Development of a Multi-rotor Aerial Vehicle with Top Mounted Counter Balanced Robotic Manipulator

Nipuna Dinendra Wijayathunga

188057R

Degree of Master of Science

Department of Mechanical Engineering

University of Moratuwa

Sri Lanka

October 2020

Development of a Multi-rotor Aerial Vehicle with Top Mounted Counter Balanced Robotic Manipulator

Nipuna Dinendra Wijayathunga

188057R

Thesis submitted in partial fulfillment of the requirements for the degree Master of Science in Mechanical Engineering

Department of Mechanical Engineering

University of Moratuwa

Sri Lanka

October 2020

DECLARATION

I declare that this is my own work and this dissertation does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgment is made in the text. Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my dissertation, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles or books).

Signature: . UOM Verified Signature .... Date: 29/10/2020

The above candidate has carried out research for the MSc thesis under my supervision.

Name of the supervisor: Dr. S.W.H.M.T.D. Lalitharatne (Senior Lecturer)
Department of Mechanical Engineering

Signature of the supervisor: UOM Verified Signature Date: 29/10/2020

Name of the supervisor: Dr. K.V.D.S. Chathuranga (Senior Lecturer)
Department of Mechanical Engineering

Signature of the supervisor: .... Date: ....

Name of the supervisor: Dr. A.G.B.P. Jayasekara (Senior Lecturer)
Department of Electrical Engineering

Signature of the supervisor: .... Date: ....

ABSTRACT

Aerial manipulation has been a growing research area within the past few years. This research area was associated with various application ideas and industries. Researchers implemented different aerial vehicle designs and manipulation techniques to accomplish these tasks in complex environmental conditions. Majority of conducted aerial manipulation research was composed of aerial vehicle bottom-mounted manipulators. These kind of aerial manipulation systems were not generally capable of achieving manipulator movements in an environment above the propeller disc plane. A few research projects were carried out by researchers to identify the performance of aerial vehicle top-mounted manipulators. Therefore, the manipulator mechanical designing step plays a challenging role in keeping the dynamic stability within the proper tolerances for manipulation systems. Center of Mass (COM) position and inertia of an aerial manipulation system become variables with respect to an inertial coordinate frame when a manipulator is attached to a multirotor. The manipulator, environmental reaction forces and torques are transferred on to the aerial vehicle as the system interacts with the external environment. Researchers had conducted a limited number of aerial manipulator system related projects with top-mounted manipulators which were capable of inspecting both vertical and overhead structures. The set of aerial manipulator systems capable of inspecting overhead structures are a small subset of the universal set of multirotor mounted manipulator projects. The literature suggests COM of an aerial manipulator system need to be placed in the propeller disc plane and closer to the central axis of a multirotor to achieve a better dynamic performance of that system. If a designer attaches manipulator on the top or bottom surface of a multirotor, the COM position moves vertically up or down from the propeller disc plane respectively. Generally, aerial vehicle top-mounted manipulators have generated more dynamic instabilities compared to manipulators mounted on the underside of multirotors.

This thesis introduces a 2 Degrees of Freedom (DOF) serial link planar manipulator which has been mounted on top of a hexacopter by the rigid manipulator base. The research focused on inspection purposes of tall structures that human reach may be costly or vulnerable to physical injuries. The developed system included a novel serial link manipulator design and a force sensor as the end effector of the manipulator. This end-effector sensor would be able to identify the contact with surfaces of high-rise buildings or structures. The manipulator consisted of a separate controller apart from the flight controller. When this manipulator achieved different poses in its planar workspace, COM position of the system varied as a result. Therefore, a novel controller strategy was developed by the author in the research to compensate for the system attitude variations. Variation of the COM position caused attitude fluctuations. The thesis proposes a specifically designed manipulator mechanical design configuration to reduce the inherent COM position variation. Another concept was introduced by the author to counterbalance the COM position variation by synchronizing the motions of the system battery. A variable gain Proportional (P) controller, followed by a Proportional Integral Derivative (PID) controller was presented in the research to maintain the aerial manipulator system attitude. This research introduces novel concepts of designing, disturbance compensation and controlling of the aerial vehicle top-mounted manipulation systems. Theoretical simulations showed the COM, inertia, joint torque, disturbance torque variations of the manipulator. Experiments were carried out by the author considering the manipulator separately and the overall system in-flight to identify the performance of the developed system.

Keywords – *Aerial manipulation, Serial manipulator, Nondestructive inspection, Dynamics modelling, PID control*

ACKNOWLEDGEMENT

I would like to offer my heartiest gratitude to my main supervisor Dr. S.W.H.M.T.D. Lalitharatne, Senior Lecturer, The Department of Mechanical Engineering, University of Moratuwa for accepting my request on M.Sc. research by trusting me and for the efforts put forward in securing a fully funded research opportunity offered by SRC. Further, I appreciate the guidance given by him throughout this research, making it a success. I also would like to thank my co-supervisors Dr. K.V.D.S. Chathuranga, Senior Lecturer, Department of Mechanical Engineering, University of Moratuwa and Dr. A.G.B.P. Jayasekara, Senior Lecturer, Department of Electrical Engineering, University of Moratuwa for their valuable guidance, extended for the success of the research.

Further, I would like to express my gratitude to my family on behalf of their support for my education. I convey my sincere thanks to friends Pasan Henadeera, Chamara Somaratne, Nuwan Rupasinghe, Rumesh Rangana, robotics and control systems laboratory staff Mr. Sandanayake, Mr. Upul and others who are not mentioned in this section but helped me for the success of this research.

Thank you.

L.M.N.D. Wijayathugna
October 2020

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBRIVIATIONS

ABS	Acrylonitrile Butadiene Styrene
COM	Center of Mass
D-H	Denavit-Hartenberg
DOF	Degrees of Freedom
DP	Dynamic Programming
ESC	Electronic Speed Controller
GCS	Ground Control Station
GPS	Global Positioning System
IMU	Inertial Measurement Unit
IR	Infrared
Li-Po	Lithium Polymer
MAV	Micro Aerial Vehicle
MDP	Markov Decision Process
MOSFET	Metal Oxide Semiconductor Field-effect Transistor
Ni-Cd	Nickel Cadmium
Ni-MH	Nickel Metal Hydride
P	Proportional
PD	Proportional Derivative
PID	Proportional Integral Derivative
RAM	Rotorcraft Aerial Manipulator
RC	Radio Control
RF	Radio Frequency
ROS	Robot Operating System
RR	Revolute-Revolute
RRR	Revolute-Revolute-Revolute
RUAV	Rotorcraft Unmanned Aerial Vehicle
UAV	Unmanned Aerial Vehicle
VTOL	Vertical Takeoff and Land