INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team Magrit

Visual Augmentation of Complex Environments

Lorraine

THEME COG

Activity Report

2006

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1. Team

Magrit is a INRIA research team issued from the INRIA ISA project.

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2. Overall Objectives

2.1. Overall Objectives

Augmented reality (AR) is a field of computer research which deals with the combination of real world and computer generated data in order to provide the user with a better understanding of his surrounding environment. Usually this refers to a system in which computer graphics are overlaid onto a live video picture or projected onto a transparent screen as in a head-up display.

Though there exist a few commercial examples demonstrating the effectiveness of the AR concept for certain applications, the state of the art in AR today is comparable to the early years of Virtual Reality. Many research ideas have been demonstrated but few have matured beyond lab-based prototypes.

Computer vision plays an important role in AR applications. Indeed, the seamless integration of computer generated objects at the right place according to the motion of the user needs automatic real-time detection and tracking. In addition, 3D reconstruction of the scene is needed to solve occlusions and light inter-reflexion between objects and to make easier the interactions of the user with the augmented scene. Since fifteen years, much work has been successfully devoted to the problem of structure and motion, but these works are often formulated as off-line algorithms and require batch processing of several images acquired in a sequence. The challenge is now to design robust solutions to these problems with the aim to let the user free of his motion during AR applications and to widen the range of AR application to large and/or unstructured environments. More specifically, the Magrit team aims at addressing the following problems:

- On-line pose computation for structured and non structured environments: this problem is the cornerstone of AR systems and must be achieved in real time with a good accuracy.
- Long term management of AR applications: a key problem of numerous algorithms is the gradual drifting of the localization over time. One of our aims is to develop methods that improve the accuracy and the repeatability of the pose during arbitrarily long periods of motion.
- 3D modeling for AR applications: this problem is fundamental to manage light interactions between real and virtual objects, to solve occlusions and to obtain realistic fused images.

3. Scientific Foundations

3.1. Scientific Foundations

The aim of the Magrit project is to develop vision based methods which allow significant progress of AR technologies in terms of ease of implementation, usability, reliability and robustness in order to widen the current application field of AR and to improve the freedom of the user during applications. Our main research directions concern two crucial issues, camera tracking and scene modeling. Methods are developed with a view to meet the expected robustness and to provide the user with a good perception of the augmented scene.

3.1.1. Camera calibration and registration

Keywords: *Registration*, *augmented reality*, *tracking*, *viewpoint computation*.

One of the most basic problems currently limiting Augmented Reality applications is the registration problem. The objects in the real and virtual worlds must be properly aligned with respect to each other, or the illusion that the two worlds coexist will be compromised.

As a large number of potential AR applications are interactive, real time pose computation is required. Although the registration problem has received a lot of attention in the computer vision community, the problem of real-time registration is still far from being a solved problem, especially for unstructured environments. Ideally, an AR system should work in all environments, without the need to prepare the scene ahead of time, and the user should walk anywhere he pleases.

For several years, the ISA project has aimed at developing on-line and markerless methods for camera pose computation. Within the European Project ARIS, we have proposed a real-time system for camera tracking designed for indoor scenes. The main difficulty with online tracking is to ensure robustness of the process. Indeed, for off-line processes, robustness is achieved by using spatial and temporal coherence of the considered sequence through move-matching techniques. To get robustness for open-loop systems, we have developed a method which combines the advantage of move-matching methods and model-based methods [5] by using a piecewise-planar model of the environment. This methodology can then be used in a wide variety of environments: indoor scenes, urban scenes ... We are also concerned with the development of methods for camera stabilization. Indeed, statistical fluctuations in the viewpoint computations lead to unpleasant jittering or sliding effects, especially when the camera motion is small. We have proved that the use of model selection allows us to noticeably improve the visual impression and to reduce drift over time.

An important way to improve the reliability and the robustness of pose algorithms is to combine the camera with another form of sensor in order to compensate for the shortcomings of each technology. Indeed, each technology approach has limitations: on the one hand, rapid head motions cause image features to undergo large motion between frame that can cause visual tracking to fail. On the other hand, inertial sensors response is largely independent from the user's motion but their accuracy is bad and their response is sensible to metallic objects in the scene. We recently proposed a system that makes an inertial sensor (MT9- Xsens) cooperate with the camera based system in order to improve the robustness of the AR system to abrupt motions of the users, especially head motion. This work contributes to reduce the constraints on the users and the need to carefully control the environment during an AR application [1]. This research area will be continued in the near future within the ASPI project in order to build a dynamic articulatory model from various image modalities and sensors data.

It must be noted that the registration problem must be addressed from the rather specific point of view of augmented reality: the success and the acceptation of an AR application does not only depend on the accuracy of the pose computation but also on the visual impression of the augmented scene. The search for the best compromise between accuracy and perception is therefore an important issue in this project. This research topic is currently addressed in our project both in classical AR [17] and in medical imaging in order to choose the camera model, including intrinsic parameters, which describes at best the considered camera.

Finally, camera tracking largely depends on the quality of the matching stage which allows to detect and to match features over the sequence. Ongoing research are conducted on the problem of establishing robust correspondences of features over time. The use of *a contrario* decision is currently under study to achieve this aim.

3.1.2. Scene modeling

Keywords: *Fusion*, *medical imaging*, *reconstruction*, *volumetric segmentation*.

Modeling the scene is a fundamental issue in AR for many reasons. First, pose computation algorithms often use a model of the scene or at least some 3D knowledge on the scene. Second, effective AR systems require a model of the scene to support occlusion and to compute light reflexions between the real and the virtual objects. Unlike pose computation which has to be computed in a sequential way, scene modeling can be considered as an off-line or an on-line problem according to the application.

Currently, we are mainly concerned with interactive scene modeling from various image modalities. This activity concerns our medical activities as well as the ASPI project where a complete dynamic articulatory model of a speaker must be designed from various image modalities (ultrasound, MRI, video and magnetic sensors).

For the last 10 years, we have been working in close collaboration with the neuroradiology laboratory (CHU-University Hospital of Nancy) and GE Healthcare. As several imaging modalities are now available in a per-operative context (2D and 3D angiography, MRI, ...), our aim is to develop a multi-modality framework to help therapeutic decision.

In previous works [3], we proposed an efficient solution to the registration of 2D/3D angiographic images and 3DXA/MRI images. Since then, we have mainly been interested in the effective use of a multimodality framework in the treatment of arteriovenous malformations (AVM). The treatment of AVM is classically a two-stage process: embolization or endovascular treatment is first performed. This step is then followed by a stereotactic irradiation of the remnant. Hence an accurate definition of the target is a parameter of great importance for the treatment. Our short term aim is to perform an accurate detection of the AVM shape within a multimodality framework. Our long term aim is to develop multimodality and augmented reality tools which make cooperate various image modalities (2D and 3D angiography, fluoroscopic images, MRI, ...) in order to help and to guide physicians in clinical routine.

Besides interactive modeling, research on on-line reconstruction are conducted in our team. Sequential reconstruction of the scene structure needed by pose or occlusion algorithms is highly desirable for numerous AR applications for which instrumentation is not conceivable. Hence, structure and pose must be sequentially estimated over time. We are currently studying this problem for multi-planar scenes.

4. Application Domains

4.1. Augmented reality

Keywords: *Multimedia*.

We have a significant experience in the AR field especially through the European project ARIS (2001–2004) which aimed at developing effective and realistic AR systems for e-commerce and especially for interior design. Beyond this restrictive application field, this project allowed us to develop nearly real time camera tracking methods for multi-planar environments. We currently continue and amplify our research on multi-planar environments in order to obtain effective and robust AR systems in such environments.

4.2. Medical imaging

Keywords: *Health*.

For ten years, we have been working in close collaboration with the University hospital and GE Healthcare in interventional neuroradiology with the aim to develop tools allowing the physicians to take advantage of the various existing imaging modalities of the brain in their clinical practice. As several imaging modalities that bring complementary information on the various brain pathologies are now available in a pre-operative context (subtracted angiography 2D and 3D, fluoroscopy, MRI,...) our aim is to develop a multi-modality framework to help therapeutic decisions. In addition, we now investigate the use of AR tools for neuronavigation. The PhD thesis of Sebastien Gorges started in February 2004 in collaboration with GE Healthcare. Its aim is to design tools for neuronavigation that take advantage of a real-time imagery (fluoroscopy) and a pre-operative imagery (3D angiography).

4.3. Talking Head

Keywords: *Multimedia*.

We are involved in the FET-STREP european ASPI project which started on November 2005. There is a strong evidence that visual information of the speaker, especially jaw and lips, noticeably improves the speech intelligibility. Hence, having a realistic talking head could help language learning technology in giving the student a feedback on how to change articulation in order to achieve a correct pronunciation. This task is complex and necessitates a multidisciplinary effort involving speech production modeling and image analysis. The long term aim of the APSI project is the design of a 3D articulatory model to be used for the realistic animation of a talking head. Within this project, we will especially work on the tracking of the visible articulators using stereo-vision techniques and we intend to supplement the model with internal articulator (tongue, larynx) obtained from medical imaging (ultrasound images for tongue tracking and MRI for global model).

5. Software

5.1. RAlib

Our software efforts are integrated in a library called RAlib which contains our research development on image processing, registration (2D and 3D) and visualization. This library is licensed by the APP (french agency for software protection).

Frédéric Speisser joined the project in September to work on two modules of RAlib: Dicom (parsing of DICOM images) and QGL (2D and 3D visualization based on Qt and OpenGL). The Dicom module has already been completely rewritten to take grounds on dcmtk, a free library to handle the DICOM format (http://dicom.offis.de/dcmtk.php.en). The QGL module enables image and 2D graphics management but only basic 3D visualization. Efforts will be carried on integrating a free visualization library, like OpenSG (http://opensg.vrsource.org) or OpenSceneGraph (http://www.openscenegraph.com) to handle 3D objects in QGL.

5.2. Patents

Our collaboration with GE Healthcare has given rise to several patent disclosures on specific calibration process, registration and visualization.

6. New Results

6.1. New Results

6.1.1. Scene reconstruction for Augmented Reality

Participants: Marie-Odile Berger, Gilles Simon, Diego Ortin Trasobares, Flavio Vigueras.

This year, two research directions for 3D reconstruction of multi-planar scene have been investigated. The first one investigates causal structure from motion methods. The second one is about incremental building of 3D maps defined as a set of rectangles.

6.1.1.1. Multi-planar structure from motion

During this year, we have studied some of the methods that, given a set of image correspondences, allow to determine a coarse, piecewise planar model of the observed scene. The aim was to explore the potential of these methods as well as new ways to streamline them in augmented reality applications. For that, we have analyzed alternative approaches that compute an initial reconstruction from image correspondences. In particular, we have studied : (a) the sequential plane+parallax approach, (b) the batch Direct Reference Plane method and (c) the iterative six-point solution particularized for the planar case. The three methods were evaluated in a wide variety of cases that include different number of views and correspondences. Regardless the theoretical foundations of the methods, both their image residual and their computing times are relatively similar in all the cases. This seems to suggest that none of them should be the critical factor used for the selection of one method or another.

The upgrade of this projective reconstruction to metric has been performed using control points and the absolute dual quadric. A specific bundle adjustement technique dedicated to planar structures has been designed and allows us to meet the required accuracy.

Our research efforts are now devoted to the identification of strategies that can speed up the solution. Two different ways of doing this are under consideration: on the one hand, the reduction of the number of object points, and on the other hand, the use of a subset of the views.

6.1.1.2. Online reconstruction for AR tasks

Incremental building of 3D maps for immediate use is a very challenging problem. Its difficulty primarily stems from the fact that it must be causal, i.e. rely only on past frames, and also permit real time implementations. Recent advances in simultaneous localization and map building (SLAM) have been made in robot navigation research. However, in most of these approaches, scene reconstruction is not the final product but an intermediary stage for pose computation. As a result, models are generally poor, i.e. a set of sparse points, and cannot easily be used to position a virtual object or manage interactions between the real and the virtual scenes (occlusions, collisions, light exchanges, ...).

During this year, a causal, real time method has been proposed to detect on-the-fly and incrementally reconstruct textured planar surfaces [16]. Our goal was not to recover a comprehensive description of the scene, but only rough surfaces (sets of coplanar rectangles) suitable to most of the AR tasks. The principle of the method is to divide the image into a grid of rectangles and track each rectangle independently. Rectangles that belong to the same planar surface are clustered around the local maxima of a hough transform. As a result, we simultaneously get clusters of coplanar rectangles and the image of their intersection line with a reference plane, which easily leads to their 3D position and orientation.

6.1.2. Shape recognition and structure from motion via a contrario models

Participants: Marie-Odile Berger, Nicolas Noury, Frédéric Sur.

Shape recognition is the field of computer vision which addresses the problem of finding out whether a (geometrical) query shape lies or not in a shape database, up to a certain invariance. Most shape recognition methods simply sort shapes from the database along some (dis-)similarity measure to the query shape. Their Achilles' heel is the decision stage, which should aim at giving a clear-cut answer to the question: "do these two shapes look alike?" In [9], the proposed solution consists in bounding the number of false correspondences of the query shape among the database shapes, ensuring that the obtained matches are not likely to occur "by chance". As an application, one can decide with a parameterless method whether any two digital images share some shapes or not. This method has been the subject of a comprehensive survey in [10]. In [13], the above *a contrario* methodology has been applied to shapes which are described by size functions, in order to design a perceptual matching algorithm.

A further step consists in grouping those matching shapes that share the same respective positions in two corresponding images, by forming spatially coherent groups of shapes. Each pair of matching shape elements indeed leads to a unique transformation (similarity or affine map). In [8], a unified *a contrario* detection method is proposed for clustering analysis. This theory is used to group shapes by detecting clusters in the transformation space.

In the same way, we currently investigate the use of *a contrario* models to the structure from motion problem. In [19], an *a contrario* model is proposed to estimate the fundamental matrix in the stereovision framework. The advantages of this approach are twofolds: 1) to get rid of several parameters in the popular Ransac approach, and 2) to build robust estimations. In the above paper, the fundamental matrix is estimated over matches that are chosen by hand. By broadening this model, we propose a model based on points of interest that are derived from Harris or Sift detectors. This enables a simultaneous estimation of the matches and the underlying motion. It also automatically strengthens the weight of the best matches in the motion estimation.

6.1.3. Medical imaging

Participants: René Anxionnat, Marie-Odile Berger, Jefferson Bourgoin, Sébastien Gorges, Erwan Kerrien, Nicolas Padoy.

6.1.3.1. New results in neuro-radiology

Augmented fluoroscopy

In order to guide tools during the procedure, the interventional radiologist uses a vascular C-arm to acquire 2D fluoroscopy images in real time. Today, 3D X-ray images (3DXA) are also available on modern vascular C-arms. A large consensus is now met in that one important next step should be to leverage the high-resolution volumetric information provided by 3DXA to complement 2D fluoroscopy images and make the tool guidance easier. In particular, the 3DXA could be superimposed onto fluoroscopy images to enhance them. We call this application "Augmented Fluoroscopy".

Such questions are investigated in Sébastien Gorges's PhD in collaboration with GE Healthcare and the University Hospital of Nancy. Following works on modeling the vascular C-arm, this year saw developments in three directions. First, further insights into the mechanical behaviour of the C-arm were brought by studying more closely the variation of the intrinsic parameters [15]. Second, results on the precision of the model-based calibration were consolidated. In parallel, GE Healthcare developed a prototype software that was installed within the operating room to enable a per-operative Augmented Fluoroscopy visualization. A first clinical evaluation was led [14] with promising results. Among the improvements required by the physicians was the visibility of the guide-wire. A tracking algorithm that works on fluoroscopy images was developed.

Contouring of arteriovenous malformations

The radiotherapic treatment of AVM requires an accurate estimation of the AVM shape. This estimation is classically obtained from the delineation of the AVM in several 2D angiographic views. Unfortunately, this delineation process suffers from high variability among the experts. Causes of variability lie in the unability of the angiographic views to depict with clarity the AVM contour, but also in medical options that the physician has to weight to make his or her decision.

Our research aims at reducing this variability by fusing information coming from other imaging modalities, and in particular 3D modalities like MRI or 3DRA. This implies that we are able to provide the physician with all the viable AVM shapes, stemming from inner variability and medical options, in 3D. A full protocol to that aim was investigated this year with the help of Jefferson Bourgoin. The physician draws all medically sound AVM contours in the 2D angiographic views. Sets of corresponding contours (one per angiographic view) are gathered to reconstruct a 3D shape only if the contours are consistent in regard to the epipolar geometry. Each 3D shape is considered as initialization to surface active evolution process. The final shapes are classified and only class representants are presented to the physician to make the final decision. This protocol showed promising results on a few test cases.

6.1.3.2. Augmented reality for mini-invasive surgery

The overall objective is to provide computer aided tools for the surgeons performing minivally invasive surgeries. The goal of this study is the automatic understanding of the surgical workflow in order to integrate such augmented reality systems within the operating room. We focus on endoscopic surgeries, which are minimally invasive and performed in modern surgery rooms, providing many signals related to the context of the operation. We want to analyse these signals automatically. The long-term achievement is to design an automatic monitoring and reporting system of the operating room for surgeon assistance. It will have to provide and display context-aware information to the surgeon and to his staff. Benefits of such a system will be for control, optimisation and documentation.

Much work is carried out in augmented reality to enhance the surgeon's capabilities during the operation, but the idea of conceiving a unified context-aware automatic system putting all together and specifying when and where to use those enhancements is rather new. Eventhough the long-term end-system will have to rely on all the available signals, we investigate the vision aspects: the visual information acquired by the endoscopic camera and by external cameras placed within the operating room are used to extract contextual information related to the surgical phases. We try to learn automatically which image/video features are relevant for phase discrimination and to design and learn a high-level probabilistic model to integrate those visual cues within the constrained workflow of the surgery. The first results consist in phase recognition based on instrument detection and background signature computation for a given patient. Future works aim at generalizing the approach to different patients.

6.1.4. Modeling face dynamics

Participants: Michael Aron, Marie-Odile Berger, Erwan Kerrien, Brigitte Wrobel-Dautcourt.

Our long term objective is to provide intuitive and near-automatic tools for building a dynamic 3D model of the vocal tract from various image and sensor modalities (MRI, US, video, magnetic sensors ...). During this year, we have concentrated our efforts on the joint use of ultrasound images and magnetic sensors for tongue tracking. Previous works have proven that the ultrasound modality was an efficient way to acquire dynamic tongue information. Unfortunately, the tip of the tongue is not visible in most US images because air stops the propagation of the ultra-sounds. In this work, we use magnetic sensors that are glued on the tongue in order to complete the tongue contour obtained from ultrasound images near the apex: interpolation and regularization schemes can be used to build the curve that matches at best the recovered tongue contour and passes through the collected magnetic data. During this year, we have focused on the calibration tasks. Spatial calibration is first needed in order to express the sensors and the US images in the same reference frame. A phantom, which is easily detectable in the two modalities, is used to this aim. Our phantom was inspired by Khamene and Sauer [18]: two magnetic coils were put at the extremities of a rigid wooden stick which is detectable in the US images. Characterising the alignment of the sensors and the detected points of the wooden stick in the US images for various positions of the probe allows us to register the sensors with the US modality. Temporal calibration is then performed in order to compute the delay between the start of the US and the magnetic acquisition.

The US/magnetic coupling system was experimented on a locutor. Two magnetic coils were glued on the tongue, one on the apex and on of the tongue dorsum. These experiments show that the two sensors were moving according to the movements of the tongue and prove the efficiency of the spatial and temporal calibration process [11]. Future works will concern the design of an algorithm for fusing sensor information and tongue tracking to recover the complete shape of the tongue.

7. Contracts and Grants with Industry

7.1. Partnerships

7.1.1. GE Healthcare

The partnership with GE Healthcare (formerly GE Medical Systems) started in 1995. In the past few years, it bore on the supervision of CIFRE PhD fellows on the topic of using a multi-modal framework in interventional neuroradiology. A new PhD started in January 2004 on the design of augmented reality tools for neuronavigation. The concept of *Augmented Fluoroscopy* is one of the main results of this PhD. A prototype that implements these results has been developed by GE Healthcare and is available at the Nancy Hospital for clinical evaluation since July 2006.

8. Other Grants and Activities

8.1. Regional initiatives

8.1.1. CPRC

Participants: René Anxionnat, Marie-Odile Berger, Erwan Kerrien.

This work is developed in close collaboration with Nancy Hospital. The aim of the CPRC (Contrat de Recherche Clinique) is to develop a multi-modality framework to help therapeutic decisions for brain pathologies.

8.2. European initiatives

8.2.1. ASPI European project

Participants: Michael Aron, Marie-Odile Berger, Erwan Kerrien, Brigitte Wrobel.

ASPI is about Audiovisual-to-articulatory inversion. Participants in this project are INRIA Lorraine, ENST (Paris), KTH (Stokholm), the University Research Institute of National Technical University of Athens and the University of Bruxelles. Audiovisual-to-articulatory inversion consists in recovering the vocal tract shape dynamics (from vocal folds to lips) from the acoustical speech signal, supplemented by image analysis of the speaker's face. Being able to recover this information automatically would be a major break-through in speech research and technology, as a vocal tract representation of a speech signal would be both beneficial from a theoretical point of view and practically useful in many speech processing applications (language learning, automatic speech processing, speech coding, speech therapy, film industry...). The Magrit team is involved in the the development of articulatory models from various image modalities (ultrasound, video, MRI) and electromagnetic sensors.

8.3. International initiatives

8.3.1. Conferences, meetings and tutorial organization

- M.-O. Berger was a member of the program committee of the conferences ECCV'06, MICCAI 06, ISMAR 06, RFIA'06 and of the workshops AMI-ARCS'06 and DEFORM'06.
- E. Kerrien was a member of the program committee of MICCAI 06.
- G. Simon was a member of the program committee of ISMAR 06.
- F. Sur was a member of the program committee of the *Conférence sur l'Apprentissage*, CAP 2006.

9. Dissemination

9.1. Teaching

- Several members of the group, in particular assistant professors and Ph.D. students, actively teach at Henri Poincaré Nancy 1, Nancy 2 universities and INPL.
- Other members of the group also teach in the computer science Master of Nancy and in the "Master en sciences de la vie et de la santé" (SVS).
- Frédéric Sur has been a member of the board of the "Banque PT" entrance examination in mathematics ("concours d'entrée aux Grandes Écoles").

9.2. Participation to conferences and workshops

Members of the group participated in the following events: International Symposium on Mixed and Augmented Reality (ISMAR'06, Santa Barbara, USA), International Conference on Medical Image Computing and Computer Assisted Intervention (MICCAI 06, Copenhagen, Denmark), International Symposium Medical Imaging (SPIE 2006, San Diego, USA), International Seminar on Speech Production (ISSP 2006, Ubatuba, Brasil), Congrès Francophone de Reconnaissance des Formes et d'Intelligence Artificielle (RFIA 2006, Tours).

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