european training network on full parallax imaging

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Plenoptic Sensing

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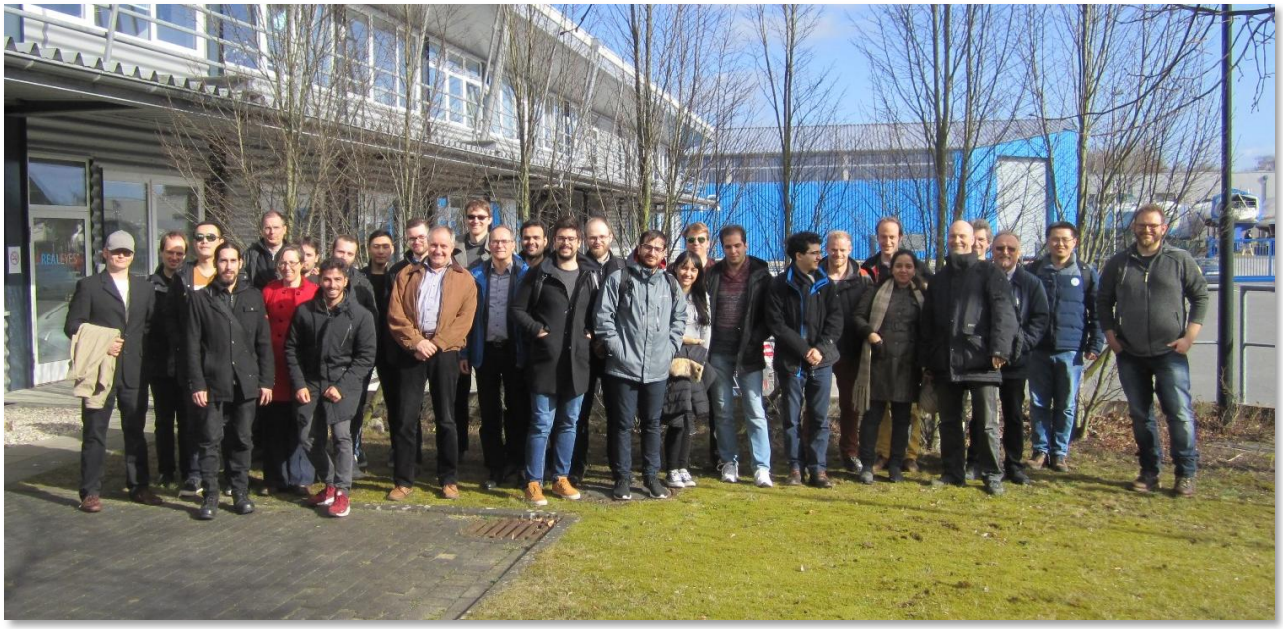
Abstract:

Report on the third Training School of the Network, “Plenoptic sensing”, organized at Christian-Albrechts-University (CAU) and Raytrix GmbH in Kiel, Germany during 13th – 17th March 2017.



Participants of the Training School 3 in Kiel, Germany, in Front of RealEyes Company.

Photos: Robert Bregovic, Sergio Moreschini

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Summary

The third ETN-FPI network's training event, "Training school on plenoptic sensing", was organized jointly at Christian-Albrechts-University (CAU) and Raytrix GmbH in Kiel 13th – 17th March 2017. The training school was attended by all fifteen of the recruited Early Stage Researchers (ESRs). In addition, the reseach advisors, the external speakers and a few external guests complemented the audience of the training school to about 25-32 persons.

The aim of this school was to give an introduction into the theory and practice of plenoptic sensing devices, *i. e.,* lens-based plenoptic cameras on the one side and large-scale multi-camera systems consisting of color and depth cameras on the other side. The lectures aimed at providing the ETN-FPI network members with the theoretical backgrounds needed to understand and interpret lightfield capturing with such devices, as well as state-of-the-art algorithms and challenges of processing the captured data for 3D lightfield displays.

The first four days of the training event were each divided into a 3-hour lecture session (sessions 1 and 2) until noon, followed by a 3-hour laboratory session in the afternoon, where the participants took part in hands-on practical experiments with plenoptic cameras and multi-camera systems. Three laboratory sessions were scheduled for Monday, Tuesday and Thursday afternoon. The school closed with a fourth laboratory session on Friday morning.

For the laboratory sessions, teams of 4–5 ESRs were formed in advance. Each team attended one of the four laboratory exercises, three taking place at Raytrix and one in the multimedia lab at Kiel University. Via a rotation principle, each team attended each of the four exercises once during the training event. The topics of the exercises included practical usage of plenoptic cameras and multi-camera systems for lightfield capturing and analysis with respect to specific tasks like 3D microscopy, particle tracking, or image based rendering. The background knowledge was mostly based on the theory provided in the first two lectures.

On Monday morning, Christian Perwass, co-founder of Raytrix GmbH, gave an introduction into lightfield capturing with different types of lens-based plenoptic cameras, supplementing the theory of lightfield formation by practical issues like camera calibration, sources of error, and design parameters, as well as providing a vivid insight into practical applications and the related algorithms. In the evening, all participants joined for dinner and a social activity to conclude the first day together and encourage bonding as a team.

On Tuesday morning, the theory and practice of lightfield capturing based on large-scale multi-camera arrays was presented by Sandro Esquivel and Reinhard Koch from the Multimedia Information Processing workgroup at Kiel University. In the first talk, basic mathematical concepts and theoretical aspects of image formation with multiple cameras were explained to provide all participants with the necessary basic notations and concepts involved in image-based modeling and rendering. The basic working principles of depth cameras – structured-light and time-of-flight approach – were explained afterwards, followed by a lecture about practical application of such RGB-D multi-camera systems. The presented applications involved content creation for 3D displays and image interpolation to sparsify the vast amount of data for such displays.

On Tuesday evening, the supervisory board members met to discuss current issues with the network and the future organisation of the online seminars. The ESRs were provided a summary of the conclusions from this meeting by ESR representative Oleksii Doronin on Wednesday morning during the lecture session.

Wednesday morning was dedicated to dense lightfield analysis, presented by Bastian Goldlücke from the Image Analysis and Computer Vision workgroup at Konstanz University. The lecture pondered on the structure of the sub-aperture view representation of the lightfield, its conclusions about the 3D scene, and how to extend state-of-the-art image analysis techniques to lightfields.

On Wednesday afternoon, the school's participants attended a visit to REALEYES, a local company producing innovative glasses-free 3D displays, which is also involved as a partner organization in the network. In the evening, the network members travelled to a restaurant at the beach where the conference dinner was held.

On Thursday morning, Karol Myszkowski, senior researcher at the Max Planck Institute for Informatics in Saarbrücken, discussed the impact of human perception on the design of lightfield displays and content presentation. Afterwards, Joachim Keinert from the Department Moving Picture Technologies at Fraunhofer IIS concluded the lecture session with insight into practical issues of lightfield capturing and processing for high-quality video production.

On Friday morning, each ESR team attended the last of the four laboratory sessions and joined for lunch, before closing of the training school on Friday noon. Four of the ESRs stayed in Kiel University in the afternoon for the oral exams of the course "Image-based 3D Reconstruction", held by Prof. Koch via the online platform of the network during the preceding winter term at Kiel University.

Most of the lecturers and network members attending the training school were accommodated in the same hotel at the seaside during the event to support the connection and development of personal relationships.

During the event, the slides for all lectures were published on the training school's website. All documents, as well as further information about the venues, schedule, and participants, are publicly available at: http://www.full-parallax-imaging.eu/TS3/

Programme and teaching material

Day 1: Monday 13th March:

Lecture 1 and 2: Tutorial on lightfield capturing with a plenoptic camera.

Instructor: Christian Perwass (CluTec, formerly at Raytrix GmbH, Kiel)

Contents: Principles of lens-based plenoptic cameras. Properties of lightfields. Algorithms for lightfield refocussing, depth estimation, and plenoptic camera calibration. Multiple-focus lightfields. Practical applications for plenoptic cameras.

Slides: Part 1: Lightfield camera and algorithms, Part 2: Multi-focus lightfield camera and applications

Photo: Dr. Perwass from Clutec presenting at TS3.

Afternoon: Laboratory session.

Day 2: Tuesday 14th March:

Lecture 1: Tutorial on sparse lightfield capturing with RGB-D multi-camera systems.

Instructor: Sandro Esquivel (Kiel University)

Contents: Principles of multi-camera systems. Camera model, Euclidean transformations and perspective projection. Basics of linear least squares and non-linear optimization. Calibration of multi-camera systems, hand-eye calibration. Working principles of depth cameras, structured-light versus time-of-flight approach.

Slides: Introduction, Part 1: Optimization, Part 2: Multi-camera calibration, Part 3: Depth cameras

Photo: The lecture room with audience following the presentations

Lecture 2: Tutorial on color and depth image fusion and interpolation for 3D displays.

Instructor: Reinhard Koch (Kiel University)

Contents: 3D-TV LDV content creation with a hybrid time-of-flight multi-camera rig. Efficient depth-compensated image interpolation for full-parallax displays.

Slides: Part 1: 3D-TV LDV content creation, Part 2: Interpolation for full-parallax displays

Afternoon: Laboratory session.

Day 3: Wednesday 15th March:

Lecture 1 and 2: Tutorial on dense lightfield analysis

Instructor: Bastian Goldlücke (Konstanz University)

Contents: Structure of the Lambertian lightfield. Disparity and depth reconstruction, inverse problems on ray space, lightfield super-resolution. Non-Lambertian lightfields and 3D reconstruction from sampled lightfields.

Slides: Part 1: Lambertian lightfields, Part 2: Non-Lambertian lightfields

Afternoon: Visit to REALEYES

Photo Left: 3D Display at Realeyes, Right: Group picture in the Labos of RealEyes.

Evening: Conference Dinner

Day 4: Thursday 16th March:

Lecture 1: Tutorial on perception of lightfield enabled visual cues.

Instructor: Karol Myszkowski (Max Planck Institute for Informatics, Saarbrücken)

Contents: Lightfield displays and human perception. Problems with temporal and spatial sampling. Binocular conflicts for rendering of highlights. Adjustment of cinematographic effects and cuts. Eye tracking for perception analysis. Quality metrics for lightfield displays.

Slides: Perceptual display

Lecture 2: Tutorial on lightfield video production.

Instructor: Joachim Keinert (Fraunhofer IIS, Erlangen)

Contents: Challenges of lightfield capturing with multi-camera systems for movie production. Sparse-to-dense lightfield conversion. Image quality factors. Challenges in rendering.

Slides: Lightfield capture for media production

Afternoon: Laboratory session.

Day 5: Friday 17th March:

Morning: Laboratory session.

Afternoon: Oral exams.

Exercises

Session 1: Lightfield capturing and processing with RGB-D multi-camera systems (CAU).

Instructor: Sandro Esquivel (Kiel University)

Contents: Intrinsic and extrinsic camera calibration with a checkerboard. Sparse lightfield capturing with a movable RGB-D multi-camera array. Depth image based rendering and synthetic aperture. Color correction with a color calibration chart.

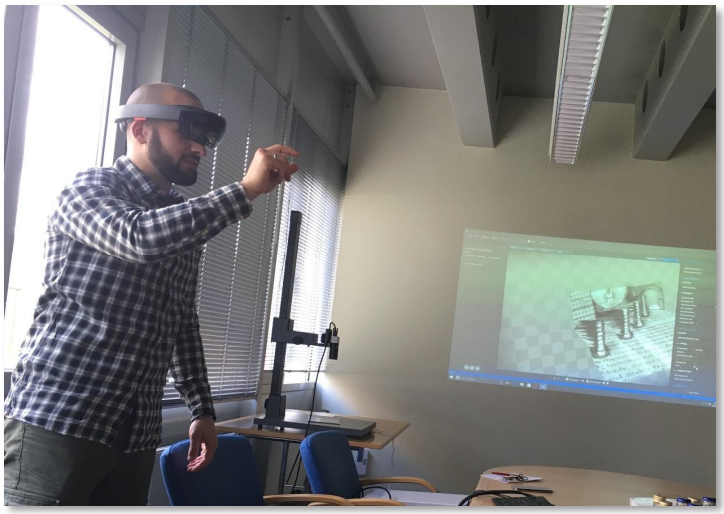
Session 2: 3D particle tracking with a plenoptic camera (Raytrix).

Instructor: Arne Erdmann (Raytrix GmbH, Kiel)

Contents: Lightfield microscopy and endoscopy. 3D vision stitching. Inspection with a plenoptic camera.

Session 3: Particle tracking with a plenoptic camera (Raytrix).

Contents: Challenges of visual 3D particle tracking. Particle image velocimetry and particle tracking velocimetry (PIV/PTV). High-speed video analysis.



Session 4: RxLive Light Field Software (Raytrix).

Instructor: Stefano Spyropoulos (Raytrix GmbH, Kiel)

Contents: Introduction to RxLive Light Field Software SDK and API for processing and visualization of plenoptic camera data. Application for metric target calibration and dense 3D filling. Usage of lightfield data in a virtual reality application.

Teachers

Lecturers:

Reinhard Koch (Professor of Multimedia Information Processing, Kiel University).
Sandro Esquivel (Post-doctoral Researcher, Kiel University).
Bastian Goldlücke (Professor of Image Analysis and Computer Vision, Konstanz University).
Joachim Keinert (Chief Scientist, Moving Picture Technologies, Fraunhofer IIS, Erlangen).
Karol Myszkowski (Senior Researcher, Max Planck Institute for Informatics, Saarbrücken).
Christian Perwass (CluTec, formerly at Raytrix GmbH, Kiel).

Instructors in laboratory sessions:

Arne Erdmann (Raytrix GmbH, Kiel).
Sandro Esquivel (Kiel University).
Arne Petersen (Raytrix GmbH, Kiel).
Stefano Spyropoulos (Raytrix GmbH, Kiel).

Feedback

Fourteen out of the fifteen ESRs attending the training event responded to the feedback questionnaire handed out during the event. The ESRs rated the lectures with respect to quality of content (QoC) and quality of presentation (QoP) on a scale from 1 (very low) to 5 (very high), resulting in an average score of 4.2 for QoC and 4.4 for QoP. Although the presentation given by Christian Perwass turned out to be a clear favourite of the audience, the other lectures scored similar with respect to each other with average values around 4.0 and slightly higher QoP than QoC. The composition of the lecture topics was mostly considered as well-balanced, indicated by an average score of 4.5. The four lab sessions scored very similar to each other, resulting in an average score of 4.3 for QoC and 4.4 for QoP.

In the free comments section, it was emphasized that the lecture topics were considered as well-balanced, informative and interesting, although some perceived parts of the talks as rather mathematical.

In comparison to lectures and exercises, the venue and overall social program scored lower with an average value of 3.5. However, the ESRs were very pleased with the visit to REALEYES and the social dinner, which scored an average of 4.6 each. The free comments section revealed that the ESRs had some discomfort with the accommodation at the Maritim hotel since it was considered as quite far from the conference venues at Kiel University, and there was some trouble with the local bus lines.

The ESRs gave positive feedback to the website and general information exchange, which achieved an average score of 4.3. Personal praise was given to the overall good organization of the event, the responsiveness of the local organizers, and the open, communicative atmosphere during the sessions.

In summary, the ESRs considered the training event as rather beneficial for their future research, which is also confirmed by an average score of 4.4 in the questionnaire. In personal feedback, the participants agreed that the lectures and exercises achieved to promote practical experience in lightfield capturing tasks and to comprehend the challenges involved in this field of research.

Annex 1. Participants

Waqas	Ahmad	Mid Sweden University (ESR)
Amir	Ansari	University of Valencia (ESR)
Mehdi Daniel	Ardebili	Raytrix, Kiel (ESR)
Robert	Bregovic	Tampere University of Technology
Matthias	Carlsohn	CVIC, Bremen
Aron	Cserkaszky	Holografika (ESR)
Elijs	Dima	Mid Sweden University
Oleksii	Doronin	Holografika (ESR)
Arne	Erdmann	Raytrix, Kiel
Sandro	Esquivel	Kiel University
Maydel	Fernandez Alonso	Newcastle University (ESR)
Filipe	Gama	Tampere University of Technology (ESR)
Yuan	Gao	Kiel University (ESR)
Bastian	Goldlücke	Konstanz University
Atanas	Gotchev	Tampere University of Technology
Seokmin	Hong	University of Valencia
Ilmari	Huttu-Hiltunen	Yleisradio Oy, Finland
Ole	Johannsen	Konstanz University
Christos	Kaspiris-Rousellis	Newcastle University (ESR)
Joachim	Keinert	Fraunhofer IIS, Erlangen
Reinhard	Koch	Kiel University
Yongwei	Li	Mid Sweden University (ESR)
Sergio	Moreschini	Tampere University of Technology (ESR)
Karol	Myszkowski	Max Planck Institute, Saarbrücken
Ron	op het Veld	Fraunhofer IIS, Erlangen (ESR)
Luca	Palmieri	Kiel University (ESR)
Christian	Perwass	CluTec, Kiel
Arne	Petersen	Raytrix, Kiel
Jenny	Read	Newcastle University
Gabriele	Scrofani	University of Valencia (ESR)
Mårten	Sjöström	Mid Sweden University
Stefano	Spyropoulos	Raytrix, Kiel
Felix	von Laffert	REALEYES, Kiel
Faezeh Sadat	Zakeri	Fraunhofer IIS, Erlangen (ESR)