THE FUTURE OF DRONES: TECHNOLOGIES, APPLICATIONS, RISKS AND ETHICS

Background and motivation

In the last few years, several public and private research developers started investing a considerable amount of resources for the construction of human-friendly unmanned aerial vehicles (UAVs), or 'drones'. These devices immediately found a great deployment in the society opening an incredible amount of new opportunities as useful tools to address a variety of societal challenges, including agriculture and forest analysis, identifying property boundaries, surveying construction sites or corridors for roads and railroads, stockpile volume calculations, flooding and coastal erosion assessments, building information management, disaster planning and handling, surveys in remote or undeveloped areas, and the delivery of goods. The possibilities of digitalisation and technology development address societal challenges such as making societal sectors and domains more ecosystem friendly, efficient and competitive. This project will work to define societal challenges and ways to address them using applications of drone technology. The project will also study potential (unintended) consequences of such applications in terms of risks and ethical questions.

Despite the enormous achievements, drones have sufficient control autonomy and capability to complete only part of these activities and the majority of the applications previously described still rely on human supervision. This platform represents an important opportunity to develop and combine cross-disciplinary research activities in several strategic fields. Lund University has several ongoing activities and expertise related to autonomous drone flights, e.g. the drone pilot education at the School of Aviation in Ljungbyhed, the infrastructure projects ICOS, ACTRIS, NordSpec, and SITES Spectral, and research in remote sensing, drone archaeology, image analysis, machine learning, robot technology, air quality, and GIS. Strengthening and coordinating this capacity will enable rapid growth in terms of research, capacity building, and collaboration within the university. It will also stimulate regional development and innovation by increasing the collaboration with local companies and authorities.

Objectives, aims and expected results

The project aims at strengthening the capacity within Lund University to address the societal needs by establishing an interdisciplinary platform for the development and application of autonomous drone systems for a variety of societal sectors. Within the platform, the aim is to connect and tie together established technology development (e.g. robotics, AI, image processing), research application (e.g. remote sensing and the study of cultural heritage) and applications in different societal sectors (e.g. forestry, agriculture, energy, construction, rescue operations) to make them inform of each other in a collaborative learning environment and create new synergies. We also aim to incorporate and integrate user views and perspectives to enable the development of knowledge and innovation directed towards private companies as well as the public sector. The project is expected to result in an increased network of collaborating partners, interdisciplinary grants for research and demonstrable applications for autonomous drone operations in the selected areas (see below).

Project description

The project is managed through a steering committee with representatives from three LU faculties (LTH, Science and Humanities and Theology). The project is coordinated by a project coordinator (the main applicant). In order to ensure the project's outreach and communication, both internally at LU but mainly externally with other partners, a communicator is also assigned part-time to the project.

The core activity of the project is the organization of six working themes for focused interdisciplinary collaboration between scientists and external partners to build a strategic network and competence for solving selected challenges. This will make it possible to identify and address strategic issues which will allow 1) increasing our understanding of limits and potentials of drones, 2) identifying key elements of major societal impact to address and 3) building a robust and versatile platform at Lund University capable of proposing innovative research for the development and use technology. The WTs with their assigned WT leaders are introduced below. The WTs are not sub-projects or with defined WT groups. Instead, the WTs are supposed to overlap and inform each other, and participants in the project are encouraged to participate in activities organised within different WTs.

WT1: Drones for addressing societal challenges. There is a very high potential for use of drone data within a variety of societal fields, however, currently there is a knowledge gap between technology developers and stakeholders. The project aims at bridging this gap by creating an arena for knowledge sharing and to identify needs and means for technology to address the societal challenges. Communication and information exchange is a key tool in this process. The project will stimulate this exchange across several sectors, and will also focus on a set of demonstration projects, initially four, that will act as models for future expansion:

- Agriculture: based on ongoing collaboration with SLU the project will focus on the societal need to make agriculture more efficient and sustainable (precision agriculture). A first focus is on technological development on the use of autonomous drone systems for optimised use of pesticides and fertilizers.
- Forestry: we will focus on the use of drones for identifying forest damage and needs for management interventions. Thus, the methods should enable rapid and automatic identification of damaged trees, but also of areas of protection, e.g. wetlands, rare tree species etc.
- Archaeology: we will focus on the study of drones for cost-efficient and automatic detection and recording of new archaeological sites. The result of such work will provide important indications on which areas need to be preserved from extent urban development.
- Town planning and management: the project will explore rational use of this new technology for 3D-mapping and surveying of urban areas.

The long-term aspects will include systems that provide a large degree of autonomy, not only in flying but also in the identification of the problem, the required action, and carrying out possible counter-active measurements. *WT Leader: Nicoló Dell'Unto*

WT2: System autonomy. One societal need is to make systems of drones more autonomous and connected. This will allow formation flying and mission-based flying, e.g. for the surveillance and assessment of the status of a particular forest at a particular time. At Lund University, the Robotics Laboratory is involved in such research which will be a key aspect of this suggested collaboration project. Already involved in the WASP programme, Robotics lab contributes to the development and testing of algorithms for formation flying, mission path planning, and sensor fusion. *WT leader: Rolf Johansson*

WT3: Sensor data analysis. Rapid advances in microelectronics have enabled small and lightweight cameras and other instruments to be mounted on-board drones for collection of a variety of data (ranging from simple commercial cameras to multispectral, thermal, and laser sensor). The technical development of new equipment is fast, and today the challenge lies in the development of efficient systems for data analysis that can appropriately serve both researchers and a wider user community.

Common to the analysis is the required capability to combine observations across space with the varying conditions encountered during flights at different times. The WT will develop and harness collaboration between LTH (Electrical and information technology) and the Faculty of Sciences (Mathematics and Physical Geography). *WT Leader: Lars Eklundh*

WT4: Computing. Drones have the capacity to acquire a huge amount of high resolute data in very short time, which, in order to be used, need to be analysed and processed rapidly. The high demand of computational resources needed to handle these data currently represent obstacles for the development of new research activities. By involving the Centre for Scientific and Technical Computing (LUNARC), at Lund university a discussion concerning the development of customized High Performance Computing facilities for drones will be defined. In specific by defining strategic datasets of information capable of serving a huge number of disciplines, the network will identify guidelines and needs for the future construction of dedicated high computational resources. *WT Leader: Jonas Lindemann*

WT5: Legal and ethical aspects. Several challenges for the operation of drones, especially for research purposes, are related to the regulatory frameworks. In January 2018 new European regulation is implemented which redefines who gets to fly in what way. Through Lund University School of Aviation (LUSA) and its recently started training programme for commercial drone operators, Lund University has a unique expertise into the regulatory frameworks surrounding drone operations. The various areas of applications for drones further necessitates an informed and critical discussion on the ethics of this technological development. The collaboration platform will include forums for asking questions related to the potential (intended and unintended) ethical consequences of the development which it is part of driving. *WT Leader: Johan Bergström*

WT6: The future of flying. Development of future drones will require combined research efforts from several disciplines. One must consider aerodynamic efficiency as well as aerodynamic stability, and if the stability should be inherent or achieved by control algorithms. New advanced materials (perhaps even "active" materials) should be developed especially for the morphing wing and ornithopter applications ("flapping wings"). In addition, one should consider the propulsion and energy system of the drone (electrical motors, solar cells, batteries etc.) and also that new designs may have complex shapes which need the use of added manufacturing. In the context of ornithopters one should also perform more studies on animal flight. Hence, this collaboration project intends to bring together scientists from several areas, such as aerodynamics, control theory, manufacturing technology, materials engineering, biology, etc. *WT Leader: Johan Revstedt*

Planned activities

The collaboration platform will be established and developed through workshops, yearly symposiums and the collaborative use of testbeds to develop, test and refine technologies, solutions and applications.

Workshops. All working themes are expected to have at least one yearly workshop (for a total of six workshops each year), inviting the project members as well as external partners to participate in discussions on core challenges, opportunities and research proposals related to the theme.

Yearly symposium. The project will each year hold a project symposium, inviting field-leading experts to participate in discussions. These symposiums are expected to widen our network of collaborators, but also deepen our knowledge in our own field of view.

Communication. The project will assign a designated communicator to ensure ongoing and active communication activities. The project's outreach will take place mainly through the development and continuous maintenance of a website. The website will ensure internal as well as external communication. With the development and application of drone technology being a societal challenge with good media impact the communicator will also make sure that the project is visual in news media and domain-specific media for the project's focus areas.

Cross-disciplinary workshops and a PhD course. The project will offer the opportunity to give cross-disciplinary workshops (at least two per year) in which MSc and PhD students from different LU faculties will be given the opportunity to share their research with the project participants and external partners. The aim is that by year three of the project, these workshops should be integrated as part of a novel PhD course on Technology and Applications of Drones related to the project's research areas.

Access to testbeds. Ultimately, project participants should come together to test and apply technologies and solutions using one or several of the projects assigned testbeds. The testbeds are represented as internal or external actors and the project coordinators will work in close collaboration with the testbed representatives to make sure that they are available for both the internal and external project partners to use. By the end of the project the aim is to demonstrate several test cases using the testbeds.

Preparing proposals for upcoming calls. An important activity for the project includes the collaborative writing of proposals for external research funding. Upcoming calls include:

- Vinnova call on 'the drone of the future', March 2018
- Upscaling of WASP to include basic research on autonomous operation and AI.
- The strategic Swedish Aviation Innovation Programme, (INNOVAIR), 2018

Project participants and resources

LU researchers

The table below lists the LU departments which are initially participating in the project. Please note that even though only one 'point of contact' is given, each department might be represented by several faculty members. In the start-up phase of the project, the LU contact list comprises 25 faculty members.

LU Faculty	**LU department**	**Point of contact**	**Title**	**Department expertise**
Faculty of Engineering, LTH	Lund University School of Aviation	Johan Bergström	Docent, senior lecturer, project coordinator	Risk/Safety, Aviation
	Automatic Control	Rolf Johansson	Professor	Control, Robotics, Automation, Autonomous systems
	Electrical and Information Technology	Fredrik Tufvesson	Professor	channel modelling, wireless communication
	Nuclear Physics	Erik Swietlicki	Professor, vice Dean	Meteorology and Atmospheric Sciences, Climate Research, Environmental Sciences
	Engineering Geology	Peter Jonsson	Lecturer	Geotechnical, Geophysical, Ocean

				and River Engineering
	Energy Sciences	Magnus Genrup	Professor, Head of Department	Thermal power engineering
	Immunotechnology	Aakash Chawade	Researcher	wheat bioinformatics, disease resistance mechanisms
	Water Resources Engineering	Hans Hanson	Professor, head of division	Coastal Processes, Coastal Engineering, Sea Level Rise
	Fluid Mechanics	Johan Revstedt	Professor	Aerodynamics, principles of flight
	Transport and Roads	Andras Varhelyi	Professor	Road Traffic Safety, Advanced Driver Assistance Systems
	Communications Engineering	Anders J Johansson	Senior Lecturer	Communication Systems, Telecommunications, Accelerator Physics and Instrumentation
Faculty of Sciences	Physical Geography and Ecosystems Science	Lars Eklundh	Professor	Remote sensing, spectral data analysis, image processing, GIS
	Centre for Mathematics Sciences	Anders Heyden	Professor	digital image analysis and computer vision
	LUNARC	Jonas Lindemann	Director	Computing, Parallel processing
	Biology	Eric Warrant	Professor	Animal sensory systems, animal navigation
	Centre for Environment and Science	Natascha Kljun	Professor	Drone remote sensing for carbon estimation
Humanities and Theology	Institute of Archaeology and Ancient History	Nicoló Dell'Unto	Docent, Senior Lecturer, project coordinator	Cultural Heritage, Landscape studies, 3D GIS, spatial analysis, remote sensing.
Social Sciences	Human Geography	Ola Hall	Associate Professor	GIS, Spatial analysis

External participants

The following ten external partners are participating in-, and contributing to, the project. Their role in the project is further outlined in the letters of intent appended the application. Throughout the project we will expand the network of external partners.

ACR, Copenhagen University, Cybaero, Lantmäteriet, LFV, Ljungbyhed Air, Lunds Kommun, University of Siena, Vultus, Wrams-Gunnarstorp

Infrastructure resources

Five infrastructure resources form testbeds for the project to use for development and testing of technologies and solutions.

Lund University School of Aviation and Ljungbyhed Airport

The Lund University facilities at Ljungbyhed Airport will in this way become an important node and testbed for the research platform including drone equipment and a large airspace. Investments in 2018 and 2019 ensure the availability of flexible drones able to carry substantial load. This equipment will be made available for the project participants. Further, the airspace of Ljungbyhed airport gives the possibility to, in a controlled airspace, to operate drones up to an altitude of 2000 meters all the way to the coast of Ängelholm. This will open up great opportunities to experiment with flying out of the line-of-sight in a controlled airspace environment. In order to establish Ljungbyhed Airport as a testbed external actors such as Ljungbyhed Air (a business community working in the interest of the airport) and ACR (the company providing air traffic control to the airspace of Ljungbyhed) are important collaborators who are giving their active support to this collaboration platform.

NordSpec infrastructure and the SITES Spectral Thematic Centre

These infrastructures include drones, personnel, soft- and hardware resources for processing of drone data. *NordSpec* is based on a five-year infrastructure grant from N-faculty (https://nordspec.nateko.lu.se/), and *SITES Spectral Thematic Centre* is a five-year commission to manage data from drones, satellites, and spectral instruments for field stations across Sweden included in the national infrastructure SITES (http://www.fieldsites.se). Both infrastructures are hosted by the Dept. of Physical Geography and Ecosystem Science (PI Lars Eklundh). Strong synergies regarding environmental data collection exist with activities at the international infrastructures ICOS and ACTRIS both with strong involvement and data collection by Lund University.

LUNARC

For computational purposes of vast image data sets, computational power is imperative. LUNARC provides access to the Aurora cluster; consisting of 180 compute nodes for SNIC use and over 50 compute nodes funded by research groups at Lund University. Software for parallel processing has recently been installed for efficient UAV image processing.

The Robotics Lab

The Lund University Robotics Laboratory is co-owned by Dept. Automatic Control and Dept. Computer Science and is centred around industrial manipulators with open control system architectures. The Robotics Lab is currently involved in research on autonomous drone technology and will offer an infrastructure for the development and testing of algorithms for indoor flight, formation flying, mission path planning, and sensor fusion.

Wrams-Gunnarstorp

Wrams-Gunnarstorp is a 3000 hectares estate which conducts farming and forestry outside of Bjuv, Sweden. For several years the estate has used drone technology to conduct different kinds of analyses of its land, including water levels in fields and forest damages. With its location, immediately outside of the controlled airspace of the Ljungbyhed airport; Wrams-Gunnarstorp offers an applied testbed for the project's tests of applications for agriculture and forestry. Wrams-Gunnarstorp is already involved in the commercial drone operator education programme run with Lund University School of Aviation as a leading actor.