Final Program
&
Book of Abstracts

IMAV 2016

Beijing Institute of Technology (BIT)
Beijing, China
October 17–21, 2016

Co-Organizers

Beijing Institute of Technology, China
National University of Singapore, Singapore

Technical Co-Sponsors

Key Laboratory of Intelligent Control and Decision of Complex Systems, BIT, China
Beijing Advanced Innovation Center for Intelligent Robots & Systems, China
Institute of UAV Autonomous Control, BIT, China
ZHZ Technology, China
AeroLion Technologies Pte. Ltd., Singapore
MathWorks
AeroTiger UAV Co. Ltd., China
Thunder Tiger Aircraft Co. Ltd., China

International Micro Air Vehicle Conference and Competition
Past, Present and Future

First

IMAV 2010
EMAV 2010 becomes IMAV 2010
6–8 July 2010, Braunschweig, Germany

Second

IMAV 2011
Thales, Delft University of Technology
12–15 September 2011, Harde, Netherlands

Third

IMAV 2012
German Institute of Navigation, Technische Universität Braunschweig
3–6 July 2012, Braunschweig, Germany

Fourth

IMAV 2013
ENAC, Isae, MAV Research Center
17–20 September 2013, Toulouse, France

Fifth

IMAV 2014
TU Delft
12–15 August 2014, Delft, The Netherlands

Sixth

IMAV 2015
Institute of Flight System Dynamics of the RWTH Aachen University
German Institute of Navigation
15–18 September 2015, Aachen, Germany

Seventh

IMAV 2016
Beijing Institute of Technology
17–21 October 2016, Beijing, China

Eighth

IMAV 2017
MAV Research Center
2017, Toulouse, France

Content

Welcome Address

We are pleased to welcome you to the International Micro Air Vehicle Conference and Competition 2016 (IMAV 2016), which takes place at Beijing Institute of Technology (BIT), Beijing, China from October 17 to 21, 2016.

IMAV is a yearly event that combines a scientific conference with a technological competition involving Micro Air Vehicles (MAVs). IMAV 2016 allows research groups from all over the world to share their knowledge, and stimulates them to focus on research that can be used in real life scenarios. IMAV 2016 is co-organized by Beijing Institute of Technology, National University of Singapore (NUS), and co-sponsored by Key Laboratory of Intelligent Control and Decision of Complex Systems, BIT, Beijing Advanced Innovation Center for Intelligent Robots and Systems, MathWorks, ZHZ Technology, AeroLion Technologies, AeroTiger UAV, and Thunder Tiger Aircraft.

We wish to express our sincere thanks to the individuals who have contributed to IMAV 2016 in various ways. Special thanks are extended to the members in the program and organizing committee who have dedicated their time and efforts in planning, promoting and organizing the workshop. Last but not least, our special thanks go to invited plenary speakers as well as all the participants in making IMAV 2016 a memorable event.

We wish you a great conference and enjoyable visits in BIT, Beijing, China.

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Jie Chen	China
Guido de Croon	Netherlands
Christophe De Wagter	Netherlands
Gautier Hattenberger	France
Abdulghani Mohamed	Australia
Jean-Marc Moschetta	France
Dieter Moormann	Germany
Tobias Ostermann	Germany
Bart Remes	Netherlands
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Yongming Guan	Beijing Institute of Technology, China
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Hao Wang	Beijing Institute of Technology, China
Yadong Wang	Beijing Institute of Technology, China
Xiwen Yang	Beijing Institute of Technology, China
Yang Cui	Beijing Institute of Technology, China

Program Schedule for IMAV 2016

<table>
<tr><th>Date</th><th>Time</th><th colspan="2">Content</th><th>Location</th></tr>
<tr><td>Oct. 16</td><td>13:00-17:00</td><td colspan="2">Registration</td><td>Beijing Friendship Hotel</td></tr>
<tr><td rowspan="5">Oct. 17</td><td rowspan="5">8:00-17:00</td><td colspan="2">Registration</td><td>Beijing Friendship Hotel</td></tr>
<tr><td colspan="2">Indoor Practice</td><td>Gymnasium in BIT Main Campus</td></tr>
<tr><td colspan="2">Outdoor Practice</td><td>Liangxiang Campus</td></tr>
<tr><td rowspan="2">Shuttle</td><td>Hotel to Outdoor Competition Site:
7:00/9:00/13:00/14:00</td><td>Beijing Friendship Hotel</td></tr>
<tr><td>Outdoor Competition Site to Hotel:
11:00/13:00/16:00/18:00</td><td>Liangxiang Campus</td></tr>
<tr><td rowspan="11">Oct. 18</td><td>8:30-9:00</td><td colspan="2">Opening Ceremony</td><td rowspan="5">Central Building in BIT Main Campus</td></tr>
<tr><td>9:00-10:00</td><td colspan="2">Keynote Speech I</td></tr>
<tr><td>10:00-10:20</td><td colspan="2">Tea Break</td></tr>
<tr><td>10:20-11:20</td><td colspan="2">Keynote Speech II</td></tr>
<tr><td>11:20-11:50</td><td colspan="2">Invited Talk</td></tr>
<tr><td>11:50-13:00</td><td colspan="2">Lunch</td><td>Beijing Friendship hotel</td></tr>
<tr><td>13:00-15:00</td><td colspan="2">Conference (3 sessions)
20 Minutes for each Presentation</td><td rowspan="3">Fifth Floor
Graduate Building in BIT Main Campus</td></tr>
<tr><td>15:00-15:20</td><td colspan="2">Tea Break</td></tr>
<tr><td>15:20-17:40</td><td colspan="2">Conference (3 sessions)
20 Minutes for each Presentation</td></tr>
<tr><td>18:00-20:30</td><td colspan="2">Banquet and Dinner Speech</td><td>Beijing Friendship Hotel</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td rowspan="4">Oct. 19</td><td rowspan="4">8:00-18:00</td><td colspan="2">Indoor Practice</td><td>Gymnasium in BIT Main Campus</td></tr>
<tr><td colspan="2">Outdoor Practice</td><td>Liangxiang Campus</td></tr>
<tr><td rowspan="2">Shuttle</td><td>Hotel to Outdoor Competition Site:
7:00/9:00/13:00/14:00</td><td>Beijing Friendship Hotel</td></tr>
<tr><td>Outdoor Competition Site to Hotel:
11:00/13:00/16:00/18:00</td><td>Liangxiang Campus</td></tr>
<tr><td rowspan="5">Oct. 20</td><td>7:00-8:00</td><td colspan="2">Transportation to Outdoor Competition Site
6 Shuttles at 7:00 a.m.</td><td>Beijing Friendship Hotel</td></tr>
<tr><td>8:30-12:00</td><td colspan="2">Outdoor Competition
30 Minutes for each Team</td><td rowspan="4">Liangxiang Campus</td></tr>
<tr><td>12:00-12:30</td><td colspan="2">Lunch/Flight Show</td></tr>
<tr><td>12:30-17:00</td><td colspan="2">Outdoor Competition
30 Minutes for each Team</td></tr>
<tr><td>17:30-18:30</td><td colspan="2">Transportation from Outdoor Competition Site to Hotel</td></tr>
<tr><td rowspan="4">Oct. 21</td><td>7:00-12:00</td><td colspan="2">Indoor Competition
30 Minutes for each Team</td><td rowspan="3">Gymnasium in BIT Main Campus</td></tr>
<tr><td>12:00-12:30</td><td colspan="2">Lunch</td></tr>
<tr><td>12:30-16:30</td><td colspan="2">Indoor Competition
30 Minutes for each Team</td></tr>
<tr><td>17:00-18:00</td><td colspan="2">Closing Ceremony & Awards</td><td>Central Building in BIT Main Campus</td></tr>
</table>

Notes:

1. Team leader of each team will draw lots to determine the order of both Indoor and Outdoor Competition during registration on Oct. 17.
2. Beijing Friendship Hotel is within walking distance from BIT Main Campus. Taxi from BIT Main Campus to Liangxiang Campus takes around 40 minutes in good traffic condition.
3. Schedules for Oct. 19 and Oct. 20 might be swapped depends on weather conditions.

Meal Time & Location

Date	Time	Location
Oct. 17	Lunch 11:30-13:00	Yashi hall, Beijing Friendship Hotel, School Dining Hall if needed (Liangxiang Campus)
	Dinner 17:30-19:30	Yashi hall, Beijing Friendship Hotel
Oct. 18	Lunch 11:50-13:00	Yashi hall, Beijing Friendship Hotel
	Banquet 18:00-21:30	Second floor in Guibin Building, Beijing Friendship Hotel
Oct. 19	Lunch 11:30-13:00	Yashi hall, Beijing Friendship Hotel, School Dining Hall if needed (Liangxiang Campus)
	Dinner 18:30-20:30	Yashi hall, Beijing Friendship Hotel
Oct. 20	Lunch 12:00-12:30	School Dining Hall in Competition Area
	Dinner 18:30-20:30	Yashi hall, Beijing Friendship Hotel
Oct. 21	Lunch 12:00-12:30	School Dining Hall in Competition Area
	Dinner 18:30-20:30	Yashi hall, Beijing Friendship Hotel

Notes:

We will provide you with meal tickets when you register. You can use them to eat in the corresponding places mentioned in the table above.

Guidelines for Presentations

All presentations are required to be presented within the time scheduled according to the schedule, including 5 minutes for questions and discussions. Session Chairs will remind the presenter 5 minutes before the end of time.

The conference room is equipped with a computer and an LCD projector. The computer is equipped with a CD-ROM drive and a USB port to read CDs and USB flash memory, respectively.

The computers are operated in Microsoft Windows 7. They are installed with Adobe Acrobat Reader (for PDF), and Microsoft Office 2007 (or newer) that includes Word, Excel, and PowerPoint. Therefore, all presentations need to be compatible with these packages.

Personal laptop computer is also permitted in the sessions. Speakers are recommended to test the connections of their personal laptop to the projector before the session starts to ensure the conference conducted timely.

Conference Program

Opening Ceremony
08:30-11:50, October 18, 2016

8:30-9:00	Opening Ceremony	Central Building
9:00-10:00	Keynote Speech I: Efficient Artificial Intelligence for Micro Air Vehicles *Professor Guido de Croon*	
10:00-10:20	Tea Break	
10:20-11:20	Keynote Speech II: On the Design of Quiet Ultra-long Endurance Micro-UAVs *Professor Jean-Marc Moschetta*	
11:20-11:50	Invited Talk: Delivery with UAVs in Germany: Challenges & Technologies *Professor Dieter Moormann*	
11:50-13:00	Lunch	

Technical Program
13:00-17:40, October 18, 2016

	Track I Conference 1	Track II Conference 2	Track III Conference 3
13:00-15:00	Session 1: UAV Intelligent Navigation	Session 3: Autonomy of UAVs	Session 5: Vision-based Intelligence for UAVs
15:00-15:20	Tea Break		
15:20-17:40	Session 2: Flight Control	Session 4: System Modeling and Identification	Session 6: Design of UAV Systems

Banquet
18:00-21:30, October 21, 2016

18:00–18:30	Cocktail Reception	Beijing Friendship Hotel
18:30–19:30	Dinner Speech: The Future of Unmanned Aerial Vehicle Systems *Professor Bangkui Fan*	
19:30–21:30	Banquet	

Technical Program

Track I
Conference 1
13:00-17:40, October 18, 2016

Session1: UAV Intelligent Navigation		
Chair: Hailong Qin		Co-chair: Kexin Guo
13:00-13:20	A 3D Rotating Laser Based Navigation Solution for Micro Aerial Vehicles in Dynamic Environments *Hailong Qin*	
13:20-13:40	Distance and Velocity Estimation using Optical Flow from a Monocular Camera *H.W. Ho*	
13:40-14:00	A Monocular Pose Estimation Strategy for UAV Autonomous Navigation in GNSS-denied Environments *Alejandro Rodríguez-Ramos*	
14:00-14:20	An Ultra-Wideband-based Multi-UAV Localization System in GPS-denied environments *Thien Minh Nguyen*	
14:20-14:40	Relative Localization for Quadcopters using Ultra-wideband Sensors *Kexin Guo*	
14:40-15:00	Autonomous Positioning and Navigation for UAV in GPS-Denied Environments *Xiaolong Zhang*	
15:00-15:20	Coffee Break	
Session 2: Flight Control		
Chair: Chan Woei Leong		Co-chair: Christophe De Wagter
15:20-15:40	Deviation Correction and Stability Augmentation Control for UAV Taxiing *Li Zhen*	
15:40-16:00	Experimental and Computational Investigation on Interaction between Nano Rotor and Aerodynamic *D. Yang*	
16:00-16:20	Experimental Investigation of Rotational Control of a Constrained Quadrotor Using Backstepping Method N.Parhizkar	
16:20-16:40	Incremental Model Based Heuristic Dynamic Programming for Nonlinear Adaptive Flight Control *Y. Zhou*	
16:40-17:00	Tailless Control of a Double Clap-and-Fling Flapping Wing MAV *Chan Woei Leong*	
17:00-17:20	Control of a hybrid helicopter with wings *Christophe De Wagter*	
17:20-17:40	Precision Position Control of the DelFly II Flapping-wing Micro Air Vehicle in a Wind-tunnel *T. Cunis*	

Track II
Conference 2
13:00-17:40, October 18, 2016

Session 3: Autonomy of Unmanned Systems	
Chair: Kun Li	Co-chair: Li Liang
13:00-13:20	Optimal Distributed Cooperative Control for Multiple Quadrotors: Heading Consensus Experiment with Paparazzi Autopilot and AR. Drone 2 *Alireza Mohamadifard*
13:20-13:40	Mixed Differential Game in Target-Attacker-Defender Problem *Li Liang*
13:40-14:00	Specifying Complex Missions for Aerial Robotics in Dynamic Environments *Martin Molina*
14:00-14:20	Role of Competition in Inspiring Robotics Innovation *Lakmal Seneviratne*
14:20-14:40	Simulation of an Obstacle Avoidance Algorithm in a Dynamic 2D Environment *J.S Coetzee*
14:40-15:00	Autonomous Navigation in Partially Observable Environments Using Hierarchical Q-Learning *Y. Zhou*
15:00-15:20	Coffee Break
Session 4: System Modeling and Identification	
Chair: Guowei Cai	Co-chair: Yijie Ke
15:20-15:40	Systematic Modeling of Rotor Dynamics for Small Unmanned Aerial Vehicles *Limin Wu*
15:40-16:00	A Preliminary Modeling and Control Framework for a Hybrid UAV J-Lion *Yijie Ke*
16:00-16:20	Parameter selection method and performance assessment for the preliminary design of electrically powered transitioning VTOL UAVs *Bart Theys*
16:20-16:40	Electric Propulsion System Characterization through Experiments *Gautier Hattenberger*
16:40-17:00	First-Principles Modeling of a Miniature Tilt-Rotor Convertiplane in Low-Speed Operation *Guowei Cai*
17:00-17:20	Measurement and Calculation of Natural Frequencies of the Longitudinal Flight Modes for Small UAVs *M. ElSalamony*
17:20-17:40	Numerical Investigation of a Proof-of-Concept Rotor in Martian Atmosphere *Peng Lv*

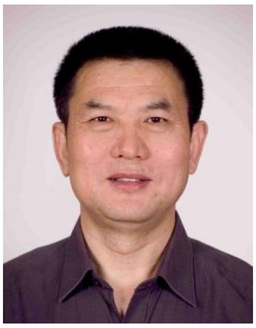
Track III
Conference 3
13:00-17:40, October 18, 2016

Session 5: Vision-based Intelligence for UAVs	
Chair: Feng Lin	Co-chair: Yingcai Bi
13:00-13:20	An MAV Localization and Mapping System Based on Dual Realsense Cameras *Yingcai Bi*
13:20-13:40	Real-time Simultaneous Localization and Mapping for UAV: A Survey *Jiaxin Li*
13:40-14:00	Salient Object Detection Using UAVs *Mo Shan*
14:00-14:20	Adaptive Path Planning for a Vision-Based quadrotor in an Obstacle Field *Jaime Junell*
14:20-14:40	Aircraft Inspection Using Unmanned Aerial Vehicles *Randa Almadhoun*
14:40-15:00	Visual Homing for Micro Aerial Vehicles using Scene Familiarity *Gerald van Dalen*
15:00-15:20	Coffee Break
Session 6: Design of UAV Systems	
Chair: Quoc-Viet Nguyen	Co-chair: Kun Li
15:20-15:40	Spring for clapping X-wing Micro Air Vehicles *Yao-Wei Chin*
15:40-16:00	Improved Efficiency Electronic Speed Controller Development for 3-Phase Brushless DC Motor in Unmanned Aerial Systems *Kun Li*
16:00-16:20	A Flying Anemometer Quadrotor: Part 1 *S. Prudden*
16:20-16:40	Experimental Investigation of Wing Flexibility on Force Generation of a Hovering Flapping Wing Micro Air Vehicle with Double Wing Clap-and-Fling Effects *Quoc-Viet Nguyen*
16:40-17:00	Design and Implementation of a Configurable Multi-rotor UAV *Yuying Qian*
17:00-17:20	Small Height Duct Design for 17” Multicopter Fan Considering Its Interference on Quad-copter *Kirill Stremousov*

Keynote Speeches

Keynote Speech at Banquet Dinner: The Future of Unmanned Aerial Vehicle Systems

Professor Bangkui Fan
Academician of Chinese Academy of Engineering
PLA General Staff Headquarters
China



Professor Bangkui Fan is an Academician of Chinese Academy of Engineering, an expert in the field of intelligence reconnaissance technology, the Executive Director of the Chinese Society for Optical Engineering, and the Director of the Science and Technology Committee of an Institute of the Headquarters of the General Staff (HGS). He was served as the Leader of the project expert group for the National 973 Program, and a member of theme expert group of the National 863 Program. As one of the academic leaders of reconnaissance technology for Unmanned Aerial Vehicles (UAVs) in China, he successively directed the development of many reconnaissance UAVs, and conquered a number of key technologies such as reconnaissance systems modeling of UAVs, target real-time positioning, and so on. The related research results have participated in the military parades of the 60th Anniversary of National Day and the 70th Anniversary of the Victory of Anti-Japanese War. He has won 6 National Scientific and Technological Progress Awards, including a Grand Prize, a First Prize and 4 Second Prize, and has received the first prize of provincial and ministerial level scientific and technological progress awards 8 times. Moreover, he was authorized 15 invention patents, and published 4 monographs and more than 20 articles.

Abstract: This presentation introduces development of unmanned aerial vehicle (UAV) system including remote telemetry, radio navigation, data link communication, full digital automatic control, artificial intelligence and system engineering concepts based on the change of the terminologies used to describe UAV from drone, remotely piloted vehicle (RPV), UAV, unmanned combat aerial vehicle (UCAV) to unmanned aircraft system (UAS). Moreover, the latest development status and six trends of UAV systems are going to be analyzed in detail, which consist of integrated reconnaissance UAV system, UCAV, micro UCAV, super long-flight-time/high-speed UAV system, civil UAV, autonomy and interoperability of UAVs. Finally, this presentation emphasizes the importance of supervision of civil UAVs which are widely used in many civil applications today. Especially, the reform of low-altitude airspace has been made a substantial progress, but the reform of low-altitude airspace is facing many security issues with civil UAVs, which are in urgent need to explore and resolve to find out a suitable measure to enhance the supervision of civil UAVs.

Keynote Speech I: Efficient Artificial Intelligence for Micro Air Vehicles

Professor Guido de Croon
Delft University of Technology
The Netherlands

Professor Guido de Croon received his M.Sc. and Ph.D. in the field of Artificial Intelligence at Maastricht University, the Netherlands. His research interest lies with computationally efficient algorithms for robot autonomy, with a particular focus on computer vision and evolutionary robotics. From 2011-2012 he worked as a Research Fellow in Artificial Intelligence at the European Space Agency. Since 2013, he is an assistant-professor at the Micro Air Vehicle lab of Delft University of Technology, the Netherlands.

Abstract: Micro Air Vehicles will only achieve their full potential if they can fly completely by themselves. This is an enormous challenge, since they are very restricted in terms of sensing, processing power, and memory. In my talk, I will first explain what consequences these restrictions have on the Artificial Intelligence necessary to make them autonomous. Subsequently I will delve into the way in which we can draw inspiration from general principles from biological intelligence to obtain an efficient form of AI suitable for MAVs. As a case study, I will discuss novel findings on how MAVs can land with the help of optical flow, which captures the way in which objects move through an image. Optical flow contains information such as the time it will take for an MAV to touch the landing surface, but in itself does not provide actual distance or velocity measurements. Since insects such as honeybees use optical flow for landing maneuvers, the general view is that they do not use distance or velocity estimates for landing. In my talk I will present a recently published theory that allows MAVs (and potentially insects) to perceive distance and hence velocity by means of oncoming instability of the optical flow control loop. I will show how this allows them to make high-performance optical flow landings without having to rely on additional sensors such as sonar or accelerometers.

Link to article that is the subject of the talk:
http://iopscience.iop.org/article/10.1088/1748-3190/11/1/016004/meta

Keynote Speech II: On the Design of Quiet Ultra-Long Endurance Micro-UAVs

Professor Jean-Marc Moschetta
ISAE-SUPAERO, Toulouse
France

Professor Jean-Marc Moschetta graduated from ISAE-SUPAERO in 1987 and obtained his PhD degree in Aerodynamics in 1991. Since 2000, he has been a full professor of Aerodynamics at ISAE-SUPAERO and a consultant at ONERA. From 2001, he organized or co-organized several MAV conferences and will host next year edition in Toulouse, France. He is currently the head of the UAV program at ISAE-SUPAERO and director of the MAV Research Center, a French research network on MAVs, which fosters a dozen research laboratories in the South West of France. Jean-Marc Moschetta has published numerous papers on the design and the aerodynamics of MAVs and is currently a member of the editorial board for the International Journal of MAVs.

Abstract: Miniaturizing UAVs is an important issue in view of reducing the logistic footprint required to operate unmanned aerial systems (UAS). Developing autonomous smaller vehicles would open the way to UAV swarming and would allow for cheaper, or even disposable flying vehicles. However, downscaling UAVs still faces the problem of limited endurance because of the energy density required by the propulsion set. The presentation will be given in two parts. The first part will address the issue of designing electrically-powered rotary-wing or fixed-wing microdrones in order to maximize their endurance under additional constraints (climb rate, minimal speed, hover flight). The design process will include the case of convertible MAVs capable of flying in airplane or helicopter modes. Special emphasis will be put on the optimization method as applied to maximizing the propulsive efficiency and minimizing the acoustic signature of MAV rotors. New quiet rotor blade geometries will be presented and discussed. The second part of the presentation will be devoted to the topic of extracting energy by dynamic soaring for ultra long-endurance MAVs. Because micro-UAVs usually fly at low speeds, their cruise speed is of the same order of magnitude than atmospheric perturbations. The idea is to benefit from the energy contained in the perturbed atmosphere by following specific trajectories as inspired by the observation of the Albatross flight. Yet, as opposed to natural flyers, UAVs can be powered so as to allow for thrust-augmented dynamic soaring which can lead to a drastic growth of the UAV flight range. Several examples of closed-loop or open-loop energy-harvesting trajectories will be given and compared to straight line trajectories. Recent results will be presented on the special case of down-the-hill dynamic soaring with the prospect of performing regenerative soaring with in-flight battery charging through propeller windmilling.

Invited Talk: Delivery with UAVs in Germany: Challenges & Technologies

Professor Dieter Moormann
RWTH Aachen University
Germany

Abstract: The talk will focus on the third Parcelcopter generation, which has successfully performed a three month delivery challenge in Winter 2015/16 in the German Alp mountains. Goods were transported by the DHL Parcelcopter 3.0, a long endurance tiltwing UAV system, to a remote location high in the mountains. The copters was loaded and unloaded automatically by a specially developed packstation, the DHL Skyport and fully integrated into the logistics chain of DHL. Fully automated high precision Take-off, Flight and Landing were performed on a regular basis during day and night also in the harsh weather conditions at the location. Besides robustness special emphasis was put on flight safety and regulatory aspects.

Abstract of Selected Papers

Session1: UAV Intelligent Navigation

A 3D Rotating Laser Based Navigation Solution for Micro Aerial Vehicles in Dynamic Environments

Hailong Qin[2*], Mo Shan[1], Yingcai Bi[2], Jiaxin Li[2],Menglu Lan[2]
F. Lin[1], Y.F. Zhang[3] and Ben M. Chen[2]
[1]Temasek Laboratories, National University of Singapore, Singapore
[2]Department of Electrical & Computer Engineering, NUS, Singapore
[3]Department of Mechanical Engineering, National University of Singapore, Singapore
**E-mail: mpeqh@nus.edu.sg*

Abstract--In this article, a 3D rotating laser-based navigation framework for a micro aerial vehicle (MAV) to fly autonomously in the dynamic environment is presented. The proposed navigation framework consists of a 6-degree of freedom (DoF) localization module and a 3D dynamic mapping module. By extracting and aligning 3D point cloud features from a dense point cloud which generates by a self-designed rotating 2D laser setup, we are able to solve the laser distortion issue while estimating the 6-DoF pose of MAV. In addition, the dynamic mapping module could further eliminate the dynamic trail so that a clean dense 3D map can be reconstructed. ur proposed navigation framework detects the dynamic target based on the spatial constraints and propagates without dense point cloud clustering. Through filtering the detected dynamic obstacles, the proposed localization approach is proven to be robust to the environment variations. We demonstrate the utility of our proposed framework in both real indoor environment with highly dynamic obstacles using a customized MAV platform.

Distance and velocity estimation using optical flow from a monocular camera

H.W. Ho*, G.C.H.E. de Croon, and Q.P. Chu
Delft University of Technology, The Netherlands
**Email: h.w.ho@tudelft.nl*

Abstract--Monocular vision is increasingly used in Micro Air Vehicles for navigation. In particular, optical flow, inspired by flying insects, is used to perceive vehicles' movement with respect to the surroundings or sense changes in the environment. However, optical flow does not directly provide us the distance to an object or velocity, but the ratio of them. Thus, using optical flow in control involves nonlinearity problems which add complexity to the controller. To deal with that, we propose an algorithm to use an extended Kalman filter to estimate the distance and velocity of the vehicles from optical flow while approaching a surface, and then use these estimates for control. We implement and test our algorithm in computer simulation and on-board a Parrot AR.Drone 2.0 to demonstrate its feasibility for MAVs landings. Both results show that the algorithm is able to estimate height and vertical velocity of the MAV correctly.

A Monocular Pose Estimation Strategy for UAV Autonomous Navigation in GNSS-denied Environments

Alejandro Rodríguez-Ramos, Carlos Sampedro, Adrian Carrio, Hriday Bavle,
Ramon A. Suárez Fernández, Zorana Milošević, and Pascual Campoy
Computer Vision Group, Center for Automation and Robotics (UPM-CSIC), Calle Jos´e Guti´errez Abascal 2, Madrid, Spain.

Abstract--In this paper, an accurate, efficient, and simple vision-based pose estimation strategy for UAV navigation in GNSS-denied environments is presented. Using visual information and previous knowledge of 3D geometries present in the environment, the pose can be estimated accurately and used for autonomous navigation. The indoor mission in the IMAV 2016 competition has been chosen for developing and evaluating this approach. Three Perspective-n-Point (PnP) algorithms have been tested and benchmarked with the purpose of selecting the most suitable for navigating in this scenario. All of them have been tested in a realistic Gazebo-based simulation using our novel UAV software, Aerostack, which allows for a fully autonomous solution. A complete flight in a GNSS-denied environment has been successfully simulated, indicating that real flights are feasible with this approach.

An Ultra-Wideband-based Multi-UAV Localization System in GPS-denied environments

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Abstract--This paper presents a technique for multi-UAV localization using ranging measurements from Two-Way Time-Of-Flight Ultra-Wideband (UWB) transceivers. In continuation with our previous work, the use of the Extended Kalman Filter (EKF) estimate is extended by fusing with other sensors to achieve a usable altitude estimate. Besides EKF, another method based on Non-linear Regression (NLR) is also developed to serve as an auxiliary localization to supplement the EKF. Experiments of autonomous flights are carried out to study the performance of these localization methods. Our success in supporting 4 UAVs demonstrates the capability of UWB for multi-UAV localization as a substitute for GPS in GPS-denied conditions. It can also serve as a cost-competitive alternative for very accurate yet expensive, highly centralized motion capture systems for indoor localization.

Relative Localization for Quadcopters using Ultra-wideband Sensors

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Abstract-- In this paper a relative localization (RL) system for quadcopters based on ultra-wideband (UWB) ranging measurements is proposed. To achieve the relative localization, UWB modules are in-stalled on the quadcopters to actively measure distances and exchange data package to a hover-ing quadcopter which is equipped with an identi-cal UWB module. Since instantaneous distance-onlymeasurements cannot provide enough infor-mation for relative position estimate, a combina-tion of nonlinear and linear trajectory is ultilized to fulfill the RL in this paper. To reduce the esti-mate error, the heading in the linear path phase is designed and chosen online. This intial relative position estimate produced by the algorithm will be further fed to the flight control loop to aid the navigation of the quadcopters. Flight tests have been conducted to validate the performance of UWB based relative localization algorithm.

Autonomous Positioning and Navigation for UAV in GPS-Denied Environments

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Abstract--A platform integrating visual camera into Unmanned Aerial Vehicle (UAV) system to realize the function of autonomous positioning and navigation in GPS-denied environments is presented. Through motion tracking and depth perception, the visual camera can provide estimated in formation on the surrounding environments for UAV to navigate. A control method of pose estimation and navigation strategy is proposed to make this system more stable and efficient, and to enhance its robustness. Several experimental tests have been carried out, illustrating the validity of the proposed approach.

Session 2: Flight Control

Deviation Correction and Stability Augmentation Control for UAV Taxiing

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Abstract--For the taxiing deviation correction control of medium and small sized UAV and the taxiing rollover problem which is likely to happen dur-ing deviation correction, this paper analyzed the force acting on UAV during taxiing, established the six degrees of freedom mathematical model of UAV taxiing, including the landing gear ab-sorber model and the tire model. The Fuzzy-PID (proportion integration differentiat ion) control system based on ACO (ant colony algorithm) was designed to optimize PID parameters of-fline and to adjust PID parameters online. The cause of UAV rollover was analyzed, the fuzzy stability augmentation control system was pre-sented to enhance the taxiing stability of UAV by synergetic controlling nose wheel, elevator and aileron. The simulat ion results show that the Fuzzy-PID control system based on ACO has obvious effect on deviation correction, and the control system can enhance the taxiing stability of UAV and keep UAV from rolling over effec-tively. the feasibility and validity of the control system was verified.

Experimental and Computational Investigation on Interaction between Nano Rotor and Aerodynamic Rudder

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Abstract--The interference effect between the nano rotor and aerodynamic rudder was studied experimentally and computationally. Propulsive performance of nano rotor and aerodynamic performance of aerodynamic rudder were achieved experimentally. The disturbed flow field of nano rotor was also analyzed computationally to disclose the flow mechanics of the interaction. Results showed that the nano rotor has a great effect on the aerodynamic performance of aerodynamic rudder. The moment of aerodynamic rudder fluctuated with the rotor-to-rudder spacing and achieved the smallest value at the spacing of 0.5 R. And the moment of aerodynamic rudder varied with deflection angle linearly. Aerodynamic rudder influenced the propulsion performance of the nanor rotor slightly. The thrust coefficient and torque coefficient increased a little with spacing but changed slightly with the deflection angle. Numerical simulation showed that aerodynamic rudder blocked the flow field of the nano rotor and the counter-clockwise rotation of the rotor drives the flow in the downstream rotating in a counterclockwise direction resulting in the different angle of attack between left and right rudder surface.

Experimental Investigation of Rotational Control of a Constrained Quadrotor Using Backstepping Method

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Abstract--Considering nonlinear and simple dynamics of quadrotors, it is feasible to implement different types of control methods, so it is an appropriate subject for experimental research. In recent years, many researchers have investigated different aspects of quadrotors. In this study, at first, the utilized quad rotor is introduced and then its dynamics is modeled. Next step is to measure physical parameters of the quadrotor that are needed for simulation. Then, PID and Backstepping controllers are implemented in Simulink and after fixing translational motion of the quadrotor, both controllers are implemented on real model using Labview. Due to having 3DOF and 4 control inputs, the system is overactuated, so an optimization is done to make the total thrust minimum. Results show that Euler angles are controlled by both PID and Backstepping controllers. Backstepping method has had better results.

Incremental Model Based Heuristic Dynamic Programming for Nonlinear Adaptive Flight Control

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Abstract--This paper presents a new and effective approach, incremental model based heuristic dynamic programming, to design an adaptive nearoptimal controller without a-prior knowledge of the dynamic model. Both traditional heuristic dynamic programming algorithm and incremental model based heuristic dynamic programming algorithm are provided and applied to an illustrative on-line learning task. The system dynamics are completely unknown at the beginning, and the agent learns the local system models and the control policies on-line to follow a reference signal. It was found that using incremental models in heuristic dynamic programming can avoid off-line learning of the system model and help to accelerate the on-line learning. This proposed method can potentially design a near-optimal controller for autonomous flight of unmanned aerial vehicles without a-prior knowledge of the system dynamics.

Tailless Control of a Double Clap-and-Fling Flapping Wing MAV

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Abstract--This paper presents the study on a tailless control mechanism designed to tilt the wing roots of a double clap-and-fling flapping wing micro-airvehicle (MAV). The MAV has made stable hovering flight with tail and stabilizers, the work presented in this paper paves the way for the implementation of tailless flight control on the MAV. A wing tilting mechanism driven by three linear servos was designed and fabricated. Study shows that tilting the wing roots creates a linear trend of pitching and rolling moments if the centre of gravity (CG) falls on the correct location. Wing kinematics was captured and it was found that the higher drag due to higher angle of attack could be a contributing factor to the pitching and rolling moments. Another contributing factor could be the lift dissymmetry of the opposite pairs of wings. The effects of pitch-roll coupling are also presented.

Control of a hybrid helicopter with wings

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Abstract--This work investigates the design parameters and consequences in the control of a helicopter rotor combined with a pair of fixed wings. This hybrid vehicle has a light and aerodynamically efficient rotor that can achieve large pitch angles to allow forward flight. Because of the light stiff rotor and heavy wings, the hybrid vehicle exhibits couplings between the roll and pitch axes during hover flight. The rotor-wing interaction depends on a lot of parameters. In this paper, we utilize a simplified theoretic model and simulations in order to gain insight in the effect of these parameters on the vehicle dynamics. Finally, a controller is designed that compensates undesired coupling between pitch and roll.

Precision Position Control of the DelFly II Flapping-wing Micro Air Vehicle in a Wind-tunnel

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Abstract--Flapping-wing MAVs represent an attractive alternative to conventional designs with rotary wings, since they promise a much higher efficiency in forward flight. However, further insight into the flapping-wing aerodynamics is still needed to get closer to the flight performance observed in natural fliers. Here we present the first step necessary to perform a flow visualization study of the air around the flapping wings of a DelFly II MAV in-flight: a precision position control of flight in a wind-tunnel. We propose a hierarchical control scheme implemented in the open-source Paparazzi UAV autopilot software. Using a decoupling, combined feed-forward and feed-back control approach as a core, we were able to achieve a precision of ±2.5 cm for several seconds, which is much beyond the requirements for a time resolved stereo PIV technique.

Session 3: Autonomy of Unmanned Systems

Optimal Distributed Cooperative Control for Multiple Quadrotors: Heading Consensus Experiment with Paparazzi Autopilot and AR. Drone 2

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Abstract--An LQR control strategy for distributed coordination of multi-vehicle systems with linear dynamics is studied in this article. Using partitioning method, linear consensus algorithms for multi-vehicle systems with single-integrator dynamics is extended for high-order integral dynamics. Then the proposed high-order consensus protocol, is modelled as an optimal linear quadratic regulator (LQR) problem. Then, consensus protocol law is modified to achieve consensus merely on state variables while applying an optimal internal controller on higher states derivatives. A theorem is proposed to formulate the consensus strategy for this control problem and the stability analysis of multi-vehicle system is discussed using Lyapunov stability criterion. To illustrate the direct application of the proposed control theory and demonstrate the effectiveness of the proposed optimal high-order consensus protocol, linear second order heading dynamics of quadrotor is utilized to implement the consensus law on a real high-order dynamic MAV. Paparazzi open-source autopilot and the Parrot AR.Drone II commercial quadrotors are providing the software and hardware test bed for this experiment.

Mixed differential game in Target-Attacker-Defender Problem

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Abstract--This paper addresses a mixed differential game with three players: Target, Attacker and Defender, where the Attacker aims to capture the Target whilst avoiding being captured by the Defender. At this point, there are two pursuit-evasion problems in this game, and two focuses should be considered: one is the cooperation between the Target and the Defender; the other one is the role changes between pursuer and evader of the Attacker. This paper discusses the mixed differential game analytically, obtains the optimal strategies of the three players, and provides numerical solutions for different initial states.

Specifying Complex Missions for Aerial Robotics in Dynamic Environments

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Abstract--To specify missions in aerial robotics, many existing applications follow an approach based on a list of waypoints, which has been proven to be useful and practical in professional do-mains (agriculture of precision, creation of terrain maps, etc.). However this approach has limitations to be used in other problems such as the one defined in the IMAV 2016 competition (e.g., a search and rescue mission). In this paper we describe a language to specify missions for aerial robotics that tries to overcome such limitations. This language has been designed as part of a complete software framework and architecture for aerial robotics called Aerostack. The pa-per describes the result of experimental evaluation in real flight and its adequacy for the IMAV 2016 competition.

Role of Competition in Inspiring Robotics Innovation

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Abstract-- Robotics is a powerful technology poised to have a dramatic economic and societal impact. This has resulted in continuing recent major investments in robotics and AI. This presentation will review the current fast developing investment landscape in robotics. We will then highlight some of the new opportunities and potential applications related to next generation robotics and AI. Many of these new opportunities will require robots to work in crowded, unstructured and dynamic environments, in close proximity to and in collaboration with humans. They will also require the robots to physically interact with the environment, cope with high levels of disturbances and work with increased autonomy. These new enabling technologies pose significant research and development challenges. In recognition of this we have seen an increased interest in robotics competitions in recent years. We will review some of these competitions and explore the role of international competitions in inspiring and catalyzing future technological progress and applications in Robotics and AI.

Simulation of an Obstacle Avoidance Algorithm in a Dynamic 2D Environment

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Abstract--This paper describes the methods followed to more accurately predict how a combination of D* Lite and the Virtual Force Field method would react when sensor as well as pose uncertainties are considered during the map building process. These uncertainties are then simulated using MATLAB where the main focus is the effect that these uncertainties have on the combined algorithms' output and whether the same results can be obtained by using simplified assumptions.

Autonomous Navigation in Partially Observable Environments Using Hierarchical Q-Learning

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Abstract--A self-learning adaptive flight control design allows reliable and effective operation of flight vehicles in a complex environment. Reinforcement Learning provides a model-free, adaptive, and effective process for optimal control and navigation. This paper presents a new and systematic approach combining Q-learning and hierarchical reinforcement learning with additional connecting Q-value functions, which separate the effect of internal rewards from the external rewards. An online navigation algorithm with both Q-learning and Hierarchical decomposition is provided and applied to an illustrative task in a complex, partially observable environment. The environment is completely unknown at the beginning, and the agent learns the most efficient path online to avoid obstacles and to get to the target area. The present work compares the results using 'flat' Q-learning and hierarchical Q-learning. The results indicate that hierarchical Q-learning can help to accelerate learning, to solve 'curse of dimensionality' in complex navigation tasks, to naturally reduce the uncertainty or ambiguity at higher levels, and to transfer the learning results within tasks and across tasks efficiently. This proposed method can potentially design a near optimal controller hierarchically for autonomous navigation without a-prior knowledge of the environment.

Session 4: System Modeling and Identification

Systematic Modeling of Rotor Dynamics for Small Unmanned Aerial Vehicles

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Abstract--This paper proposes a systematic modeling approach of rotor dynamics for small unmanned aerial vehicles (UAVs) based on system identification and first principle based methods. Both static state response analysis and frequency domain identifications are conducted for rotor, and CIFER software is mainly utilized for frequency-domain analysis. Moreover, a novel semi-empirical model integrating rotor and electrical speed controller is presented and verified. The demonstrated results and model are promising in UAV dynamics and control applications.

A Preliminary Modeling and Control Framework for a Hybrid UAV J-Lion

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Abstract--J-Lion is a tail-sitter UAV platform developed to perform both VTOL and cruise flight missions. This paper presents a preliminary modeling and control framework for our hybrid UAV J-Lion. A unified model structure including comprehensive model components is derived for full envelop flight conditions. Currently, model-based controller has been specifically designed for VTOL mode that can handle large angle deviations. Our method is verified by outdoor flight tests with existence of strong wind gust.

Parameter selection method and performance assessment for the preliminary design of electrically powered transitioning VTOL UAVs

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Abstract--This paper describes a parameter selection method and performance assessment for the preliminary design of Vertical Take-Off and Landing Unmanned Aerial Vehicles (VTOL UAVs) that use a combination of wings and a set of electrically powered propellers for providing lift and thrust during cruise flight. This method allows us to quickly evaluate the possibilities of current technology for a given set of user and mission-specific requirements, and to create a preliminary design to meet these requirements. To this end, the acceptable range for the variable design parameters is predetermined and the parameters to optimize are identified. Mass and power models are presented for the components of the UAV and a novel model for a propeller in oblique flow conditions is applied. The models are used in a design algorithm that calculates all combinations of components. All feasible solutions are selected and displayed to the user after which the optimal solution can be chosen. A design case is presented and a sensitivity analysis shows the influence of different design parameters on this case.

Electric Propulsion System Characterization through Experiments

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Abstract--Electrical propulsion system characteristics are very important in UAV design, operation and control. This article presents the characterization of electric propulsion sets through experiments. A motor test bench have been build based on previous experience in order to improve the quality of the measurements. Moreover, the bench fits in a wind tunnel, allowing to perform a complete characterization over the full airspeed range of the considered mini and micro-UAVs. After re-calling the general theoretical model of an electric motor, results from various combinations are presented.

First-Principles Modeling of A Miniature Tilt-Rotor Convertiplane in Low-Speed Operation

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Abstract--In this paper, we present a comprehensive first-principles model that is developed for a miniature tilt-rotor convertiplane with Y-6 configuration. First, a flight dynamics model architecture is proposed based on the physical principle of the tilt-rotor convertiplane. Next, the parameter identification is conducted to determine the numerical values of all necessary parameters. The model fidelity is finally evaluated using practical data collected in flight experiments

Measurement and Calculation of Natural Frequencies of the Longitudinal Flight Modes for Small UAVs

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Abstract--In order to design the good controller for an unmanned aerial vehicle (UAV), an accurate mathematical model of aircraft must be constructed first. Geometry and mass of an aircraft are important factors in flight mechanics and in the calculations of stability and natural frequencies of its flight modes, which are of great importance in controller designing process. In this paper, comparison between the formulae of the large aircrafts applied on small UAVs scale, XFLR5 as a numerical commercial vortex lattice method (VLM) program and experimental data obtained from flight tests is made to investigate their accuracy.

Numerical Investigation of a Proof-of-Concept Rotor in Martian Atmosphere

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Abstract--This paper presents 2-D Blade Element Momentum Theory predictions and 3-D Reynolds-averaged Navier-Stokes calculations for a proof-of-concept rotor in Martian atmosphere. The rotor that operates on Mars will experience a unique low Reynolds number and high Mach number environment, thus it presents a new challenge. The sectional aerodynamic characteristics of Eppler 387 airfoil are obtained from a 2-D Reynolds-Averaged Navier-Stokes solver. Based on the sectional aerodynamic characteristics, the thrust coefficient and Figure of Merit of rotor are initially predicted by Blade Element Momentum Theory. Then, the rotor with a collective pitch of 10 is investigated using a 3-D Reynolds-Averaged Navier Stokes solver. The results show a clear discrepancy between 2-D predictions and 3-D calculations due to 3-D rotation effect, such as stall modification and root vortices. In addition, the 3-D calculations are not sensitive to the usage of turbulent model or transition model when compared to 2-D predictions.

Session 5: Vision-based Intelligence for UAVs

An MAV Localization and Mapping System Based on Dual Realsense Cameras

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Abstract--Online localization and mapping in unknown environment is essential for Micro Aerial Vehicles (MAVs). Both accuracy and robustness are required in the realtime applications. In this paper, we present a dual camera system to estimate the pose of an MAV and generate an obstacle map for navigation. The recently released light-weight Intel Realsense depth cameras are utilized to build the system, one is forward-facing and the other is downwardfacing. The downward-facing camera provides a high-frequency (60hz) velocity measurement while the forward-facing camera computes a low-frequency (10hz) position measurement. Experiments demonstrate the good performance of our proposed system.

Real-time Simultaneous Localization and Mapping for UAV: A Survey

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Abstract--Simultaneous Localization and Mapping (SLAM) refers to the problem of using various sensors like laser scanner, RGB cameras, RGB-D cameras, etc, to estimate the position of the robot, and concurrently construct the 2D/3D map of the environment. The SLAM community has made great progress in the past few decades. So far the 2D SLAM problem with range finders is considered as solved, while the real-time 3D SLAM, especially robust and high quality visual SLAM on UAVs, remains an open problem. This article aims to give a picture of the evolution and very recent development of SLAM algorithms, and emphasis is given on real-time SLAM methods that are suitable for Unmanned Aerial Vehicles (UAVs).

Salient Object Detection Using UAVs

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Abstract--A salient object detection approach is proposed in this paper, tailored to the aerial images collected by Unmanned Aerial Vehicles (UAVs). In particular, the aerial images are classified. The selected image is segmented using superpixels, and then a weak saliency map is constructed based on image priors. Positive and negative samples are selected in accordance with the weak saliency map for training a boosted classifier. Consequently, the classifier is used to pro-duce a strong saliency map. The weak and strong saliency maps are integrated to locate the candidate objects, and false alarms are pruned after post-processing. Experiments on aerial images collected above meadow and roof demonstrate the effectiveness of the proposed approach.

Adaptive Path Planning for a Vision-Based quadrotor in an Obstacle Field

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Abstract--This paper demonstrates a real life approach for quadrotor obstacle avoidance in indoor flight. A color-based vision approach for obstacle detection is used to good effect conjointly with an adaptive path planning algorithm. The presented task is to move about a set indoor space while avoiding randomly located obstacles and adapting a path to prevent future confrontation with the obstacles all together. The goal is to complete this task with a solution that is simple and efficient. The result is an adaptive path planning algorithm that evades obstacles when necessary and uses these interactions to find an obstacle-free path with simple logic. The whole task is implemented within Paparazzi, an open source autopilot software. Flight tests are performed in an indoor flight arena with simulated GPS from a camera tracking system. Through these flight tests, the approach proves to be reliable and efficient.

Aircraft Inspection Using Unmanned Aerial Vehicles

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Abstract--In this paper, we propose a coverage planning algorithm for inspecting an aircraft, using an Unmanned Ariel Vehicle (UAV). Inspecting structures (e.g. bridges, buildings, ships, wind turbines, aircrafts) is considered a hard task for humans to perform, and of critical nature since missing any detail could affect the structure's performance and integrity. Additionally, structure inspection is a time and resource intensive task that should be performed as efficiently and accurately as possible. In this paper we introduce a search space coverage path planner (SSCPP) with a heuristic reward function that exploits our knowledge of the structure model, and the UAV's onboard sensors' models to generate resolution optimal paths that maximizes coverage. The proposed method follows a model based coverage path planning approach to generate an optimized path that passes through a set of admissible waypoints to fully cover a complex structure. The algorithm predicts the coverage percentage by using an existing model of the complex structure as a reference. A set of experiments were conducted in a simulated environment to test the validity of the proposed algorithm.

Visual Homing for Micro Aerial Vehicles using Scene Familiarity

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Abstract--Autonomous navigation is a major challenge in the development of Micro Aerial Vehicles(MAVs). Especially when an algorithm has to be efficient, insect intelligence can be a source of inspiration. An elementary navigation task is homing, which means autonomously returning to the initial location. A promising approach uses learned visual familiarity of a route to determine reference headings during homing. In this paper an existing biological proof-of-concept is transferred to an algorithm for micro drones, using vision-in-the-loop experiments in indoor environments. An artificial neural network determines which control actions to take.

Session 6: Design of UAV Systems

Spring for clapping X-wing Micro Air Vehicles

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Abstract--Four-winged ornithopters like Delfly make use of clap and fling to enhance thrust generation. Yet, clapping of the four wings (forming a cross) requires high energetic cost and their wing kinetic energy is not recovered using rigid-body mechanism. To help recover the wings' kinetic energy, we designed and developed a compact T-shaped elastic flexures, replacing a pivot revolute joint for this X-wing micro air vehicles (MAV). The elastic mechanism is made of flexible polyimide film and rigid carbon fiber plates. The polyimide film is capable of storing elastic strain energy for large bending. Higher elastic storage in the film hinges improved the clapping speed of the X-wing flapper to generate higher thrust without incurring additional energetic costs. Hence, it is useful to enhance the thrust of low-frequency clappers. This X-wing clapper of a 13.4g total weight is able to generate thrust up to 20.7g force and demonstrates tethered hovering and climbing.

Improved Efficiency Electronic Speed Controller Development for 3-Phase Brushless DC Motor in Unmanned Aerial Systems

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Abstract--This paper presents the methodology and technique of implementing vector control method on brushless DC (BLDC) motors. Traditional scalar control method and the advanced field oriented control (FOC) are compared with the aspects of efficiency, control performance and reference speed range. Theoretical analysis of both methods are explained with their decomposed function components in detail. To obtain rotor position and its angular rate, a nonlinear observer based on the motor mathematical model is adopted to estimate these unknown states, for feedback to the control process. Customized hardware kit is designed and developed for implementation of the FOC algorithm. Several experiments are conducted to test the convergence speed, efficiency and reference speed range for both methods. The results show the superiority of FOC scheme with a properly tuned gain and parameter set.

A Flying Anemometer Quadrotor: Part 1

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Abstract--The feasibility of using a Multi-rotor Unmanned Aerial System (MUAS) as flying anemometers for measurement of wind in urban environments was investigated. Flow mapping was conducted around the MUAS using smoke flow visualization and multi-hole pressure probes to analyse the effects of the propellers on the measured flow speed and direction and determine a suitable mounting location for an on-board multihole pressure probe sensor system. It was determined that propeller-induced effects extended beyond a feasible on-board probe length. Therefore correction factors were developed from experimental measurements for application to the output of the on-board multi-hole pressure probe.

Experimental Investigation of Rotational Control of a Constrained Quadrotor Using Backstepping Method

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Abstract--Considering nonlinear and simple dynamics of quadrotors, it is feasible to implement different types of control methods, so it is an appropriate subject for experimental research. In recent years, many researchers have investigated different aspects of quadrotors. In this study, at first, the utilized quad rotor is introduced and then its dynamics is modeled. Next step is to measure physical parameters of the quadrotor that are needed for simulation. Then, PID and Backstepping controllers are implemented in Simulink and after fixing translational motion of the quadrotor, both controllers are implemented on real model using Labview. Due to having 3DOF and 4 control inputs, the system is overactuated, so an optimization is done to make the total thrust minimum. Results show that Euler angles are controlled by both PID and Backstepping controllers. Backstepping method has had better results.

Design and Implementation of a Configurable Multi-rotor UAV

Yuying Qian[1]*, Kan Liu[1], Lijun Zhang[1], Junzhe Lin[1], Zixuan Lu[1], and Swee King Phang[2]
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[2]National University of Singapore, Singapore
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Abstract-- This manuscript details the design process and implementation considerations of a configurable multi-rotor unmanned aerial vehicle (UAV), which is switchable between quadcopter mode and hexacopter mode in easy plug-and-play action. The design includes customized detachable rotor arms, complemented with an altered arrangement of motors to enable the simple switching feature between the two types of platforms. An innovative flight control architecture is formulated to handle both types of platforms using a single control algorithm. Mathematical modelling of the platforms is crucial to the proposed flight control algorithm and it will be briefly discussed in this manuscript. The configurable platform is implemented and actual flying tests have been conducted in both configurations to verify the feasibility of the design.

Small Height Duct Design for 17” Multicopter Fan Considering Its Interference on Quad-copter

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** Moscow Institute of Physics and Technology, Department of Aeromechanics and Flight Engineering 16, Gagarina str.,*
140180, Zhukovsky, Moscow Region, Russia
*** Central Aerohydrodynamic Institute, 1, Zhukovsky str., 140180, Zhukovsky, Moscow Region, Russia*

Abstract--The 17 inch ducted fan with a 50mm height was studied in hover. Numerical simulations were provided by solving RANS equations with SST turbulence model using actuator disc with radial distribution of pressure difference according to numerical and experimental investigations of 17” propeller in hover. Optimal airfoil for axisymmetric duct was found. The 3D numerical simulations of four ducted fans interference were carried out. The geometry of duct was improved in term of power consumption considering interference of quad copter ducted fans.

Local Information

Time

Beijing is eight hours ahead of the Coordinated Universal Time (UTC/GMT +8).

Banks and Foreign Exchange

China currency is the China Yuan (CNY). Beijing's banking hours are generally 9:00 – 17:00, Monday to Friday. Exchanging of foreign currency can be made in all major banks, Monday to Friday. You may also exchange foreign currency at the airport (available 24 hours a day).

First Aid and Hospital Services

Campus hospitals and ambulance will be available to you during the conference and competition. In the event of an emergency, transport to the nearest hospital will be provided by ambulance.

In the Event of an Emergency

Call 110 to reach police, Call 119 in case of fire, Call 120 for ambulance services.

Electric Current

Electric power is 220 Volt, 50Hz.

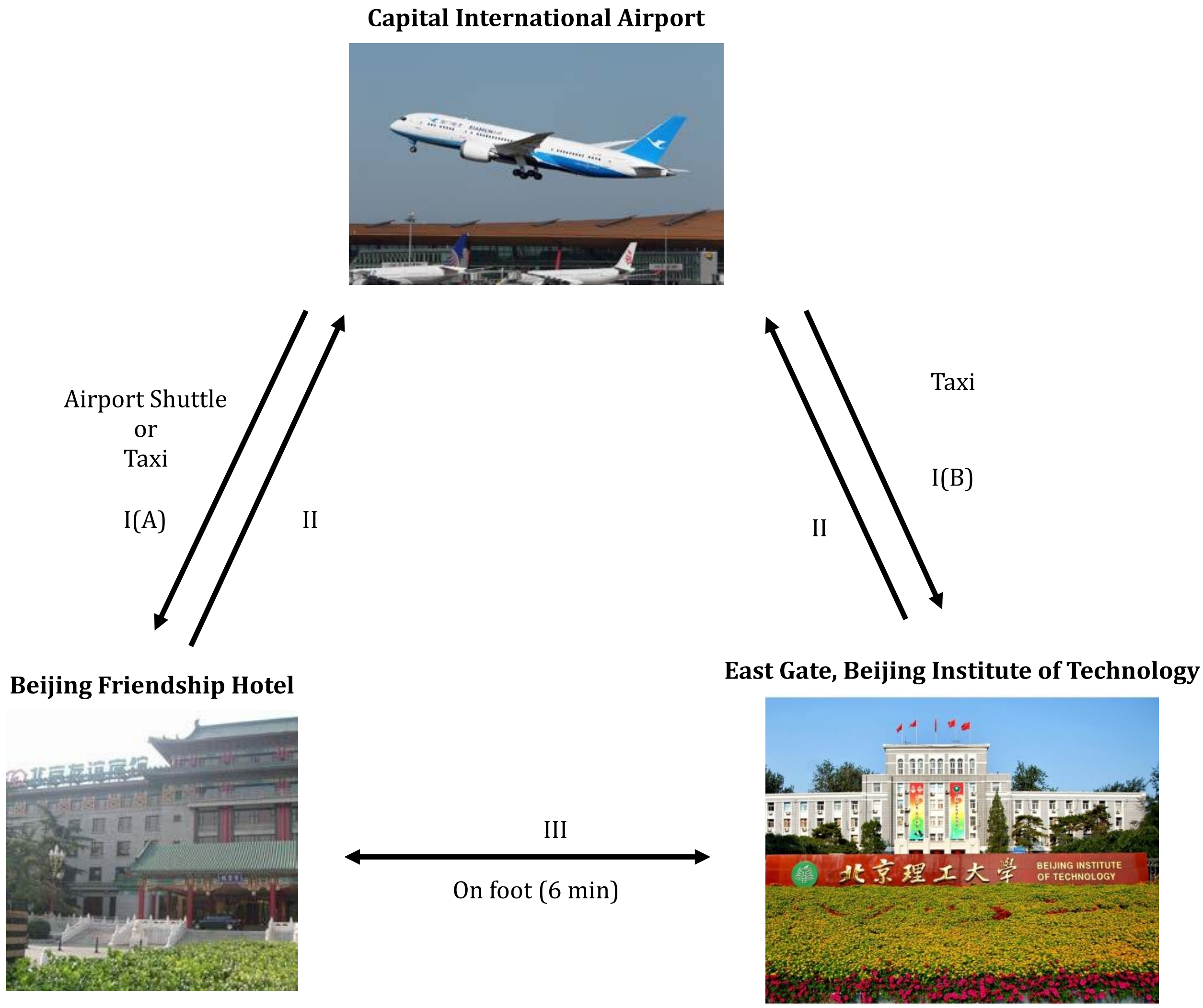
Network

Most area in campus is covered by school WLAN, you can use the account and password provided by us when you register in Beijing Friendship Hotel to connect the network. The WLAN name is BIT-Web (for computer or mobile phone) or BIT- Mobile (for mobile phone).

Drinking Water

You are recommended to drink bottle water provided in the conference and competition during the five days. There are also many chain convenient stores located around the city for drinkable bottle water.

Transportation Guide



I. From *Capital International Airport* to *Beijing Friendship Hotel/East Gate, Beijing Institute of Technology*

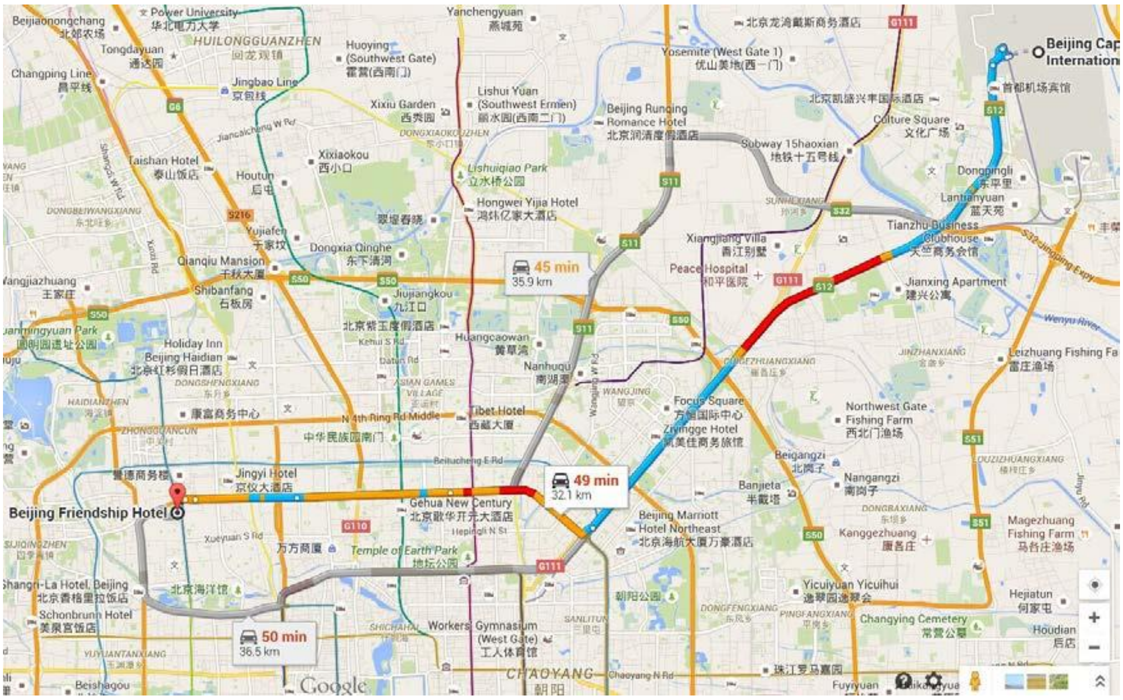
II. From *Beijing Friendship Hotel/East Gate, Beijing Institute of Technology* to *Capital International Airport*

III. From *Beijing Friendship* to *East Gate, Beijing Institute of Technology*

IV. Map of *Beijing Institute of Technology*, including Opening Ceremony and Closing Ceremony area, Conference area, Outdoor Competition area and Indoor Competition area.

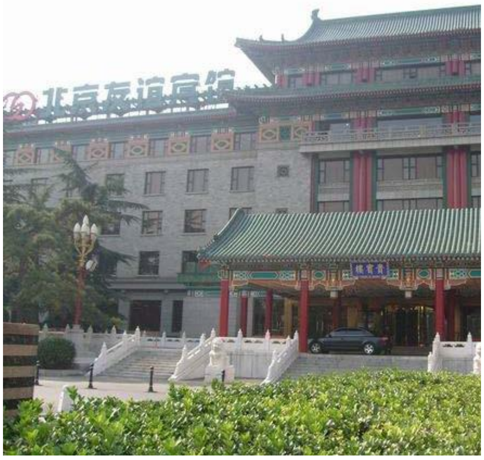
I. From *Capital International Airport* to *Beijing Friendship Hotel/East Gate, Beijing Institute of Technology*

When you arrive at Capital International Airport, you may take airport shuttle or taxi to *Beijing Friendship Hotel*. If you are going to *East Gate, Beijing Institute of Technology,* you have two choices: taxi, or take airport shuttle to *Friendship Hotel* then walk to the East Gate.



Traffic route on Google map

East Gate, Beijing Institute of Technology



Beijing Friendship Hotel

1. Airport Shuttle (to Beijing Friendship Hotel only)

You can enjoy round trip, *line 4*, between *Capital International Airport* and *Gongzhufen*, *Beijing Friendship Hotel* in the 6th stop.

Ticket Price: RMB 24/person
(See more detail on *http://en.bcia.com.cn/traffic/airbus/index.shtml*)

Local buses(Click route for more)

Route Name	Route
Line 1	BCIA ⟷ Fangzhuang Route
Line 2	BCIA ⟷ Xidan Route
Line 3	BCIA ⟷ Beijing Railway Station
Line 4	BCIA ⟷ Gongzhufen
Line 5	BCIA ⟷ Zhongguancun
Line 6	BCIA ⟷ ShangDi & Olympic Village
Line 7	BCIA ⟷ Beijing West Railway Station
Line 8	BCIA ⟷ Huilongguan
Line 9	BCIA ⟷ Tongzhou Route

Line 4

BCIAGongzhufen

Line Sanyuan West Bridge[RMB 15] Xiba River[RMB 18] Anzhen Bridge[RMB 21] Madian Bridge[RMB 21] Beitaipingzhuang[RMB 21] -- Jimen Bridge[RMB 21] -- Friendship Hotel[RMB 24] -- Zizhu Bridge[RMB 24] -- Hangtian Bridge[RMB 24] -- Gongzhufen[RMB 24]

Time From 6:50 a.m. to the last domestic arrival of the day.

Every 20 minutes. Buses depart when fully seated.

2. Taxi

Capital Airport provides taxi stops at the airport, so you can take a taxi to *Beijing friendship Hotel* or *East Gate, Beijing Institute of Technology*

Taxi Stops Location:
T1: Outside Gate 1 on F1
T2: Outside Gate 5 to 9 on F1
T3: Please refer to the signs inside the terminal building

Taxi Charges:

- The minimum charge is RMB 13 covering the first 3km. The rest will be charged at RMB 2.3/km;
- RMB 1 Fuel Surcharge/Drive;
- Low-speed drive and stand-by charge: When the speed is lower than 12km/hr, the surcharge is equivalent to 2-km rent (excluding no-occupancy surcharge) every five minutes during rush hours from 7:00 (including 7:00 sharp) to 9:00 (excluding 9:00 sharp), and from 17:00 (including 17:00 sharp) to 19:00 (excluding 19:00 sharp); the surcharge is equivalent to 1-km rent (excluding no-occupancy surcharge) for the rest of the day.
- RMB 6 for Each Reservation at Least 4 Hours in Advance; RMB 5 for Each Reservation Within 4 Hours in Advance;
- Additional 50% of the total fee will be charged as an allowance for the return trip if the single trip has exceeded 15km;
- No no-occupancy surcharge shall be collected for drive to and from certain spots, i.e., the distance between the starting and ending spots is no more than 2km;
- From 23:00 (including 23:00 sharp) to 5:00 of the next day (excluding 5:00 sharp), the surcharge for each kilometer is 20% of the rent.

The above charges are for your information. Should they differ from the regulations of the taxi management authorities, the latter shall prevail.

Charge: usually no more than 120RMB depends on the traffic condition.

You can write down the destination in Chinese characters as follow, and show it to taxi driver.

A) to Beijing Friendship Hotel

目的地：北京友谊宾馆
位置：海淀区中关村南大街 1 号
（人民大学附近）

Destination: Beijing Friendship Hotel
Location: No.1 South Street, Zhongguancun, Haidian District
(Near the Renmin University of China)

B) to East Gate, Beijing Institute of Technology

目的地：北京理工大学东门
位置：中关村南大街 5 号北京理工大学
（北京理工大学东门）

Destination:East Gate, Beijing Institute of Technology
Location: No.5 Zhong Guancun South Street
(East Gate, Beijing Institute of Technology)

Tips:

- *Please pay attention to the Standard TAXI Rates on the side windows of the taxi, and the service name card of the taxi driver.*
- *Road toll and bridge toll will be afforded by the passengers.*
- *Please ask the taxi driver for invoice and take down the car number if necessary.*
- *Please take a taxi with official certification at the airport. Don't forget your belongings when getting off.*

II. From *Beijing Friendship Hotel/East Gate, Beijing Institute of Technology* to *Capital International Airport*

From *Beijing Friendship Hotel*, you may take airport shuttle or taxi to *Capital International Airport*. From *East Gate, Beijing Institute of Technology*, you may take taxi directly, or walk to the East Gate of *Friendship Hotel*, then take airport shuttle.

1. Airport Shuttle (from *Beijing Friendship Hotel* only)

The place for picking up (●): Air Ticket Office at the East gate (▲) of Friendship Hotel.

(See more detail on *http://en.bcia.com.cn/traffic/airbus/index.shtml*)

GongzhufenBCIA

Line Gongzhufen[RMB 24] -- Friendship Hotel[RMB 24] -- Beitaipingzhuang [RMB 21] -- Anzhen Bridge[RMB 21] -- Xiba River[RMB 18] -- T2 -- T1 -- T3

Time 4:30~22:00 Every 30 minutes, stop over at Anzhen Bridge and Xiba River only after 21:00.

2. Taxi

Tips:

- *Taxi on the road to airport takes about 1 hour, it is faster than taking airport shuttle, and the expense is about 120RMB.*

You can write down the destination, Capital International Airport, in Chinese characters as follow, and show to taxi driver.

目的地：北京首都机场 1/2/3 号航站楼
位置：北京市东北郊 顺义境内

Destination: Terminal 1/2/3 Capital International Airport
Location: Shunyi District, Northeastern Suburb of Beijing

III. From *Beijing Friendship Hotel* to *East Gate, Beijing Institute of Technology*

Start from the East Gate of *Beijing Friendship Hotel*, turn right, then go along the Zhongguancun South Street, until you see the *East gate of Beijing Institute of Technology*.

Map of Beijing Institute of Technology

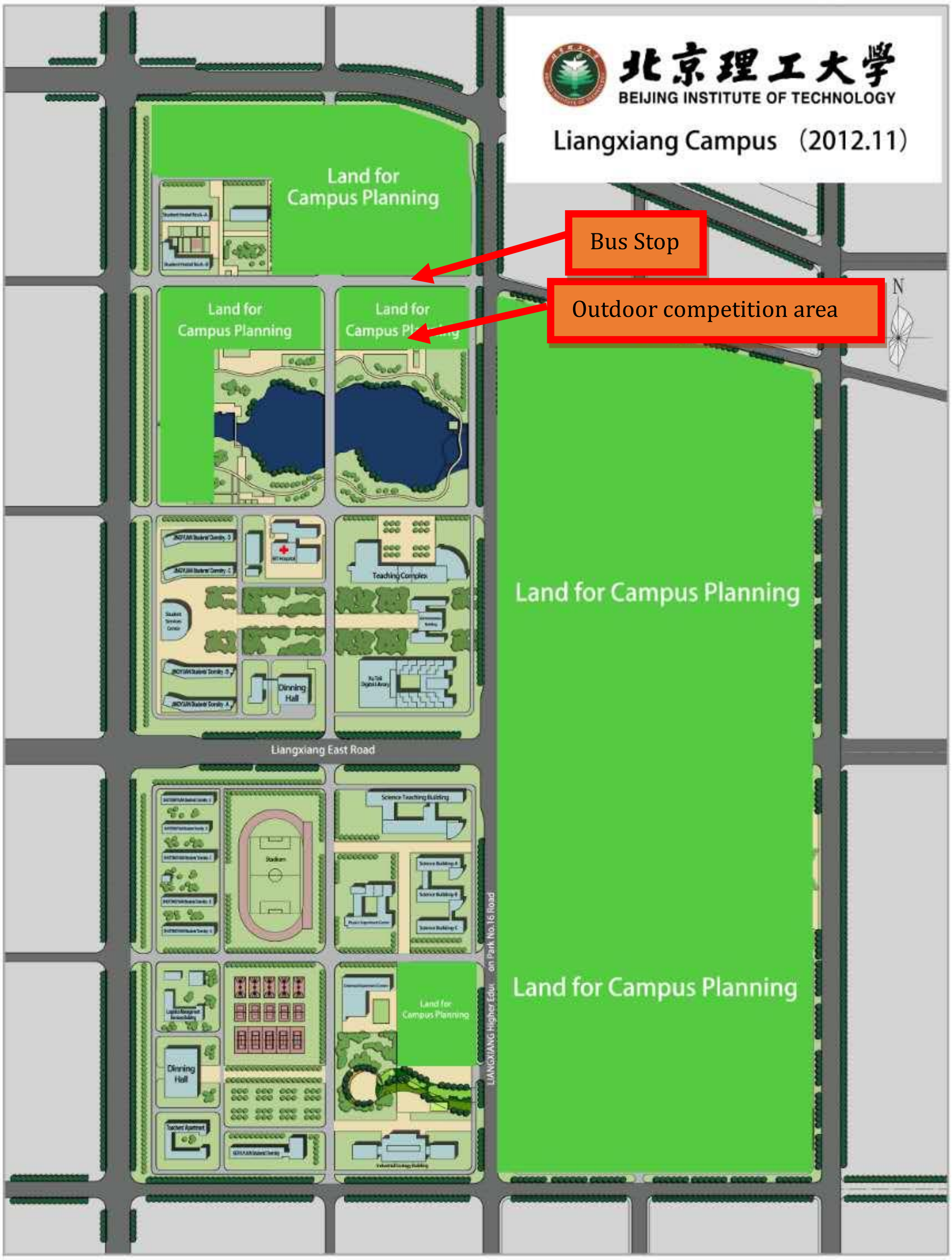
Beijing Institute of Technology ( ): East gate

Opening /Closing Ceremony area ( ): First floor of Central Building

Conference area ( ): Fifth floor of Graduate Building

Indoor Competition area ( ): Gymnasium of Beijing Institute of Technology

Outdoor Competition area



Beijing Institute of Technology

Founded in Yan'an in 1940, Beijing Institute of Technology (BIT) is a national key university, an open, international and research-oriented university of science, engineering and humanities. It is one of the first universities to run a graduate school and receive privileged funding from the central government in the consecutive "Five Year Plan". BIT is also one of the national "Project 211" universities receiving preferential support from the state. In 2000, BIT was listed in the "985 Project", which gives priority to development by Commission of Science Technology and Industry for National Defense (COSTIND), Ministry of Education (MOE) and Beijing Municipal Government. In 1999, BIT passed the evaluation for "Outstanding in Undergraduate Program" sponsored by MOE. Under the administration of Ministry of Information and Industry, BIT ranks among the first-class universities for its high education and research performance, strong faculty, and distinctive academic programs. In 2007, BIT got straight A's in MOE undergraduate program evaluation. This year is the 75 anniversary of the foundation of Beijing Institute of Technology.

Tour Guide

The Forbidden City

The Forbidden City was the Chinese imperial palace from the Ming Dynasty to the end of the Qing Dynasty. It is located in the middle of Beijing, China, and now houses the Palace Museum. For almost five hundred years, it served as the home of emperors and their households, as well as the ceremonial and political centre of Chinese government.

Built from 1406 to 1420, the complex consists of 980 buildings with 8,707 bays of rooms and covers 720,000 m2 (7,800,000 sq.ft.). The palace complex exemplifies traditional Chinese palatial architecture, and has influenced cultural and architectural developments in East Asia and elsewhere. The Forbidden City was declared a World Heritage Site in 1987, and is listed by UNESCO as the largest collection of preserved ancient wooden structures in the world.

Since 1925, the Forbidden City has been under the charge of the Palace Museum, whose extensive collection of artwork and artifacts were built upon the imperial collections of the Ming and Qing Dynasties. Part of the museum's former collection is now located in the National Palace Museum in Taipei. Both museums descend from the same institution, but were split after the Chinese Civil War.

The Great Wall

He who doesn't reach the Great Wall is not a true man.

The majestic Great Wall touches the billows of the Bohai Sea in the east, and traverses the vast expanse of the Gobi Desert in the west. It crosses prairies and deserts, nestles up to the Yellow River, surmounts high mountains, stretches 10,000 li and, like a soaring dragon, leaps over the boundless land of China. It was built with the blood and sweat of the laboring people of ancient China. It is a symbol of the brilliance of China's ancient culture and a pride of the Chinese nation.

The Great Wall of China possesses thousands of famous passes. Badaling, located in the outer town of Juyong Pass, is eulogized as one of the top nine passes in the world. It boasts strategically important position, long history, rich culture, spectacular architecture, inspiring sight, and great fame. For these reasons, it is rated as the best of all famous passes. Badaling Great Wall is the outstanding representative of the Great Wall of China. It is the best part of Ming Dynasty Great Wall. It is a precious part of human cultural heritages and a center of attention for world tourists.

Badaling Great Wall embodies the wisdom and civilization of the Chinese nation. It is laid with historical heritages of thousands of years. Badaling Great Wall, a place contested by all strategists since ancient times, is endowed with new historical missions these days. It strides across high mountains, straddles deep oceans, crosses time and space, and serves as a bridge of friendship for all people of the world. The seeds of friendship are sown here. The songs of peace are sung here. Let us pray – May the flowers of true friendship never fade at Badaling Great Wall!

The Summer Palace

The Summer Palace is a monument to classical Chinese architecture, in terms of both garden design and construction. Borrowing scenes from surrounding landscapes, it radiates not only the grandeur of an imperial garden but also the beauty of nature in a seamless combination that best illustrates the guiding principle of traditional Chinese garden design: "The works of men should match the works of Heaven". In December 1998, UNESCO included the Summer Palace on its World Heritage List with the following comments: 1) The Summer Palace in Beijing is an outstanding expression of the creative art of Chinese landscape garden design, incorporating the works of humankind and nature in a harmonious whole; 2) The Summer Palace epitomizes the philosophy and practice of Chinese garden design, which played a key role in the development of this cultural form throughout the east; 3) The imperial Chinese garden, illustrated by the Summer Palace, is a potent symbol of one of the major world civilizations.

The Summer Palace, originally named Qingyi Yuan or the Garden of Clear Ripples, was first constructed in 1750. It was razed to the ground by the Anglo-French Allied Forces in 1860. The Government of the Qing Dynasty started to rebuild it in 1886 with funds that it had misappropriated from the Imperial Navy and other sources. Renamed two years later as Yihe Yuan or the Garden of Health and Harmony, it was supposed to serve as a summer resort for the Empress Dowager Cixi. Known also as the Summer Palace, it was ravaged by the Allied Forces of the Eight Powers that invaded China in 1900. The damage was repaired in 1902. Since the founding of the People's Republic of China, the Summer Palace has undergone several major renovations. Its major attractions such as the Four Great Regions, Suzhou Street, the Wenchang Galleries and the Plowing and Weaving Scenery Area have been successively restored.

Beihai Park

Beihai park is located in the center of Beijing, it was first built more than 1,000 years ago during Liao Dynasty. It is also the best-preserved imperial garden in China.

Hall of Heavenly King

It was built in the Ming Dynasty and was the place to translate and print the Tibetan Buddhist scriptures.

Nine-Dragon Screen

There are three Nine-Dragon Screens in China, the largest one is in the city of Datong, Shanxi Province. The other one is in the Forbidden City. The one in Beihai park is the best one because it is the only one in China that nine dragons were built on double sides. Originally, the screen served as a screen for a temple behind it, but in 1900, the temple was destroyed and only the screen has remained.

Iron Screen Wall

This wall is actually a piece of artwork carved from lapillus, but as the brown color looks like the color of iron, people named it “Iron Screen Wall”. It is a masterpiece of Yuan Dynasty and was finally moved to Beihai Park as a decoration. Nowadays in Beijing, there are a lot of carving sculptures made in Ming and Qing Dynasty, but rarely can we find one made in Yuan Dynasty. So the Iron screen wall has great artistic value.

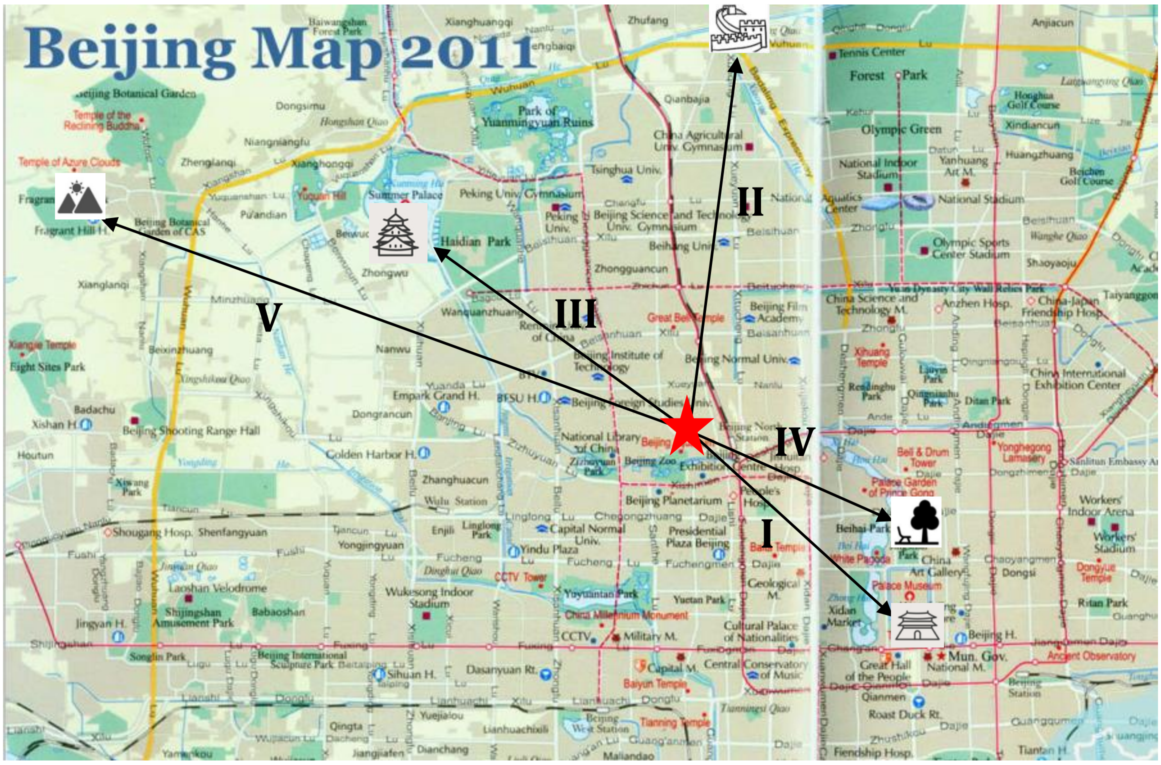
The Fragrant Hill

The Fragrant Hill, as the most beautiful sight in autumn Beijing, wins its fame all over the world with its maple leaves. The park is beautiful in other seasons too. The park has a long history.

Palace were built up here for the royal sojourns in Jin, Yuan, Ming and Qing Dynasties. In the 10th year of the Qianlong Era of the Qing Dynasty, Jingyi Garden was set up here which consists of 28 scenic sports and was known as the famous "three hills and five parks" in the suburbs of the city.

In 1956 the Garden first opened to the public. Three best routes are recommended to the tourists to climb the hill for sightseeing and each winds through respectively the northern, the middle, the southern part of the hill. Touring through the hill takes about 2 hours. The Fragrant Hills boasts of its beautiful landscape and tourists through out the four seasons. The most beautiful sight here is the maple leaves. They grow on the smoke trees and turn red after frosts in late autumn. Then all the hills are attired in these maple leaves which seem to reach the rosy clouds in the sky.

Tour Map



I: From BIT to The Forbidden City.	Distance: about 11.8km
II: From BIT to Badaling Great Wall.	Distance: about 67.3km
III: From BIT to The Summer Palace.	Distance: about 7.5km
IV: From BIT to Beihai Park.	Distance: about 10.5km
V: From BIT to The Fragrant Hills.	Distance: about 11.8km

Coordinator Information

Roles and Responsibilities	Contact Person	Contact Number	E-mail
General Enquiries	Pei Pei	+8618810577613	344905713@qq.com
Registration	Wanming Yu	+8613717583794	591389818@qq.com
Conference program	Zhihong Peng	+8613910437979	Peng@bit.edu.cn
Outdoor Competition	Teng Long	+8613810027020	tenglong@bit.edu.cn
Indoor Competition	Tao Song	+8618610806873	10901034@bit.edu.cn
Lodging Meals and Transportation	Yinan Yu	+8613439696962	caesar.happy@163.com