ERCIM "ALAIN BENSOUSSAN" FELLOWSHIP PROGRAMME

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Scientific Report

First name / Family name	Byung-Kuk Seo
Nationality	South Korea
Name of the *Host Organisation*	Fraunhofer IGD
First Name / family name of the *Scientific Coordinator*	Harald Wuest
Period of the fellowship	01/10/2014 to 30/09/2016

I – SCIENTIFIC ACTIVITY DURING YOUR FELLOWSHIP

During my fellowship period, I carried out my research in continuation and extension of my research interests in 3D visual tracking under the guidance of Dr. Harald Wuest at Fraunhofer IGD in Darmstadt, Germany. As originally planned, my research mainly focused on exploring how to reliably estimate 6DOF poses using challenging 3D objects, which have more complicated shapes with poor texture and few color. In this regard, I developed a novel method of 3D visual tracking, which does not depend on feature types.

In the literature, direct methods have been attractive for 6DOF pose estimation because they allow that rich information in an image can be contributed to pose estimation, instead of being limited by local features. In direct methods, the brightness (intensity) constancy is commonly assumed, but it is often violated by intensity variations, which are induced by illumination changes, surface reflectance properties, or even changes in camera gain. In this manner, I conducted my research and proposed a novel direct method for robust 3D object tracking from a monocular RGB image when an object model is available.

In the context of image formation, the appearance of an object on an image is characterized into image intensity that relies on surface normal, surface reflectance, and illumination. Though its complete modeling is very difficult on the physical real world,

each attribute can provide good knowledge related to image intensity on certain conditions. In the proposed method, the main idea was inspired by that surface normal variations can give rise to image intensity variations. In this sense, I investigated the relation between image intensity and surface normal to tackle 6DOF pose estimation problems. Some details of the main contributions are as follows:

- I newly modeled intensity variations by deriving differential entities from image formation under the Lambertian assumption, and defined a compensation parameter using the surface normal of a 3D target object.

- From the prediction about image intensity in this model, I formulated a constrained objective function, leading to the improved tracking performance (suppressing the error accumulation and converging with less iteration).

I also comprehensively examined and implemented other direct methods to evaluate and compare their performances. Furthermore, I created new datasets that comprise 3D objects in industrial areas, which are relevant to on-going research projects of my hosting group; and challenging conditions such as partial occlusions, background clutters, and illumination changes, in order to evaluate the proposed method in an intensive manner and explicitly demonstrate its advantages. Currently, I am conducting on integrating the proposed method into the development framework of my hosting group, and preparing paper presentations about scientific contributions and results of my research.

In addition, I collaborated with former colleagues in several research works, such as papers and patents. As a part of scientific activities, I served as a reviewer for several conferences (International Symposium on Mixed and Augmented Reality 2015, 2016) and journals (Multimedia Tools and Applications, IPSJ Transactions on Computer Vision and Applications).

II – PUBLICATION(S) DURING YOUR FELLOWSHIP

- Title: 3D trajectory reconstruction under refraction at a cylindrical surface
  Authors: Byung-Kuk Seo, Jungsik Park, and Jong-Il Park
  Publication: Proc. IEEE International Conference on Image Processing (ICIP), pp. 2660–2664, Sep 2015 (published)

  Abstract: In conventional imaging, the geometry of image formation is described by the pinhole camera model, and it allows multiview reconstruction based on the perspective projection. If a light ray passes through different media, however, the pinhole camera model becomes invalid due to refraction, causing changes in direction. In this paper, we present a method for 3D trajectory reconstruction under refraction at a cylindrical surface. In the proposed method, the refractive geometry is represented by a geometric mapping from image points to refracted rays, instead of physically modeling it. 3D points inside the cylindrical surface are estimated by computing intersection points between segments of corresponding refracted rays in multiview. In our experiments, we demonstrate that 3D trajectories of multiple moving objects inside a transparent cylinder, which is

filled with water, are successfully recovered using multiple cameras.

- Title: Subjective evaluation on perceptual tracking errors from modeling errors in model-based tracking
  Authors: Eun Joo Rhee, Jungsik Park, Byung-Kuk Seo, and Jong-Il Park
  Publication: IEIE Transactions on Smart Processing and Computing (TSPC), vol. 4, no. 6, pp. 407–412, Dec 2015 (published)

  Abstract: This paper presents a new method for 3D object tracking from monocular RGB images. The proposed method is based on exploring the relationship between image intensity and surface normal. Given a 3D object model with a known camera pose, surface normals are described as per-pixel normal values through the graphics pipeline. A similarity measure is formulated on joint probability distributions between image intensities and normal values using the sum of conditional variance, and it is optimized to align the object model with the images over 6DOF camera poses. Experimental results demonstrate that our method is promising for augmented reality applications using poorly textured 3D objects.

- Title: Robust 3D object tracking using an elaborate motion model
  Authors: Byung-Kuk Seo and Harald Wuest
  Publication: Proc. International Symposium on Mixed and Augmented Reality (ISMAR), Sep 2016 (accepted)

  Abstract: This paper proposes a new method for robust 3D object tracking from a single RGB image when an object model is available. The proposed method is based on image alignment between consecutive frames over a 3D target object. Different from conventional methods that only rely on image intensity for the alignment, we model intensity variations using the surface normal of the object. From this model, we also define a new constraint for the pose estimation, leading to significant improvement in the tracking robustness. In experiments, we demonstrate the benefits of our method by evaluating it under challenging tracking conditions.

- Title: A direct method for robust model-based 3D object tracking from a monocular RGB image
  Authors: Byung-Kuk Seo and Harald Wuest
  Publication: Proc. European Conference on Computer Vision Workshops (ECCVW), Oct 2016 (accepted)

  Abstract: This paper proposes a novel method for robust 3D object tracking from a monocular RGB image when an object model is available. The proposed method is based on direct image alignment between consecutive frames over a 3D target object. Unlike conventional direct methods that only rely on image intensity, we newly model intensity variations using the surface normal of the object under the Lambertian assumption. From the prediction about image intensity in this model, we also employ a constrained objective function, which significantly alleviates degradation of the tracking performance. In experiments,

we evaluate our method using datasets that consist of test sequences under challenging conditions, and demonstrate its benefits compared to other methods.

- Title: Binocular mobile augmented reality based on stereo camera tracking
  Authors: Jungsik Park, Byung-Kuk Seo, and Jong-Il Park
  Publication: Journal of Real-Time Image Processing (RTIP) (under review after minor revision)

  Abstract: Mobile augmented reality (AR) applications have become feasible with the evolution of mobile hardware. For example, the advent of the smartphone allowed implementing real-time mobile AR, which triggered the release of various applications. Recently, rapid development of display technology, especially for stereoscopic displays, has encouraged researches to implement more immersive and realistic AR. In this paper, we present a framework of binocular augmented reality based on stereo camera tracking. Our framework was implemented on a smartphone and supports autostereoscopic display and video see-through display in which a smartphone can be docked. We modified edge-based 3-D object tracking in order to estimate poses of left and right cameras jointly; this guarantees consistent registration across left and right views. Then, virtual contents were overlaid onto camera images using estimated poses, and the augmented stereo images were distorted to be shown through a video see-through display. The feasibility of the proposed framework is shown by experiments and demonstrations.

III – ATTENDED SEMINARS, WORKHOPS, CONFERENCES

- Internal group seminars

IV – RESEARCH EXCHANGE PROGRAMME (REP)

- REP host institute: INRIA Grenoble Rhône-Alpes
  Location: Grenoble, France
  Date: 26/07/2015 - 01/08/2015
  Working group: STEEP research team
  REP scientific coordinator: Dr. Peter Sturm

  Summary: During the visiting, I introduced my on-going research issues to Dr. Peter Sturm and his group members. We also exchanged valuable idea and had good discussions about them. Even the short visiting, it was very helpful to refresh myself as well as keep doing my research works.