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Modular embedded lightfield system for road condition assessment

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Abstract. To satisfy the requirements of road condition assessment an embedded lightfield system, combining 2D texture and 3D geometry, is required. An experimental prototype is proposed. Various approaches for lightfield acquisition were considered. In the end multi-view stereo was identified as the most suitable. Four camera pairs provide the raw data which is preprocessed and transmitted to the main processing unit, where the data is fused into one coherent dataset, via HDMI/DVI. Hybrid Zynq SoC technology was chosen to be able to support sequential and parallel computation paradigms. The system is adaptable to different fields of application due to its modular setup.

1. Introduction

Automation and quality assurance reach into more and more fields of application. One recent field is the road condition assessment. Conventionally it is performed by a human expert evaluating image recordings of the road segments. Since this is not very economic and sometimes tedious and unattractive, there is incentive to aid the experts with computer vision technology. One important milestone for this is the acquisition of the lightfield, i.e. the combination of geometry and texture, of the roads. Small fissures are detectable using 2D features while e.g. rut is oftentimes hardly visible let alone assessable using just only information and thus requires depth information. The acquired raw data for this can easily reach excessive amounts, which require extensive storage capacities. Therefore, it is desirable to process the raw data, calculate the lightfield and classify road segments on embedded systems. In this paper a hardware prototype for this task is proposed.

2. Overview of lightfield technology

Lightfield systems are able to acquire the geometry and the texture of the scene. Various different approaches to lightfield acquisition were considered: structure from motion, (multi-view) stereo and plenoptic cameras. In structure from motion different perspectives of the same scene are provided by the same camera. Compared to the other approaches it requires the least expensive hardware. On the other hand, it inherently has worse accuracy compared to a true stereo setting since the camera trajectory has to be estimated in addition to the scene geometry.

Plenoptic cameras utilise micro lens arrays to divide the main image in smaller micro images which contain different perspectives and angular information. Depth estimation can be performed by the application of stereovision algorithms to neighbouring micro images [1]. At the moment plenoptic

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cameras can economically not compete with classical (multi-view) stereo approaches and do not offer significant advantages. Tests with a Raytrix R8 camera showed unsatisfactory results.

Due to the aforementioned reasons, a stereo approach was chosen. Early tests with a single camera pair showed promising results for asphalt.

3. Concept of the experimental prototype

To keep the stereotypical proof-of-concept system adaptable to different application scenarios a modular setup was designed. For a marketable product reduction of redundant hardware is possible (and advisable). Road condition assessment requires the prototype to be real-time capable and keep the power consumption low. Zynq technology was chosen for the aforementioned reasons and to be able to choose from a multitude of interface options. Zynq technology combines FPGA-based Programmable Logic and an ARM-based Processing System and thus allows for the combination of fast sequential and highly parallel computation.

One stereo pair would not suffice to provide the required depth resolution over the full width of a road. For this reason, the modular setup combines the data of multiple camera pairs. At the moment 4 cameras are planned. In case the empirical evaluation reveals that more cameras are required, the modular setup allows for a comparatively easy addition. Although early tests with a single camera pair showed promising results for asphalt, it is nevertheless possible to extend the system with pseudo-random pattern projectors and additional cameras with spectral filters, should the textural contrast of the roads not suffice for reliable matching point detection and stereovision.

The planned experimental setup is illustrated in figure 1. The camera pairs are based on the stereo image processing system by Fütterer et al. [2]. Triangulation is possible in areas where neighbouring cameras in a pair show overlapping content. Each of the four camera pairs is connected to a Zynq7020 SoC which performs pre-processing and stereo matching. The pre-processed image data and depth maps are streamed to a Zynq Ultrascale+ ZU9EG SoC on a ZCU102 development board, which combines the data of the four camera pairs into one coherent data set of geometry and texture – the lightfield. The data stream transmission utilises the HDMI/DVI protocol to allow for the required distance between the camera pairs. A custom-build FMC connector board connects the HDMI/DVI cables to the Programmable Logic banks of the Zynq Ultrascale+ device.

Neighbouring camera pairs have slightly overlapping content to allow for coherent data fusion. The data fusion almost exclusively uses resources of the Programmable Logic. A pipelined implementation allows for high frame rates without frame drops caused by processor blocking. The ARM system is operated by a lightweight, embedded GNU/Linux system. This enables easy ways of communication with external systems and storages, e.g. via SSH. After the initialisation the processing system is in an idle state most of the time and can be used for the classification of the road on basis of the calculated lightfield.

4. Conclusions

In this paper the concept for an embedded lightfield system intended for application in road condition assessment was presented. After the evaluation of different approaches to the acquisition of the lightfield, passive stereo imaging was identified as the most promising. Regardless of the presented scenario the system is modularised to satisfy various conditions of different fields of applications.

The data from multiple stereo pairs is fused into one coherent data set. The system utilises Zynq SoC technology to offer embedded, real-time capable lightfield computation and a low energy footprint, which is important for road condition assessment.

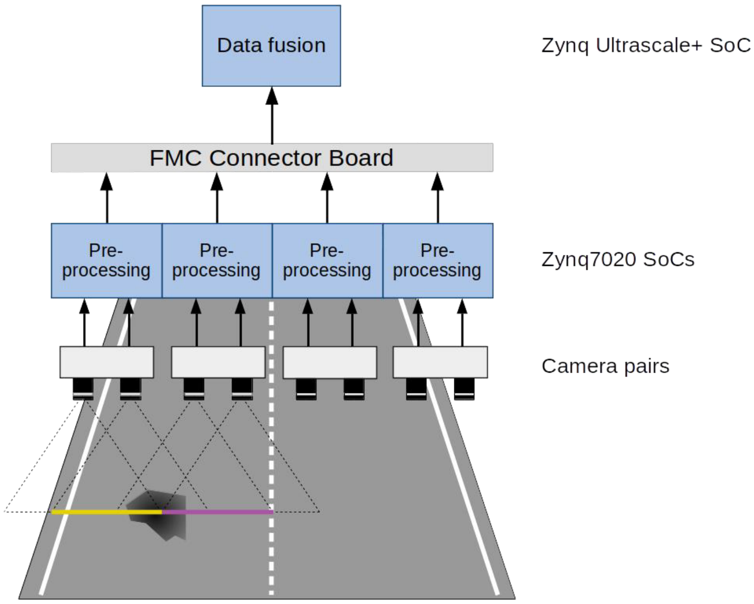

Figure 1. Schematical illustration of the embedded lightfield system prototype for road condition assessment – not true to scale.

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