IN PARTNERSHIP WITH:
CNRS
Université de Lorraine

Activity Report 2011

Project-Team MAGRIT

Visual Augmentation of Complex Environments

IN COLLABORATION WITH: Laboratoire lorrain de recherche en informatique et ses applications (LORIA)

RESEARCH CENTER
Nancy - Grand Est

THEME
Vision, Perception and Multimedia Understanding

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Project-Team MAGRIT

Keywords: Computer Vision, Tracking, 3D Modeling, Augmented Reality, Medical Images

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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.

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. Scientific Foundations

3.1. Camera calibration and registration

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 Magrit project has been aiming at developing on-line and markerless methods for camera pose computation. We have especially proposed a real-time system for camera tracking designed for indoor scenes [1]. The main difficulty with online tracking is to ensure robustness of the process. 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 by using a piecewise-planar model of the environment. This methodology can 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.

The succes of pose computation largely depends on the quality of the matching stage which allows to detect and to match features over the sequence. Research are conducted in the team on the use of probabilistic methods to establish robust correspondences of features over time. The use of *a contrario* decision is under investigation to achieve this aim [3]. We especially address the complex case of matching in scenes with repeated patterns which are common in urban scenes. We also consider learning based techniques to improve the robustness of the matching stage.

Another 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. Each technology approach has limitations: on the one hand, rapid head motions cause image features to undergo large motion between frames that may 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 sensitive to metallic objects in the scene. In past works [1], we have proposed a system that makes an inertial sensor cooperate with the camera-based system in order to improve the robustness of the AR system to abrupt motions of the users, especially head motions. This work contributes to the reduction of the constraints on the users and the need to carefully control the environment during an AR application. Ongoing research on such hybrid systems are under consideration in our team with the aim to improve the accuracy of reconstruction techniques as well as to obtain dynamic model of organs in medical applications.

Finally, it must be noted that the registration problem must be addressed from the specific point of view of augmented reality: the success and the acceptance 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 has been addressed in our project both in classical AR and in medical imaging in order to choose the camera model, including intrinsic parameters, which describes at best the considered camera.

3.2. Scene 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 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. Within the team we have developped interactive in-situ modeling technique dedicated to classical AR applications. We also developp off-line multimodal technique dedicated to AR medical applications.

In-situ modeling
Most automatic techniques aim at reconstructing a sparse and thus unstructured set of points of the scene. Such models are obviously not appropriate to perform interaction with the scene. In addition, they are incomplete in the sense that they may omit features which are important for the accuracy of the pose recovered from 2D/3D correspondences. We have thus investigated interactive techniques with the aim to obtain reliable and structured models of the scene. The goal of our approach is to develop immersive and intuitive interaction techniques which allow scene modeling during the application [11].

Multimodal modeling 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 are acquired on the patient or possibly on the operating room through sensing technologies or various image acquisitions. 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's view of the environment.

Methods for multimodal modeling are strongly dependent on the image modalities and the organ specificities. We thus only address a restricted number of medical applications -interventional neuro-radiology and the Augmented Head project- 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 surgeon's training or patient's re-education/learning.

One our main applications is about neuroradiology. For the last 15 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 intraoperative context (2D and 3D angiography, MRI, ...), our aim is to develop a multi-modality framework to help 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. An accurate definition of the target is a parameter of great importance for the success of the treatment. We have proposed and developed multimodality and augmented reality tools which make cooperate various image modalities (2D and 3D angiography, fluoroscopic images, MRI, ...) in order to help 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 Shacra EPI, we have proposed new methods for implicit modeling of the aneurysms with the aim to obtain near real time simulation of the coil deployment in the aneurysm [4]. Multi-modality techniques for reconstruction are also considered within the european ASPI project, the aim of which is to build a dynamic model of the vocal tract from various images modalities (MRI, ultrasound, video) and magnetic sensors.

4. Application Domains

4.1. Augmented reality

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. Since then, we have amplified our research on multi-planar environments in order to obtain effective and robust AR systems in such environments. We currently investigate both automatic and interactive techniques for scene reconstruction/structure from motion methods in order to be able to consider large and unknown environments.

4.2. Medical Imaging

For 15 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 help therapeutic decisions and interventional gestures. In particular, we aim at developing tools allowing the physicians to take advantage of the various existing imaging modalities on the brain in their clinical practice: 2D subtracted angiography (2DSA), 3D rotational angiography (3DRA), fluoroscopy, MRI,...Recent works concern the use of AR tools for neuronavigation and the development of simulation tools of the interventional act for training or planning. This last project is developed in collaboration with the EPI Shacra.

4.3. Augmented head

Visual information on a speaker, especially jaws and lips but also tongue position, noticeably improves speech intelligibility. Hence, having a realistic augmented head displaying both external and internal articulators could help language learning technology progress in giving the student a feedback on how to change articulation in order to achieve a correct pronunciation. The long term aim of the project is the acquisition of articulatory data and the design of a 3D+t articulatory model from various image modalities: external articulators are extracted from stereovision data, the tongue shape is acquired through ultrasound imaging, 3D images of all articulators can be obtained with MRI for sustained sounds, magnetic sensors are used to recover the tip of the tongue.

5. Software

5.1. Software

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).

The visualization module is called QGLSG: it enables the visualization of images, 2D and 3D objects under a consistent perspective projection. It is based on Qt[1] and OpenScenegraph[2] libraries. The QGLSG library integrates innovative features such as online camera distortion correction, and invisible objects that can be incorporated in a scene so that virtual objects can cast shadows on real objects, and occlusion between virtual and real objects are easier to handle. The library was also ported to Mac OS and Windows and a full doxygen documentation was written.

6. New Results

6.1. Scene and camera reconstruction

Participants: Marie-Odile Berger, Srikrishna Bhat, Nicolas Noury, Gilles Simon, Frédéric Sur.

6.1.1. Image point correspondences and repeated patterns

Matching or tracking interest points between several views is one of the keystones of many computer vision applications, especially when considering structure and motion estimation. The procedure generally consists in several independent steps: interest point extraction, then interest point matching by keeping only the "best correspondences" with respect to the similarity between some local descriptors, and final correspondence pruning to keep those that are consistent with a realistic camera motion (here, consistent with epipolar constraints or homography transformation.) Each step in itself is a delicate task which may endanger the whole process. In particular, repeated patterns give rise to lots of false correspondences in descriptor-based matching. Actual correspondences are thus hardly, if ever, recovered by the final pruning step. Dealing with repeated patterns is of crucial importance in man-made environments. Starting from a statistical model by Moisan and Stival [25], we have proposed a one-stage approach for matching interest points based on simultaneous descriptor similarity and geometric constraint. The resulting algorithm has adaptive matching thresholds and is able to pick up point correspondences beyond the nearest neighbour. We have also shown how to improve ASIFT [26], an effective point matching algorithm to make it more robust to the presence of repeated patterns [5], [23], [8].

6.1.2. Visual words for pose computation

Visual vocabularies are standard tools in the object/ image classification literature, and are emerging as a new tool for building point correspondences for pose estimation. Within S. Bhat's PhD thesis, we have proposed several methods for visual word construction dedicated to point matching, with structure from motion and pose estimation applications in view. The three dimensional geometry of a scene is first extracted with bundle adjustment techniques based on keypoint correspondences. These correspondences are obtained by grouping the set of all SIFT descriptors from the training images into visual words using transitive closure (TC) techniques. We obtain a more accurate 3D geometry than with classical image-to-image point matching. In a second on-line step, these visual words serve as 3D point descriptors that are robust to viewpoint change, and are used for building 2D-3D correspondences on-line during application, yielding the pose of the camera by solving the PnP problem. Several visual word formation techniques have been compared with respect to robustness to viewpoint change between the learning and the test images. Our experiments showed that the adaptive TC visual words are better in many ways when compared to other classical techniques such as K-means [12].

6.1.3. Tracking by synthesis using point features and pyramidal blurring

Tracking-by-synthesis is a promising method for markerless vision-based camera tracking, particularly suitable for Augmented Reality applications. In particular, it is drift-free, viewpoint invariant and easy-to-combine with physical sensors such as GPS and inertial sensors. While edge features have been used succesfully within the tracking-by-synthesis framework, point features have, to our knowledge, still never been used. This is probably due to the fact that real-time corner detectors are weakly repeatable between a camera image and a rendered texture.

[1] http://www.trolltech.com
[2] http://www.openscenegraph.org/projects/osg

We compared the repeatability of commonly used FAST, Harris and SURF interest point detectors across view synthesis [17]. We showed that adding depth blur to the rendered texture can drastically improve the repeatability of FAST and Harris corner detectors (up to 100% in our experiments), which can be very helpful, e.g., to make tracking-by-synthesis running on mobile phones. We proposed a method for simulating depth blur on the rendered images using a pre-calibrated depth response curve. In order to fulfil the performance requirements, a pyramidal approach was used based on the well-known MIP mapping technique. We also proposed an original method for calibrating the depth response curve, which is suitable for any kind of focus lenses and comes for free in terms of programming effort, once the tracking-by-synthesis algorithm has been implemented.

6.1.4. Acquisition of 3D calibrated data

Christel Leonet joined the team in october 2010 as an INRIA assistant engineer with the aim to build an integrated 3D acquisition system. More specifically, the objective of her work is to combine an IMU (Inertial Measurement Unit), a GPS receiver, a laser rangefinder and a video camera for ground truth data acquisitions of camera movements and scene structures. These data will be useful to validate several algorithms developped in our team. This year she dealt with the hand-eye coordination between the different devices. Moreover, a 3D laser pointer has being built, which allows to acquire textured 3D polygons by pointing them with the laser attached to the camera and the IMU put on a tripod.

6.2. Medical imaging

Participants: René Anxionnat, Marie-Odile Berger, Abdulkadir Eryildirim, Erwan Kerrien, Pierre-Frédéric Villard, Brigitte Wrobel-Dautcourt, Ahmed Yureidini.

6.2.1. Vessel reconstruction with implicit surfaces

Our research activity is led in collaboration with Shacra project-team from INRIA Lille-Nord Europe and the Department of Interventional Neuroradiology from Nancy University Hospital. It was pursued this year in the context of the SOFA-InterMedS INRIA Large-Scale Initiative.

Our objective is the implicit modeling of blood vessels from 3DRA data, with the aim to use these models for real time simulation of interventional procedures. Within A. Yureidini's PhD thesis, a new model was developed consisting of a tree of local implicit blobby models. This model was implemented in Sofa simulation platform, enabling interactive simulation time (60 fps) and thereby showing an impressive realism during tool navigation [20]. We focused this year on the extensive validation of our RANSAC-based vessel tracking algorithm, by comparison with state of the art Multiple Hypothesis Testing [24] on 10 patient data [18]. Our initial mechanism to fit the implicit model to patient data relies on the minimization of a multi-termed energy. This energy was put under scrutiny, assessing the contribution of each energy term [19]. Our current goal is to reintroduce the raw image data for a more accurate energy computation, with the aim to design a blobby deformable model.

6.2.2. A variational framework for automatic modeling of the vocal tract

Segmenting the vocal tract in MRI is difficult especially because the tongue may move near other edges in the oral cavity, such as the palate or the teeth, which may disturb the segmentation process. The idea explored in our past work was to guide the segmentation with shape priors learnt on a reference speaker within a shape-based variational framework.

Shape priors were incorporated into segmentation via a PCA model with a relatively large number of components to enable the adaptation of the model to strong morphological differences. During this year, this work was continued with the aim to detect tongue contours in physical correspondences, thus allowing us to build a model of the vocal tract. An automatic method for the identification of the end points as well as an improved variational framework to obtain curves in physical correspondences was described in [15]. Second, we extensively assessed the segmentation process. We experimentally showed that the reference model is able to cope with strong morphological differences between speakers with a limited numbers of modes.

6.2.3. Medical simulators based on task analysis

We present here two works done within a collaboration with Imperial College of London.

In order to validate a virtual reality ultrasound-guided targeted liver biopsy procedure simulators previously designed [22], we have worked on task analysis to deconstruct individual procedural tasks followed by metric definition and critical performance indicator identification. Consultant and trainee scores on the performance metrics were compared. Independent t-tests revealed significant differences between trainees and consultants on 3 performance metrics: targeting, probe usage time and mean needle length in beam. ANOVA reported significant differences across years of experience on seven performance metrics: no-go area touched, targeting, length of session, probe usage time, total needle distance moved, number of skin contacts, total time in no-go area. More experienced participants consistently received better performance scores on all 19 performance metrics [9].

We used the same task analysis technique to design an inguinal hernia repair simulator [16]. The task analysis allowed to break down the complex operation into sub-tasks and it also provided the foundation for useful and productive discussions between clinical staff and developers. We deployed our system as an e-learning application, allowing surgeons to easily access the application.

6.3. National Initiatives

- SOFA-InterMedS (2009–) Participants: R. Anxionnat, M.O. Berger, E. Kerrien, A. Yureidini.
  The SOFA-InterMedS large-scale INRIA initiative is a research-oriented collaboration across several INRIA project-teams, international research groups and clinical partners. Its main objective is to leverage specific competences available in each team to further develop the multidisciplinary field of Medical Simulation research. Our action within the initiative takes place in close collaboration with both Shacra INRIA project-team in Lille and the Department of diagnostic and therapeutic interventional neuroradiology of Nancy University Hospital. We aim at providing in-vivo models of the patient's organs, and in particular a precise geometric model of the arterial wall. Such a model is used by Shacra team to simulate the coil deployment within an intracranial aneurysm. The associated medical team in Nancy, and in particular our external collaborator René Anxionnat, is in charge of validating our results.
- ANR ARTIS (2009-2012)
  Participants: M.O. Berger, A. Eryildirim, E. Kerrien.
  The main objective of this fundamental research project is to develop inversion tools and to design and implement methods that allow for the production of augmented speech from the speech sound signal alone or with video images of the speaker's face. The Magrit team is especially concerned with the development of procedures allowing for the automatic construction of a speaker's model from various imaging modalities.
- ANR Visac (2009-2012)
  Participants: M.O. Berger, B. Wrobel-Dautcourt.
  The ANR Visac is about acoustic-visual speech synthesis by bimodal concatenation. The major challenge of this project is to perform speech synthesis with its acoustic and visible components simultaneously. Within this project, the role of the Magrit team is twofold. One of them is to build a stereovision system able to record synchronized audio-visual sequences at a high frame rate. Second, a highly realistic dense animation of the head must be produced.

6.4. European Initiatives

6.4.1. Major European Organizations with which you have followed Collaborations

Partner 1: Imperial College, London.

Pierre-Frédéric Villard has a Honorary Research Fellow contract with Imperial College. The research focusing on medical simulators based on task analysis have been done within this link. The collaboration has involved 2 research visits in London to mainly incorporate work done in Lorraine both at the LORIA and with Nancy University intern students. There was also a participation as an activity leader in a one-week summer school on Haptic Technology (to give the basics of computer haptics, including visual and haptics rendering, force feedback, haptic interfaces, collision detection, collision response and deformation modelling).

7. Dissemination

7.1. Animation of the scientific community

- Invited Conference: F. Sur gave the presentation *Similarity and affine invariant point detectors and descriptors* within the tutorial *Tools and Methods for Image Registration* , *IEEE International Conference on Computer Vision and Pattern Recognition* (CVPR), Colorado Springs, USA, 2011.
- Talk given within the GdR ISIS day dedicated to *SfM-SfX – Structure à partir du mouvement et d'autres indices visuels : état de l'art et évolution du domaine* , ENST, Paris. *Appariement de points entre images: le cas des forts changements de point de vue et des motifs répétés* (F. Sur).
- The members of the team reviewed articles for Elsevier Computational Statistics and Data Analysis, Image Processing On Line, Springer International Journal of Computer Vision, IEEE Transactions on Evolutionary Computation, IEEE Transaction on Haptics, IEEE Transactions on Medical Imaging, Medical Physics, Virtual Reality, Computer and Graphics, ARIMA-CARI.
- M.O. Berger was a member of the program committee of the following conferences: IEEE International Symposium on Mixed and Augmented Reality (ISMAR 2011), International Conference on Medical Image Computing and Computer Assisted Intervention (MICCAI 2011), the IEEE International Symposium on Biomedical Imaging (ISBI) 2011. She was also a member of the program committee of the French conference on pattern recognition (RFIA 2012) and of ORASIS 2011.
- E. Kerrien was a member of the program committee of MICCAI 2011.
- G. Simon was a member of the program committee of ISMAR 2011 and ORASIS 2011.
- F. Sur is a member of the editorial board of the journal Image Processing On Line.
- P.F. Villard was a member of the program committee of MICCAI 2011 and ISBI 2011.
- Members of the team are members of local management committees (Conseil de Laboratoire and Comité de Centre), and participate on a regular basis, to scientific awareness and mediation actions.

7.2. Teaching

Permanent members of the team are involved in the following teaching activities:

Master: Reconnaissance des formes statistiques, 15h, M2, UHP, France

Master: Perception de la structure et du mouvement, 15h, M2, UHP, France

Master: Outils pour le traitement et l'analyse d'images, 21h, 2A, École des Mines de Nancy, France

Licence: Mathématiques (analyse complexe, distributions), 20h, École des Mines de Nancy, France

Master: Modélisation et prévision (régression linéaire, séries chronologiques), 48h, École des Mines de Nancy, France

Master: Recherche opérationnelle, 59h, École des Mines de Nancy, France

Master: Initiation au traitement du signal et applications, 21h, Ecole des Mines de Nancy, France

Licence: Graphic and haptic rendering (30h), IUT Saint-Dié des Vosges, France

Licence: Image processing(30h), IUT Saint-Dié des Vosges, France

Licence: 3D programming (30h), IUT Saint-Dié des Vosges, France

Licence: Object oriented programming (110h),IUT Saint-Dié des Vosges, France

Licence: Programmation shell-script sous Linux, 30 h, L2, UHP, France

Licence: Conception et programmation langage objet, 60 h, L2, UHP, France

Licence: Programmation avancée en langage imperatif classique, 14h, L3, UHP, France

Licence: Bases geométriques de l'imagerie, 25h, L3, UHP, France

Licence: Programmation et bases de donnees, 35h, L3, UHP, France

Licence: Modélisation 3D, 40h, LP, UHP, France

Master: Perception et raisonnement, 50h, M1, UHP, France

Master: Réalite augmentée, 30h, M2, UHP, France

Master: Réalite augmentée, 24h, 2A, ESIAL (Ecole Superieure d'Informatique et Applications de Lorraine), France

SUPELEC: Réalite augmentée, 3h, 3A, SUPELEC Metz, France

DIU: Robotique chirurgicale, 1h, CHU Nancy Univ. Hospital, France.

PhD & HdR:

PhD: Nicolas Noury, Mise en correspondance A Contrario de points dintérêt sous contraintes géométriques et photométriques, Université Henri Poincaré, 13 Octobre 2011, Marie-Odile Berger, Frédéric Sur [8].

PhD in progress: S. Bhat, Learning methods for pose computation, December 2008, Marie-Odile Berger, Frédéric Sur.

PhD in progress: Ahmed Yureidini, Modélisation implicite des vaisseaux sanguins pour la simulation interactive d'actes de radiologie interventionnelle, January 2010, Erwan Kerrien, Stéphane Cotin (Shacra, Lille).

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Publications of the year

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