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Team members

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Abstract

We present the design and development of a novel VTOL UAV to tackle two main issues with unmanned aerial systems, namely flight endurance and carrying large payloads. This new design is the result of significant improvements of an existing commercial product from *4Front Robotics* called Navig8. The design consists of a central gas-powered engine and three rotors. Each rotor is equipped with one variable pitch propeller where the pitch angle is controlled by individual servo motors. In addition, two out of the three rotors are allowed to tilt independently about the lateral axis of the vehicle to increase maneuverability in the system allowing the vehicle to reach speeds up to 200 km/hr. Furthermore, the propellers are also ducted to increase their efficiency in hover and the fuselage is streamlined to minimize drag forces in forward flight. The vehicle is designed such that it could be scaled easily and could be used in a variety of applications.

The use of gas-powered engine not only allows the vehicle to reach flight times up to 150 minutes but also makes it possible to carry payloads ranging from 5 lbs to 70 lbs (depending on the size of the vehicle). We are in the process to extend these limits by experimenting different configurations and optimizing power to weight ratio.

The vehicle also has a variety of sensors including: Dual IR Cameras, LiDAR, GPS, Altimeter, 3D Camera, etc. The vehicle has a computing unit which is responsible for controlling the vehicle. The control is achieved through thrust vectoring and actively changing the location of center of mass of the vehicle. The vehicle could be controlled manually, semi-autonomous or fully-autonomous depending on the application and situation. The vehicle could also connect to the ground control station or mobile devices to communicate with firefighters.

In terms of safety, we propose the following main options: i) a parachute will be added to the system which will be activated in case of engine failure or loss of control, and ii) a small additional battery and electric motor is onboard the vehicle for emergency situations when the gas-powered engine fails. In the second scenario, when the gas-powered engine fails, the electric motor will be engaged automatically and using the emergency battery pack it could power the main rotors for a short period of time (up to 3 minutes) to land the vehicle safely. Another safety feature in the vehicle is the use of ducts for propellers which makes the vehicle safer when operating in public.

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Project Description

Strategic Alignment

Our design is portable, scalable and gas-powered VTOL UAV for helicopter impenetrable (confined) environments. This UAV is capable of performing highly stable knife-edge acrobatic maneuvers that no other gas VTOL aircraft can execute such as pitched hover, and landing & taking off from highly slopped surfaces (e.g., 40 degrees and larger depending on the terrain characteristics) use of variable-pitch propellers and an active center of mass change enables this UAV to execute a wide variety of missions in and fly at low altitudes & in close proximity to objects. It also features long endurance flights up to 150 minutes and exceeds the speed limit of most of the UAVs in the market (up to 200 km/hr). The gas-powered engine also enables us to carry heavier payloads compared to the competitors in the market.

This UAV can be manufactured in various sizes depending on mission requirements such as payload, range and autonomy. The UAV can be controlled manually (via a RC control joystick) or via an onboard computer connected to a ground control station or a mobile device from where flight missions can be loaded or changed as the aircraft flies. These capabilities could be used by firefighters (or other users) to plan their missions or control the vehicle within a specified range from the UAV.

Technical Outcome

Our design is based upon a commercially available vehicle called Navig8 from 4Front Robotics company based in Calgary. Figure 1 depicts the schematic of Navig8 UAV. Navigate is currently using three motors working independently. Also, the safety features mentioned in the abstract are absent in this design. We are improving the vehicle significantly by replacing all the motors with one central motor that is gas-powered. In addition, we will implement new control strategies by taking into account the effects of adding the central engine to the vehicle and studying its effects on stability and power consumption. Our preliminary results show that these improvements leads to significantly changing the power consumption of the vehicle.

Furthermore, we are adding two important safety features to the vehicle by adding a parachute which activates in case failure in the central engine. Also, we are adding an emergency battery and motor set to the vehicle which will be automatically engaged in case of failure in the main engine and could power the rotors up to three minutes which would be enough for safe landing of the vehicle.

Finally, using computer vision techniques, the vehicle will be able to navigate safely in GPS denied environments and explore places where humans cannot go.

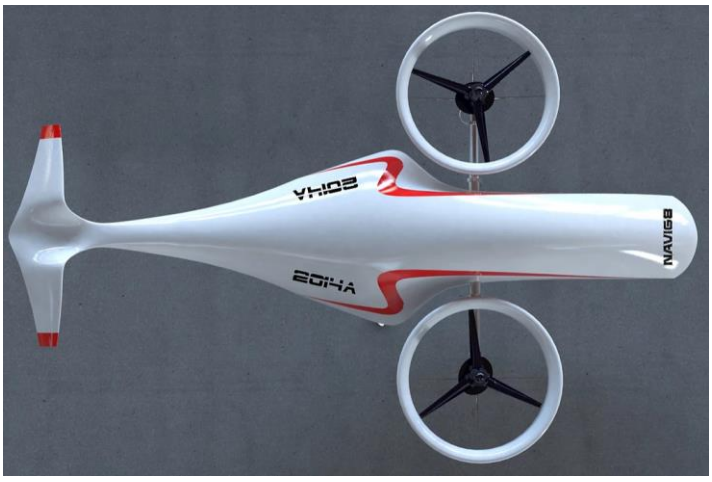

Figure 1. Navig8 UAV from 4Front Robotics company.

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Team

Our team is consisted of four members, three of which are university professors with more than 10 years collaborating with companies in north America and with decades of research experience related to unmanned systems and aerial vehicles. The fourth member of the team is a recent graduate and is holding a bachelor's degree in aerospace engineering and a master's degree in industrial systems engineering. Below you can find background information about each individual which clearly shows the relevance of their qualifications and achievements to the theme of the competition.

Dr. M. Mehrandezh is a full time professor in the Faculty of Engineering & Applied Science at the University of Regina. Mehrandezh's research revolves around, robotics, vision, and control. The synergetic connection between these applied to the design of mechatronic systems has been the main focus of his work for the past decade. Dr. Mehrandezh has a Bachelor degree in Mechanical Engineering (from the Sharif University of Technology in Tehran - Iran), a Master of Science degree in Mechanical Engineering (from the Queens University in Kingston - Canada) and a Doctorate degree in Mechanical & Industrial Engineering (from the University of Toronto - Canada). He also spent 2 years as a post-doctoral fellow at the Simon Fraser University in Burnaby, Canada. Dr. Mehrandezh's current projects include work with diverse companies including SeedHawk, SeedMaster, Salford Group, Inuktun, and Quanser on design and development of unmanned systems for industrial inspection of the infrastructure, precision agriculture, and industrial automation. A paper on mono-spinners under the title: "Revised propeller dynamics and energy optimal hovering in a mono-spinner" received the best paper award in the 4th International Conference of Control, Dynamic Systems, and Robotics (CDSR'17) held in Toronto, Canada in August 2017. The pipe crawling robot developed in Mehrandezh's group was highlighted as one of the 5 high-tech fixes to infrastructure in the Popular Mechanics magazine in 2009. A team lead by Mehrandezh won the completion in 2016 AgBOT challenge held in Indiana in summer 2016 with a prize money of US$50K. The theme of the challenge was on design and development of fully automated seeding in agriculture. Dr. Mehrandezh's next set of goals is to improve the VTOL UAV technology making them safer, being able to stay airborne longer, and more energy efficient. Mehrandezh holds a patent on adaptable climbing machines under the US provision category: US20130328290 A1.

Dr. A. Ramirez-Serrano is a full time professor at the University of Calgary, where he has served on diverse roles including a former director of the graduate program and current founder and director of the Autonomous Reconfigurable Robotic Systems Research Laboratory. Dr. Ramirez-Serrano performs research and development activities in the area of unmanned vehicle systems (UVS). Dr. Ramirez-Serrano is also the founder and CEO of 4Front Robotics, a Calgary based robotic company that develops highly maneuverable drones and custom field unmanned vehicles for deployment in highly confined spaces such as collapsed building. Dr. Ramirez-Serrano has a bachelor degree in Mechanical Engineering (from the Universidad Autonoma Metropolitana - Mexico), two Master of Science degrees, one in Mechanical & Aerospace engineering (from the Illinois Institute of Technology - USA) and a second in Computer Science in the area of Artificial Intelligence (from the Monterrey Tech - Mexico). He also has a Doctorate degree in Mechanical & Industrial Engineering (from the University of Toronto - Canada). His industrial experience includes mechatronic engineer at ABB Corporate Research (Sweden), and research engineer at Argonne National Laboratory - West (USA) where he developed smart field robotic devices. His areas of expertise are in the design of VTOL (Vertical Takeoff and Landing) and transitional aircrafts, control, navigation, and modeling of UVS and robots for deployment in search and rescue operations. His work also includes the development of humanoid robotics with applications to pediatric care where Dr. Ramirez-Serrano has employed robots to significantly reduce children stress, increase children's hospital experience, and reduce the time nurses and doctors take to apply a given procedure in some cases by more than 50%. Current projects of Dr. Ramirez-Serrano include work with diverse organizations and companies including NASA, Genesis, and Veerum. Dr. Ramirez-Serrano's next set of goals in pushing UAV technology to the next level include the development of highly maneuverable transitional UAV systems and aerial manipulators. His work includes aircraft design and control,

reconfigurable ground and aerial systems, development of humanoid robots for health care, and development of high speed unmanned vehicle for challenging operations.

Dr. R. Paranjape's research interests are in both physical systems and software systems. Research in physical systems has focused on the development of sensor systems and new technologies in image and signal processing for real world applications in robotics and automated systems. Within the area of sensor technologies research applications include sensor packs for robotics in charged water pipe inspection, and flying robots (UAVs) using both vision and inertial sensor arrays. Dr. Paranjape also has a strong research program in mobile and software agent systems in Simulation and Modeling. There are two main areas in this work: Analysis and Retrieval of Medical Data and Modeling of Power Systems and Smart Grids. Dr. Paranjape has worked as a Research Scientist, Software Engineer, Project Leader, and Project Manager in Canadian Industry. He is currently the Professor of Electronic Systems Engineering at the University of Regina. He has published 51 reviewed journal articles and book chapters, 84 conference papers and has numerous grants and research projects.

Mojtaba Hedayatpour is a lecturer at university of Regina focusing on design and development of unmanned aerial vehicles and robotic systems. He is the recipient of graduate studies scholarship. He earned his bachelor's degree in aerospace engineering at Sharif University of Technology as the most prestigious university in Iran. He is experienced in robotics, automation and artificial intelligence. In 2015, he joined university of Regina Unmanned Aerial Vehicles laboratory. In 2016, he was a speaker at the second world congress on Industrial Automation and Robotics in Philadelphia talking about applications of artificial intelligence in industrial systems. He also has published several academic papers in internationally renowned conferences. A paper on mono-spinners under the title: "Revised propeller dynamics and energy optimal hovering in a mono-spinner" received the best paper award in the 4th International Conference of Control, Dynamic Systems, and Robotics (CDSR'17) held in Toronto, Canada in August 2017. Outside of work, he is mostly involved in developing his own ideas in robotics and sometimes is trading in financial markets.

Plan

Using the expertise and years of experience of the team members, we are confident that we could manage to improve the Navig8 platform (provided by the 4Front Robotics) in a reasonable time frame in line with the requirements of the challenge.

The competitive advantages offered by our team could be summarized as follows:

1. Increasing the power to mass ratio in UAVs by using a central gas-powered engine and transferring torque to all the rotors in the system.
2. Improving payload carrying capabilities of UAVs by using gas-powered engines
3. Increasing the endurance of UAVs using gas-powered engines (up to 150 minutes) which is perfect for hovering applications such as monitoring, surveillance and etc.
4. Using our proposed aerodynamic and streamlined design of the fuselage as well as the configuration of the rotors, we could reach speeds up to 200 km/hr in forward flight which could be useful in emergency situations and acting as first responders.
5. Using computer vision techniques, our vehicle is able to navigate and operate in GPS-denied environments which is again crucial in emergency situations where humans cannot go simply because the environment is could be hazardous.
6. Adding redundant communication devices to the vehicle to make sure it will stay connected to the ground control station or the mobile devices given to the users (e.g., firefighters) such that they can control the vehicle manually or define autonomous missions on the fly.

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Resume Information for Key Team

Dr. Mehran Mehrandezh

Professor, University of Regina. Author and co-author in 55 Conference and 28 Journal papers:

Selected Conference Papers:

[**C1**] M. Hedayatpour, M. Mehrandezh, F. Janabi-Sharifi, "A Unified Approach in Configuration-based Dynamic Analysis of Quadcopters for Optimal Stability", in 2017 "IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS'17)", September 2017, Vancouver, Canada.

[**C2**] M. Hedayatpour, M. Mehrandezh, F. Janabi-Sharifi, "Design and Development of a Holonomic and Power Efficient Multi-rotor UAV", in 2017 "IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS'17)", September 24-28, 2017, Vancouver, Canada.

[**C3**] M. Hedayatpour, M. Mehrandezh, F. Janabi-Sharifi, "Revised propeller dynamics and energy-optimal hovering in a monospinner', in the "Proceedings of the 4th International Conference of Control, Dynamic Systems, and Robotics (CDSR'17)", August 2017, Toronto, Canada, pp. 135-1 - 135-8 (Best Paper Award).

[**C4**] M. Kazemi, M. Mehrandezh, and K. Gupta, "Sensor-based Robot path Planning using Harmonic Function-based probabilistic Roadmaps", Proc. of the International Conference on Advanced Robotics (ICAR), Seattle, WA, USA, July 18-20, 2005, pp. 84-89.

Selected Journal Papers:

[**J1**] A. Dehghan, M. Mehrandezh, R. Paranjape, "Optimal Spatial Resolution of Dioptric and Catadioptric Imaging Systems with Collimated Laser Light in Pipe Inspection Applications", International Journal of Opto-mechatronics, Vol. 9, pp. 261-294, 2015.

[**J2**] M. Alizadeh, M. Mehrandezh, and R. Paranjape, "Vision-based Adaptive Prediction, Planning and Execution of Permissible and Smooth Trajectories for a 2-DOF Model helicopter", Canadian Aeronautics and Space Journal (CASJ), Vol. 59, Issue 3, 2014.

[**J3**] M. Kazemi, K. Gupta, and M. Mehrandezh, "Randomized Kinodynamic Planning for Robust Image-based Visual Servoing", IEEE Transaction on Robotics, Vol. 29, Issue 5, 2013, pp. 1197-1211.

[**J4**] M. He, C. Ratanasawanya, M. Mehrandezh, and R. Paranjape, "UAV Pose Estimation using POSIT Algorithm", International Journal of Digital Content Technology and its Applications (JDCTA), Vol. 5, No. 4, pp. 153-159, 2011.

Recent Graduate Students – last 10 years [Graduated (current students under supervision)]

Post-doc-fellows: 1 *PhD: 2 (3)* *MSc: 16 (5)* *BSc:* 6 (1)

Dr. Alejandro Ramírez-Serrano

Professor University of Calgary, and Founder/CEO 4Front Robotics Ltd.

Selected Conference Papers:

[**C1**] Ashraf M. Kamal D., and Ramirez-Serrano A., "Development of a Preliminary Design Methodology for Transitional UAV", AIAA Science and Technology Forum and Exposition, January 8-12, 2018, Gaylord Palms, Kissimmee, Florida, USA.

[**C2**] Majnoon, M., Samsami, K., Mehrandezh, M., and Ramirez-Serrano, A., "Mobile-target Tracking via Highly-maneuverable VTOL UAVs with EO Vision", Conference on Computer and Robot Vision, Victoria, BC, Canada, June 1-3, 2016.

[**C3**] Bagheri, P., Ramirez-Serrano, A., and Pieper, J.K., "Adaptive Nonlinear Robust Control of a Novel Unconventional Unmanned Aerial Vehicle", 14th Intl. Conf. on Intelligent Systems and Control, November 11-13, 2013, Marina del Rey, USA.

Selected Journal Papers:

[**J1**] Gress, G., and Ramirez-Serrano, A., "Enabling passive hover stability in bicopters using lift-propeller gyroscopic properties", J. of American Institute of Aeronautics and Astronautics (AIAA), (Under review).

[**J2**] Bagheri, P., Ramirez-Serrano, A., and Pieper, J.K., "Adaptive Nonlinear Robust Control of a Novel Unconventional Unmanned Aerial Vehicle", J. of Control and Intelligent Systems, Vol. 43, No. 1, 2015.

[**J3**] Amiri N., Ramirez-Serrano A. and Davies R., "Integral Backstepping Control of an Unconventional Dual-Fan Unmanned Aerial Vehicle", J. of Intelligent and Robotic Systems, 2012.

Dr. Raman B. Paranjape

Professor, Electronic Systems Engineering, University of Regina

Career Highlights and Achievements:

1. Selection of the TransitLive Configuration (TLC) by Association of Professional Engineers and GeoScientists of Saskatchewan (APEGS) for the 2010 Exceptional Engineering/Geosciences Project Award.
2. Selection of the Regina Pipe Crawler to be presented in Popular Mechanics – international magazine and web site. See: http://www.popularmechanics.com/technology/gadgets/news/4322589.
3. Successful NSERC Strategic Award – for $360,000 over 3 years. (with M. Mehrandezh, L. Benedicenti, N. Sarshar) This NSERC application was led by R. Paranjape and was in a ground-breaking new area of Unmanned Aerial Vehicles (UAVs) for the University.
4. Chief Executive Officer (CEO) of CRL Engineering Ltd., an information technology startup based in Regina with five employees.
5. Invited to participate in the IBM Almaden Research Conference 2010, Smarter Health through Modeling and Simulation, April 28-29, 2010, in San Jose, California, (this is a by-invitation-only conference organized annually by IBM Almaden). This is a bull-pit session in which IBM tries to distill the various trends, pressures and expectations in order to determine their strategy in this multi-billion dollar business.
6. Publication of major Agent Systems monographs titled, "Multi-Agent Systems for Healthcare Simulation and Modeling" (IGI Global) and "The Diabetic Patient Agent" (Springer).