Part A
Introduction

A.1 Unmanned Aerial Vehicles (UAVs)

Over the last few years, one of the fastest growing fields of Robotics and Autonomous Systems is the Unmanned Aerial Vehicles (UAVs). There are also other names that refer to this specific fields likes drones, Unmanned Aircraft Systems (UAS) or Unpiloted Aerial Vehicles, all having similar meaning and subtle differences. In general, an Unmanned Aerial Vehicle is an aircraft that can be controlled without humans on board, either remotely or autonomously. Unfortunately, UAVs were made popular when they first appeared because they reduce collateral damage in wars and because were convenient seeing as the controller can be thousands of miles away from the UAV itself. However, this is not the whole truth and the UAVs' field has the potential to be exploited in a wide range of non-military activities with impressive outcomes. The development of this technology has a field of great competence of countries around the globe. Nevertheless, the deployments are not solely based on the technological progress but also on the operation framework that will be imposed by national administration aviation authorities like Federal Aviation Administration (FAA) the States and Civil Aviation Authority (CAA) in the UK.

Similar to any other revolutionary technological development, like the Internet for example, UAVs have faced controversial reactions. Many people feel that UAVs threat their privacy while others look forward to using them to facilitate their business. Furthermore, political and ethical problems pose an issue. The reality is that technologies develop regardless of public issues. It is a question of how they will be used and for what reason. There are cases though, where everyone unambiguously agrees that it is better to use an UAV than the human presence. For example, when the Fukushima Daiichi nuclear power plant was severely stricken by the tsunami, there was no way to assess the contamination since static radiation monitoring stations around the site were disabled. Because of that, a traditional manned airborne was conducted at the nuclear site. Beside the poor resolution of the measurements due to the unfriendly environment, it is clear that the flight crew was exposed to a significant amount of radiation. Consequently, the exploitation of UAVs in places where humans must not be exposed to dangerous situations is of great interest and therefore deserves further research.

The development of the UAVs has related impacts on the national economies as well. However, because of the current airspace restrictions non-defense use of UAS has been extremely limited. A well-known case is Amazon's prime air concept, a futuristic delivery system for his company's products. The biggest hurdle facing Amazon Prime Air is that commercial use of UAV technology is not yet legal in the United States.

A.1.1 Social impact

Unmanned Aerial Vehicles at the early stages of their existence were primarily used for military purposes. UAVs are well suited for long distance missions, reconnaissance, and keeping soldiers safe. They are cheaper than many fighter jets, and their smaller size allows drones. In nine years the Pentagon has raised the drone fleet thirteen times and the military is spending at least $5 billion a year in addition (The Economist, 2011). Generally speaking, there is a concern that attacks and civilian deaths may increase as drone technology becomes available to many militaries (fig.A.1). There are also concerns about safety. Opponents of the UAVs fear that there will be cases where UAVs crashes, collisions with airplanes, or that remote control over them could be lost. Essentially, the facts related with the military use of drones are so obvious that it is difficult to combat the criticism, although this is definitely not the only way to use UAVs. There are many other applications, which can improve peoples' lives drastically.

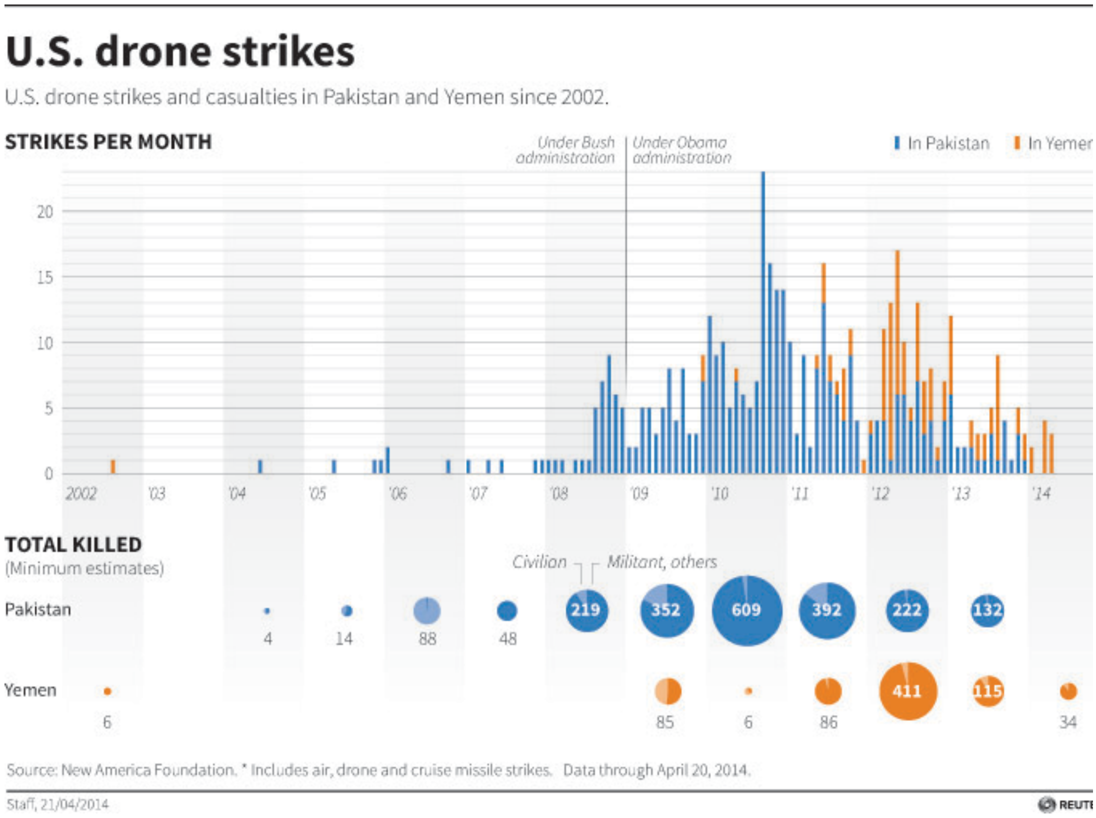

Fig.A.1 This figure displays the number of US drone strikes in Pakistan and Yemen from 2002 to 2013, with an upward trend in drone usage. (image from Reuters, 21/4/2014)

UAVs are increasingly performing civilian tasks as the technology becomes more common (57 countries and 270 companies were producing UAVs in 2013). In the U.S., the Federal Aviation Administration (FAA) predicts that approximately 7,500 commercial small UAVs could be flying in the U.S. within the next five years. Among the wide range of possible applications a general classification of the basic categories is: safety control, scientific research and commercial applications. In order to depict the wide variety of specific areas that will benefit from the UAV usage, I can mention fields like:

- Wildfire mapping
- Agricultural monitoring
- Disaster management
- Thermal infrared power line surveys
- Law enforcement
- Telecommunication

- Weather monitoring
- Aerial imaging/mapping
- Television news coverage, sporting events, movie-making
- Environmental monitoring
- Oil and gas exploration and
- Freight transport.

One additional social dimension of using UAVs is in humanitarian applications. Humanitarian organizations have started to use UAVs for data collection and information tasks that include real time information and situation monitoring, public information and advocacy, search and rescue, and mapping (fig.A.2). Furthermore, they can be used in the area of delivery and logistics for the transportation of small medical supplies, such as vaccines. To address the good practices and guidance related to this approach, the United Nations Office for the Coordination of Humanitarian Affairs (OCHA) has published a pivotal policy document on the use of civilian UAVs in humanitarian settings (Unmanned Aerial Vehicles in Humanitarian Response, 2014).

Fig.A.2 A Sky-Watch Huginn X1 supports the humanitarian response in Tacloban, Philippines after Typhoon Haiyan in 2014 (image from www.irevolution.net)

A.1.2 Ethical impact

It is helpful before analyzing the ethical impacts of UAVs to gain some understanding of the notion of ethics. Ethics in a basic definition relates to agents who execute actions which are then deemed ethical or unethical. As Dwight Furrow states (Wilson, 2014), ethics are related to appraising actions and actions are performed by those capable of being moral agents. Continuing Furrow says, "When we evaluate an action, we can focus on various dimensions of the action. We can evaluate the person who is acting, the intention or motive of the person acting, the nature of the act itself, or the consequences." Consequently, the actions of UAVs are only capable of being assessed based upon the actions of the person controlling them. The ethical issues emerge as the result of the interaction of how the UAV is operated by an operator in contrast with those who experience the UAV's function. There is the controller of the UAV, the UAV, and those who are affected by the activities of the UAV.

One of the simplest applications of an UAV is to use it for aerial photographs. Even an inexperienced hobbyist can buy a ready-to-use kit (UAV equipped with cam) and use it straight away in a park. If the user wants to take photographs for artistic purposes there is no problem. One the other hand, if the picture contains inadvertently other people, this could be considered as an invasion of privacy. It can be made even clearer in a case where someone who wants to follow or stalk another person controls the UAV. It is clear that even the simplest case of using drones for recreational purposes raise ethical problems. Essentially, the great mobility and capabilities of UAVs combined with their wide availability can lead to serious problems. The situation can get even more serious when the operators are experienced and can use special devices to spy on communications. One is for sure, the debate has just started and that it is only going to increase in intensity as the numbers of drones used increase in the near future.

There are many organizations related to civil rights, which already have published recommendations for the civil use of UAVs. For example in the States, the American Civil Liberties Union (ACLU) (Protecting Privacy From Aerial Surveillance, 2011) fears that UAVs' deployment has been held up by the Federal Aviation Administration (FAA) over safety concerns, but the agency is under strong industry and Congressional pressure to pave the way for domestic deployment. It refers to the increasing interest by police to deploy drones for various surveillance tasks but there is a lack of privacy laws strong enough to ensure that the new technology will be used responsibly and in consistence with democratic values. Consequently, they believe that we will end up being a "surveillance society" in which our every move will be monitored, an unfortunate development that would profoundly change the character of public life.

A.1.3 Legal impact

Up to this point I have referred to the numerous concerns about the safety, ethics and privacy impacts of UASs which demonstrates that the use of these devices needs to be regulated. One of the most difficult parts of this task is that the regulatory parameters for the use of UASs is that UAVs range between small size model aircrafts for recreational purposes and military aerial vehicles such as planes and helicopters which are remote-operated. Consequently, UAS law frame are likely to present variations depending on the model, size, weight and speed, leading to regulations significantly more complex and difficult to understand and enforce. The second issue that presents difficulties when it comes to imposing new regulations is the wide range of UAVs applications. The legal frameworks should include policies ranging from surveillance to delivery of goods. Thus, there will inevitably be many legal issues: accidents involving personal injury and property damage, intellectual property issues implicated by the technology used to control UAVs, individual privacy rights, as well as criminal laws coming into play such as stalking, harassment, and wiretapping.

In the States the Federal Aviation Administration (FAA) is in charge of overseeing airspace in the US and the guidance for non-commercial users. What it holds at the moment is that the commercial use of UAVs is illegal although many entrepreneurs envision the next killing?? commercial application of the drones, like amazon's air prime. The rules that apply for the UAV operators can be found in (Faa.gov, 2015). According to FAA's road map of the integration of drones by the self-imposed deadline of 2015, the FAA looks at the use of drones for commercial purposes in order to develop a plan for boosting the use of drones in the US.

In the UK the Civil Aviation Authority (CAA) governs the use of drones. A summary of the legal requirements related to the UAVs can be found in (Caa.co.uk, 2015). Anyone who is using a drone under 20kg for commercial purposes has to be licensed to ensure that they are sufficiently trained to fly the plane and have the appropriate insurance in place.

A.1.4 Industrial impact

Over the past few years, the prospects for a UAV civil market have distinctly improved. The UAV industry is an emerging domain in a worldwide scale. It is dominated by the US and Israeli suppliers followed by the European companies. Less aerospace-developed countries such as China, Turkey and Pakistan are focusing on UAV development. It is predicted that Asia is set to become the second most important UAS market behind the US. China and Japan are likely to be the primary industrial players (Royal Aeronautical Society, 2013). Other countries showing signs of related industrial activity are Poland and South Korea.

The diversity of the companies, which are engaged, with the industry of the UAVs is also an interesting point to investigate. The emergence of the UAS and predictions of future business growth has led established aerospace companies to take an interest either by developing technology by themselves or by acquiring smaller specialist companies. For example I can refer to

Boeing, BAE, Thales and many more. At the same time partly due to the relatively primitive nature of the standard UAV platform, it was made possible for new companies to enter the market and stake their percentage. For instance, there are many cases of spin off companies that combine innovative research concepts, produced in the institutes, with practical engineering suitable for manufacture.

A.1.5 Economic impact

A recent study (Jenkins and Vasigh, 2013) by the Association for Unmanned Vehicle Systems International (AUVSI) predicts that in a matter of years UAV industry in the U.S. could produce up to 100,000 new jobs and add $82 billion in economic activity between 2015 and 2025. Of course this prediction is based on the fact that federal law mandates FAA to open up the National Airspace System (NAS) by 2015. The UAV industry is looking forward to this development since current restrictions prohibit individuals from flying drones for commercial purposes. It has been estimated that every year that this integration is delayed, the US loses more than $10 billion in potential economic impact (a loss of $27.6 million per day that UAS are not integrated into the NAS).

In Europe the landscape is almost the same. The European Commission likens the economic impact of UAVs to the development of the Internet in the nineties. However, in order to avoid problems emerged from the ethical and legal issues they address the need of regulation.

Unlike the US and EU, Canada is one of the leaders in commercial applications for UAVs and this happens due to progressive legislation. UAVs are already being used in Canada for the monitoring of piping and power lines, as well as various other uses including crop monitoring.

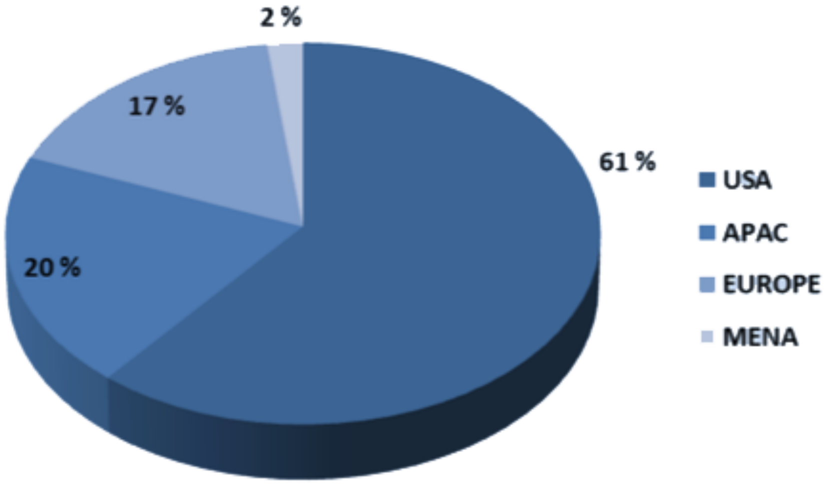

Fig.A.3 Regional breakdown of the global commercial and civil UAV market in 2013, source (INEA consulting, 2015)

A.2 Interface Analysis Centre (IAC)

Interface Analysis Centre is a university research group, hosted in the School of Physics at Bristol University. IAC combines material scientists and engineers that concentrate on answering why the materials have certain properties and behaviors and how these can be exploited to compose something better or cheaper. Using special equipment, IAC aims to deduce how the properties (like strength, transparency, flexibility, conductivity) are related to the structure (like crystal size, alignment of fibres). After all, the challenge is to use this knowledge to design and manufacture materials, which have better properties for the required purpose (Bristol.ac.uk, 2015).

One of the specific tasks in which IAC focuses is the visual and thermal monitoring of radiation after a release of nuclear material. It has already developed a semi-autonomous drone, called Advance Airborne Radiation Monitoring (AARM) system, which was jointly funded by the Engineering and Physics Sciences Research Council (EPSRC) and Sellafield Ltd. The latter is the national organization tasked with the managing and safely storing the

UK's nuclear waste. The initiation of this idea happened in response to requirements for radiation monitoring needed at Fukishima Daiichi Nuclear Power Plant and in the surrounding affected prefecture. After the first successful mission (Imitec, 2014) of flying at Sellafield nuclear site in spring 2014, a small team led by Dr. Tom Scott employed two AARM systems to provide an initial assessment of contamination in one of the most highly contaminated prefecture areas within the Abukuma river basin, in the Kawamata area of Japan (Scott, 2014). Sellafield and the Bristol-Kyoto Strategic Partnership Fund jointly sponsored this expedition.

A.3 The project

The purpose of this project is to advance the existing capability for radiation surveillance at civil nuclear sites of the first generation AARM system. The primary goal is to utilize commercial off-the-shelf (COTS) technologies combined with algorithms used in the robotics fields to design a more sophisticated AARM version. More precisely, it is desirable to develop an assisted flight method in which the UAS operator is aided actively during the flight to avoid collisions with obstacles. In addition to that, a mobile application for visualising the individual gamma energies and intensities (cps) on a map is implemented. Using this app, the users will be able to observe in real time the contamination levels being recorded by the UAS and focus accordingly to the areas of interest.

The overall task can be divided to the following individual objectives:

- Literature review of up-to-date related papers found in IEEE explore website. The subject of the research is the development of autonomous UASs and collision avoidance techniques as well as UAV stabilization, proximity sensors, radiation mapping and UAV simulations.

- Experimentation with a range of proximity sensors, from ultrasound to laser scanners, and comparing them in terms of functionality, power consumption and size. Ensuingly, the sensors are adapted to the UAS and are used to take measurements in various conditions. During that procedure, existing problems and the limiting factors are identified. Moreover, possible solutions are proposed including additional 3D-printed structures that improve the performance.
- Employment of a realistic 3D simulation to experiment with various collision avoidance maneuvers that can be used in an assisted flight method. Henceforth, the same techniques are applied to a real UAV. Comparison of the performance in both situations is conducted.
- Design and development of a mobile application that depicts the level of radiation contamination on a map in real time, taking wireless measurements from a gamma spectrometer. This task improves the human-robot communication to a friendlier interface and takes advantage of the ubiquity of the smart devices.

As a general approach in this project, it has been decided to engage with a range of different tasks like sensors, simulation, real UAV and human-robot interface rather than focus and specialise in a specific task. This decision is preferable in order to gain experience and understanding from a wider range of domains. The work of this project was conducted in the IAC lab using the provided equipment and parts that were acquired only for the specific project. For all the objectives, the approach was to study the available options and follow the one that was the best suited for my case.