THE DETERMINATION OF AN EFFECTIVE RADIUS OF AN OPTICALLY TRAPPED POLYSTYRENE MICROBEAD DISTRIBUTION NEAR A WATER–AIR INTERFACE

MUHAMAD SAFUAN BIN MAT YENG @ MAT ZIN

UNIVERSITI PENDIDIKAN SULTAN IDRIS

2019

THE DETERMINATION OF AN EFFECTIVE RADIUS OF AN OPTICALLY TRAPPED POLYSTYRENE MICROBEAD DISTRIBUTION NEAR A WATER-AIR INTERFACE

MUHAMAD SAFUAN BIN MAT YENG @ MAT ZIN

05-4506832 pustaka.upsi.edu.my Perpustakaan Tuanku Bainun Kampus Sultan Abdul Jalil Shah PustakaTBainun ptbupsi

THESIS SUBMITTED IN FULLFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF SCIENCE (PHYSICS)
(MASTER BY RESEARCH)

FACULTY OF SCIENCE AND MATHEMATICS
UNIVERSITI PENDIDIKAN SULTAN IDRIS

2019

05-4506832 pustaka.upsi.edu.my Perpustakaan Tuanku Bainun Kampus Sultan Abdul Jalil Shah PustakaTBainun ptbupsi

UPSI/IPS-3/BO 32
Pind : 00 m/s: 1/1

UNIVERSITI PENDIDIKAN SULTAN IDRIS
يونيۏرسيتي ڤنديديقن سلطان ادريس
SULTAN IDRIS EDUCATION UNIVERSITY

Please tick (√)

Project Paper	
Masters by Research	√
Master by Mixed Mode	
PhD	

INSTITUTE OF GRADUATE STUDIES

DECLARATION OF ORIGINAL WORK

This declaration is made on the ....19.....day of........NOVEMBER........20..19

i. Student's Declaration:

I, MUHAMAD SAFUAN BIN MAT YENG @ MAT DIN, M20162001639 ~~FACULTY SCIEN~~ SCIENCE AND MATHEMATICS (PLEASE INDICATE STUDENT'S NAME, MATRIC NO. AND FACULTY) hereby declare that the work entitled THE DETERMINATION OF AN ~~OPTI~~ EFFECTIVE RADIUS OF AN OPTICALLY TRAPPED POLYSTYERENE MICROBEAD NEAR WATER-AIR INTERFACE is my original work. I have not copied from any other students' work or from any other sources except where due reference or acknowledgement is made explicitly in the text, nor has any part been written for me by another person.

____
Signature of the student

ii. Supervisor's Declaration:

I SHAHRUL KADRI BIN AYOP (SUPERVISOR'S NAME) hereby certifies that the work entitled THE DETERMINATION OF AN ~~OPTICAL~~ EFFECTIVE RADIUS OF AN OPTICALLY TRAPPED POLYSTYRENE MICROBEAD NEAR A WATER-AIR INTERFACE (TITLE) was prepared by the above named student, and was submitted to the Institute of Graduate Studies as a * partial/full fulfillment for the conferment of MASTER IN SCIENCE (PHYSICS) (PLEASE INDICATE THE DEGREE), and the aforementioned work, to the best of my knowledge, is the said student's work.

____
Date

____
Signature of the Supervisor

UNIVERSITI PENDIDIKAN SULTAN IDRIS
SULTAN IDRIS EDUCATION UNIVERSITY

INSTITUT PENGAJIAN SISWAZAH /
INSTITUTE OF GRADUATE STUDIES

BORANG PENGESAHAN PENYERAHAN TESIS/DISERTASI/LAPORAN KERTAS PROJEK
DECLARATION OF THESIS/DISSERTATION/PROJECT PAPER FORM

Tajuk / *Title*: THE DETERMINATION OF AN EFFECTIVE RADIUS OF AN OPTICALLY TRAPPED POLYSTYRENE MICROBEAD NEAR A WATER-AIR INTERFACE

No. Matrik /*Matric No.*: M20162001629

Saya / *I* : MUHAMAD SAFUAN BIN MAT YENG @ MAT ZIN

(Nama pelajar / *Student's Name*)

mengaku membenarkan Tesis/Disertasi/Laporan Kertas Projek (Kedoktoran/Sarjana)* ini disimpan di Universiti Pendidikan Sultan Idris (Perpustakaan Tuanku Bainun) dengan syarat-syarat kegunaan seperti berikut:-
acknowledged that Universiti Pendidikan Sultan Idris (Tuanku Bainun Library) reserves the right as follows:-

1. Tesis/Disertasi/Laporan Kertas Projek ini adalah hak milik UPSI.
   The thesis is the property of Universiti Pendidikan Sultan Idris

2. Perpustakaan Tuanku Bainun dibenarkan membuat salinan untuk tujuan rujukan dan penyelidikan.
   Tuanku Bainun Library has the right to make copies for the purpose of reference and research.

3. Perpustakaan dibenarkan membuat salinan Tesis/Disertasi ini sebagai bahan pertukaran antara Institusi Pengajian Tinggi.
   The Library has the right to make copies of the thesis for academic exchange.

4. Sila tandakan (√) bagi pilihan kategori di bawah / *Please tick (√) from the categories below:-*

☐	**SULIT/*CONFIDENTIAL***	Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub dalam Akta Rahsia Rasmi 1972. / *Contains confidential information under the Official Secret Act 1972*
☐	**TERHAD/*RESTRICTED***	Mengandungi maklumat terhad yang telah ditentukan oleh organisasi/badan di mana penyelidikan ini dijalankan. / *Contains restricted information as specified by the organization where research was done.*
☑	**TIDAK TERHAD / *OPEN ACCESS***	

(Tandatangan Pelajar/ Signature)

Profesor Madya Dr. Shahrul Kadri Bin Ayop
Jabatan Fizik, Fakulti Sains dan Matematik
Universiti Pendidikan Sultan Idris

(Tandatangan Penyelia / *Signature of Supervisor*)
& (Nama & Cop Rasmi / *Name & Official Stamp*)

Tarikh: 19-11-2019

Catatan: Jika Tesis/Disertasi ini **SULIT @ TERHAD**, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali sebab dan tempoh laporan ini perlu dikelaskan sebagai **SULIT** dan **TERHAD**.

Notes: If the thesis is CONFIDENTAL or RESTRICTED, please attach with the letter from the related authority/organization mentioning the period of confidentiality and reasons for the said confidentiality or restriction.

ACKNOWLEDGEMENT

First and foremost I would like to thank Allah SWT for everything. Without his blessing I might not able to complete this thesis.

Alhamdulilah I finally succeed to complete my thesis writing that entitle "The determination of an effective radius of an optically trap polystyrene microbead distribution near a water-air interface". This thesis focused on optical trapping near water-air interface which much more complex and critical than optical trapping in water medium. This study was helpful to understanding the behavior of trapped particle at interface.

I would like to thank my supervisor, Prof Madya Dr. Shahrul Kadri bin Ayop. He is one of the expertise in optical trapping and manipulation field in Malaysia. He introduced me to optical trapping (principle and theory) very well. He used simple example to explain complex physics which make physics was fun to be learnt. He gave me well supervision, helping my research in term of discussing and suggestion to levitate my research quality. I also would thank Dr Izan Roshwaty binti Mustapa for helping me in discussing and reviewing my thesis.

I also would like to thank Ministry of Education Malaysia for rewarding me with MyBrainSc scholarship. This funding helped me a lot to support my life in education and life in university. I hope that this program will be offered at all time to support the scientist in field of pure sciences.

Last but not least, I would also like to thank to my dear friends who willing to share their knowledge with me. To my lovely parent, thanks a lot for always be my backbone, motivator for me to success in my life.

ABSTRACT

The research aimed to determine the effective radius (*r**) of a trapped polystyrene microbead near a water-air interface and to develop a 3-dimensional piezostage control module for optical trapping within micrometre range. This study involved the development of a control program so called PZStage and the determination of *r** near the water-air interface. PZStage was developed on the LabVIEW platform to control laser focus location in the trapping medium. A 3 µm bead was trapped in water at several heights towards the free space in a special design test cell. The temporal displacement data of the trapped bead was recorded by a quadrant photodiode (QPD) and analysed by a custom made program namely OSCal to determine *r**. PZStage was well developed which enabled precise laser focus control in 20 µm range in three mutually orthogonal directions. The result showed that *r** was constant at any focus height at fixed water thickness and laser power. Besides, *r** depended on laser power at fixed laser focus height and water thickness in the form of exponentially decaying relation. In conclusion, PZStage was successfully developed to precisely control laser focus toward water-air interface, and the *r** was found to be dependent on laser power rather than laser focus height within the set experimental conditions. The research implied that the low laser power was possible for optical trapping near the water-air interface with appropriate water thickness selection. However, consideration must be taken into account since the trap was shifted away from the laser focus as the focus height increases due to scattering force.

PENENTUAN JEJARI BERKESAN BAGI TABURAN MIKROMANIK POLISTERINA YANG TERPERANGKAP SECARA OPTIK BERDEKATAN ANTARAMUKA AIR-UDARA

ABSTRAK

Kajian ini bertujuan untuk menentukan jejari berkesan ($r*$) bagi mikromanik yang terperangkap berdekatan antaramuka air-udara dan untuk membangunkan modul kawalan piezopentas 3-dimensi untuk perangkap optik dalam julat mikrometer. Kajian ini melibatkan pembangunan program pengawal yang dinamakan PZStage dan penentuan $r*$ berdekatan antaramuka air-udara. PZStage dibangunkan di atas platform LabVIEW untuk mengawal lokasi fokus laser di dalam medium perangkap. Manik 3 µm diperangkap dalam air pada beberapa ketinggian menghampiri ruang bebas dalam sel uji yang direka khas. Data sesaran temporal manik terperangkap tersebut direkod dengan fotodiod kuadran (QPD) dan dianalisis dengan program buatan tersuai iaitu OSCal untuk penentuan $r*$. PZStage yang telah dibangunkan dengan baik membolehkan lokasi fokus laser dilaras dalam julat 20 µm pada tiga arah berortogon. Keputusan menunjukkan $r*$ tidak berubah dengan tinggi fokus dalam keadaan ketebalan air dan kuasa laser dimalarkan. Tambahan pula, $r*$ bergantung kepada kuasa laser pada ketinggian fokus laser dan ketebalan air dimalarkan membentuk hubungan pereputan eksponen. Sebagai kesimpulan, PZStage berhasil dibangunkan dengan jayanya untuk mengawal fokus laser secara tepat berdekatan antaramuka air-udara dan $r*$ bergantung kepada kuasa laser berbanding tinggi fokus laser dalam keadaan experimen yang ditetapkan. Implikasi kajian ini adalah pemerangkapan optik berdekatan antaramuka air-udara boleh dilakukan pada kuasa laser yang rendah dengan ketebalan air yang sesuai. Namun begitu, pertimbangan hendaklah diambil kira kerana perangkap akan beralih jauh dari fokus laser apabila ketinggian fokus meningkat disebabkan oleh daya serakan.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

Figure No. **Page**

LIST OF SYMBOLS

$r*$	Effective radius [m]
k_B	Boltzman constant [J/K]
T	Temperature [K]
d	Diameter [m]
Λ	Wavelength [m]
γ	Decay constant [µm/mW]
T	Thickness [m]
β	Conversion factor [V/m]
P	Laser power [W]
F_0	Optical force [N]
k	Optical stiffness [N/m]
Δx	Displacement of trapped bead [m]
n	Refractive index
h_{piezo}	Height of Piezostage [m]
h_{focus}	Height of laser focus [m]
$< x >$	Standard average displacement [m]

05-4506832 pustaka.upsi.edu.my Perpustakaan Tuanku Bainun Kampus Sultan Abdul Jalil Shah PustakaTBainun ptbupsi

LIST OF ABBREVIATIONS

ASCII	American Standard Code for Information Interchange
CCD	Charged Couple Device
GUI	Graphical User Interface
NA	Numerical Aperture
PSD	Power Spectrum Density
PZStage	Piezostage Control Program
QPD	Quadrant-Photodiode
WD	Working distance

LIST OF APPENDICES

05-4506832 pustaka.upsi.edu.my Perpustakaan Tuanku Bainun Kampus Sultan Abdul Jalil Shah PustakaTBainun ptbupsi

CHAPTER 1

INTRODUCTION

1.1 Background of Research Study

Optical tweezers is one of the tools being used to manipulate micron sized objects or smaller using light. The optical tweezers fundamentally works by highly focus a laser beam via a high numerical aperture objective to produce a trap spot. Optical trapping field pioneered by Arthur Ashkin is awarded by Nobel Prize in Physics 2018 due to his invention on using optical tweezers to manipulate biology particle (The Nobel Prize, 2018). In the same manner, optical trapping term refers to the technique of using the optical trap force that can attract transparent microscopic particle to get stuck in it a trap center. The optical trap force is produced due to two different forces which are gradient and scattering forces. The gradient force is depended on light intensity profile while the scattering force is due to change of momentum of light (photon). The resultant of these two forces will result an optical force or trapped force. To sum up, optical tweezers create a certain level of intensity gradient by highly concentrating beam laser to a single point to physically hold and manipulate micron sized particle (Gutiérrez-Campos, 2010).

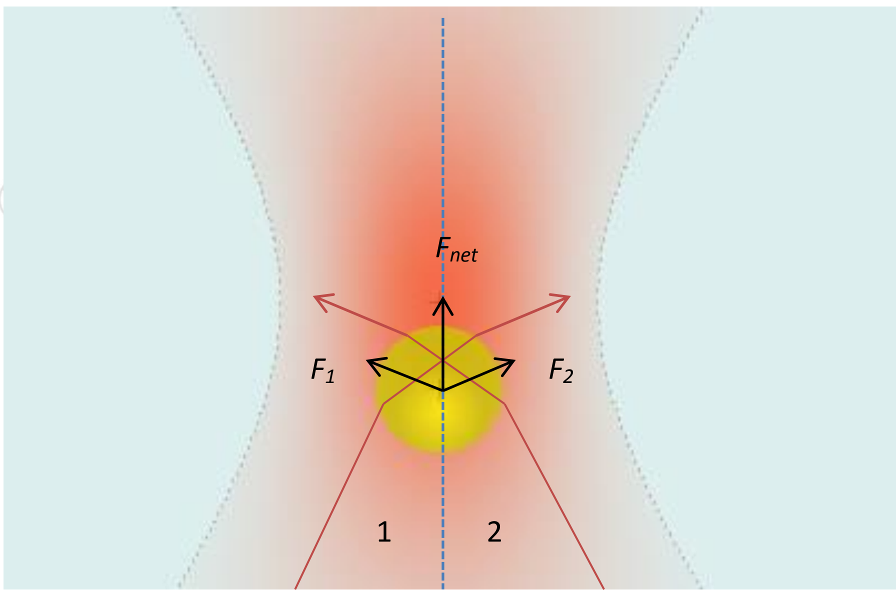

Figure 1.1. The working principle of optical trapping (Lynn, 2003).

The working principle of optical trapping is illustrated in Figure 1.1. In this study, the trapped particle size is bigger than laser wavelength. Thus, ray optics approach is used to explain the trapping mechanism. Ray 1 and ray 2 are refracted when they enter the dielectric sphere due to the difference in refractive indices of the two media. The refracted ray 1 and 2 resulted a net force on the particle that has a direction toward to the focus of the laser beam. This resulted net force causes the particle to get pushed trapped toward to the focus of rays and finally being trapped. That was the summarization on how optical trapping occurred and caused it to be significance in manipulating micron-sized particles (Ashkin, 1992).

The optical tweezers nowadays become very significance tool compared to traditional mechanical tweezers such as micropipette (Jiao & Zhang, 2013). This is because optical tweezers provide manipulation of a particle without being contacted physically. Therefore the damage minimization of delicate samples is made possible. Optical tweezers are widely used to study biological microscopic particle. Optical force is used in optical tweezers to control and dominate bacteria and small cells rather than using mechanical force. As biological sample is fragile and sensitive, non-contact tweezers can prevent flaw of sample and satisfy the requirement of application such as in biomedical field (Conteduca, Dell'Olio, Ciminelli, Krauss, & Armenise, 2016). There are many applications of optical tweezers. The mechanical learning of single biological molecules has been revolutionized with the advance of optical trapping techniques for the last 20 years. Optical trapping are worthwhile tools to study the properties of micro-molecules such as position, stiffness, elasticity and viscosity (Aziz, Ayop, & Riyanto, 2015; Deufel & Wang, 2006).

Most of the applications involve in manipulation of microscopic particles are in liquid. It would be interesting to study the ability of optical force at another level to open up a wide research opportunity; trapping particle at liquid-air interface.

1.2 Problem Statement

Optical tweezers have been widely used to trap and manipulate particle in a liquid. For example, most of biological microscopic particle need to be trapped in liquid. Measurement of viscoelasticity of numerous biopolymers like DNA, protein fibers, chromosomes, cell membrane and others in aqueous solution can be done with the help of optical tweezers as a probe (Gow, 2000). These types of samples need fluidic environment. However, not all the time, trapping is done in a liquid system. Some system needs the optical tweezers to trap particle at the interface between two media. For example, a particle needs to be brought at the interface then the extended potential benefit of optical trapping can take place. Laser trapping of calixarene thin film on water surface at the interface causes it to change in assembly form; is one of the possible applications of trapping at interface opening a new area of field of trapping chemistry. A crystallization of molecular system such as glycerin in supersaturated solution occurs when trapping is performed at liquid-air interface (Sugiyama, Adachi, & Masuhara, 2007). It is very challenging to trap particle at the interface of two media. The different of two or more media will cause the highly focused laser beam to change its refraction angle. This will result the loss of energy. The loss of energy will affect the ability of optical tweezers to hold and trap particle at the interface. The existing system needs modification in order to maintain trapping condition. Since trapping particle is very critical at the interface, high precision control of the laser spot is very significant to avoid mechanical vibration due to manual adjustment. Therefore, a mechanical control of piezostage which hold the objective lens of optical trapping is very important. The optical trap must be located precisely using piezostage at the interface. So the aim is to establish a micrometer range control of optical tweezers for trapping near water-air interface by using piezostage. Prior research qualitatively describes the behavior of trapped bead at interface (Dasgupta, Ahlawat, & Gupta, 2007). To date, no research has been reported to quantify the optical force for optical trapping at liquid-air interface. This proposed research also attempts to quantify the behavior by determining the optical stiffness near water-air interface in term of effective radius of particle displacement distribution at the trap spot.

1.3 Research Objective

There are two objectives as the core of this study:

- To develop 3D piezostage control module for optical trapping within micrometer range.
- To determine the effective radius near water-air interface.

1.4 Significance of Research

The aim of this study is to develop a 3D control optical tweezers for water-air interface applications. This would be useful for researcher that studies light and matter interaction of the particle at liquid-air interface. This study provides understanding related manipulation of particle at the interface region. Besides, this study also provides the precision improvement for the piezostage control compared to manual adjustment. The additional vibration that might influence the particle motion can be reduced and minimized. This is important because trapped particle hold by pico newton optical force might get away from trap spot due to external mechanical vibration.

This research is not limited to study the optical trap near interface of water-air but it is useful for study another type of liquid. Each liquid has different viscosity. The optical stiffness also depends on the liquid viscosity. For example, the researcher might substitute the liquid-air interface with other liquid like oil, alcohol, maybe solutions or others. Therefore, this research would contribute to the study of optical trap near and at liquid-air interface; specifically water-air interface for this research.

1.5 Limitation of Research

This research is limited to study the trapping of particle towards water-air interface. Therefore the trapping of micron sized dielectric particle was done near water-air interface region. In this study, 3 micrometer polystyrene bead size was used as probe.

The Optical Tweezers was established using Modular Optical Tweezers, OTKB (/M) series. Since every optical tweezers is unique and have different sensitivity, we would expect the different results if different of optical tweezers is used. The laser power used is relatively low within 1.7 mW until 16.1 mW. The optical stiffness was expected weak due to low laser power used. However, low power trapping is preferable to avoid heating effect on the trapped particle.

In addition, the oil–immersion objective lens with 1.25 numerical aperture was used throughout the study. The laser trap force was directly influenced by the type of objective lens used. The immersion objective lens are powerful than air-type objective lens in minimizing laser power loss due to different in media.

The working distance of the objective lens used was 0.23 mm which is very short. The range of axial distance was limited by this working distance. No optical trapping is possible beyond this limit.

1.6 Thesis Outline

This thesis mainly made up of 6 chapters. Chapter 1 highlights on the background of study and the direction goal of research. The main part of this chapter is problem statement and research objective.

Chapter 2 discusses the history of software platform and optical stiffness at water-air interface. Advantage and disadvantage of software is discussed. Also, the previous study of optical trapping at water-air interface is reviewed and compared. Optical stiffness is also included for discussion and its relation with effective radius.

Chapter 3 consists of three parts: development of control program, effective radius determination toward water-air interface and sample preparation procedure . Part 1 discusses on a control program development on LabVIEW platform. The second part discusses on how depth dependent optical trapping and determination of optical stiffness towards water – air interface is made. The third part discusses sample preparation procedure.

Chapter 4 discusses the developed control program, performance and modeling of piezostage voltage.

Chapter 5 discusses on results and discussion of effective radius near water air interface and also optical stiffness toward water – air interface.

Chapter 6 discusses the conclusion of the research finding on the results of research. A few recommendations are made to improve research and extend research for further study.

1.7 Summary

This chapter introduces background of the study, problem statement, research objectives, significant of study and scope and limitation of study.