(Revised 07/09)

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NSFC/RGC Joint Research Scheme
Joint Completion Report

(Please attach a copy of the completion report submitted to the NSFC by the Mainland researcher)

Part A: The Project and Investigator(s)

1. Project Title

Study on Magnetorheological Fluid Jet Polishing of Optical Freeform Surfaces (OFS) Using Computer-Controlled Polishing (CCP) Combined With Non-symmetrical Tool Functions

2. Investigator(s) and Academic Department/Units Involved

	Hong Kong Team	Mainland Team
Name of Principal Investigator *(with title)*	Professor YAM Yeung	Professor CHENG Haobo
Post	Professor	Professor
Unit / Department / Institution	Department of Mechanical and Automation Engineering / The Chinese University of Hong Kong	Department of Optical Engineering / Beijing Institute of Technology, China
Co-investigator(s) *(with title)*		

3. Project Duration

	Original	Revised	Date of RGC/ Institution Approval *(must be quoted)*
Project Start date	Jan. 1, 2011		
Project Completion date	Dec. 31, 2013		
Duration *(in month)*	36		

Part B: The Completion Report

5. Project Objectives

5.1 Objectives as per original application

1. To study the performance and control of magnetic jet fluid polishing on material removal, surface error convergence and process optimization
2. To design an effective fluid jet nozzle and associating magnetic field generation and pumping system for precise and controllable polishing of freeform optical surfaces
3. To develop and construct a multi-axis computer-controlled MJF prototype system of enhanced efficient and accuracy
4. To demonstrate applications of the developed technologies on optical surfaces of diameter of 30 mm or more

5.2 Revised Objectives

Date of approval from the RGC: ____________________

Reasons for the change: ____

(Revised 07/09)

1.
2.
3. ....

6. Research Outcome

Major findings and research outcome
(maximum 1 page; please make reference to Part C where necessary)

Major findings and research contribution of the present project include:

The project achieved the design and construction of a novel self-developed MJP machine comprising of 8 DOFs. Referring to Fig. 1, the machine is divided into three layers. The top layer houses the X-axis and Y-axis rails and motors and the nozzle assembly. The middle layer houses the workpiece holder and Z-axis actuation motor. Sufficient workspace is provided to accommodate optical elements up to 150 mm diameter, which is beyond the 30 mm called for in the proposed project objective. The lower layer houses the worm and gear drive, and the corresponding Z-rotation motor of the workpiece holder. The mechanical frame is composed of aluminum alloy to facilitate a rigid and yet light structure. Structural deformation was studied via Finite Element Analysis to assure that vibrations during operations are of acceptable level. The hardware are of industrial grade to ensure sufficient precision and reliability. The platform constitutes a rigorous prototype to explore the economical application and study of the MJF technology.

Particularly, the project produced a novel design of nozzle assembly for the platform. The assembly is comprised of the nozzle itself, a magnetic coil and a sleeve. The magnet coil serves to generate axial magnetic field to induce the MR effect. The steel sleeve tends to isolate the magnetic field to within the inside of the nozzle structure. To ensure the performance of the assembly, the resulting magnetic field subject to various geometric and electrical parameters were extensively studied, simulated and optimized. Experiments were carried out to maximize and stabilize the jet stream formed during the operation. As designed, the nozzle assembly is able to exhibit relative sliding, swinging and rotating DoFs. These DoFs enable three possible jetting modes of polishing processing: simple vertical jetting, eccentric rotating jetting, and eccentric rotating jetting with tilting angle. The above achievements are detailed in the publication in the first paper in Part C. 9.

Another major contribution of the project is on the development and implementation of an iterative technique to step by step improve the quality of the optical workpiece. The technique is comprised of two main procedures: path planning and position mapping. The former is to generate surface error profile between the measured workpiece and its target profile, and then automatically produces the polishing path for the nozzle tool head to effectively reduce the error. The key challenge, however, is the proper mapping of this corrective path to the platform when the workpiece is put back after having been taken out for the measurement. The present project proposed and successfully demonstrated a positon mapping procedure to overcome this challenge. The procedure works with circular workpiece and can readily be extended to more general shape. The technique essentially enables a feedback loop to iteratively improve the workpiece surface profile with respect to a target profile. Experimentations of the proposed technique using the MJP platform for polishing and a Fisba interferometer as measurement unit were conducted with satisfactory performance. The technique yields a PV value of $1/7\lambda$ in the polishing of flat optical elements. The results are detailed in the publication in the paper in the paper listed in Part C. 8.

The project also conducted a preliminary study of freeform optical elements as possible subjects of MJP processing. Freeform optics is of emerging importance due to its ability to greatly simplify a bulky assembly of conventional lenses by a single piece of freeform optical element. Our studies led to the proposing of a new and simplified design of convex–plano Head Mounted Display (HMD) prism based on ray tracing and optical theories. We also fabricated a low cost prototype of this HMD prism and conducted experiments to confirm the resulting performance as consistent with that predicted by theory and simulation studies. The work paved the way for future studies involving MJP of freeform optical elements and was published as a conference paper with credit given to the project in the second paper in Part C.9.

Potential for further development of the research and the proposed course of action *(maximum half a page)*

The present project amounts to a first feasibility study in the adaptation of MJP theory and public domain information on a self-developed MJP machine, and to study its performance and limitation. Overall, the project was able to meet the goals it sets out to achieve. The developed platform and proposed procedures indeed produced acceptable performance in the surface polishing of the optical workpiece. For further development and study, we can explore the following three directions:

- Optimized utilizing of platform: Our path planning procedures did not optimize the use of the 8 DoFs of the platform in polishing experiments, especially the DoFs related to the nozzle head. The resulting paths hence were able to complete the task but may not be the most efficient. Optimizing the full use of the DoFs available for error removal will enhance the polishing performance in effectiveness, energy/material utilization, and time.
- Polishing of freeform optical elements: Freeform optical elements are emerging as the new frontiers in optics. Application of the MJP platform to polish freeform optical element will be a great direction in both research and engineering practice. The feat will call for a new design of path planning scheme and iterative technique to map the planned path onto the MJP platform.
- Polishing of other materials: We have also conducted preliminary study on applying our MJP platform to other type of materials, such as metal, and not glass. The result is as shown in Fig. 5. This direction will open up a new application for MJP in new kinds of materials for industrial uses.

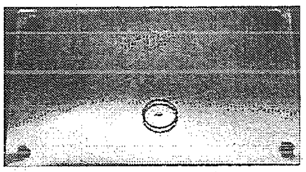

Figure 5

7. The Layman's Summary

(describe in layman's language the nature, significance and value of the research project, in no more than 200 words)

QED is the most famous company for pioneering the research and application of MJP technology. However, their machines and accessory (like MR fluid) are of relatively high cost. The present project, on the other hand, sets out to explore the economical development of a self-developed MJP machine and to study its utilization and performance. Overall, the project is able to meet this goal. It came up with a MJP machine that embeds a total of 8 DoFs in the nozzle assembly and workpiece movements. Many commercially available MJP machines actually feature a smaller number of DoFs and hence exhibit skewed polishing abilities. The self-developed machine accommodates optical pieces of up to 150 mm diameter, which is large than the project objective of 30 mm. Design of the nozzle assembly was meticulously optimized through simulation studies of the various parameters for maximized performance in jet stream formation. The removal function associated of the nozzle head was also experimentally determined. More importantly, the project successfully demonstrated a novel iterative technique alternating between operations via MJP machine for error correction and a Fisba interferometric system for error profile assessment to step by step improve the quality surface of an optical workpiece.

Part C: Research Output

(Revised 07/09)

8. **Peer-reviewed journal publication(s) arising <u>directly</u> from this research project**
(Please attach a copy of each publication and/or the letter of acceptance if not yet submitted in the previous progress report(s). All listed publications must acknowledge RGC's funding support by quoting the specific grant reference.))

The Latest Status of Publications				Author(s) *(bold the authors belonging to the project teams and denote the corresponding author with an asterisk*)*	Title and Journal/Book *(with the volume, pages and other necessary publishing details specified)*	Submitted to RGC *(indicate the year ending of the relevant progress report)*	Attached to this report *(Yes or No)*	Acknowledged the support of this Joint Research Scheme *(Yes or No)*
Year of publication	Year of Acceptance *(For paper accepted but not yet published)*	Under Review	Under Preparation *(optional)*					
2014				Pak-yin Adam Lia, Ming-fu Melvin Cheung, Hang Tong, Haobo Cheng & Yeung Yam	Design and Implementation of a Technique for Iterative Magnetorheological Jet Polishing, *International Journal of Optomechatronics*, Taylor and Francis, Volume 8, Issue 3, 2014, pp. 195-205	No	Yes	Yes

9. **Recognized International conference(s) in which paper(s) related to this research project was/were delivered** *(Please attach a copy of each delivered paper)*

Month/Year/ Place	Title	Conference Name	Submitted to RGC *(indicate the year ending of the relevant progress report)*	Attached to this report *(Yes or No)*	Acknowledged the support of this Joint Research Scheme *(Yes or No)*
11/2011/ Hong Kong	Design and Analysis of a Magnetorheological Jet Polishing Machine	2011 International Symposium on Optomechatronic Technologies	Yes, 2012	Yes	Yes
11/2012/ Paris, France	Computational Design and Prototype Development of Optical Prism for Augmented Reality Projection	2012 International Symposium on Optomechatronic Technologies	No	Yes	Yes

10. **Student(s) trained** *(Please attach a copy of the title page of the thesis.)*

Name	Degree registered for	Date of registration	Date of thesis submission/ graduation
Miss Coco Pui Lam Ho	M.Phil	September 2010	September 2012

11. Other impact *(e.g. award of patents or prizes, collaboration with other research institutions, technology transfer, etc.)*

During the course of the project, the mainland and Hong Kong team communicated with each other frequently and paid research visits to each other. Specifically, the Hong Kong team members visited the mainland PI's laboratory on March 26-31 and March 26-27, 2012, respectively. The Mainland PI visited CUHK quite frequently (more than 10 times during the course of the project) for discussion on various technical matters related to the project. The collaboration strengthened the Joint Research Centre on Optical Design and Engineering established between CUHK and the Beijing Institute of Technology.

Other activities related to the present project include:

- Organized a workshop on *Advanced Optical Manufacturing Technology* held in Hong Kong on March 29, 2011 focusing on Magnetorheological fluid technologies for optical processing.
- Organized the *2011 International Symposium on Optomechatronic Technologies* (ISOT) to be held in Hong Kong on November 1-3, 2011. ISOT is a key international conference in the field and the event attracted 100 top researchers and scholars from all over the world to the CUHK campus. Results of the project were presented during the Symposium. The event led to the beginning of overseas collaboration for some faculty members of CUHK. The Hong Kong PI was invited to be a member of the Steering Committee for the ISOT society.