UNIVERSITÀ DEGLI STUDI DI NAPOLI FEDERICO II

DOTTORATO DI RICERCA / PHD PROGRAM IN
INFORMATION TECHNOLOGY AND ELECTRICAL ENGINEERING

Activities and Publications Report

PhD Student: HAMEED ULLAH

Student DR number: 157880

PhD Cycle: XXXVII
PhD Cycle Chairman: Prof. Stefano Russo

PhD program student's start date: 01/11/2021
PhD program student's end date: 31/10/2024

Supervisor: Fabio Ruggiero

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Co-supervisor:

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PhD scholarship funding entity: AERO-TRAIN, EU Project (Marie-Sklodowska Curie)

General information

Hameed Ullah received in year 2019 the Master Science degree in Electrical Engineering from the National University of Sciences and Technology, Islamabad, Pakistan. He attended a curriculum in control of aerial manipulators within the PhD program in Information Technology and Electrical Engineering. He received a grant from AEROTRAIN Project under Marie Curie Scholarship Funded by EU.

Study activities

Attended Courses

Year	Course Title	Type	Credits	Lecturer	Organization
1st	Field and Service Robotics	Course	**6.0**	**Prof. Fabio Ruggiero**	ITEE
1st	Robotics Lab	Course	**6.0**	**Dr. Jonathan Cacace**	ITEE
1st	Robot Interaction Control	Course	**6.0**	**Prof. Bruno Siciliano**	ITEE

Attended PhD Schools

Year	School title	Location	Credits	Dates	Organization
1st	Training School on Unmanned Aerial Systems for Inspection and Maintenance	Seville, Spain	2.0	7th -11th March, 2022	University of Seville, Spain
1st	Training School on Autonomous systems working in uncertain environments	DTU Denmark	2.0	13th -17th June, 2022	DTU, Denmark
1st	Summer School on "Multi-Robot Systems"	Prague, Czech Republic	2.0	1st -5th Aug, 2022	Czech Technical University, Prague, Czech Republic
2nd	3rd Training School (TS3) of AERO-TRAIN project | "Training School on Field experimentation"	Lulea, Sweeden	2.0	5th – 9th December, 2022	Lulea University of Technology Sweeden
2nd	1st Integration Week (IW-1) of AERO-TRAIN project	Tampere, Finland	2.0	20th – 24th March, 2023	Tampere University Finland
2nd	2nd Integration Week (IW-2) of AERO-TRAIN project	Barcelona Spain	2.0	3rd – 7th July 2023	Eurecat, Centre Tecnològic de Catalunya, Barcelona Spain
3rd	3nd Integration Week (IW-3) of AERO-TRAIN project	Seville, Spain	2.0	20th –24th November 2024	CATEC (Advanced Center for Aerospace Technologies), in Spain (Seville
3rd	AERO-TRAIN Grand Challenge	Roskildi, Denmark	2.0	6th –10th May 2024	Technical University of Denmark

Attended Seminars

Year	Seminar Title	Credits	Lecturer	Lecturer affiliation	Organization
1st	AERO-TRAIN PhD Data Management Plan webinar - part 1	0.2	Jitlka Stilund Hansen,	Technical University of Denmark	AERO-TRAIN
1st	AERO-TRAIN PhD Data Management Plan webinar - part 2	0.2	Jitlka Stilund Hansen,	Technical University of Denmark	AERO-TRAIN
1st	Using delays for control	0.4	Prof. Emilia Fridman	Tel Aviv University - Israel	ITEE
1	Introduction to Deep Learning for Natural Language Processing & Explainable Natural Language Inference	0.5	Dr. Marco Valentino	University of Manchester, United Kingdom.	ITEE
1st	AERO-TRAIN 1st Exploitation Workshop: Intellectual Property Management	0.4	Julian Cayero Becerra	Eurecat	AERO-TRAIN
1	Potential and challenges of next generation railway signaling systems: Moving Block and Virtual Coupling	0.2	Eng. Joelle Aoun	TU Delf, Netherlands	ITEE
1st	Service and companion robots in healthcare	0.3	Pasquale Arpaia	University of Naples Federico II, Italy	ITEE
1	IEEE Authorship and Open Access Symposium: Tips and Best Practices to Get Published from IEEE Editors	0.3	IEEE	IEEE	IEEE
1st	Springer Nature Author Workshop: Open Access and Transformative Agreements in Italy	0.2	Spring Nature	Spring Nature	Spring Nature
1	On using simple optimization techniques for tuning of UAVs	0.4	Prof. Dariusz Horla	Poznan University of Technology - Poland	ITEE
1st	5G Networks in Action - The PrivateMobileEra	0.3	Ing. Marco Centenaro Ing. Nicola Di Pietro. Ing. Daniele Munaretto	University of Naples Federico II, Italy	University of Naples Federico II, Italy
1st	5G FWA project, Engineering and Implementation Process Phases and Actors	1.0	A. Delugan, L. Mazza and M. Fazzari	University of Naples Federico II, Italy	University of Naples Federico II, Italy

1st	Vine Robot: Design Challenges and unique opportunities	0.2	Mario Selvaggio	University of Naples Federico II, Italy	ITEE
1st	Shared Autonomy in Physical Human-Robot Interaction: Adaptability and Trust	1.6	Mario Selvaggio	University of Naples Federico II, Italy	ICRA 2022
2nd	Is control a solved problem for aerial robotics research?	0.2	Prof. Antonio Franchi	University of Twente	ITEE
2nd	AI, Robots and Society: Challenges and Opportunities for Social Innovation	0.2	DR. AMIT KUMAR PANDEY	Chief Robotics and AI Officer Rovial Space, France	ITEE
2nd	Migration of legacy IT infrastructures into the cloud: approaches and strategies	0.4	Ing. Claudio Perrotta	CTO Epsilon S.r.l.	ITEE
2nd	Inspection-based robotics for society	0.5	Dr. Antidio Viguria Jiménez	CATEC, Spain	ITEE
2nd	Optimization of a mobile clinic routing and scheduling problem in equitable vaccination outreach	0.2	Prof. Mingyao Qi	Tsinghua University	ITEE
2nd	Traffic Engineering with Segment Routing: optimally dealing with most popular use-cases	0.2	Prof. Valerio Persico	University of Naples Federico II, Italy	University of Naples Federico II, Italy
2nd	Quantum communications with continuous variables of light	0.2	Procolo Lucignano, Domenico Montemurro, Davide Massarotti, Vincenzo D'Ambrosio, and Martina Esposito.	University of Naples Federico II, Italy	University of Naples Federico II, Italy
2nd	Exploring Advanced Aerial Robotics: A Journey into Cutting-Edge Projects and Neural Control	0.2	Engr. Eugenio Cuniato	ETH Zürich	ITEE
2nd	BGP & Hot-Potato Routing: graceful and optimal convergence in case of IGP events	0.2	Prof. Pascal Merindol	University of Strasbourg - France	ITEE
2nd	IEEE Authorship and Open Access Symposium: Tips	0.3	IEEE	IEEE	IEEE

	and Best Practices to Get Published from IEEE Editors				
3rd	Energy-Efficient Data Science	0.2	Dr. Carlos Ordonez	University of Housto	ITEE
3rd	Multi-agent autonomous flight at Leonardo Labs	0.2	DR. FABRIZIO SCHIANO	Leonardo Labs	ITEE
3rd	Analytic center selection of optimization-based controllers for robot ecology	0.2	Prof. Gennaro Notomista	University of Waterloo	ITEE
3rd	Aerial Workers for infrastructure and asset maintenance: The journey from "Lab" to "Real-World", Full Day Workshop at ICUAS	1.4	AEROTRAIN	AEROTRAIN	ICUAS 2024

Research activities

Hameed Ullah participated in the research activities focused on the stabilization and control of an aerial manipulator particularly for aerial physical interaction (AphI) with the environment. He designed various control techniques, with a special emphasis on contact operations. He introduced a novel hybrid force/position control system tailored for aerial manipulators, aimed at enabling efficient and sustained delivery of horizontal forces. This system demonstrated effectiveness in generating large and controlled forces over extended periods, surpassing comparable hybrid controllers. These contributions hold promise for various applications, including search and rescue operations, infrastructure maintenance, and environmental monitoring, thereby advancing aerial manipulation technologies. In addition, he contributed to research on the pushing and rotation of heavy rigid bodies using an omnidirectional, actively tilted aerial manipulator controlled via a hybrid force/position controller. The proposed system enables precise horizontal force application, making it ideal for aerial physical interaction tasks. It also has the capability to follow complex trajectories with high accuracy and sustain forces for object manipulation.

Moreover, he contributed to the design of a nonlinear model predictive controller for an actively tilted omnidirectional aerial manipulator to perform push and slide operations. He also worked on the design of omni-wheels for two-dimensional push-and-slide tasks, improving the stability and effectiveness of aerial manipulators interacting with rigid environments. Additionally, he contributed to the design and implementation of a hyperbolic controller for a fully actuated, omnidirectional tilting octarotor equipped with an omni-wheel and an external wrench estimator.

During his research period at the Technical University of Denmark, he studied, developed, and implemented Arduino programming, controller design, and practical hardware applications.

Tutoring and supplementary teaching activities

No tutoring and supplementary teaching activities

Credits summary

PhD Year	Courses	Seminars	Research	Tutoring / Supplementary Teaching
1st	24	6.2	41.8	0
2nd	6	2.6	51.4	0
3rd	4	2.0	46.8	0
Total	34	10.8	140	0

Research periods in institutions abroad and/or in companies

PhD Year	Institution / Company	Hosting tutor	Period	Activities
3rd	Technical University of Denmark	Matteo Fumagalli	6 Months	Research on the development and implemented Arduino programming. Controller design in Arduino programming and connection of Arduino with ROS. Experience on Practical hardware applications.
3rd	Neabotics	Prof. Vincenzo Lippiello	2 Months	Practical experimentation on Aerial robotics.

PhD Thesis

In the PhD Thesis, Hameed Ullah worked on the stabilization and control of an aerial manipulator particularly for aerial physical interaction (AphI) with the environment to perform various tasks. Unmanned Aerial Vehicles (UAVs) have become integral across various applications, benefiting from their versatility, manoeuvrability, and cost-effectiveness. Their utility spans from cinematography to critical infrastructure inspections and environmental monitoring, expanding to include tasks once deemed inaccessible or hazardous for humans. However, a significant limitation arises when these UAVs need to actively interact with their surroundings. To address these constraints, UAVs have transitioned from passive tasks to active ones that involve manipulation and physical interactions with the environment. These active tasks encompass a wide range of activities, including push and slide operations, grasping, picking and placing objects, positioning, cleaning tall buildings, and working in hazardous environments. This transition necessitates equipping drones with manipulative capabilities, often in the form of robotic arms or attached tools. This integration, known as aerial manipulation, enables UAVs to perform a wide array of tasks, from infrastructure maintenance to disaster response. However, stabilizing aerial

manipulators while performing physical tasks poses significant control challenges, especially in delivering controlled forces to the environment.

This PhD thesis mainly explores the development of innovative control strategies for aerial manipulators, focusing on their interaction with external environments to perform complex tasks such as push-and-slide operations, sustained horizontal force delivery, and manipulation of heavy rigid bodies. This thesis investigates an omnidirectional, actively tilting multirotor platform designed to facilitate robust and precise physical interactions in aerial settings, addressing the unique challenges associated with aerial manipulation.

The first contribution was designing a hybrid force/position control strategy tailored to an omnidirectional aerial manipulator for sustained horizontal force application. The system is validated through physics-engine simulations, achieving force delivery of up to 8 N over extended periods. The control framework surpasses existing models by effectively regulating large forces, maintaining system stability, and facilitating interactions essential for tasks like structural reinforcement, debris clearing, and environmental monitoring.

The second contribution focuses on the rotation and manipulation of heavy objects using the aerial manipulator. The hybrid control approach enables the precise exertion of forces required for rotating a heavy 20 kg rigid body. The research underscores the system's ability to maintain stability and accurately follow complex trajectories during manipulation tasks. Experiments conducted in Gazebo verify the efficacy of the system in handling heavy objects, showcasing its potential for high-impact applications in hazardous or otherwise inaccessible environments.

The third contribution of this thesis is the design of a novel 2-dimensional Omni-wheel. An interaction control framework was developed for an aerial manipulator with omni-wheel that uses an omnidirectional actively tilting rotor system to execute two-dimensional push-and-slide tasks. By employing a momentum-based external wrench estimator, the manipulator achieves stable force application without relying on traditional force/torque sensors. Extensive simulations highlight the platform's effectiveness in achieving precise trajectory tracking and stable physical interaction, demonstrating its applicability in scenarios requiring dexterous manipulation, such as infrastructure inspection and maintenance.

Overall, this PhD thesis contributes to the advancement of aerial manipulation by integrating robust and hybrid control techniques with an actively tilting multirotor platform. The proposed frameworks demonstrate improved accuracy, stability, and versatility, laying the groundwork for real-world applications across industrial maintenance, search and rescue, and other operations requiring precise aerial physical interaction. Future work will explore real-world implementations and adaptive control strategies to enhance system robustness in dynamic and unpredictable environments.

Research products

Research results appear in 1 paper published in international Conference and 1 paper submitted in international Conference, 1 Journal paper write up is completed and will submit soon. 2 Journal papers in contributions are under writing phase and will submit soon. Furthermore, in collaborations with others, 3 journal papers are published in international journals and 2 conference papers are publish in international conferences.

List of scientific publications

International conference papers

Ullah, H., D'Angelo, S., Ruggiero, F., Lippiello, V., & Soto, S. M. O. (2024, May). "Horizontal Sustained Force Delivery with an Aerial Manipulator using Hybrid Force/Position Control". 25th International Carpathian Control Conference (ICCC) (pp. 1-5). Poland, 22-24 May 2024, IEEE.

DOI: 10.1109/ICCC62069.2024.10569948.

Ullah, H., Soto, S. M. O., Mazhar, N., Ahmad, I., Lippiello, V., & Ruggiero, F.

Pushing and Rotating a Heavy Mass Rigid Body Using an Omnidirectional Aerial Manipulator

6th International Conference on Robotics and Automation in Industry, ICRAI 2024, IEEE. (Paper Submitted, Under review).

Publications In Progress (Work completed, not submitted yet)

International journal papers (Complete write up, to be submitted soon)

Ullah, H., Julien Mellet, Ruggiero, F., Lippiello, V., & Soto, S. M. O.

"Interaction Control for an Aerial Manipulator Performing Two-dimensional Push-and-Slide Tasks", *Drones*, MDPI.

International journal papers (Experimental work completed, in write up phase, to be submitted soon).

Hameed Ullah., Manuel J. Fernandez, Riccardo Franceschini, Antonia H¨ufner, Fernando Ruiz, Julian Cayero, Lionel Ott, Fabio Ruggiero, Anibal Ollero, Matteo Fumagalli

"Assisted Aerial Inspection",

IEEE TRANSACTIONS ON FIELD ROBOTICS

International journal papers (Experimental work completed, in write up phase, to be submitted soon)

Simone D'Angelo∗, **Hameed Ullah,** Fabio Ruggiero, Bruno Siciliano.

"Nonlinear Model Predicative Controller for aerial manipulator using to perform push and slide operations with constraints".

(Journal is to be decided yet)

Publications In collaboration:

International journal papers

Mazhar, N., Khan, R., Raza, A., Malik, F. M., Azim, R. A., & **Ullah, H.** (2024). "Robust Decentralized Formation Tracking Control of Complex Multiagent Systems". *Complexity*, 2024(1), 5088698.
DOI. https://doi.org/10.1155/2024/5088698

Shah, S. A. A., Gao, B., Ahmad, I., **Ullah, H.,** Ahmed, N., & Saeed, A. (2023). "Adaptive backstepping integral sliding mode control for 5DOF barge-type OFWT under output constraint".
Journal of Marine Science and Engineering, 11(3), 492. (2023).
DOI: *https://doi.org/10.3390/jmse11030492*

Khan, R., Azim, R. A., Malik, F. M., Mazhar, N., Raza, A., & **Ullah, H.** "Fixed settling time control for self-driving car: two-timescales approach". (2022). *IEEE Access*, *10*, 36518-36537.
DOI: 10.1109/ACCESS.2022.3163299

International conference papers

Khan, A., **Ullah, H.,** Faisal, U., Mazhar, N., & Khan, M. Y. (2023, March). "Visual-Inertial State-Estimation Using Ground Station for UAV". In *2023 4th International Conference on Computing, Mathematics and Engineering Technologies (iCoMET)* (pp. 1-6). IEEE.
DOI: 10.1109/iCoMET57998.2023.10099145

*Raza, A., Mazhar, N., Malik, F. M., Khan, R., Khan, A., & **Ullah, H**. "Output Feedback Control of Two-Time-Scale Permanent-Magnet DC Motor Using High-Gain Observers". (2023), Engineering Proceedings, 45(1), 20.* DOI: **https://doi.org/10.3390/engproc2023045020**

***Hameed Ullah.,** Owais Zarin, Malik, Irfan Ahmad, Sarfraz Ahmad, Ansar Abbas. "Robust Sliding Mode Control of a Quadrotor with Disturbance Rejection for Enhanced Stability and Performance".* 6th International Conference on Robotics and Automation in Industry, ICRAI 2024, IEEE. (Paper Submitted, Under review).

Date 13/10/2024

PhD student signature 

Supervisor signature