MALIS, F. CHAUMETTE, S. BOUDET. *2 1/2 D visual servoing*, in "IEEE Transactions on Robotics and Automation", vol. 15, n° 2, April 1999, p. 238-250.

[4] E. MARCHAND, F. CHAUMETTE. *Virtual Visual Servoing: a framework for real-time augmented reality*, in "Eurographics 2002 Conference Proceedings, Saarebrücken, Germany", Computer Graphics Forum, vol. 21, n° 3, 2002, p. 289–298.

[5] E. MARCHAND, F. CHAUMETTE. *An autonomous active vision system for complete and accurate 3D scene reconstruction*, in "Int. Journal of Computer Vision", vol. 32, n° 3, August 1999, p. 171-194.

Doctoral dissertations and Habilitation theses

[6] E. MARCHAND. *Contributions à la commande d'une caméra réelle ou virtuelle dans des mondes réels ou virtuels*, Habilitation à diriger des recherches, Université de Rennes 1, Rennes, November 2004.

[7] A. REMAZEILLES. *Navigation à partir d'une mémoire d'images*, Ph. D. Thesis, Université de Rennes 1, mention Informatique, Rennes, December 2004.

[8] O. TAHRI. *Application des moments à l'asservissement visuel et au calcul de pose*, Ph. D. Thesis, Université de Rennes 1, mention informatique, Rennes, March 2004.

Articles in referred journals and book chapters

[9] F. CHAUMETTE. *Image moments: a general and useful set of features for visual servoing*, in "IEEE Trans. on Robotics", vol. 20, n^o 4, August 2004, p. 713–723.

Publications in Conferences and Workshops

[10] F. CHAUMETTE, E. MARCHAND. *Recent results in visual servoing for robotics applications*, in "8th ESA Workshop on Advanced Space Technologies for Robotics and Automation, ASTRA 2004, Noordwijk, The Netherlands", November 2004.

[11] C. COLLEWET, A. ALHAJ, F. CHAUMETTE. *Model-free visual servoing on complex images based on 3D reconstruction*, in "IEEE Int. Conf. on Robotics and Automation, ICRA'04, New Orleans, LA", vol. 1, April 2004, p. 751–756.

[12] A. COMPORT, E. MARCHAND, F. CHAUMETTE. *Complex articulated object tracking*, in "Int. Workshop on Articulated Motion and Deformable Objects, AMDO'04, Palma de Mallorca, Spain", J. PERALES, B. DRAPER (editors)., Lecture Notes in Computer Science, vol. 3179, September 2004, p. 189–201.

[13] A. COMPORT, E. MARCHAND, F. CHAUMETTE. *Object-based visual 3D tracking of articulated objects via kinematic sets*, in "IEEE Workshop on Articulated and Non-Rigid Motion, Washington, DC", June 2004.

[14] A. COMPORT, E. MARCHAND, F. CHAUMETTE. *Robust model-based tracking for robot vision*, in "IEEE/RSJ Int. Conf. on Intelligent Robots and Systems, IROS'04, Sendai, Japan", vol. 1, September 2004, p. 692–697.

[15] A. COMPORT, M. PRESSIGOUT, E. MARCHAND, F. CHAUMETTE. *Une loi de commande robuste aux mesures aberrantes en asservissement visuel*, in "14ème Congrès Francophone AFRIF-AFIA de Reconnaissance des Formes et Intelligence Artificielle, RFIA'04, Toulouse, France", January 2004.

[16] A. COMPORT, O. TAHRI, E. MARCHAND, F. CHAUMETTE. *Visual servoing with respect to complex objects*, in "Int. Symp. on Robotics, ISR'04, Paris, France", March 2004.

[17] J.-T. LAPRESTÉ, F. JURIE, M. DHOME, F. CHAUMETTE. *An Efficient Method to Compute the Inverse Jacobian Matrix in Visual Servoing*, in "IEEE Int. Conf. on Robotics and Automation, ICRA'04, New Orleans, LA", vol. 1, April 2004, p. 727–732.

[18] J.-T. LAPRESTÉ, F. JURIE, M. DHOME, F. CHAUMETTE. *Nouvelle approche pour le calcul du jacobien inverse en asservissement visuel 2D*, in "14ème Congrès Francophone AFRIF-AFIA de Reconnaissance des Formes et Intelligence Artificielle, RFIA 2004, Toulouse, France", January 2004.

[19] P. LI, F. CHAUMETTE. *Image Cues Fusion for Contour Tracking Based on Particle Filter*, in "Int. Workshop on Articulated Motion and Deformable Objects, AMDO'04, Palma de Mallorca, Spain", J. PERALES, B. DRAPER (editors)., Lecture Notes in Computer Science, vol. 3179, September 2004, p. 99–107.

[20] N. MANSARD, F. CHAUMETTE. *Tasks sequencing for visual servoing*, in "IEEE/RSJ Int. Conf. on Intelligent Robots and Systems, IROS'04, Sendai, Japan", vol. 1, September 2004, p. 992–997.

[21] E. MARCHAND, F. CHAUMETTE. *Features tracking for visual servoing purpose*, in "Advances in Robot Vision - From Domestic Environments to Medical Applications, Sendai, Japan", D. KRAGIC, H. CHRISTENSEN (editors)., September 2004, p. 10–20.

[22] E. MARCHAND, A. COMPORT, F. CHAUMETTE. *Improvements in robust 2D visual servoing*, in "IEEE Int. Conf. on Robotics and Automation, ICRA'04, New Orleans, LA", vol. 1, April 2004, p. 745–750.

[23] Y. MEZOUAR, H. HADJ ABDELKADER, P. MARTINET, F. CHAUMETTE. *Visual Servoing from 3D Straight Lines with Central Catadioptric Cameras*, in "Fifth Workshop on Omnidirectional Vision, Omnivis'2004, Prague, Czech Republic", May 2004.

[24] Y. MEZOUAR, H. HAJ ABDELKADER, P. MARTINET, F. CHAUMETTE. *Central Catadioptric Visual Servoing From 3D Straight Lines*, in "IEEE/RSJ Int. Conf. on Intelligent Robots and Systems, IROS'04, Sendai, Japan", vol. 1, September 2004, p. 343–349.

[25] J. PAGÈS, C. COLLEWET, F. CHAUMETTE, J. SALVI. *Plane-to-plane positioning from image-based visual servoing and structured light*, in "IEEE/RSJ Int. Conf. on Intelligent Robots and Systems, IROS'04, Sendai, Japan", vol. 1, September 2004, p. 1004–1009.

[26] M. PRESSIGOUT, E. MARCHAND. *Model-free augmented reality by virtual visual servoing*, in "IAPR Int. Conf. on Pattern Recognition, ICPR'04, Cambridge, UK", vol. 2, August 2004, p. 887–891.

[27] A. REMAZEILLES, F. CHAUMETTE, P. GROS. *Contrôle des mouvements d'un robot à l'aide d'une mémoire visuelle*, in "14ème Congrès Francophone AFRIF-AFIA de Reconnaissance des Formes et Intelligence Artificielle, RFIA 2004, Toulouse, France", January 2004.

[28] A. REMAZEILLES, F. CHAUMETTE, P. GROS. *Robot motion control from a visual memory*, in "IEEE Int. Conf. on Robotics and Automation, ICRA'04, New Orleans, LA", vol. 4, April 2004, p. 4695–4700.

[29] O. TAHRI, F. CHAUMETTE. *Image Moments: Generic Descriptors for Decoupled Image-based Visual Servo*, in "IEEE Int. Conf. on Robotics and Automation, ICRA'04, New Orleans, LA", vol. 2, April 2004, p. 1185–1190.

Miscellaneous

[30] J. PAGÈS, C. COLLEWET, F. CHAUMETTE, J. SALVI. *Couplage asservissement visuel et lumière stucturée pour la réalisation d'une tâche de positionnement plan à plan*, September 2004, 18èmes Journées des Jeunes Chercheurs en Robotique.

Bibliography in notes

[31] S. HUTCHINSON, G. HAGER, P. CORKE. *A tutorial on visual servo control*, in "IEEE Transactions on Robotics and Automation", vol. 12, n° 5, octobre 1996, p. 651-670.

[32] C. SAMSON, M. L. BORGNE, B. ESPIAU. *Robot Control: the Task Function Approach*, Clarendon Press, Oxford, 1991.