VISION BASED PLATFORM FOR DRUG DELIVERY MICROROBOT

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DEDICATION

This project report is dedicated to my parents, who encouraged me to pursue my dreams and supported me during my journey. A special feeling of gratitude to my beloved family who stood by me throughout the process of achieving this Master degree. They all taught me that a dream doesn't come true unless by determination and hard work.

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ABSTRACT

In recent decades, permanent magnet end-effectors have been used in several fields and applications due to their unique ability to remotely control any magnetized object's positions via delivering the magnetic flux through space and non-magnetic materials. The reason of choice for magnetic end-effectors is because of their precision of control in comparison to other analog systems. This end-effector is able to move in three dimensions with a micro-precision of 0.05mm. In this thesis, this unique ability of magnetic material is further advanced to produce an optimized local maximum magnetic field. As part of this work, a Genetic Algorithm and Exhaustive search algorithm are implemented to get this optimized magnetic field. This method is suitable for medical domain applications such as magnetic microrobot drug delivery. A 3D actuator system had been designed to control the magnetic end-effector for this purpose. An open-loop system architecture is proposed to control the movement of the microrobot. The results of the microrobot drug delivery experiment proved to be promising. The results show that the end-effector is able to navigate the microrobot in 2-dimension space, having an error of less than 0.1mm. A tracking system based on the Lucas-Kanade Optical Flow algorithm is implemented using the open-CV library. The optimized magnetic field was validated in an experiment using a 3D Tesla meter.

ABSTRAK

Dalam beberapa dekad kebelakangan ini, efektor magnet kekal telah digunakan dalam beberapa bidang dan aplikasi kerana kemampuannya yang unik untuk mengawal kedudukan objek magnetis dari jarak jauh dengan menyampaikan fluks magnet melalui ruang dan bahan bukan magnet. Sebab pilihan untuk pengesan akhir magnetik adalah kerana ketepatan kawalannya berbanding sistem analog yang lain. Pengaruh akhir ini mampu bergerak dalam tiga dimensi dengan ketepatan mikro 0.05mm. Dalam tesis ini, kemampuan unik bahan magnetik ini terus maju untuk menghasilkan medan magnet maksimum tempatan yang dioptimumkan. Sebagai sebahagian daripada karya ini, algoritma Genetik Algoritma dan Ekzos carian dilaksanakan untuk mendapatkan medan magnet yang dioptimumkan ini. Kaedah ini sesuai untuk aplikasi domain perubatan seperti penyampaian ubat mikrotobot magnetik. Sistem penggerak 3D telah dirancang untuk mengawal efektor magnetik untuk tujuan ini. Senibina sistem gelung terbuka dicadangkan untuk mengawal pergerakan mikrorobot. Hasil percubaan penyampaian ubat microrobot terbukti menjanjikan. Hasilnya menunjukkan bahawa end-effector dapat menavigasi mikrorobot dalam ruang 2 dimensi, mengalami kesalahan kurang dari 0.1mm. Sistem penjejakan berdasarkan algoritma Lucas-Kanade Optical Flow dilaksanakan menggunakan perpustakaan open-CV. Medan magnet yang dioptimumkan disahkan dalam eksperimen menggunakan meter Tesla 3D.

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LIST OF ABBREVIATIONS

UTM	-	Universiti Teknologi Malaysia
DOF	-	Degree Of Freedom
GN	-	Genetic algorithm
ES	-	Exhaustive Search
PS	-	Particle Swarm
PSO	-	Particle Swarm Optimization
EPM	-	External Permanent Magnet
RGB	-	Red, Blue, and Green
2D	-	Two Dimensional
3D	-	Three Dimensional
OF	-	Optical flow
OpenCV	-	Open Source Computer Vision Library
HSV	-	Hue Saturation Value

LIST OF SYMBOLS

θ	-	Theta
σ	-	Sigma
∇	-	Nabla
δ	-	Delta
ϕ	-	Phi
α	-	Alpha
τ	-	Tau
μ	-	Mu
λ	-	Lambda
ω	-	Omega
∂	-	Partial

CHAPTER 1

INTRODUCTION

1.1 Background

In recent decades, permanent magnet end-effectors have been used in several fields and applications due to their unique ability to control the positions of any magnetic materials in the distance via delivering the magnetic flux through space and non-magnetic materials. It contributes significantly to potential applications in the medical field like Positioning of Drug Carriers [1], magnetically actuated capsule endoscopes [2] and dual-arm magnetically actuated soft robots [8] and in industry field like vibration suppression in polishing robots [3]. These applications are described in the following paragraphs.

1.1.1 Magnetic end-effector applications

Three degrees of freedom (DOFs) Permanent magnet-based system with an accuracy of ±0.1 mm and an open-configuration was used to control and position paramagnetic microparticles drug carriers to be used in vivo applications (in vivo alludes to when research or work is done with or inside a complete, living organism) as shown in figure 1.1. The microparticles' control was in three-dimensional (3D) space employing a cylindrical permanent magnet (NdFeB) of 20 mm diameter and 4.3 mm height and it generates on its surface about 400 mT. The magnet was settled to the robotic arm end-effector. A kinematic map was developed between the microparticles position and the robotic arm configuration. This map is used in the closed-loop control system of the microparticles movement. The microparticles were with a diameter of less than 100μm. The experimental results appear the capacity of the robot configuration to control the applied field gradient on the dipole of the microparticles and accomplish situating in 3D space with maximum errors within the steady-state in set-point of 300μm and in trajectory tracking of 600μm [1].

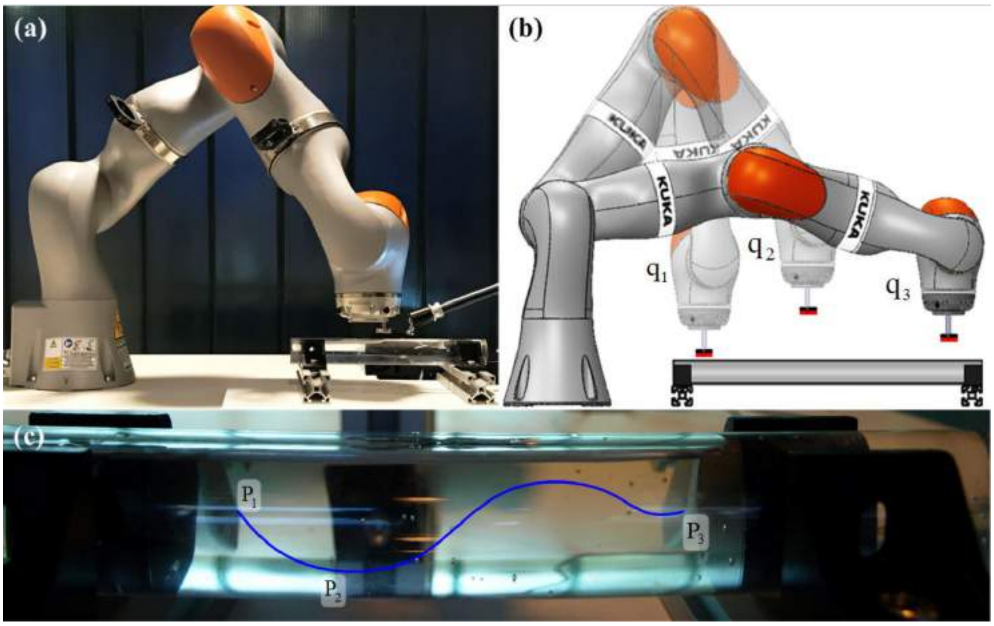

Figure 1.1 Robotic arm with permanent magnet end-effector that control and position particles in 3D to follow a path from P1 to P3 [1].

A magnetic end-effector had been used on the magnetically robotic manipulation system to estimate the pose of the actuated capsule endoscope in real-time. figure 1.2 showed the schema of the five DOFs magnetically robotic manipulation hybrid system. In this work, a hybrid system of static and time-varying magnetic field sources had been developed. The goal of this system was to develop a clinically and robust magnetic pose estimate approach for robotically guided magnetic capsule endoscopy. The magnetic end-effector was developed with an electromagnetic coil and perpendicular external permanent magnet (EPM). The produced magnetic field was used to obtain equations that help to estimate the capsule position and angle[2].

The eight DOFs dual-arm robot used two EPMs end-effectors to prove that it could be used for minimally invasive treatment and diagnosis procedures. An example of the dual-robot magnetic system is shown in figure 1.3 that it could magnetically actuate the lung endoscopes. The experiment proved that the minimum magnetic field sources (2 EMPs) could be capable of controlling a single magnetized object in the space with the

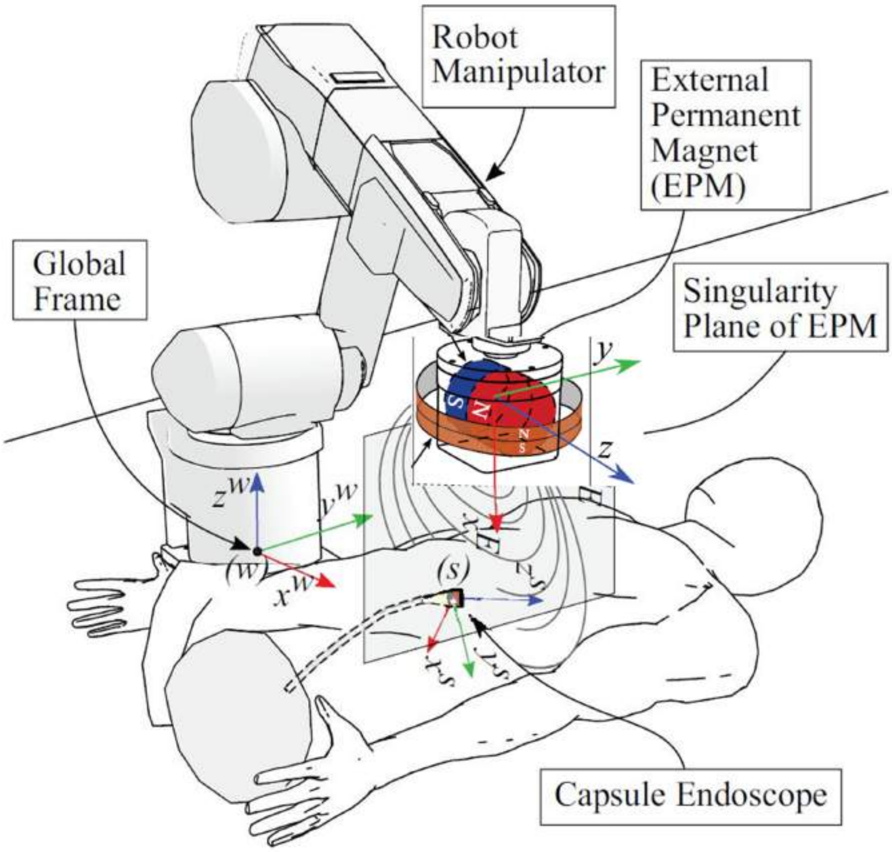

Figure 1.2 Schema of the magnetically robotic manipulation hybrid system [2].

highest number of DOFs (8 DOFs). The controlled magnetized object (Cubic interior permanent magnet (IPM) with 2.1 Am^2 (N42) axial magnetization and 12.6 mm length) was attached to a 6-axis load cell to measure all the affected forces that could translate or rotate the IPM. The actuating EPMs have a Cylindrical shape permanent magnet with 101.6mm length and diameter and 970.1 Am^2 (N52) axial magnetization. The theoretical and the experimental results proved that the permanent magnetic actuated system was effective and achieved the same coil actuator system capabilities [8].

When polishing thin-walled blisks, vibrations can readily occur, affecting the surface quality. An innovative smart magnetic end-effector for active contact force control and vibration suppression in robotic polishing of thin-walled blisks was introduced to overcome this challenge. To keep the contact force between the polishing tool and the workpiece at an expected level, a gravity-compensated force controller was designed. The smart end-effector was designed of a single polishing tool, force sensor that can measure the forces in the three-axis, tilt sensor (measure the three-axis), one

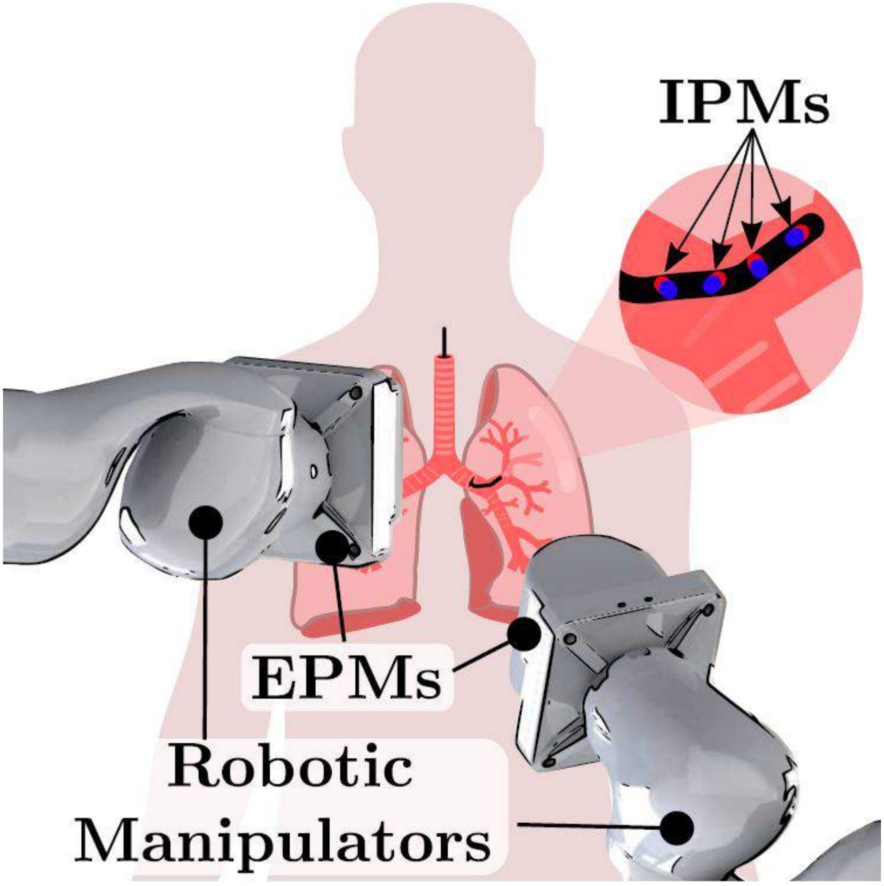

Figure 1.3   Example of how dual-arm robot multi-DOFs attractive control can be used in endoscopy [3]

DOF positioning table and two magnetic eddy current dampers (ECDs) as shown in figure 1.4. The ECD's mover consists of a middle plate of steel and 12 permanent magnets (six up the plate and six down with the opposite magnetization directions). The ECD aimed to suspend the vibration forces and keep the polishing tool stable by using the closed-loop control method.

1.1.2 Magnetic Actuation Principle

Magnetic actuation involves applying force and/or torque to magnetic objects that are embedded with magnets or formed of magnetizable materials using magnetic fields that are applied remotely as shown in figure 1.5. Because there is no current in the manipulation region, Maxwell's equation can be used to explain the quasistatic magnetic field as followed [9]:

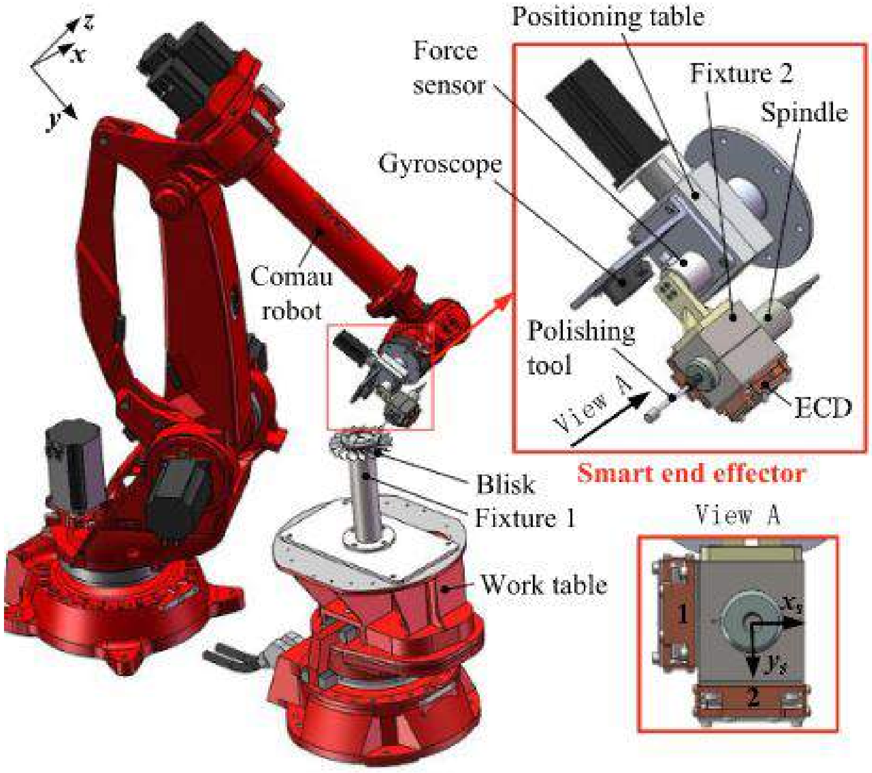

Figure 1.4 Polishing robotic arm with a smart magnetic suspension end-effector .[4]

$$\nabla \cdot \mathbf{B} = 0$$
$$\nabla \times \mathbf{B} = 0 \tag{1.1}$$

Maxwell's equation of quasistatic magnetic field

Where B is the magnetic field from external source and ∇ is the gradient operation. According to the equation equation (1.1), B's gradient matrix is symmetric and trace-free. A magnetic torque τ applies on a magnetic object m when the magnetization of the object and the direction of the magnetic field are misaligned, as shown below in the next equation:

$$\boldsymbol{\tau} = \mathbf{m} \times \mathbf{B} = \begin{bmatrix} 0 & B_z & -B_Y \\ -B_z & 0 & B_x \\ B_Y & -B_x & 0 \end{bmatrix} \begin{bmatrix} m_x \\ m_Y \\ m_z \end{bmatrix} \tag{1.2}$$

In addition, if the magnetic field is nonuniform and the magnetic object is this nonuniform field, a magnetic field f will be appeared as in the following equation:

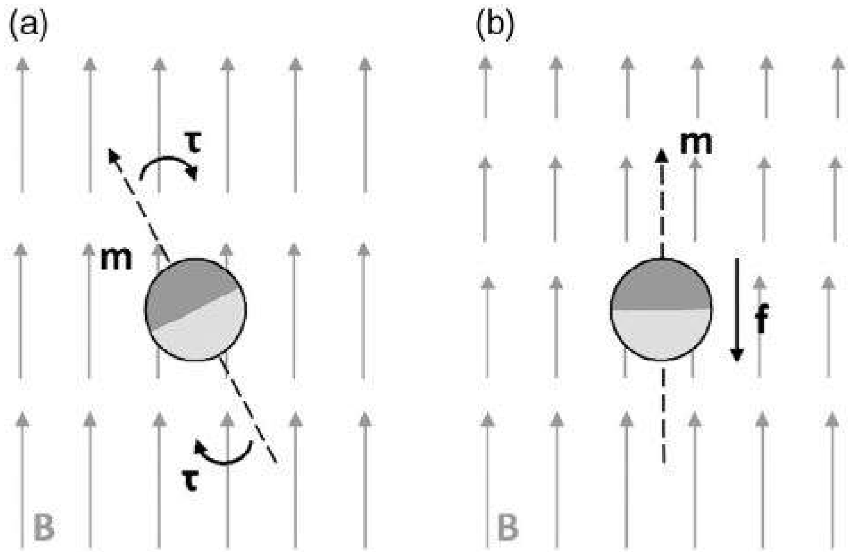

Figure 1.5 magnetic interaction diagram of: a) the pure torque shape in magnetic field (uniform); b) the pure force shape in magnetic field (nonuniform).[5]

$$\mathbf{f} = (\mathbf{m} \cdot \nabla)\mathbf{B} = \begin{bmatrix} \frac{\partial B_x}{\partial x} & \frac{\partial B_x}{\partial y} & \frac{\partial B_x}{\partial z} \\ \frac{\partial B_x}{\partial y} & \frac{\partial B_y}{\partial y} & \frac{\partial B_y}{\partial z} \\ \frac{\partial B_x}{\partial z} & \frac{\partial B_y}{\partial z} & -\left(\frac{\partial B_x}{\partial x} + \frac{\partial B_y}{\partial Y}\right) \end{bmatrix} \begin{bmatrix} m_x \\ m_y \\ m_z \end{bmatrix} \tag{1.3}$$

These two effects (magnetic torque and force) can actuate either individually or concurrently, allowing for up to 6-DOF motion control, as will be illustrated in the following chapters.

1.2 Problem statement

Forcing the magnetic microrobot to go to a desired point in the space needs to be in a magnetic field that has:

1. A local maximum value in this desired point.
2. A sharp shape around the desired point.

Producing this magnetic field requires to optimize the locations of a number of permanent magnets. Continues reallocation of the optimized magnets-set force the microrobot to move in any the desired path using open-loop control method.

1.3 Objectives

This study aims to design a magnetic end-effector that can move a magnetic microrobot remotely to follow any path. Mainly five objectives were required and achieved in this project which are:

1. Calculation of the magnetic field equation and the force equation of a magnets-set of four magnets.
2. Optimize the magnet's locations to produce a high force that can move the microrobot.
3. Design and control an actuator that can move its magnetic end-effector in the 3D space to follow any path with constant velocity.
4. Design a vision tracking system to track the movement of the microrobot and the end effector
5. Validations by simulation and experiment results.

1.4 Report Organization

The rest of the report is organized as follows; Chapter 2 illustrates the previous methods of optimization algorithms, magnetic microrobot drug delivery and vision tracking algorithms. Chapter 3 discusses all the steps of building a magnetic microrobot drug delivery system from calculating the magnetic field, optimizing the magnet's locations, designing the 3D actuators and controlling it to detect the microrobot. Chapter 4 presents the validation of the work by proposing the simulation and the experiment results of the magnetic field map and the microrobot drug delivery with the comparison of the previous results. Chapter 5 proposes the conclusion of the whole work and the possible future work.

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