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CRADA Final Report: CRADA Number NFE-19-07847 with MantaPoole Technologies

Jesse Claypoole

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1. Abstract

As the world becomes more automated, smart and autonomous systems that utilize advanced 3D machine vision are becoming ever more prevalent. To function autonomously, these smart machines need to be able to identify the "what" and "where" of their application by capturing color and depth information. The color information provides the needed contrast information to identify the "what" of a scene while the depth information allows the smart machine to identify "where" an object in a 3D environment is. To capture both the color and depth information using only a single sensor, MantaPoole Technologies (MPT) is developing a new type of 3D light field camera. The approach leverages MPT's active micro-optics technology which when aligned and placed over an imaging detector are designed to act as an advanced optical filter that controls the direction of light that reaches the underlying pixels.

2. Statement of Objectives

For smart machines to perceive and interact with the real world, they need to be able to identify the "what" and "where" of their application. To do this in an unstructured environment, color and 3D depth datasets offer a robust dataset to extract this information from. To get these color and 3D depth datasets from a single viewpoint, light field cameras offer a compact single camera solution. To capture the 3D depth information about a scene, light field cameras control which direction of light reaches each pixel on an imaging sensor. In current generation of light field cameras to capture this directional information, an array of geometric micro-lens arrays a few hundred microns above the imaging sensor surface. During operation, light from the scene is focused by the lens optics onto the plane of the micro-lens array. Each micro-lens then acts to redirect light rays focused by the lens optics onto individual pixels located under each micro-lens. Each of these pixels then measures the intensity of light from that dedicated direction. The directional and color information of the scene is encoded into the standard two-dimensional image taken by the light field camera sensor. To extract the "what" and "where of the scene, post processing algorithms are then done on the light field dataset.

One of the main limitations of the current generation of light field cameras is that spatial resolution on the sensor or final image resolution is traded to measure the directional information of the light. This is due to the micro lens array being a passive geometric element. Each pixel measures a fixed direction of light which ultimately results in the output image have a 4x to 100x reduction in image quality. To get around this spatial resolution trade off, MantaPoole Technologies is developing a new type of micro-optics called active micro-optics which can actively control the angle of light that reaches each pixel. At the system level, MantaPoole's light field camera utilizes the active micro-optics to control the angle of and trades frame rate for this directional information. This approach allows for the MPT's light field camera to capture many times more 3D directional information about a scene at a given sensor resolution.

Our research project involved investigating ways to overcome the spatial resolution trade off of traditional light field cameras and further developing a light field camera system capable of doing this. To accomplish this, our research project involved four research areas called active micro-optics development, camera electronic development, firmware development, and light field software development.

3. Benefits to the Funding DOE Office's Mission

Smart and autonomous machines are a key enabling class of technologies that are increasingly being used in a variety of market sectors including agriculture, industrial manufacturing, and automotive to maximize the use of resources and operational efficiency of a processes and minimize the direct and indirect production greenhouse gas emissions. To function, these smart and autonomous machines need to collect information about the real-world using sensors so they can perceive the "what" and "where" of there environment.

The data-sets that these smart machines are capable of capturing can limit the decisions they can make and ultimately limit the green house emission saving actions they can perform. To enable these smart machines to capture these higher quality 2D and 3D datasets, Dr. Claypoole researched and developed an active micro-optics technology during his time at ORNL. The active micro-optics technology has the potential to be an enabling technology to improve the 3D resolution of variety of different types of 3D sensors including 3D light field cameras, Time of Flight, and LiDAR. These 3D different types of improved 3D sensors are using in a large number of robotic assemblies, machine vision inspection, and industrial process monitoring tasks.

4. Technical Discussion of Work Performed by All Parties

The first research area, active micro-optics development, involved developing the design and manufacturing approach of Mantapoole's enabling optical component called active micro-optics. The initial development of the manufacturing approach for the active micro-optics was done using several of the semiconductor fabrication tools in the National Science and Technology Laboratory Cleanroom (Figure 1). In Mantapoole's light field camera, the active micro-optics replace the current generation of passive geometric micro-lens array elements which are placed a few hundred microns above the imaging sensor surface. The use of passive geometric micro-lens arrays results in each pixel only being able to measure one fixed direction of light. By replacing the passive geometric micro-lens arrays with the active micro-optics, it enables the light field camera change the direction of light that reaches each pixel. For operation of the light field camera, the micro-optics and camera sensor are synchronized and work together using a space time modulation technique. The active micro-optics control and transition the acceptance angle of light that pass through them and the imaging sensor measures the intensity of the light. Multiple exposures and acceptance angle transition are then done to capture a larger number of directions per pixel.

Figure 1: Dr. Claypoole performing a metallization step during
the active micro-optics development in the
National Science and Technology Laboratory Cleanroom.

The second research area involved designing the electronics of the light field camera and involved integrating a FPGA, imaging sensor, data interface chip, and the control electronics for the active micro-optics onto a printed circuit board.

The third research area involved designing the firmware for the FPGA and basic interface to the computer.

The fourth research area involved designing the basic light field math functions to convert the encoded light field data in the 2D images into a ray database which could be further processed.

The sum of these research efforts enabled MPT to get close to a completed prototype light field camera seen in Figure 2.

Figure 2 - MPT Prototype Light Field

5. Subject Inventions (As defined in the CRADA)

None

6. Commercialization Possibilities

During our time in the Innovation Crossroads program, a large number of different practical skills were acquired. On the business side, we learned a lot about grant writing, developing the business model canvas, financial projections, capitalization tables, and cash flow models. On the management side, we learned a lot about how to work with various suppliers, the importance of contract terms, estimating and managing lead times, how to navigate the national lab environment, and more about the terms that should be in an employment and confidentiality agreements. On the active micro-optics side, we learned about photolithography mask design, materials identification and selection, procedures for getting materials approved, additional semiconduction fabrication experience, and how to design for FAB manufacturing. On the electronics side of the project, we learned a lot about how to read electronics IC data sheets, sourcing electronic components in a pandemic, power IC design, designing using FPGAs, LVDS signaling, PCB design principals, PCB design for manufacturing requirements, producing PCB manufacturing design files required by suppliers.

7. Conclusion

Dr. Claypoole contributed to many different aspects of the light field camera development project. This included developing the design and manufacturing approach for the active micro-optics, designing the printed circuit board and control electronics, and developing the math model for the light field software. His appointment in the Innovation Crossroads program has had a tremendous impact on transitioning him from a pure academic and technical background to having a more well-rounded background on the business side of running the company. The experience has and will greatly help Dr. Claypoole be able to effectively manage a company and work with collaborators.