Activity Report 2019

Team MAGRIT

Visual Augmentation of Complex Environments

Inria teams are typically groups of researchers working on the definition of a common project, and objectives, with the goal to arrive at the creation of a project-team. Such project-teams may include other partners (universities or research institutions).

RESEARCH CENTER
Nancy - Grand Est

THEME
Vision, perception and multimedia interpretation

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Team MAGRIT

Creation of the Team: 2019 January 01

Keywords:

Computer Science and Digital Science:

A5.3. - Image processing and analysis
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A5.4.1. - Object recognition
A5.4.5. - Object tracking and motion analysis
A5.4.6. - Object localization
A5.6. - Virtual reality, augmented reality
A5.10.2. - Perception

Other Research Topics and Application Domains:

B2.6. - Biological and medical imaging
B5.9. - Industrial maintenance
B9.5.3. - Physics

1. Team, Visitors, External Collaborators

Research Scientists

Marie-Odile Berger [Team leader, Inria, Senior Researcher, HDR]
Erwan Kerrien [Inria, Researcher, HDR]

Faculty Members

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Frédéric Sur [Univ de Lorraine, Professor, HDR]
Pierre-Frédéric Villard [Univ de Lorraine, Associate Professor]
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PhD Students

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Vincent Gaudilliere [Inria, PhD Student]
Daryna Panicheva [Univ de Lorraine, PhD Student]
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Matthieu Zins [Inria, PhD Student, from Oct 2019]

Technical staff

Thomas Mangin [Univ de Lorraine, Engineer, from Mar 2019]

Interns and Apprentices

Mohamed Alami Chehboune [Inria, from Apr 2019 until Aug 2019]
Paul Festor [Univ de Lorraine, until Sep 2019]
Anastasiia Onanko [Univ de Lorraine, Kiev Polytechnique Institute]

2. Overall Objectives

2.1. Augmented Reality

The basic concept of Augmented Reality (AR) is to place information correctly registered with the environment into the user's perception. What makes AR stand out is that this new technology offers the potential for big changes in many application fields such as industrial maintenance, creative technologies, image guided medical gestures, entertainment...

Augmented reality technologies have made major advances in recent years, both in terms of capability, mobile development and integration into current mobile devices. Most applications are dedicated to multimedia and entertainment, games, lifestyle and healthcare and use rough localization information provided by the sensors of the mobile phones. Cutting-edge augmented reality applications which take place in complex environments and require high accuracy in augmentation are less prevalent. There are indeed still technological barriers that prevent applications from reaching the robustness and the accuracy required by such applications.

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, reliability and robustness. An expected consequence is the widening of the current application field of AR.

The team is active in both medical and classical applications of augmented reality for which accurate integration of the virtual objects within the scene is essential. Key requirements of AR systems are the availability of registration techniques, both rigid and elastic, that allow the virtual objects to be correctly aligned with the environment, as well as means to build 3D models which are appropriate for pose computation and for handling interactions between the virtual objects and the real scene. Considering the common needs for tracking, navigation, advanced modeling and visualization technologies in both medical and industrial applications, the team focuses on three main objectives: matching, localization and modeling. Methods are developed with a view to meet the expected robustness and accuracy over time and to provide the user with a realistic perception of the augmented scene, while satisfying the real-time achievements required by these procedures.

3. Research Program

3.1. Matching and 3D tracking

One of the most basic problems currently limiting AR 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, independently of the variations in experimental conditions (lighting, weather condition,...)

For several years, the MAGRIT project has been aiming at developing on-line and marker-less methods for camera pose computation. The main difficulty with on-line tracking is to ensure robustness of the process over time. For off-line processes, robustness is achieved by using spatial and temporal coherence of the considered sequence through move-matching techniques. To get robust open-loop systems, we have investigated various methods, ranging from statistical methods to the use of hybrid camera/sensor systems. Many of these methods are dedicated to piecewise-planar scenes and combine the advantage of move-matching methods and model-based methods. In order to reduce statistical fluctuations in viewpoint computation, which lead to unpleasant jittering or sliding effects, we have also developed model selection techniques which allow us to noticeably improve the visual impression and to reduce drift over time. Another line of research which has been considered in the team 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.

The success of pose computation over time largely depends on the quality of the matching at the initialization stage. Indeed, the current image may be very different from the appearances described in the model both on the geometrical and the photometric sides. Research is thus conducted in the team on the use of probabilistic methods to establish robust correspondences of features. The use of *a contrario* methods has been investigated to achieve this aim [7]. We especially addressed the complex case of matching in scenes with repeated patterns which are common in urban scenes. We are also investigating the problem of matching images taken from very different viewpoints which is central for the re-localization issue in AR. Within the context of a scene model acquired with structure-from-motion techniques, we are currently investigating the use of viewpoint simulation in order to allow successful pose computation even if the considered image is far from the positions used to build the model [15].

Recently, the issue of tracking deformable objects has gained importance in the team. This topic is mainly addressed in the context of medical applications through the design of bio-mechanical models guided by visual features [2]. We have successfully investigated the use of such models in laparoscopy, with a vascularized model of the liver and with a hyper-elastic model for tongue tracking in ultrasound images. However, these results have been obtained so far in relatively controlled environments, with non-pathological cases. When clinical routine applications are to be considered, many parameters and considerations need to be taken into account. Among the problems that need to be addressed are more realistic model representations, the specification of the range of physical parameters and the need to enforce the robustness of the tracking with respect to outliers, which are common in the interventional context.

3.2. Image-based Modeling

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 interactions between the virtual and the real objects such as occlusions, lighting reflections, contacts... in real-time. Unlike pose computation which has to be performed in a sequential way, scene modeling can be considered as an off-line or an on-line problem depending on the requirements of the targeted application. Interactive in-situ modeling techniques have thus been developed with the aim to enable the user to define what is relevant at the time the model is being built during the application. On the other hand, we also proposed off-line multimodal techniques, mainly dedicated to AR medical applications, with the aim of obtaining realistic and possibly dynamic models of organs suitable for real-time simulation [3].

In-situ modeling

In-situ modeling allows a user to directly build a 3D model of his/her surrounding environment and verify the geometry against the physical world in real-time. This is of particular interest when using AR in unprepared environments or building scenes that either have an ephemeral existence (e.g., a film set) or cannot be accessed frequently (e.g., a nuclear power plant). We have especially investigated two systems, one based on the image content only and the other based on multiple data coming from different sensors (camera, inertial measurement unit, laser rangefinder). Both systems use the camera-mouse principle [34] (i.e., interactions are performed by aiming at the scene through a video camera) and both systems have been designed to acquire polygonal textured models, which are particularly useful for camera tracking and object insertion in AR.

Multimodal modeling for real-time simulation

With respect to classical AR applications, AR in medical context differs in the nature and the size of the data which are available: a large amount of multimodal data is acquired on the patient or possibly on the operating room through sensing technologies or various image acquisitions [32]. The challenge is to analyze these data, to extract interesting features, to fuse and to visualize this information in a proper way. Within the MAGRIT team, we address several key problems related to medical augmented environments. Being able to acquire multimodal data which are temporally synchronized and spatially registered is the first difficulty we face when considering medical AR. Another key requirement of AR medical systems is the availability of 3D (+t) models of the organ/patient built from images, to be overlaid onto the users' view of the environment.

Methods for multimodal modeling are strongly dependent on the imaging modalities and the organ specificities. We thus only address a restricted number of medical applications –interventional neuro-radiology, laparoscopic surgery– for which we have a strong expertise and close relationships with motivated clinicians. In these applications, our aim is to produce realistic models and then realistic simulations of the patient to be used for the training of surgeons or the re-education of patients.

One of our main applications is about neuroradiology. For the last 20 years, we have been working in close collaboration with the neuroradiology laboratory (CHRU-University Hospital of Nancy) and GE Healthcare. As several imaging modalities are now available in an intraoperative context (2D and 3D angiography, MRI, ...), our aim is to develop a multi-modality framework to assist therapeutic decision and treatment.

We have mainly been interested in the effective use of a multimodality framework in the treatment of arteriovenous malformations (AVM) and aneurysms in the context of interventional neuroradiology. The goal of interventional gestures is to guide endoscopic tools towards the pathology with the aim to perform embolization of the AVM or to fill the aneurysmal cavity by placing coils. We have proposed and developed multimodality and augmented reality tools which make various image modalities (2D and 3D angiography, fluoroscopic images, MRI, ...) cooperate in order to assist physicians in clinical routine. One of the successes of this collaboration is the implementation of the concept of *augmented fluoroscopy*, which helps the surgeon to guide endoscopic tools towards the pathology. Lately, in cooperation with the team MIMESIS, we have proposed new methods for implicit modeling of the vasculature with the aim of obtaining near real-time simulation of the coil deployment in the aneurysm [3]. These works open the way towards near real-time patient-based simulations of interventional gestures both for training and for planning.

3.3. Parameter estimation

Many problems in computer vision or image analysis can be formulated in terms of parameter estimation from image-based measurements. This is the case of many problems addressed in the team such as pose computation or image-guided estimation of 3D deformable models. Often traditional robust techniques which take into account the covariance on the measurements are sufficient to achieve reliable parameter estimation. However, depending on their number, their spatial distribution and the uncertainty on these measurements, some problems are very sensitive to noise and there is a considerable interest in considering how parameter estimation could be improved if additional information on the noise were available. Another common problem in our field of research is the need to estimate constitutive parameters of the models, such as (bio)-mechanical parameters for instance. Direct measurement methods are destructive, and elaborating image-based methods is thus highly desirable. Besides designing appropriate estimation algorithms, a fundamental question is to understand what group of parameters under study can be reliably estimated from a given experimental setup.

This line of research is relatively new in the team. One of the challenges is to improve image-based parameter estimation techniques considering sensor noise and specific image formation models. In a collaboration with the Pascal Institute (Clermont Ferrand), metrological performance enhancement for experimental solid mechanics has been addressed through the development of dedicated signal processing methods [6]. In the medical field, specific methods based on an adaptive evolutionary optimization strategy have been designed for estimating respiratory parameters [8]. In the context of designing realistic simulators for neuroradiology, we are now considering how parameters involved in the simulation could be adapted to fit real images.

4. Application Domains

4.1. Augmented reality

We have a significant experience in AR that allowed good progress in building usable, reliable and robust AR systems. Our contributions cover the entire process of AR: matching, pose initialization, 3D tracking, in-situ modeling, handling interaction between real and virtual objects....

4.2. Medical Imaging

For 20 years, we have been working in close collaboration with University Hospital of Nancy and GE Healthcare in interventional neuroradiology. Our common aim is to develop a multimodality framework to assist therapeutic decisions and interventional gestures. Contributions of the team focus on the development of AR tools for neuro-navigation as well as the development of simulation tools for training or planning. Laparoscopic surgery is another field of interest with the development of methods for tracking deformable organs based on bio-mechanical models. Some of these projects are developed in collaboration with the MIMESIS project team.

4.3. Experimental mechanics

In experimental solid mechanics, an important problem is to characterize properties of specimens subject to mechanical constraints, which makes it necessary to measure tiny strains. Contactless measurement techniques have emerged in the last few years and are spreading quickly. They are mainly based on images of the surface of the specimen on which a regular grid or a random speckle has been deposited. We are engaged since June 2012 in a transdisciplinary collaboration with Institut Pascal (Clermont-Ferrand Université). The aim is to characterize the metrological performances of these techniques limited by, e.g., the sensor noise, and to improve them by several dedicated image processing tools.

5. Highlights of the Year

5.1. Highlights of the Year

Two patents have been filed during this year: [28] relates to computational photomechanics and [27] relates to localization from objects.

6. New Software and Platforms

6.1. PoLAR

Portable Library for Augmented Reality

FUNCTIONAL DESCRIPTION: PoLAR (Portable Library for Augmented Reality) is a framework which aims to help creating graphical applications for augmented reality, image visualization and medical imaging. PoLAR was designed to offer powerful visualization functionalities without the need to be a specialist in Computer Graphics. The framework provides an API to state-of-the-art libraries: Qt to build GUIs and OpenSceneGraph for high-end visualization, for researchers and engineers with a background in Computer Vision to be able to create beautiful AR applications, with little programming effort. The framework is written in C++ and published under the GNU GPL license

- Contact: Erwan Kerrien
- URL: http://polar.inria.fr

6.2. Fast>VP

KEYWORDS: Vanishing points - Image rectification

FUNCTIONAL DESCRIPTION: Fast>VP is a fast and effective tool to detect vanishing points in uncalibrated images of urban or indoor scenes.

This tool also allows automatic rectification of the vertical planes in the scene, namely generating images where these planes appear as if they were observed from a fronto-parallel view.

It is the Matlab implementation of the algorithm described in [5].

- Contact: Gilles Simon
- URL: https://members.loria.fr/GSimon/fastvp/

6.3. NoLoDuDoCT

A non-local dual-domain cartoon and texture decomposition

KEYWORDS: Image analysis - Cartoon and texture decomposition

FUNCTIONAL DESCRIPTION: This is an algorithm decomposing images into cartoon and texture components. Spectrum components of textures are detected on the basis of a statistical hypothesis test, the null hypothesis modeling a purely cartoon patch. Statistics are estimated in a non-local way.

- Contact: Frédéric Sur
- Publication: A non-local dual-domain approach to cartoon and texture decomposition
- URL: https://members.loria.fr/FSur/software/NoLoDuDoCT/

6.4. TheGridMethod

The grid method toolbox

KEYWORD: Experimental mechanics

FUNCTIONAL DESCRIPTION: This Matlab toolbox implements several efficient and state-of-the art algorithms to estimate displacement and strain fields from grid images deposited on the surface of a specimen submitted to mechanical testing.

NEWS OF THE YEAR: Informal contacts told us that this library is used in academia and industry.

- Contact: Frédéric Sur
- Publication: The grid method for in-plane displacement and strain measurement: a review and analysis
- URL: http://www.thegridmethod.net/

6.5. BSpeckleRender

A Boolean model for deformed speckle rendering

KEYWORDS: Boolean model - Monte Carlo estimation - Experimental mechanics - Displacement fields

FUNCTIONAL DESCRIPTION: This library implements a new method for synthesizing speckle images deformed by an arbitrary deformation field set by the user. Such images are very useful for assessing the different methods based on digital image correlation (DIC) for estimating displacement fields in experimental mechanics. Since the deformations are very small, it is necessary to ensure that no additional bias is introduced by the image synthesis algorithm. The proposed method is based on the Monte Carlo evaluation of images generated by a Boolean model.

- Contact: Frédéric Sur
- Publication: Rendering Deformed Speckle Images with a Boolean Model
- URL: https://members.loria.fr/FSur/software/BSpeckleRender/

7. New Results

7.1. Matching and localization

Participants: Marie-Odile Berger, Vincent Gaudilliere, Gilles Simon, Frédéric Sur, Matthieu Zins.

7.1.1. View synthesis for efficient and accurate pose computation

Estimating the pose of a camera from a scene model is a challenging problem when the camera is in a position not covered by the views used to build the model, because feature matching is difficult. Several viewpoint simulation techniques have been recently proposed in this context. They generally come with a high computational cost, are limited to specific scenes such as urban environments or object-centred scenes, or need an initial pose guess. A new method based on viewpoint simulation is presented in [15]. In this article, we show that view synthesis dramatically improves pose computation and that both the synthesis process and pose computation can be done in a very efficient way. Two major problems are especially addressed: the positioning of the virtual viewpoints with respect to the scene, and the synthesis of geometrically consistent patches. Experiments show that patch synthesis dramatically improves the accuracy of the pose in case of difficult registration, with a limited computational cost.

7.1.2. Localization from objects

We are interested in AR applications which take place in man-made GPS-denied environments, such as industrial or indoor scenes. In such environments, relocalization may fail due to repeated patterns and large changes in appearance which occur even for small changes in viewpoint. During this year, we have investigated a new method for relocalization which operates at the level of objects and takes advantage of the impressive progress realized in object detection. Recent works have opened the way towards object oriented reconstruction from elliptic approximation of objects detected in images. We have gone beyond that and have proposed a new method for pose computation based on ellipse/ellipsoid correspondences. In [18], we have proved that a closed form estimate of the translation can be uniquely inferred from the rotation matrix of the pose. When two or more correspondences are available, the rotation matrix is deduced through an optimization problem with three degrees of freedom. However, the pose cannot be uniquely computed from one correspondence. In [19], we consider the practical common case where an initial guess of the rotation matrix of the pose is known, for instance with an inertial sensor or from the estimation of orthogonal vanishing points [10]. The translation is recovered as in [18], [24]. We proved the effectiveness of the method on real scenes from a set of object detections generated by YOLO [33]. Globally, considering pose at the level of objects allows us to avoid common failures due to repeated structures. In addition, due to the small combinatorics induced by object correspondences, our method is well suited to fast rough localization even in large environments.

A patent was filed on this method in May 2019 [27]. An Inria technological transfer action (ATT) on the subject of object based localization will start in January 2020 with the aim to produce a demonstrator for industrial maintenance in complex environments.

7.2. Handling non-rigid deformations

Participants: Marie-Odile Berger, Jaime Garcia Guevara, Erwan Kerrien, Daryna Panicheva, Raffaella Trivisonne, Pierre-Frédéric Villard.

7.2.1. Compliance-based non rigid registration

Within J. Guevara's PhD thesis, we are investigating non rigid registration methods which exploit the matching of the vascular trees and are able to cope with large deformations of the organ. This year, we have developed a matching method which is entirely based on the mechanical properties of the organ. We thus avoid tedious parameter tuning which is required by many methods and instead use parameters whose values are known or can be measured. Our method makes use of an advanced biomechanical model which handles heterogeneities and anisotropy due to vasculature. The main originality of the method lies in the definition of a better and novel metric for generating improved graph-matching hypotheses, based on the notion of compliance, the inverse of stiffness. This method reduces the computation time by predicting first the most plausible matching hypotheses on a mechanical basis and reduces the sensitivity on the search space parameters. These contributions improve the registration quality and meet intra-operative timing constraints. Experiments have been conducted on ten realistic synthetic datasets and two real porcine datasets which where automatically segmented. This work was recently accepted in the journal *Annals of Biomedical Engineering* [9], [11].

7.2.2. Individual-specific heart valve modeling

Recent works on computer-based models of mitral valve behavior rely on manual extraction of the complex valve geometry, which is tedious and requires a high level of expertise. On the contrary, in the context of D. Panicheva's PhD thesis, we are investigating methods to segment the chordae with little human supervision which produce mechanically-coherent simulations of the mitral valve.

Valve chordae are generalized cylinders: Instead of being limited to a line, the central axis is a continuous curve; instead of a constant radius, the radius varies along the axis. Most of the time, chordae sections are flattened ellipses and classical model-based methods commonly used for vessel enhancement or vessel segmentation fail. We have exploited the fact that there are no other generalized cylinders than the chordae in the CT scan and we have proposed a topology-based method for chordae extraction. This approach is flexible and only requires the knowledge of an upper bound of the maximum radius of the chordae. The method has been tested on three CT scans. Overall, non-chordae structures are correctly identified and detected chordae ending points match up with actual chordae attachment points [21].

We then worked on evaluating the effectiveness of our approach. The valve behavior was simulated with a biomechanical framework based on the Finite Element Method. A structural model with no fluid-structure interaction was used. Physiological behavior was simulated by mechanical forces such as blood pressure, contact forces and tension forces applied from chordae tensions. The chordae segmentation was validated by comparing the simulation results to those obtained with manually segmented chordae [22].

7.2.3. Image-based biomechanical simulation of the diaphragm during mechanical ventilation

When intensive care patients are subjected to mechanical ventilation, the ventilator causes damage to the muscles that govern the normal breathing, leading to Ventilator Induced Diaphragmatic Dysfunction (VIDD). The INVIVE project aims to study the mechanics of respiration through numerical simulation in order to learn more about the onset of VIDD. We have worked during this year on how to compute solutions of the static linear elasticity equation using last year's work on the diaphragm geometry [26]. Since obtaining an analytical formulation of the boundary conditions in 3D is complex, we have worked on adapting our method to implicit geometries built from 2D data of the diaphragm. The idea is to have an analytical formulation of both the geometry and the boundary conditions to validate our radial basis framework. It is based on points belonging to a cross-section that has been chosen in the middle of the diaphragm. Points are gathered in groups inside rectangles based on a K-means classification. Rectangle dimensions are set so as to ensure cross-coverage. Curve patches are then computed for each rectangle using radial basis functions. A list of local curves is obtained from both the thoracic and abdomen zones and by combining them it is possible to evaluate the global implicit curve of the diaphragm.

7.2.4. 3D catheter navigation from monocular images

In interventional radiology, the 3D shape of the micro-tool (guidewire, micro-catheter or micro-coil) can be very difficult, if not impossible to infer from fluoroscopy images. We consider this question as a single view 3D curve reconstruction problem. Our aim is to assess whether, and under which conditions, a sophisticated physics-based model can be effective to compensate for the incomplete data in this ill-posed problem.

Raffaella Trivisonne started her PhD thesis in November 2015 (co-supervised by Stéphane Cotin, from MIMESIS team in Strasbourg) to address this research topic. An unscented Kalman filter is used as a fusion mechanism, in a non-rigid shape-from-motion approach: the observations are image data (opaque markers placed along the device), and the model is implemented through interactive physics-based simulation. Our contribution is to handle contacts, which introduce discontinuities in the first and second order derivatives of motion (resp. velocity and forces). Extensive validation on both synthetic and phantom-based data has been carried out this year [30], and various state vector parametrizations have been investigated, in particular in a view to achieve data assimilation of mechanical parameters to improve the predictability of simulation.

In this context, validation is made very complex by the need to acquire ground truth 3D curve shapes that are subjected to contacts and demonstrate highly transient dynamic deformations (e.g. stick and slip transitions after contact). Thomas Mangin was hired on a 1-year engineer contract (started in March 2019) to design and develop an experimental platform to acquire such ground truth data. The catheter is inserted in a translucent, silicon vascular phantom to generate contacts with no visual occlusion of the catheter shape. It is reconstructed from images acquired by a stereo rig made of two orthogonal high speed cameras. The motion is fully controlled by an original 3D-printed active device that induces accurate translation and rotation motions to the micro-tool. Monte-Carlo simulations are currently being carried out to certify the accuracy of the ground truth data produced by this system.

7.3. Image processing

Participants: Marie-Odile Berger, Fabien Pierre, Frédéric Sur.

7.3.1. *Computational photomechanics*

In computational photomechanics, mainly two methods are available for estimating displacement and strain fields on the surface of a material specimen subjected to a mechanical test, namely digital image correlation (DIC) and localized spectrum analysis (LSA). With both methods, a contrasted pattern marks the surface of the specimen: either a random speckle pattern for DIC or a regular pattern for LSA, this latter method being based on Fourier analysis. It is a challenging problem since strains are tiny quantities giving deformations often not visible to the naked eye. The recent outcomes of our collaboration with Institut Pascal (Université Clermont-Auvergne) focus on two areas.

We have investigated the optimization of the pattern marking the specimen [13], which is the topic of several recent papers. Checkerboard is the optimized pattern in terms of sensor noise propagation when the signal is correctly sampled, but its periodicity causes convergence issues with DIC. The consequence is that checkerboards are not used in DIC applications although they are optimal in terms of sensor noise propagation. We have shown that it is possible to use LSA to estimate displacement and strain fields from checkerboard images, although LSA was originally designed to process 2D grid images. A comparative study of checkerboards and grids shows that, under similar experimental conditions, the noise level in displacement and strain maps obtained with checkerboards is lower than that obtained with classic 2D grids. A patent on this topic was filed [28].

Another scientific contribution concerns the restoration of displacement and strain maps. DIC and LSA both provide displacement fields equal to the actual one convoluted by a kernel known a priori. The kernel indeed corresponds to the Savitzky-Golay filter in DIC, and to the analysis window of the windowed Fourier transform used in LSA. While convolution reduces noise level, it also gives a systematic measurement error. We have proposed a deconvolution method to retrieve the actual displacement and strain fields from the output of DIC or LSA [12]. The proposed algorithm can be considered as a variant of Van Cittert deconvolution, based on the small strain assumption. It is demonstrated that it allows enhancing fine details in displacement and strain maps, while improving spatial resolution.

7.3.2. *Cartoon-texture decomposition*

Decomposing an image as the sum of geometric and textural components is a popular problem of image analysis. In this problem, known as cartoon and texture decomposition, the cartoon component is piecewise smooth, made of the geometric shapes of the images, and the texture component is made of stationary or quasi-stationary oscillatory patterns filling the shapes. Microtextures being characterized by their power spectrum, we propose to extract cartoon and texture components from the information provided by the power spectrum of image patches. The contribution of texture to the spectrum of a patch is detected as statistically significant spectral components with respect to a null hypothesis modeling the power spectrum of a non-textured patch. The null-hypothesis model is built upon a coarse cartoon representation obtained by a basic yet fast filtering algorithm of the literature. The coarse decomposition is obtained in the spatial domain and is an input of the proposed spectral approach. We thus design a "dual domain" method. The statistical model is also built upon the power spectrum of patches with similar textures across the image. The proposed approach therefore falls within the family of non-local methods. Compared to variational methods or fast filers, the proposed non-local dual-domain approach [16] is shown to achieve a good compromise between computation time and accuracy. Matlab code is publicly available.

7.3.3. Variational methods for image processing

The work described in [20] aims to couple the powerful prediction of the convolutional neural network (CNN) to the accuracy at pixel scale of the variational methods. We have focused on a CNN which is able to compute a statistical distribution of the colors for each pixel of the image based on a learning stage on a large color image database. A variational method able to select a color candidate among a given set while performing regularization of the result is combined with a CNN, to design a fully automatic image colorization framework with an improved accuracy in comparison with CNN alone. To solve the proposed model, we have proposed in [17] a novel accelerated alternating optimization scheme to solve block biconvex nonsmooth problems whose objectives can be split into smooth (separable) regularizers and simple coupling terms. The proposed method performs a Bregman distance-based generalization of the well-known forward–backward splitting for each block, along with an inertial strategy which aims at getting empirical acceleration. We discuss the theoretical convergence of the proposed scheme and provide numerical experiments on image colorization.

8. Partnerships and Cooperations

8.1. Regional Initiatives

The project *Imagerie et Robotique Médicale Grand Est (IRMGE)* started in 2018. Clinical and interventional imagery is a major public health issue. Teams from the Grand-Est region involved in medical imaging (Inria, ICuve, CRESTIC) have thus proposed a research project to broaden and strenghten cooperation. The three axes of the project are about optic imagery, nuclear imagery and medical image processing. The Magrit team is especially involved in the third axis, with the aim to improve interventional procedures.

8.2. National Initiatives

8.2.1. ANR JCJC ICaRes

Participant: F. Sur

This 3-year project (2019-2022) headed by B. Blaysat (Université Clermont-Auvergne), is supported by the Agence Nationale de la Recherche. It addresses residual stresses, which are introduced in the bulk of materials during processing or manufacturing. Since unintended residual stresses often initiate early failure, it is of utmost importance to correctly measure them. The goal of the ICaRes project is to improve the performance of residual stress estimation through the so-called virtual digital image correlation (DIC) which will be developed. The basic idea of virtual DIC is to mark the specimen with virtual images coming from a controlled continuous image model, instead of the standard random pattern. Virtual DIC is expected to outperform standard DIC by, first, matching real images of the materials with the virtual images, then, to run DIC on the virtual images on which strain fields are estimated, giving ultimately residual stresses.

8.2.2. Projet RAPID EVORA

(2016-2010) Participants: M.-O. Berger, V. Gaudillière, G. Simon.

This 4-years project is supported by DGA/DGE and led by the SBS-Interactive company. The objective is to develop a prototype for location and object recognition in large-scale industrial environments (factories, ships...), with the aim to enrich the operator's field of view with digital information and media. The main issues concern the size of the environment, the nature of the objects (often non textured, highly specular...) and the presence of repeated patterns.

This year we have built a demonstrator to locate a camera in a factory modeled by a set of registered RGB-D panoramic images. The panoramic image closest to the current image is selected using a CNN descriptor calculated inside proposed boxes. Points and edges are then detected and matched between the current image and the selected panoramic image by using our method published at ICIP 2018 [31]. The camera pose can finally be obtained with regard to the scene by transitivity (image $\longleftrightarrow$ panoramic view $\longleftrightarrow$ scene).

8.3. International Initiatives

8.3.1. Inria International Labs

Inria@EastCoast
Associate Team involved in the International Lab:

8.3.1.1. CURATIVE

Title: CompUteR-based simulAtion Tool for mItral Valve rEpair

International Partner (Institution - Laboratory - Researcher):

Harvard University (United States) - Harvard Biorobotics Lab (HBL)- Robert Howe

Start year: 2017

See also: https://team.inria.fr/curative/

The mitral valve of the heart ensures one-way flow of oxygenated blood from the left atrium to the left ventricle. However, many pathologies damage the valve anatomy producing undesired backflow, or regurgitation, decreasing cardiac efficiency and potentially leading to heart failure if left untreated. Such cases could be treated by surgical repair of the valve. However, it is technically difficult and outcomes are highly dependent upon the experience of the surgeon.

One way to facilitate the repair is to simulate the mechanical behavior of the pathological valve with subject-specific data. Our main goal is to provide surgeons with a tool to study solutions of mitral valve repairs. This tool would be a computer-based model that can simulate a potential surgical repair procedure in order to evaluate its success. The surgeons would be able to customize the simulation to a patient and to a technique of valve repair. Our methodology will realistically simulate valve closure based on segmentation methods faithful enough to capture subject-specific anatomy and based on a biomechanical model that can accurately model the range of properties exhibited by pathological valves.

8.3.2. Inria International Partners

8.3.2.1. Informal International Partners

- Pierre-Frédéric Villard is a co-investigator in the INVIVE project (http://www.it.uu.se/research/scientific_computing/project/rbf/biomech) funded by the Swedish Research Council and realized within a collaboration with Uppsala University and Karolinska Institute. Within this project, he is the co-supervisor of Igor Tominec (Uppsala University) with Elisabeth Larsson (Uppsala University) as the main advisor.
- Gabriele Steidl (Technische Universität Kaiserslautern, Germany) invited Fabien Pierre during two days in her team to work on convolution on Riemannian manifolds for color images. The goal of this collaboration is the design of a CNN to process images which values are on a Manifolds.

8.4. International Research Visitors

8.4.1. Visits of International Scientists

- Pete Hammer, a senior researcher at Harvard University (http://www.childrenshospital.org/researchers/peter-e-hammer), visited the MAGRIT team in July 2019. He gave a talk to the Department 1 in Loria, he helped out with mechanical modeling of the mitral valve and he provided advice to Daryna Panicheva during one week.
- Douglas Perrin, a senior researcher at Harvard University (http://www.childrenshospital.org/researchers/douglas-perrin), visited the MAGRIT team in September 2019. He gave a talk to the Department 1 in Loria, he worked on the segmentation of the mitral valve leaflet and he provided advice to Daryna Panicheva during one week.

- Ioana Ilea, Technical University Cluj-Napoca visited the Magrit team in October. She gave a talk entitled “Robust classification on covariance matrix space: Application to texture”.

8.4.1.1. Internships

Anastasiia Onanko from Kiev Polytechnique Institute was hosted to fulfill her Master internship (Erasmus mobility program). She worked to initiate a new research line in collaboration with our partners from CHRU Nancy, who were interested in having faster, more automated, but still faithful, means of detecting intracranial aneurysms from 3D magnetic resonance angiography (MRA) images. The deep learning approach that was followed addressed three challenges: the impossibility to use full-sized 3D MRA as input to a deep Convolutional Neural Network (CNN), the difficulty to collect annotated data, and the scarcity of aneurysms within the whole brain vasculature (about 50 voxels in a volume that counts millions of voxels). We designed two patch-based classification approaches, with roughly annotated data, and experimented with various data augmentation protocols. Results are preliminary and need to be consolidated. In particular, the current (limited) database will be expanded in the next few months.

8.4.2. Visits to International Teams

8.4.2.1. Research Stays Abroad

- Pierre-Frédéric Villard spent one month (May 2019) at Uppsala University working on the INVIVE project. His work there includes supervising PhD student Igor Tominec, meeting with a physiologist expert in respiration muscles and working on an implicit surface representation of the diaphragm.
- Daryna Panicheva and Pierre-Frédéric Villard stayed in Harvard University in Cambridge (USA) respectively 2 weeks and 1 month in the context of the CURATIVE team. Each of them gave a talk to the Harvard Biorobotics Lab. An acquisition of a porcine mitral valve was done with 4 different amounts of pressure with a microCT scan. Biomechanical simulations on the mitral valve were also studied in term of stability and convergence.

9. Dissemination

9.1. Promoting Scientific Activities

9.1.1. Scientific Events: Selection

9.1.1.1. Reviewer

- Marie-Odile Berger was reviewer for ISMAR (International Symposium for Mixed and Augmented Reality), IPCAI (International Conference on Information Processing in Computer-Assisted Interventions), IROS (International Conference on Intelligent Robots and Systems), ICRA (International conference on Robotics and Automation), RSS (Robotics: Science and Systems), AE-CAI (Workshop on Augmented Environments for Computer Assisted Interventions), ORASIS (French conference on computer vision)
- Erwan Kerrien was reviewer for MICCAI 2019, IPCAI 2020, MIAR/AE-CAI/CARE 2019 workshop and Orasis 2019
- Gilles Simon was reviewer for IEEE VR 2019 and IEEE ISMAR 2019
- Pierre-Frederic Villard was a reviewer for MICCAI 2019, the Eurographics Workshop on Visual Computing for Biology and Medicine 2019 and the International Conference on Computer Graphics, Visualization, Computer Vision And Image Processing 2019

9.1.2. Journal

- Marie-Odile Berger was a reviewer for the International Journal of Computer Assisted Radiology and Surgery.
- Erwan Kerrien was a reviewer for IEEE Transactions on Medical Imaging

- Frédéric Sur was a reviewer for IEEE Transactions on Medical Imaging, Experimental Mechanics, Signal Processing: Image Communication, Digital Signal Processing, IEEE Transactions on Image Processing, SIAM Journal on Imaging Science
- Gilles Simon was a reviewer for IEEE Transactions on Visualization & Computer Graphics
- Pierre-Frédéric Villard was a reviewer for the International Journal of Computer Assisted Radiology and Surgery.

9.1.3. Invited Talks

- Fabien Pierre gave an invited talk entitled “Coupling Variational Method with CNN for Image Colorization” at the workshop “Variational methods and optimization in imaging” (Paris), at Jean Kuntzmann’s laboratory (Grenoble), at ENSEEIHT(Toulouse) and at the one day workshop géométrie de la couleur, organized by GDR ISIS.
- Gilles Simon gave an invited talk at the Nanjing Institute of Advanced AI in China entitled "Camera localization for AR in large indoor environments".
- Pierre-Frédéric Villard gave a seminar at the department of information technology of Uppsala University. Title: “Segmentation of Mitral Valve Chordae”.
- Daryna Panicheva gave a talk at the Harvard Biorobotics Lab. Title: “Physically-coherent Extraction of Mitral Valve Chordae”.
- Pierre-Frederic Villard gave a talk at the Harvard Biorobotics Lab. Title: “An Overview of Deformable Models”.

9.1.4. Scientific Expertise

- Erwan Kerrien was an expert to evaluate NExT Isite (https://next-isite.fr/) calls for projects.

9.1.5. Research Administration

- Marie-Odile Berger is the president of the Association française pour la reconnaissance et l’interprétation des formes (AFRIF).
- Marie-Odile Berger was a member of the Inria evaluation committee.
- Frédéric Sur was a member of the recruitment committee for a Professor at IUT Charlemagne.

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

The academic members of the MAGRIT team actively teach at Université de Lorraine with an annual number of around 200 teaching hours in computer sciences each, some of them being accomplished in the field of image processing. Inria researchers have punctual teaching activities in computer vision and shape recognition mainly in the computer science Master of Nancy and in several Engineering Schools near Nancy (ENSMN Nancy, SUPELEC Metz, ENSG). Our goal is to attract Master students with good skills in applied mathematics towards the field of computer vision.

The complete list of courses given by staff members is detailed below:

- M.-O. Berger
  - Master : Shape recognition, 24 h, Université de Lorraine.
  - Master : Introduction to image processing, 12 h, École des Mines de Nancy .
  - Master : Image processing for Geosciences, ENSG, 12h.
- E. Kerrien
  - Master : Introduction to image processing, 15 h, École des Mines de Nancy.
  - Licence: Basics of computer science, 71h, IUT Saint-Dié-des-Vosges.

  - Professional training: Computer science unplugged for science teachers, 6h, INSPE de Lorraine.
- Fabien Pierre
  - Licence: Introduction au traitement d'image, 30h, IUT Saint-Dié des Vosges.
  - Master: Introduction à l'apprentissage automatique, 16 h, Université de Lorraine.
  - Licence: Algorithmique et programmation, 87h, IUT Saint-Dié des Vosges
  - Licence: Culture scientifique et traitement de l'information, 69h, IUT Saint-Dié des Vosges
  - Licence: Programmation objet et évènementielle, 35h, IUT Saint-Dié des Vosges
  - Licence: Initiation à l'intelligence artificiell, 8h, IUT Saint-Dié des Vosges
- G. Simon
  - Master: Augmented reality, 24 h, Télécom-Nancy.
  - Master : Augmented reality, 3 h, SUPELEC Metz.
  - Master: Augmented reality, 24h, M2 Informatique FST
  - Master: Visual data modeling, 12h, M1 Informatique FST
  - Image processing and computer vision, 12h, M1 informatique, FST
  - Licence pro : 3D modeling and integration, 40h FST - CESS d'Epinal
- F. Sur
  - Master: Introduction to machine learning, 60 h, Mines Nancy
  - Master: Time series analysis, 30h, Mines Nancy
  - Licence: Javascript programming, 150h, IUT Charlemagne
  - Introduction to signal processing, 20h, IUT Charlemagne
- P.-F. Villard
  - Licence: Computer Graphics with webGL, 30h, IUT Saint-Dié des Vosges.
  - Licence: Game design with Unity3D, 15h, IUT Saint-Dié des Vosges.
  - Licence: Virtual and Augmented Reality in Industrial Maintenance, 2h, Faculty of Science and Technology, Université de Lorraine
  - Master : Augmented and Virtual Reality, 16h, M2 Cognitive Sciences and Applications, Institut des Sciences du Digital, Université de Lorraine
  - Virtual and Augmented Reality within Unity, 15h, Glyndwr University, Wrexham, UK (ERASMUS+ program)
  - Licence: Web programming, 20h, IUT Saint-Dié des Vosges.
  - Licence: Graphical user interface programming, 30h, IUT Saint-Dié des Vosges.
  - Licence: Object-oriented programming, 20h, IUT Saint-Dié des Vosges.
  - Licence: UML modeling,16h, IUT Saint-Dié des Vosges.
  - Licence: Security and life privacy with internet, 2h, IUT Saint-Dié des Vosges.
  - Licence: Parallel programming, 18h, IUT Saint-Dié des Vosges.
- Brigitte Wrobel-Dautcourt
  - Master: modélisation objet et conception des systèmes d'information, 30h, Télécom
  - Master: projet de conception et développement java, 27h, Télécom 2A
  - Licence: bases de la programmation objet, 44h, Faculté des Sciences et Techniques, Université de Lorraine
  - Licence: interfaces graphiques,22h, Faculté des Sciences et Techniques, Université de Lorraine
  - Licence: projet de synthèse (activité intégratrice), 30 h, Faculté des Sciences et Techniques, Université de Lorraine
  - Licence: système, 24h, Faculté des Sciences et Techniques, Université de Lorraine
  - Licence: compilation, 16, Faculté des Sciences et Techniques, Université de Lorraine

9.2.2. Supervision

PhD: Jaime Garcia Guevara, Biomechanical graph matching for hepatic intra-operative image registration, October 2015, Marie-Odile Berger, Stéphane Cotin (MIMESIS). PhD defended in December 2019.

PhD in progress: Raffaella Trivisonne, Image-guided real-time simulation using stochastic filtering, November 2015, Erwan Kerrien, Stéphane Cotin (MIMESIS).

PhD in progress: Vincent Gaudillière, Reconnaissance de lieux et d'objets pour la réalité augmentée en milieux complexes, December 2016, Marie-Odile Berger, Gilles Simon.

PhD in progress: Daryna Panicheva, Image-based Biomechanical Simulation of Mitral Valve Closure, October 2017, Marie-Odile Berger, Pierre-Frédéric Villard.

PhD in progress: Matthieu Zins, Localization in a world of objects, October 2019, Marie-Odile Berger, Gilles Simon.

9.2.3. Juries

- Marie-Odile Berger was an external reviewer of the PhD of Karim Makki (IMT Atlantique, Brest) and of the HdR of Guillaume Caron (Univ Picardie Jules Verne). She was examiner of the PhD of Yilin Zhou (IGN, Paris), Florian Tilquin (ICUBE, Strasbourg) and of the HdR of Omar Ait Aider (Institut Pascal, Clermont Ferrand)
- Erwan Kerrien was an external reviewer for the PhD of Alessio Virzì (Université Paris Saclay and Telecom ParisTech) and Emmanuelle Poulain (I3S, Université Côte d'Azur)
- Frédéric Sur was an external reviewer for the PhD thesis of Debolina Chakraborty (IIEST Shibpur, India) and Alberto Lavatelli (Polytecnico di Milano, Italy)

9.3. Popularization

9.3.1. Internal or external Inria responsibilities

Erwan Kerrien is Chargé de Mission for scientific mediation at Inria Nancy-Grand Est, and thereby is part of the Inria scientific mediation network. As such, he is a member of the steering committee of "la Maison pour la Science de Lorraine" [1], and member of the IREM [2] steering council.

9.3.2. Education

- Pierre-Frédéric Villard is involved with the secondary school of Champigneulles (France) as a "Collège Pilote" of "La Main à la pâte" foundation. He gave a seminar on augmented and virtual realities to the pupils, he helped the teacher with preparing some activities with augmented and virtual reality technologies. Finally, he is supervising Université de Lorraine students to produce teaching applications with augmented and virtual reality technologies that will be used in secondary school classes.
- Erwan Kerrien participated in the creation and animation of a MOOC for teachers of the new SNT class (Sciences du Numérique et Technologie - *Digital Science and Technology* included in the 1st year of core curriculum in upper secondary education, see https://www.fun-mooc.fr/courses/course-v1:inria+41018+session01/about), where he brought his expertise in image processing. This MOOC is part of the Class'Code project (https://pixees.fr/classcode-v2).

  He also participates in *MOOCFOLIO*, a PIA3-funded project https://www.fun-mooc.fr/news/pia-3-le-projet-moocfolio-est-laureat/). The objective is to create a MOOC to help students choose their undergraduate studies to pursue after high schools. Erwan is part of a working group to create a module about studies and professions related to digital usages and sciences.

[1] "Houses for Science" project, see http://maisons-pour-la-science.org/en
[2] Institut de Recherche sur l'Enseignement des Mathématiques - *Research Institute for Teaching Mathematics*

He also participated in the creation, and teaching, of a 5-day training course for scientific animators (in a broad sense, from science club animators to science teachers). This course was funded by Région Grand-Est (see https://fan.loria.fr).

He gave a 2-day class about the use of unplugged computer science to introduce computer science in science class, along with another researcher and 2 secondary school maths teachers. This class has been organized with Maison pour la Science since 2015, and is proposed to around 20 maths and science secondary school teachers each year.

9.3.3. Interventions

Erwan Kerrien was an associate researcher to a MATh.en.JEANS workshop (https://www.mathenjeans.fr) within Loritz high school in Nancy.

He also regularly intervenes to demonstrate computer science unplugged activities and/or give conferences to secondary school pupils and teachers.

9.3.4. Internal action

Pierre-Frédéric Villard participated to open days and science festival in the IUT of Saint-Dié des Vosges. He presented augmented and virtual reality demos and their link to the high school mathematics program.

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