Emerging technologies

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Sources:

https://en.wikipedia.org/wiki/Internet_of_things

https://en.wikipedia.org/wiki/3D_printing

https://en.wikipedia.org/wiki/Self-driving_car

Fig.1 https://en.wikipedia.org/wiki/Internet_of_things#/media/File:Internet_of_Things.jpg

Fig.2 https://en.wikipedia.org/wiki/Internet_of_things#/media/File:Internet_of_Things.svg

Fig.3 https://en.wikipedia.org/wiki/3D_printing#/media/File:MakerBot_ThingOMatic_Bre_Pettis.jpg

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1 Internet of things

1 .1.2 Outline

The Internet of things (IoT) is the network of physical devices, vehicles, home appliances, and other items embedded with electronics, software, sensors, actuators, and connectivity which enables these things to connect, collect and exchange data. IoT involves extending Internet connectivity beyond standard devices, such as desktops, laptops, smartphones and tablets, to any range of traditionally dumb or non-internet-enabled physical devices and everyday objects. Embedded with technology, these devices can communicate and interact over the Internet, and they can be remotely monitored and controlled. With the arrival of driverless vehicles, a branch of IoT, i.e. the Internet of Vehicle starts to gain more attention.

1.1.3 History

The definition of the Internet of things has evolved due to convergence of multiple technologies, real-time analytics, machine learning, commodity sensors, and embedded systems. Traditional fields of embedded systems, wireless sensor networks, control systems, automation (including home and building automation), and others all contribute to enabling the Internet of things.

The concept of a network of smart devices was discussed as early as 1982, with a modified Coke machine at Carnegie Mellon University becoming the first Internet-connected appliance, able to report its inventory and whether newly loaded drinks were cold. Mark Weiser's 1991 paper on ubiquitous computing, "The Computer of the 21st Century", as well as academic venues such as UbiComp and PerCom produced the contemporary vision of IoT. In 1994, Reza Raji described the concept in IEEE Spectrum as "[moving] small packets of data to a large set of nodes, so as to integrate and automate everything from home appliances to entire factories". Between 1993 and 1997, several companies proposed solutions like Microsoft's at Work or Novell's NEST. The field gained momentum when Bill Joy envisioned Device to Device (D2D) communication as part of his "Six Webs" framework, presented at the World Economic Forum at Davos in 1999.

The term "Internet of things" was likely coined by Kevin Ashton of Procter & Gamble, later MIT's Auto-ID Center, in 1999, though he prefers the phrase "Internet for things". At that point, he viewed Radio-frequency identification (RFID) as essential to the Internet of things, which would allow computers to manage all individual things.

A research article mentioning the Internet of things was submitted to the conference for Nordic Researchers in Logistics, Norway, in June 2002, which was preceded by an article published in Finnish in January 2002. The implementation described there was developed by Kary Främling and his team at Helsinki University of Technology and more closely matches the modern one, i.e. an information system infrastructure for implementing smart, connected objects.(Fig. 1)

Defining the Internet of things as "simply the point in time when more 'things or objects' were connected to the Internet than people", Cisco Systems estimated that IoT was "born" between 2008 and 2009, with the things/people ratio growing from 0.08 in 2003 to 1.84 in 2010.

1.2 Applications

1.2.1 Consumer applications

Smart home

IoT devices are a part of the larger concept of home automation, which can include lighting, heating and air conditioning, media and security systems. Long term benefits could include energy savings by automatically ensuring lights and electronics are turned off.

A smart home or automated home could be based on a platform or hubs that control smart devices and appliances. For instance, using Apple's HomeKit, manufacturers can get their home products and accessories be controlled by an application in iOS devices such as the iPhone and the Apple Watch. This could be a dedicated app or iOS native applications such as Siri. This can be demonstrated in the case of Lenovo's Smart Home Essentials, which is a line of smart home devices that are controlled through Apple's Home app or Siri without the need for a Wi-Fi bridge. There are also dedicated smart home hubs that are offered as standalone platforms to connect different smart home products and these include the Amazon Echo, Apple's HomePod, and Samsung's SmartThings Hub.

Elder care

One key application of smart home is to provide assistance for those with disabilities and elderly individuals. These home systems use assistive technology to accommodate an owner's specific disabilities. Voice control can assist users with sight and mobility limitations while alert systems can be connected directly to cochlear implants worn by hearing impaired users. They can also be equipped with additional safety features. These features can include sensors that monitor for medical emergencies such as falls or seizures. Smart home technology applied in this way can provide users with more freedom and a higher quality of life.

Figure 1: Internet of Things

1.2.2. Commercial applications

Medical and healthcare

The Internet of Medical Things (also called the internet of health things) is an application of the IoT for medical and health related purposes, data collection and analysis for research, and monitoring. This 'Smart Healthcare', as it can also be called, led to the creation of a digitized healthcare system, connecting available medical resources and healthcare services.

IoT devices can be used to enable remote health monitoring and emergency notification systems. These health monitoring devices can range from blood pressure and heart rate monitors to advanced devices capable of monitoring specialized implants, such as pacemakers, Fitbit electronic wristbands, or advanced hearing aids. Some hospitals have begun implementing "smart beds" that can detect when they are occupied and when a patient is attempting to get up. It can also adjust itself to ensure appropriate pressure and support is applied to the patient without the manual interaction of nurses. A 2015 Goldman Sachs report indicated that healthcare IoT devices "can save the United States more than $300 billion in annual healthcare expenditures by increasing revenue and decreasing cost." Moreover, the use of mobile devices to support medical follow-up led to the creation of 'm-health', used "to analyze, capture, transmit and store health statistics from multiple resources, including sensors and other biomedical acquisition systems".

Specialized sensors can also be equipped within living spaces to monitor the health and general well-being of senior citizens, while also ensuring that proper treatment is being administered and assisting people regain lost mobility via therapy as well. These sensors create a network of intelligent sensors that are able to collect, process, transfer and analyse valuable information in different environments, such as connecting in-home monitoring devices to hospital-based systems. Other consumer devices to encourage healthy living, such as connected scales or wearable heart monitors, are also a possibility with the IoT. End-to-end health monitoring IoT platforms are also available for antenatal and chronic patients, helping one manage health vitals and recurring medication requirements.

As of 2018 IoMT was not only being applied in the clinical laboratory industry, but also in the healthcare and health insurance industries. IoMT in the healthcare industry is now permitting doctors, patients and others involved (i.e. guardians of patients, nurses, families, etc.) to be part of a system, where patient records are saved in a database, allowing doctors and the rest of the medical staff to have access to the patient's information. Moreover, IoT-based systems are patient-centered, which involves being flexible to the patient's medical conditions. IoMT in the insurance industry provides access to better and new types of dynamic information. This includes sensor-based solutions such as biosensors, wearables, connected health devices and mobile apps to track customer behaviour. This can lead to more accurate underwriting and new pricing models.

Transportation

The IoT can assist in the integration of communications, control, and information processing across various transportation systems. Application of the IoT extends to all aspects of transportation systems (i.e. the vehicle, the infrastructure, and the driver or user). Dynamic interaction between these components of a transport system enables inter and intra vehicular communication, smart traffic control, smart parking, electronic toll collection systems, logistic and fleet management, vehicle control, and safety and road assistance. In Logistics and Fleet Management for example, The IoT platform can continuously monitor the location and conditions of cargo and assets via wireless sensors and send specific alerts when management exceptions occur (delays, damages, thefts, etc.). If combined with Machine Learning then it also helps in reducing traffic accidents by introducing drowsiness alerts to drivers and providing self driven cars too.

Building and home automation

IoT devices can be used to monitor and control the mechanical, electrical and electronic systems used in various types of buildings (e.g., public and private, industrial, institutions, or residential) in home automation and building automation systems. In this context, three main areas are being covered in literature:

The integration of the Internet with building energy management systems in order to create energy efficient and IOT driven "smart buildings".

The possible means of real-time monitoring for reducing energy consumption and monitoring occupant behaviors.

The integration of smart devices in the built environment and how they might to know who to be used in future applications.

1.3 Industrial applications

Manufacturing

The IoT can realize the seamless integration of various manufacturing devices equipped with sensing, identification, processing, communication, actuation, and networking capabilities. Based on such a highly integrated smart cyberphysical space, it opens the door to create whole new business and market opportunities for manufacturing. Network control and management of manufacturing equipment, asset and situation management, or manufacturing process control bring the IoT within the realm of industrial applications and smart manufacturing as well. The IoT intelligent systems enable rapid manufacturing of new products, dynamic response to product demands, and real-time optimization of manufacturing production and supply chain networks, by networking machinery, sensors and control systems together.

Digital control systems to automate process controls, operator tools and service information systems to optimize plant safety and security are within the purview of the IoT. But it also extends itself to asset management via predictive maintenance, statistical evaluation, and measurements to maximize reliability. Smart industrial management systems can also be integrated with the Smart Grid, thereby enabling real-time energy optimization. Measurements, automated controls, plant optimization, health and safety management, and other functions are provided by a large number of networked sensors.

The term industrial Internet of things (IIoT) is often encountered in the manufacturing industries, referring to the industrial subset of the IoT. IIoT in manufacturing could generate so much business value that it will eventually lead to the fourth industrial revolution, so the so-called Industry 4.0. It is estimated that in the future, successful companies will be able to increase their revenue through Internet of things by creating new business models and improve productivity, exploit analytics for innovation, and transform workforce. The potential of growth by implementing IIoT may generate $12 trillion of global GDP by 2030.

Agriculture

There are numerous IoT applications in farming such as collecting data on temperature, rainfall, humidity, wind speed, pest infestation, and soil content. This data can be used to automate farming techniques, take informed decisions to improve quality and quantity, minimize risk and waste, and reduce effort required to manage crops. For example, farmers can now monitor soil temperature and moisture from afar, and even apply IoT-acquired data to precision fertilization programs.

In August 2018, Toyota Tsusho began a partnership with Microsoft to create fish farming tools using the Microsoft Azure application suite for IoT technologies related to water management. Developed in part by researchers from Kindai University, the water pump mechanisms use artificial intelligence to count the number of fish on a conveyor belt, analyze the number of fish, and deduce the effectiveness of water flow from the data the fish provide. The specific computer programs used in the process fall under the Azure Machine Learning and the Azure IoT Hub platforms.

1.4 Infrastructure applications

Monitoring and controlling operations of sustainable urban and rural infrastructures like bridges, railway tracks and on- and offshore wind-farms is a key application of the IoT. The IoT infrastructure can be used for monitoring any events or changes in structural conditions that can compromise safety and increase risk. IoT can benefit the construction industry by cost saving, time reduction, better quality workday, paperless workflow and increase in productivity. It can help in taking faster decisions and save money with Real-Time Data Analytics. It can also be used for scheduling repair and maintenance activities in an efficient manner, by coordinating tasks between different service providers and users of these facilities. IoT devices can also be used to control critical infrastructure like bridges to provide access to ships. Usage of IoT devices for monitoring and operating infrastructure is likely to improve incident management and emergency response coordination, and quality of service, up-times and reduce costs of operation in all infrastructure related areas. Even areas such as waste management can benefit from automation and optimization that could be brought in by the IoT.

Metropolitan scale deployments

There are several planned or ongoing large-scale deployments of the IoT, to enable better management of cities and systems. For example, Songdo, South Korea, the first of its kind fully equipped and wired smart city, is gradually being built, with approximately 70 percent of the business district completed as of June 2018. Much of the city is planned to be wired and automated, with little or no human intervention.

Another application is a currently undergoing project in Santander, Spain. For this deployment, two approaches have been adopted. This city of 180,000 inhabitants has already seen 18,000 downloads of its city smartphone app. The app is connected to 10,000 sensors that enable services like parking search, environmental monitoring, digital city agenda, and more. City context information is used in this deployment so as to benefit merchants through a spark deals mechanism based on city behavior that aims at maximizing the impact of each notification.

Other examples of large-scale deployments underway include the Sino-Singapore Guangzhou Knowledge City; work on improving air and water quality, reducing noise pollution, and increasing transportation efficiency in San Jose, California; and smart traffic management in western Singapore. French company, Sigfox, commenced building an ultra-narrowband wireless data network in the San Francisco Bay Area in 2014, the first business to achieve such a deployment in the U.S. It subsequently announced it would set up a total of 4000 base stations to cover a total of 30 cities in the U.S. by the end of 2016, making it the largest IoT network coverage provider in the country thus far.

Another example of a large deployment is the one completed by New York Waterways in New York City to connect all the city's vessels and be able to monitor them live 24/7. The network was designed and engineered by Fluidmesh Networks, a Chicago-based company developing wireless networks for critical applications. The NYWW network is currently providing coverage on the Hudson River, East River, and Upper New York Bay. With the wireless network in place, NY Waterway is able to take control of its fleet and passengers in a way that was not previously possible. New applications can include security, energy and fleet management, digital signage, public Wi-Fi, paperless ticketing and others.

Energy management

Significant numbers of energy-consuming devices (e.g. switches, power outlets, bulbs, televisions, etc.) already integrate Internet connectivity, which can allow them to communicate with utilities to balance power generation and energy usage and optimize energy consumption as a whole. These devices allow for remote control by users, or central management via a cloud-based interface, and enable functions like scheduling (e.g., remotely powering on or off heating systems, controlling ovens, changing lighting conditions etc.). The smart grid is a utility-side IoT application; systems gather and act on energy and power-related information to improve the efficiency of the production and distribution of electricity. Using advanced metering infrastructure (AMI) Internet-connected devices, electric utilities not only collect data from end-users, but also manage distribution automation devices like transformers.

Environmental monitoring

Environmental monitoring applications of the IoT typically use sensors to assist in environmental protection by monitoring air or water quality, atmospheric or soil conditions, and can even include areas like monitoring the movements of wildlife and their habitats. Development of resource-constrained devices connected to the Internet also means that other applications like earthquake or tsunami early-warning systems can also be used by emergency services to provide more effective aid. IoT devices in this application typically span a large geographic area and can also be mobile. It has been argued that the standardization IoT brings to wireless sensing will revolutionize this area.

1.5 Trends and characteristics

The IoT's major significant trend in recent years is the explosive growth of devices connected and controlled by the Internet. The wide range of applications for IoT technology mean that the specifics can be very different from one device to the next but there are basic characteristics shared by most. IoT creates opportunities for more direct integration of the physical world into computer-based systems, resulting in efficiency improvements, economic benefits, and reduced human exertions.

The number of IoT devices increased 31% year-over-year to 8.4 billion in the year 2017 and it is estimated that there will be 30 billion devices by 2020. The global market value of IoT is projected to reach $7.1 trillion by 2020 (Fig. 2).

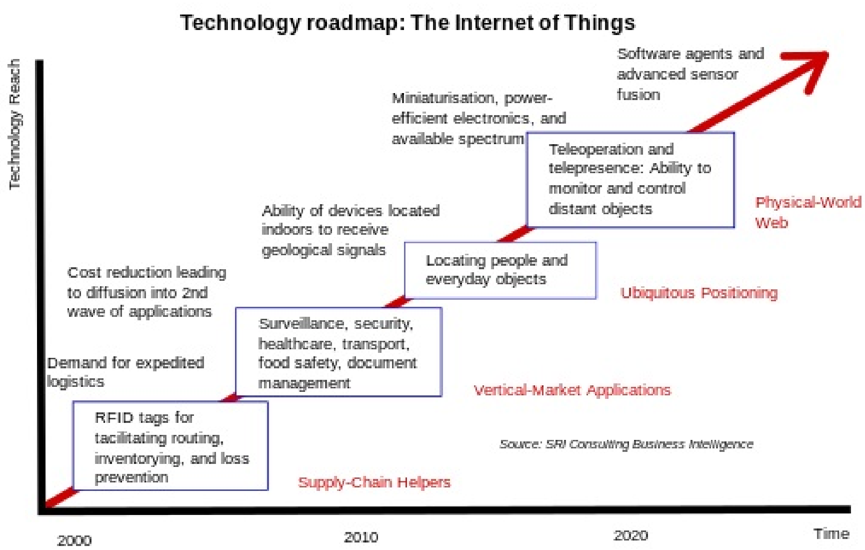

Figure 2: Technology roadmap: Internet of things.

Intelligence

Ambient intelligence and autonomous control are not part of the original concept of the Internet of things. Ambient intelligence and autonomous control do not necessarily require Internet structures, either. However, there is a shift in research (by companies such as Intel) to integrate the concepts of IoT and autonomous control, with initial outcomes towards this direction considering objects as the driving force for autonomous IoT.

In the future, the Internet of Things may be a non-deterministic and open network in which auto-organized or intelligent entities (web services, SOA components) and virtual objects (avatars) will be interoperable and able to act independently (pursuing their own objectives or shared ones) depending on the context, circumstances or environments. Autonomous behavior through the collection and reasoning of context information as well as the object's ability to detect changes in the environment (faults affecting sensors) and introduce suitable mitigation measures constitutes a major research trend, clearly needed to provide credibility to the IoT technology. Modern IoT products and solutions in the marketplace use a variety of different technologies to support such context-aware automation, but more sophisticated forms of intelligence are requested to permit sensor units and intelligent cyber-physical systems to be deployed in real environments.

Architecture

Tier 1 of the IIoT architecture consists of networked things, typically sensors and actuators, from the IIoT equipment, which use protocols such as Modbus, Zigbee, or proprietary protocols, to connect to an Edge Gateway. Tier 2 includes sensor data aggregation systems called Edge Gateways that provide functionality, such as pre-processing of the data, securing connectivity to cloud, using systems such as WebSockets, the event hub, and, even in some cases, edge analytics or fog computing. Tier 3 includes the cloud application built for IIoT using the microservices architecture, which are usually polyglot and inherently secure in nature using HTTPS/OAuth. Tier 3 also includes storage of sensor data using various database systems, such as time series databases or asset stores using backend data storage systems such as Cassandra or Postgres. In addition to the data storage, we analyze the data using various analytics, predictive or threshold-based or regression-based, to get more insights on the IIoT equipment.

Building on the Internet of things, the web of things is an architecture for the application layer of the Internet of things looking at the convergence of data from IoT devices into Web applications to create innovative use-cases. In order to program and control the flow of information in the Internet of things, a predicted architectural direction is being called BPM Everywhere which is a blending of traditional process management with process mining and special capabilities to automate the control of large numbers of coordinated devices.

The Internet of things requires huge scalability in the network space to handle the surge of devices. IETF 6LoWPAN would be used to connect devices to IP networks. With billions of devices being added to the Internet space, IPv6 will play a major role in handling the network layer scalability. IETF's Constrained Application Protocol, ZeroMQ, and MQTT would provide lightweight data transport.

Complexity

In semi-open or closed loops (i.e. value chains, whenever a global finality can be settled) IoT will often be considered and studied as a complex system due to the huge number of different links, interactions between autonomous actors, and its capacity to integrate new actors. At the overall stage (full open loop) it will likely be seen as a chaotic environment (since systems always have finality). As a practical approach, not all elements in the Internet of things run in a global, public space. Subsystems are often implemented to mitigate the risks of privacy, control and reliability. For example, domestic robotics (domotics) running inside a smart home might only share data within and be available via a local network. Managing and controlling high dynamic ad hoc IoT things/devices network is a tough task with the traditional networks architecture, Software Defined Networking (SDN) provides the agile dynamic solution that can cope with the special requirements of the diversity of innovative IoT applications.

Size considerations

The Internet of things would encode 50 to 100 trillion objects, and be able to follow the movement of those objects. Human beings in surveyed urban environments are each surrounded by 1000 to 5000 trackable objects. In 2015 there were already 83 million smart devices in people‘s homes. This number is about to grow up to 193 million devices in 2020 and will for sure go on growing in the near future.

The figure of online capable devices grew 31% from 2016 to 8.4 billion in 2017.

Space considerations

In the Internet of things, the precise geographic location of a thing—and also the precise geographic dimensions of a thing—will be critical. Therefore, facts about a thing, such as its location in time and space, have been less critical to track because the person processing the information can decide whether or not that information was important to the action being taken, and if so, add the missing information (or decide to not take the action). (Note that some things in the Internet of things will be sensors, and sensor location is usually important.) The GeoWeb and Digital Earth are promising applications that become possible when things can become organized and connected by location. However, the challenges that remain include the constraints of variable spatial scales, the need to handle massive amounts of data, and an indexing for fast search and neighbor operations. In the Internet of things, if things are able to take actions on their own initiative, this human-centric mediation role is eliminated. Thus, the time-space context that we as humans take for granted must be given a central role in this information ecosystem. Just as standards play a key role in the Internet and the Web, geospatial standards will play a key role in the Internet of things.

A solution to “basket of remotes”

Many IoT devices have a potential to take a piece of this market. Jean-Louis Gassée (Apple initial alumni team, and BeOS co-founder) has addressed this topic in an article on Monday Note, where he predicts that the most likely problem will be what he calls the “basket of remotes” problem, where we’ll have hundreds of applications to interface with hundreds of devices that don’t share protocols for speaking with one another. For improved user interaction, some technology leaders are joining forces to create standards for communication between devices to solve this problem. Others are turning to the concept of predictive interaction of devices, “where collected data is used to predict and trigger actions on the specific devices” while making them work together.

Frameworks

IoT frameworks might help support the interaction between “things” and allow for more complex structures like distributed computing and the development of distributed applications. Currently, some IoT frameworks seem to focus on real-time data logging solutions, offering some basis to work with many “things” and have them interact. Future developments might lead to specific software-development environments to create the software to work with the hardware used in the Internet of things. Companies are developing technology platforms to provide this type of functionality for the Internet of things. Newer platforms are being developed, which add more intelligence.

REST is a scalable architecture that allows things to communicate over Hypertext Transfer Protocol and is easily adopted for IoT applications to provide communication from a thing to a central web server.

2. 3D printing

2.1.1 Outline

3D printing is any of various processes in which material is joined or solidified under computer control to create a three-dimensional object, with material being added together (such as liquid molecules or powder grains being fused together). 3D printing is used in both rapid prototyping and additive manufacturing. Objects can be of almost any shape or geometry and typically are produced using digital model data from a 3D model or another electronic data source such as an Additive Manufacturing File (AMF) file (usually in sequential layers). There are many different technologies, like stereolithography (SLA) or fused deposit modeling (FDM). Thus, unlike material removed from a stock in the conventional machining process, 3D printing or Additive Manufacturing builds a three-dimensional object from a computer-aided design (CAD) model or AMF file, usually by successively adding material layer by layer.

The term “3D printing” originally referred to a process that deposits a binder material onto a powder bed with inkjet printer heads layer by layer. More recently, the term is being used in popular vernacular to encompass a wider variety of additive manufacturing techniques. United States and global technical standards use the official term additive manufacturing for this broader sense (Fig. 3)

2.2 Terminology

The umbrella term additive manufacturing (AM) gained wide currency in the 2000s, inspired by the theme of material being added together (in any of various ways). In contrast, the term subtractive manufacturing appeared as a retronym for the large family of machining processes with material removal as their common theme. The term 3D printing still referred only to the polymer technologies in most minds, and the term AM was likelier to be used in metalworking and end use part production contexts than among polymer, inkjet, or stereolithography enthusiasts.

By the early 2010s, the terms 3D printing and additive manufacturing evolved senses in which they were alternate umbrella terms for additive technologies, one being used in popular vernacular by consumer-maker communities and the media, and the other used more formally by industrial end-use part producers, machine manufacturers, and global technical standards organizations. Until recently, the term 3D printing has been associated with machines low-end in price or in capability. Both terms reflect that the technologies share the theme of material addition or joining throughout a 3D work envelope under automated control. Peter Zelinski, the editor-in-chief of Additive Manufacturing magazine, pointed out in 2017 that the terms are still often synonymous in casual usage but that some manufacturing industry experts are increasingly making a sense distinction whereby Additive Manufacturing comprises 3D printing plus other technologies or other aspects of a manufacturing process.

Other terms that have been used as synonyms or hypernyms have included desktop manufacturing, rapid manufacturing (as the logical production-level successor to rapid prototyping), and on-demand manufacturing (which echoes on-demand printing in the 2D sense of printing). That such application of the adjectives rapid and on-demand to the noun manufacturing was novel in the 2000s reveals the prevailing mental model of the long industrial era in which almost all production manufacturing involved long lead times for laborious tooling development. Today, the term subtractive has not replaced the term machining, instead complementing it when a term that covers any removal method is needed. Agile tooling is the use of modular means to design tooling that is produced by additive manufacturing or 3D printing methods to enable quick prototyping and responses to tooling and fixture needs. Agile tooling uses a cost effective and high quality method to quickly respond to customer and market needs, and it can be used in hydro-forming, stamping, injection molding and other manufacturing processes.

2.2 History

1981

Early additive manufacturing equipment and materials were developed in the 1980s. In 1981, Hideo Kodama of Nagoya Municipal Industrial Research Institute invented two additive methods for fabricating three-dimensional plastic models with photo-hardening thermoset polymer, where the UV exposure area is controlled by a mask pattern or a scanning fiber transmitter.

1984

On 16 July 1984, Alain Le Méhauté, Olivier de Witte, and Jean Claude André filed their patent for the stereolithography process. The application of the French inventors was abandoned by the French General Electric Company (now Alcatel-Alsthom) and CILAS (The Laser Consortium). The claimed reason was "for lack of business perspective".

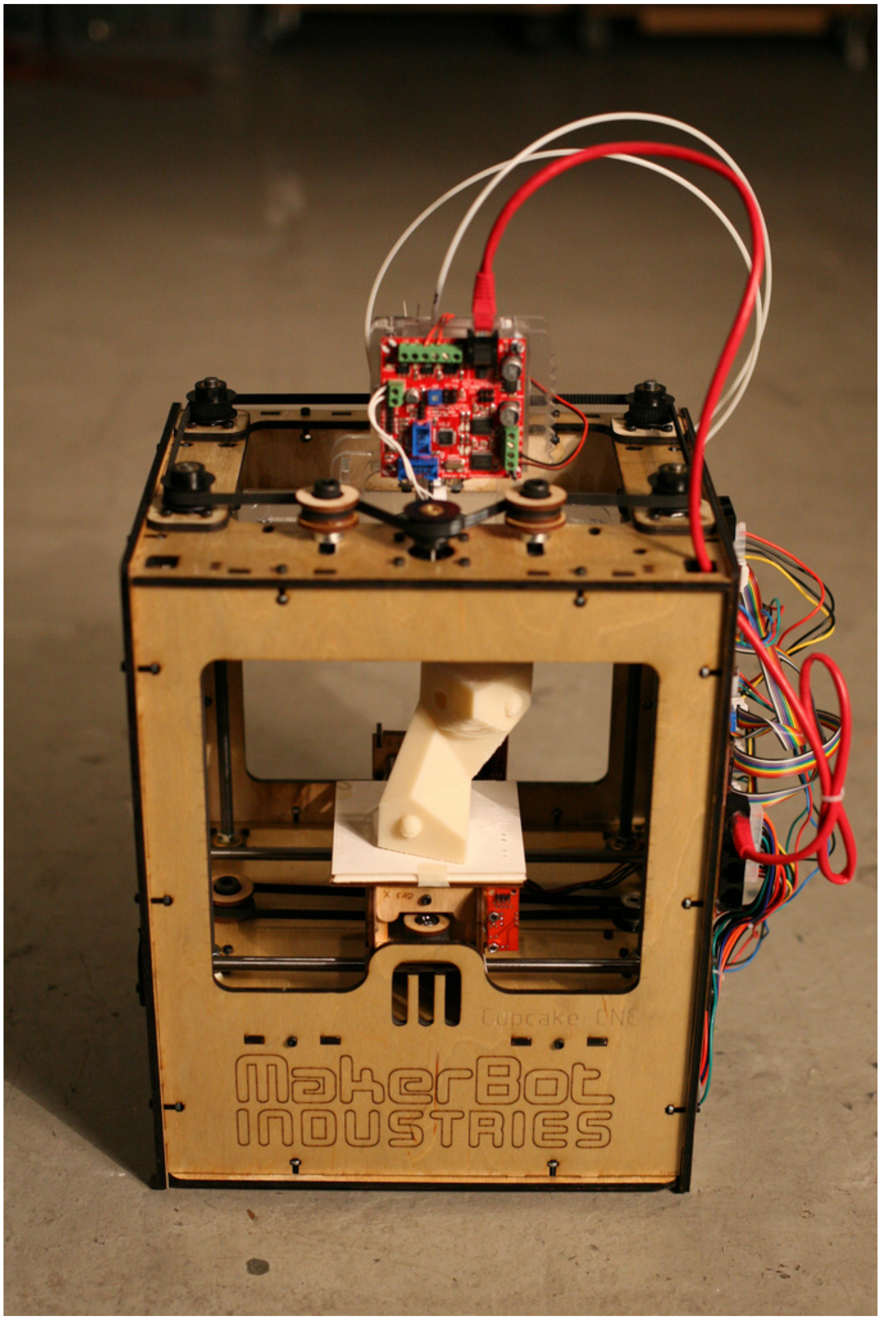

Figure 3: A MakerBot three-dimensional printer.

Three weeks later in 1984, Chuck Hull of 3D Systems Corporation filed his own patent for a stereolithography fabrication system, in which layers are added by curing photopolymers with ultraviolet light lasers. Hull defined the process as a "system for generating three-dimensional objects by creating a cross-sectional pattern of the object to be formed,". Hull's contribution was the STL (Stereolithography) file format and the digital slicing and infill strategies common to many processes today.

1988

The technology used by most 3D printers to date—especially hobbyist and consumer-oriented models—is fused deposition modeling, a special application of plastic extrusion, developed in 1988 by S. Scott Crump and commercialized by his company Stratasys, which marketed its first FDM machine in 1992.

AM processes for metal sintering or melting (such as selective laser sintering, direct metal laser sintering, and selective laser melting) usually went by their own individual names in the 1980s and 1990s. At the time, all metalworking was done by processes that we now call non-additive (casting, fabrication, stamping, and machining); although plenty of automation was applied to those technologies (such as by robot welding and CNC), the idea of a tool or head moving through a 3D work envelope transforming a mass of raw material into a desired shape with a toolpath was associated in metalworking only with processes that removed metal (rather than adding it), such as CNC milling, CNC EDM, and many others. But the automated techniques that added metal, which would later be called additive manufacturing, were beginning to challenge that assumption. By the mid-1990s, new techniques for material deposition were developed at Stanford and Carnegie Mellon University, including microcasting and sprayed materials. Sacrificial and support materials had also become more common, enabling new object geometries.

1993

The term 3D printing originally referred to a powder bed process employing standard and custom inkjet print heads, developed at MIT in 1993 and commercialized by Soligen Technologies, Extrude Hone Corporation, and Z Corporation.

The year 1993 also saw the start of a company called Solidscape, introducing a high-precision polymer jet fabrication system with soluble support structures, (categorized as a “dot-on-dot” technique).

1995

In 1995 the Fraunhofer Institute developed the selective laser melting process.

2009

Fused Deposition Modeling (FDM) printing process patents expired in 2009. As the various additive processes matured, it became clear that soon metal removal would no longer be the only metalworking process done through a tool or head moving through a 3D work envelope transforming a mass of raw material into a desired shape layer by layer. The 2010s were the first decade in which metal end use parts such as engine brackets and large nuts would be grown (either before or instead of machining) in job production rather than obligately being machined from bar stock or plate. It is still the case that casting, fabrication, stamping, and machining are more prevalent than additive manufacturing in metalworking, but AM is now beginning to make significant inroads, and with the advantages of design for additive manufacturing, it is clear to engineers that much more is to come.

As technology matured, several authors had begun to speculate that 3D printing could aid in sustainable development in the developing world.

2013

NASA employees Samantha Snabes and Matthew Fiedler create first prototype of large-format, affordable 3D printer, Gigabot, and launch 3D printing company re:3D.

2018

re:3D develops a system that uses plastic pellets that can be made by grinding up waste plastic.

2.3 General principles

Modeling

3D printable models may be created with a computer-aided design (CAD) package, via a 3D scanner, or by a plain digital camera and photogrammetry software. 3D printed models created with CAD result in reduced errors and can be corrected before printing, allowing verification in the design of the object before it is printed. The manual modeling process of preparing geometric data for 3D computer graphics is similar to plastic arts such as sculpting. 3D scanning is a process of collecting digital data on the shape and appearance of a real object, creating a digital model based on it.

Printing

Before printing a 3D model from an STL file, it must first be examined for errors. Most CAD applications (Fig. 4) produce errors in output STL files of the following types:

holes,

- faces normal,
- self-intersections,
- noise shells,
- manifold errors.

A step in the STL generation known as "repair" fixes such problems in the original model. Generally STLs that have been produced from a model obtained through 3D scanning often have more of these errors. This is due to how 3D scanning works-as it is often by point to point acquisition, reconstruction will include errors in most cases.

Once completed, the STL file needs to be processed by a piece of software called a "slicer," which converts the model into a series of thin layers and produces a G-code file containing instructions tailored to a specific type of 3D printer (FDM printers). This G-code file can then be printed with 3D printing client software (which loads the G-code, and uses it to instruct the 3D printer during the 3D printing process).

Printer resolution describes layer thickness and X–Y resolution in dots per inch (dpi) or micrometers (µm). Typical layer thickness is around 100 µm (250 DPI), although some machines can print layers as thin as 16 µm (1,600 DPI). X–Y resolution is comparable to that of laser printers. The particles (3D dots) are around 50 to 100 µm (510 to 250 DPI) in diameter. For that printer resolution, specifying a mesh resolution of 0.01–0.03 mm and a chord length ? 0.016 mm generate an optimal STL output file for a given model input file. Specifying higher resolution results in larger files without increase in print quality.

Construction of a model with contemporary methods can take anywhere from several hours to several days, depending on the method used and the size and complexity of the model. Additive systems can typically reduce this time to a few hours, although it varies widely depending on the type of machine used and the size and number of models being produced simultaneously.

Traditional techniques like injection moulding can be less expensive for manufacturing polymer products in high quantities, but additive manufacturing can be faster, more flexible and less expensive when producing relatively small quantities of parts. 3D printers give designers and concept development teams the ability to produce parts and concept models using a desktop size printer.

Seemingly paradoxic, more complex objects can be cheaper for 3D printing production than less complex objects.

Finishing

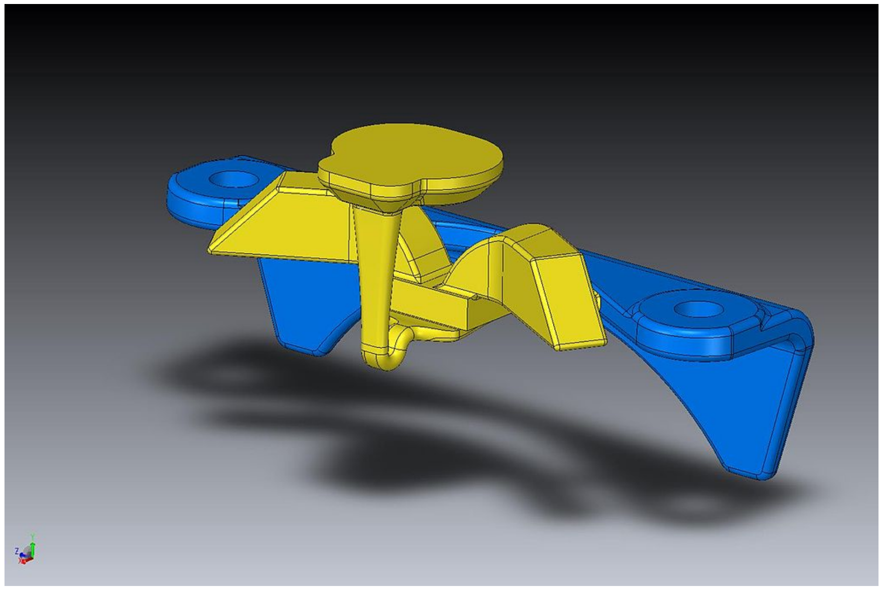

Figure 4: CAD model used for 3D printing.

Though the printer-produced resolution is sufficient for many applications, printing a slightly oversized version of the desired object in standard resolution and then removing material with a higher-resolution subtractive process can achieve greater precision.

The layered structure of all Additive Manufacturing processes leads inevitably to a strain-stepping effect on part surfaces which are curved or tilted in respect to the building platform. The effects strongly depend on the orientation of a part surface inside the building process.

Some printable polymers such as ABS, allow the surface finish to be smoothed and improved using chemical vapor processes based on acetone or similar solvents.

Some additive manufacturing techniques are capable of using multiple materials in the course of constructing parts. These techniques are able to print in multiple colors and color combinations simultaneously, and would not necessarily require painting.

Some printing techniques require internal supports to be built for overhanging features during construction. These supports must be mechanically removed or dissolved upon completion of the print.

All of the commercialized metal 3D printers involve cutting the metal component off the metal substrate after deposition. A new process for the GMAW 3D printing allows for substrate surface modifications to remove aluminum or steel.

2.4 Processes and printers

A large number of additive processes are available. The main differences between processes are in the way layers are deposited to create parts and in the materials that are used. Each method has its own advantages and drawbacks, which is why some companies offer a choice of powder and polymer for the material used to build the object. Others sometimes use standard, off-the-shelf business paper as the build material to produce a durable prototype. The main considerations in choosing a machine are generally speed, costs of the 3D printer, of the printed prototype, choice and cost of the materials, and color capabilities. Printers that work directly with metals are generally expensive. However less expensive printers can be used to make a mold, which is then used to make metal parts.

ISO/ASTM52900-15 defines seven categories of Additive Manufacturing (AM) processes within its meaning: binder jetting, directed energy deposition, material extrusion, material jetting, powder bed fusion, sheet lamination, and vat photopolymerization.

Some methods melt or soften the material to produce the layers. In Fused filament fabrication, also known as Fused deposition modeling (FDM), the model or part is produced by extruding small beads or streams of material which harden immediately to form layers. A filament of thermoplastic, metal wire, or other material is fed into an extrusion nozzle head (3D printer extruder), which heats the material and turns the flow on and off. FDM is somewhat restricted in the variation of shapes that may be fabricated. Another technique fuses parts of the layer and then moves upward in the working area, adding another layer of granules and repeating the process until the piece has built up. This process uses the unfused media to support overhangs and thin walls in the part being produced, which reduces the need for temporary auxiliary supports for the piece.

Laser sintering techniques include selective laser sintering, with both metals and polymers, and direct metal laser sintering. Selective laser melting does not use sintering for the fusion of powder granules but will completely melt the powder using a high-energy laser to create fully dense materials in a layer-wise method that has mechanical properties similar to those of conventional manufactured metals. Electron beam melting is a similar type of additive manufacturing technology for metal parts (e.g. titanium alloys). EBM manufactures parts by melting metal powder layer by layer with an electron beam in a high vacuum. Another method consists of an inkjet 3D printing system, which creates the model one layer at a time by spreading a layer of powder (plaster, or resins) and printing a binder in the cross-section of the part using an inkjet-like process. With laminated object manufacturing, thin layers are cut to shape and joined together.

Schematic representation of Stereolithography; a light-emitting device a) (laser or DLP) selectively illuminate the transparent bottom c) of a tank b) filled with a liquid photo-polymerizing resin; the solidified resin d) is progressively dragged up by a lifting platform e)

Other methods cure liquid materials using different sophisticated technologies, such as stereolithography. Photopolymerization is primarily used in stereolithography to produce a solid part from a liquid. Inkjet printer systems like the Objet PolyJet system spray photopolymer materials onto a build tray in ultra-thin layers (between 16 and 30 µm) until the part is completed. Each photopolymer layer is cured with UV light after it is jetted, producing fully cured models that can be handled and used immediately, without post-curing. Ultra-small features can be made with the 3D micro-fabrication technique used in multiphoton photopolymerisation. Due to the nonlinear nature of photo excitation, the gel is cured to a solid only in the places where the laser was focused while the remaining gel is then washed away. Feature sizes of under 100 nm are easily produced, as well as complex structures with moving and interlocked parts. Yet another approach uses a synthetic resin that is solidified using LEDs.

In Mask-image-projection-based stereolithography, a 3D digital model is sliced by a set of horizontal planes. Each slice is converted into a two-dimensional mask image. The mask image is then projected onto a photocurable liquid resin surface and light is projected onto the resin to cure it in the shape of the layer. Continuous liquid interface production begins with a pool of liquid photopolymer resin. Part of the pool bottom is transparent to ultraviolet light (the "window"), which causes the resin to solidify. The object rises slowly enough to allow resin to flow under and maintain contact with the bottom of the object. In powder-fed directed-energy deposition, a high-power laser is used to melt metal powder supplied to the focus of the laser beam. The powder fed directed energy process is similar to Selective Laser Sintering, but the metal powder is applied only where material is being added to the part at that moment.

As of December 2017, additive manufacturing systems were on the market that ranged from $99 to $500,000 in price and were employed in industries including aerospace, architecture, automotive, defense, and medical replacements, among many others. For example, General Electric uses the high-end model to build parts for turbines. Many of these systems are used for rapid prototyping, before mass production methods are employed. Higher education has proven to be a major buyer of desktop and professional 3D printers which industry experts generally view as a positive indicator. Libraries around the world have also become locations to house smaller 3D printers for educational and community access. Several projects and companies are making efforts to develop affordable 3D printers for home desktop use. Much of this work has been driven by and targeted at DIY/Maker/enthusiast/early adopter communities, with additional ties to the academic and hacker communities.

2.5 Applications

In the current scenario, 3D printing or Additive Manufacturing has been used in manufacturing, medical, industry and sociocultural sectors which facilitate 3D printing or Additive Manufacturing to become successful commercial technology (Fig. 5). The earliest application of additive manufacturing was on the toolroom end of the manufacturing spectrum. For example, rapid prototyping was one of the earliest additive variants, and its mission was to reduce the lead time and cost of developing prototypes of new parts and devices, which was earlier only done with subtractive toolroom methods such as CNC milling, turning, and precision grinding. In the 2010s, additive manufacturing entered production to a much greater extent.

Additive manufacturing of food is being developed by squeezing out food, layer by layer, into three-dimensional objects. A large variety of foods are appropriate candidates, such as chocolate and candy, and flat foods such as crackers, pasta, and pizza.

3D printing has entered the world of clothing, with fashion designers experimenting with 3D-printed bikinis, shoes, and dresses. In commercial production Nike is using 3D printing to prototype and manufacture the 2012 Vapor Laser Talon football shoe for players of American football, and New Balance is 3D manufacturing custom-fit shoes for athletes. 3D printing has come to the point where companies are printing consumer grade eyewear with on-demand custom fit and styling (although they cannot print the lenses). On-demand customization of glasses is possible with rapid prototyping.

Vanessa Friedman, fashion director and chief fashion critic at The New York Times, says 3D printing will have a significant value for fashion companies down the road, especially if it transforms into a print-it-yourself tool for shoppers. "There's real sense that this is not going to happen anytime soon," she says, "but it will happen, and it will create dramatic change in how we think both about intellectual property and how things are in the supply chain." She adds: "Certainly some of the fabrications that brands can use will be dramatically changed by technology."

In cars, trucks, and aircraft (Fig. 6), Additive Manufacturing is beginning to transform both (1) unibody and fuselage design and production and (2) powertrain design and production. For example:

- in early 2014, Swedish supercar manufacturer Koenigsegg announced the One:1, a supercar that utilizes

Figure 5: A 3D selfie in 1:20 scale printed by Shapeways using gypsum-based printing.

many components that were 3D printed. Urbee is the name of the first car in the world car mounted using the technology 3D printing (its bodywork and car windows were "printed"),

- in 2014, Local Motors debuted Strati, a functioning vehicle that was entirely 3D Printed using ABS plastic and carbon fiber, except the powertrain. In May 2015 Airbus announced that its new Airbus A350 XWB included over 1000 components manufactured by 3D printing,
- in 2015, a Royal Air Force Eurofighter Typhoon fighter jet flew with printed parts. The United States Air Force has begun to work with 3D printers, and the Israeli Air Force has also purchased a 3D printer to print spare parts,
- in 2017, GE Aviation revealed that it had used design for additive manufacturing to create a helicopter engine with 16 parts instead of 900, with great potential impact on reducing the complexity of supply chains.

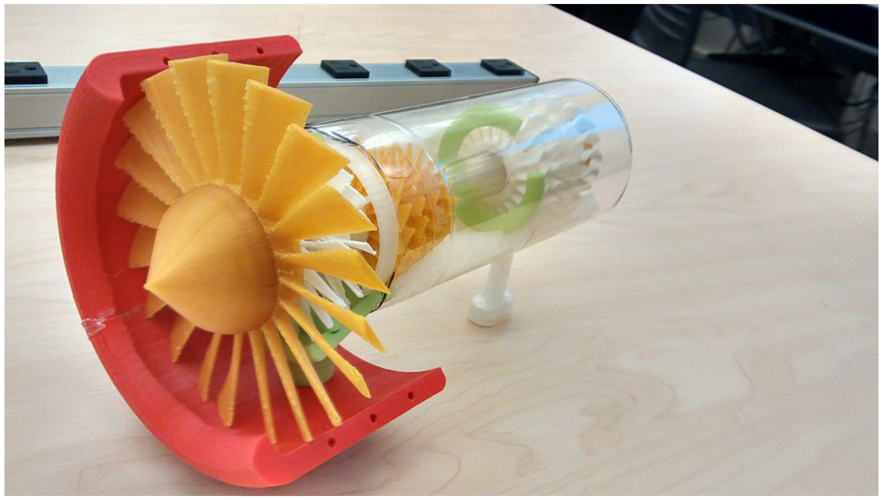

Figure 6: A Jet Engine turbine printed from the Howard Community College Makerbot.

AM's impact on firearms involves two dimensions: new manufacturing methods for established companies, and new possibilities for the making of do-it-yourself firearms. In 2012, the US-based group Defense Distributed disclosed plans to design a working plastic 3D printed firearm "that could be downloaded and reproduced by anybody with a 3D printer." After Defense Distributed released their plans, questions were raised regarding the effects that 3D printing and widespread consumer-level CNC machining may have on gun control effectiveness.

Surgical uses of 3D printing-centric therapies have a history beginning in the mid-1990s with anatomical modeling for bony reconstructive surgery planning. Patient-matched implants were a natural extension of this work, leading to truly personalized implants that fit one unique individual. Virtual planning of surgery and guidance using 3D printed, personalized instruments have been applied to many areas of surgery including total joint replacement and craniomaxillofacial reconstruction with great success. One example of this is the bioresorbable trachial splint to treat newborns with tracheobronchomalacia developed at the University of Michigan. The use of additive manufacturing for serialized production of orthopedic implants (metals) is also increasing due to the ability to efficiently create porous surface structures that facilitate osseointegration. The hearing aid and dental industries are expected to be the biggest area of future development using the custom 3D printing technology.

In March 2014, surgeons in Swansea used 3D printed parts to rebuild the face of a motorcyclist who had been seriously injured in a road accident. In May 2018, 3D printing has been used for the kidney transplant to save a three-year-old boy. As of 2012, 3D bio-printing technology has been studied by biotechnology firms and academia for possible use in tissue engineering applications in which organs and body parts are built using inkjet printing techniques. In this process, layers of living cells are deposited onto a gel medium or sugar matrix and slowly built up to form three-dimensional structures including vascular systems. Recently, a heart-on-chip has been created which matches properties of cells.

In 2018, 3D printing technology was used for the first time to create a matrix for cell immobilization in fermentation. Propionic acid production by Propionibacterium acidipropionici immobilized on 3D-printed nylon beads was chosen as a model study. It was shown that those 3D-printed beads were capable to promote high density cell attachment and propionic acid production, which could be adapted to other fermentation bioprocesses.

In 2005, academic journals had begun to report on the possible artistic applications of 3D printing technology. As of 2017, domestic 3D printing was reaching a consumer audience beyond hobbyists and enthusiasts. Off the shelf machines were increasingly capable of producing practical household applications, for example, ornamental objects. Some practical examples include a working clock and gears printed for home woodworking machines among other purposes. Web sites associated with home 3D printing tended to include backscratchers, coat hooks, door knobs, etc.

3D printing, and open source 3D printers in particular, are the latest technology making inroads into the classroom. Some authors have claimed that 3D printers offer an unprecedented "revolution" in STEM education. The evidence for such claims comes from both the low cost ability for rapid prototyping in the classroom by students, but also the fabrication of low-cost high-quality scientific equipment from open hardware designs forming open-source labs. Future applications for 3D printing might include creating open-source scientific equipment.

In the last several years 3D printing has been intensively used by in the cultural heritage field for preservation, restoration and dissemination purposes. Many Europeans and North American Museums have purchased 3D printers and actively recreate missing pieces of their relics. The Metropolitan Museum of Art and the British Museum have started using their 3D printers to create museum souvenirs that are available in the museum shops. Other museums, like the National Museum of Military History and Varna Historical Museum, have gone further and sell through the online platform Threeding digital models of their artifacts, created using Artec 3D scanners, in 3D printing friendly file format, which everyone can 3D print at home.

3D printed soft actuators is a growing application of 3D printing technology which has found its place in the 3D printing applications. These soft actuators are being developed to deal with soft structures and organs especially in biomedical sectors and where the interaction between human and robot is inevitable. The majority of the existing soft actuators are fabricated by conventional methods that require manual fabrication of devices, post processing/assembly, and lengthy iterations until maturity in the fabrication is achieved. To avoid the tedious and time-consuming aspects of the current fabrication processes, researchers are exploring an appropriate manufacturing approach for effective fabrication of soft actuators. Thus, 3D printed soft actuators are introduced to revolutionize the design and fabrication of soft actuators with custom geometrical, functional, and control properties in a faster and inexpensive approach. They also enable incorporation of all actuator components into a single structure eliminating the need to use external joints, adhesives, and fasteners.

2.4 Legal aspects

Intellectual property

3D printing has existed for decades within certain manufacturing industries where many legal regimes, including patents, industrial design rights, copyright, and trademark may apply. However, there is not much jurisprudence to say how these laws will apply if 3D printers become mainstream and individuals or hobbyist communities begin manufacturing items for personal use, for non-profit distribution, or for sale.

Any of the mentioned legal regimes may prohibit the distribution of the designs used in 3D printing, or the distribution or sale of the printed item. To be allowed to do these things, where an active intellectual property was involved, a person would have to contact the owner and ask for a license, which may come with conditions and a price. However, many patent, design and copyright laws contain a standard limitation or exception for 'private', 'non-commercial' use of inventions, designs or works of art protected under intellectual property (IP). That standard limitation or exception may leave such private, non-commercial uses outside the scope of IP rights.

Patents cover inventions including processes, machines, manufactures, and compositions of matter and have a finite duration which varies between countries, but generally 20 years from the date of application. Therefore, if a type of wheel is patented, printing, using, or selling such a wheel could be an infringement of the patent.

Copyright covers an expression in a tangible, fixed medium and often lasts for the life of the author plus 70 years thereafter. If someone makes a statue, they may have copyright on the look of that statue, so if someone sees that statue, they cannot then distribute designs to print an identical or similar statue.

When a feature has both artistic (copyrightable) and functional (patentable) merits, when the question has appeared in US court, the courts have often held the feature is not copyrightable unless it can be separated from the functional aspects of the item. In other countries the law and the courts may apply a different approach allowing, for example, the design of a useful device to be registered (as a whole) as an industrial design on the understanding that, in case of unauthorized copying, only the non-functional features may be claimed under design law whereas any technical features could only be claimed if covered by a valid patent.

Gun legislation and administration

The US Department of Homeland Security and the Joint Regional Intelligence Center released a memo stating that "significant advances in three-dimensional (3D) printing capabilities, availability of free digital 3D printable files for firearms components, and difficulty regulating file sharing may present public safety risks from unqualified gun seekers who obtain or manufacture 3D printed guns" and that "proposed legislation to ban 3D printing of weapons may deter, but cannot completely prevent, their production. Even if the practice is prohibited by new legislation, online distribution of these 3D printable files will be as difficult to control as any other illegally traded music, movie or software files."

Attempting to restrict the distribution of gun plans via the Internet has been likened to the futility of preventing the widespread distribution of DeCSS, which enabled DVD ripping. After the US government had Defense Distributed take down the plans, they were still widely available via the Pirate Bay and other file sharing sites. Downloads of the plans from the UK, Germany, Spain, and Brazil were heavy. Some US legislators have proposed regulations on 3D printers to prevent them from being used for printing guns. 3D printing advocates have suggested that such regulations would be futile, could cripple the 3D printing industry, and could infringe on free speech rights, with early pioneer of 3D printing Professor Hod Lipson suggesting that gunpowder could be controlled instead.

Internationally, where gun controls are generally stricter than in the United States, some commentators have said the impact may be more strongly felt since alternative firearms are not as easily obtainable. Officials in the United Kingdom have noted that producing a 3D printed gun would be illegal under their gun control laws. Europol stated that criminals have access to other sources of weapons but noted that as technology improves, the risks of an effect would increase.

Aerospace regulation

In the United States, the FAA has anticipated a desire to use additive manufacturing techniques and has been considering how best to regulate this process. The FAA has jurisdiction over such fabrication because all aircraft parts must be made under FAA production approval or under other FAA regulatory categories. In December 2016, the FAA approved the production of a 3D printed fuel nozzle for the GE LEAP engine. Aviation attorney Jason Dickstein has suggested that additive manufacturing is merely a production method, and should be regulated like any other production method. He has suggested that the FAA's focus should be on guidance to explain compliance, rather than on changing the existing rules, and that existing regulations and guidance permit a company "to develop a robust quality system that adequately reflects regulatory needs for quality assurance."

2.5 Health and safety

Research on the health and safety concerns of 3D printing is new and in development due to the recent proliferation of 3D printing devices. In 2017 the European Agency for Safety and Health at Work has published a discussion paper on the processes and materials involved in 3D printing, potential implications of this technology for occupational safety and health and avenues for controlling potential hazards. Most concerns involve gas and material exposures, in particular nanomaterials, material handling, static electricity, moving parts and pressures.

A National Institute for Occupational Safety and Health (NIOSH) study noted particle emissions from a fused filament peaked a few minutes after printing started and returned to baseline levels 100 minutes after printing ended. Emissions from fused filament printers can include a large number of ultrafine particles and volatile organic compounds (VOCs).

The toxicity from emissions varies by source material due to differences in size, chemical properties, and quantity of emitted particles. Excessive exposure to VOCs can lead to irritation of the eyes, nose, and throat, headache, loss of coordination, and nausea and some of the chemical emissions of fused filament printers have also been linked to asthma. Based on animal studies, carbon nanotubes and carbon nanofibers sometimes used in fused filament printing can cause pulmonary effects including inflammation, granulomas, and pulmonary fibrosis when at the nanoparticle size.

As of March 2018, the US Government has set 3D printer emission standards for only a limited number of compounds. Furthermore, the few established standards address factory conditions, not home or other environments in which the printers are likely to be used.

Carbon nanoparticle emissions and processes using powder metals are highly combustible and raise the risk of dust explosions. At least one case of severe injury was noted from an explosion involved in metal powders used for fused filament printing. Other general health and safety concerns include the hot surface of UV lamps and print head blocks, high voltage, ultraviolet radiation from UV lamps, and potential for mechanical injury from moving parts.

The problems noted in the NIOSH report were reduced by using manufacturer-supplied covers and full enclosures, using proper ventilation, keeping workers away from the printer, using respirators, turning off the printer if it jammed, and using lower emission printers and filaments. At least one case of severe injury was noted from an explosion involved in metal powders used for fused filament. Personal protective equipment has been found to be the least desirable control method with a recommendation that it only be used to add further protection in combination with approved emissions protection.

Hazards to health and safety also exist from post-processing activities done to finish parts after they have been printed. These post-processing activities can include chemical baths, sanding, polishing, or vapor exposure to refine surface finish, as well as general subtractive manufacturing techniques such as drilling, milling, or turning to modify the printed geometry. Any technique that removes material from the printed part has the potential to generate particles that can be inhaled or cause eye injury if proper personal protective equipment is not used, such as respirators or safety glasses. Caustic baths are often used to dissolve support material used by some 3D printers that allows them to print more complex shapes. These baths require personal protective equipment to prevent injury to exposed skin.

Although no occupational exposure limits specific to 3D printer emissions exist, certain source materials used in 3D printing, such as carbon nanofiber and carbon nanotubes, have established occupational exposure limits at the nanoparticle size.

Since 3-D imaging creates items by fusing materials together, there runs the risk of layer separation in some devices made using 3-D Imaging. For example, in January 2013, the US medical device company, DePuy, recalled their knee and hip replacement systems. The devices were made from layers of metal, and shavings had come loose – potentially harming the patient.

2.6 Impact

Additive manufacturing, starting with today's infancy period, requires manufacturing firms to be flexible, ever-improving users of all available technologies to remain competitive. Advocates of additive manufacturing also predict that this arc of technological development will counter globalization, as end users will do much of their own manufacturing rather than engage in trade to buy products from other people and corporations. The real integration of the newer additive technologies into commercial production, however, is more a matter of complementing traditional subtractive methods rather than displacing them entirely.

The futurologist Jeremy Rifkin claimed that 3D printing signals the beginning of a third industrial revolution, succeeding the production line assembly that dominated manufacturing starting in the late 19th century.

Since the 1950s, a number of writers and social commentators have speculated in some depth about the social and cultural changes that might result from the advent of commercially affordable additive manufacturing technology. Amongst the more notable ideas to have emerged from these inquiries has been the suggestion that, as more and more 3D printers start to enter people's homes, the conventional relationship between the home and the workplace might get further eroded. Likewise, it has also been suggested that, as it becomes easier for businesses to transmit designs for new objects around the globe, so the need for high-speed freight services might also become less. Finally, given the ease with which certain objects can now be replicated, it remains to be seen whether changes will be made to current copyright legislation so as to protect intellectual property rights with the new technology widely available.

As 3D printers became more accessible to consumers, online social platforms have developed to support the community. This includes websites that allow users to access information such as how to build a 3D printer, as well as social forums that discuss how to improve 3D print quality and discuss 3D printing news, as well as social media websites that are dedicated to share 3D models. RepRap is a wiki based website that was created to hold all information on 3d printing, and has developed into a community that aims to bring 3D printing to everyone. Furthermore, there are other sites such as Pinshape, Thingiverse and MyMiniFactory, which were created initially to allow users to post 3D files for anyone to print, allowing for decreased transaction cost of sharing 3D files. These websites have allowed greater social interaction between users, creating communities dedicated to 3D printing.

Some call attention to the conjunction of Commons-based peer production with 3D printing and other low-cost manufacturing techniques. The self-reinforced fantasy of a system of eternal growth can be overcome with the development of economies of scope, and here, society can play an important role contributing to the raising of the whole productive structure to a higher plateau of more sustainable and customized productivity. Further, it is true that many issues, problems, and threats arise due to the democratization of the means of production, and especially regarding the physical ones. For instance, the recyclability of advanced nanomaterials is still questioned; weapons manufacturing could become easier; not to mention the implications for counterfeiting and on IP. It might be maintained that in contrast to the industrial paradigm whose competitive dynamics were about economies of scale, Commons-based peer production 3D printing could develop economies of scope. While the advantages of scale rest on cheap global transportation, the economies of scope share infrastructure costs (intangible and tangible productive resources), taking advantage of the capabilities of the fabrication tools. And following Neil Gershenfeld in that "some of the least developed parts of the world need some of the most advanced technologies," Commons-based peer production and 3D printing may offer the necessary tools for thinking globally but acting locally in response to certain needs.

Larry Summers wrote about the "devastating consequences" of 3D printing and other technologies (robots, artificial intelligence, etc.) for those who perform routine tasks. In his view, "already there are more American men on disability insurance than doing production work in manufacturing. And the trends are all in the wrong direction, particularly for the less skilled, as the capacity of capital embodying artificial intelligence to replace white-collar as well as blue-collar work will increase rapidly in the years ahead." Summers recommends more vigorous cooperative efforts to address the "myriad devices" (e.g., tax havens, bank secrecy, money laundering, and regulatory arbitrage) enabling the holders of great wealth to "avoid paying" income and estate taxes, and to make it more difficult to accumulate great fortunes without requiring "great social contributions" in return, including: more vigorous enforcement of anti-monopoly laws, reductions in "excessive" protection for intellectual property, greater encouragement of profit-sharing schemes that may benefit workers and give them a stake in wealth accumulation, strengthening of collective bargaining arrangements, improvements in corporate governance, strengthening of financial regulation to eliminate subsidies to financial activity, easing of land-use restrictions that may cause the real estate of the rich to keep rising in value, better training for young people and retraining for displaced workers, and increased public and private investment in infrastructure development—e.g., in energy production and transportation.

Michael Spence wrote that "Now comes a ... powerful, wave of digital technology that is replacing labor in increasingly complex tasks. This process of labor substitution and disintermediation has been underway for some time in service sectors—think of ATMs, online banking, enterprise resource planning, customer relationship management, mobile payment systems, and much more. This revolution is spreading to the production of goods, where robots and 3D printing are displacing labor." In his view, the vast majority of the cost of digital technologies comes at the start, in the design of hardware (e.g. 3D printers) and, more important, in creating the software that enables machines to carry out various tasks. "Once this is achieved, the marginal cost of the hardware is relatively low (and declines as scale rises), and the marginal cost of replicating the software is essentially zero. With a huge potential global market to amortize the upfront fixed costs of design and testing, the incentives to invest [in digital technologies] are compelling."

Spence believes that, unlike prior digital technologies, which drove firms to deploy underutilized pools of valuable labor around the world, the motivating force in the current wave of digital technologies "is cost reduction via the replacement of labor." For example, as the cost of 3D printing technology declines, it is "easy to imagine" that production may become "extremely" local and customized. Moreover, production may occur in response to actual demand, not anticipated or forecast demand. Spence believes that labor, no matter how inexpensive, will become a less important asset for growth and employment expansion, with labor-intensive, process-oriented manufacturing becoming less effective, and that re-localization will appear in both developed and developing countries. In his view, production will not disappear, but it will be less labor-intensive, and all countries will eventually need to rebuild their growth models around digital technologies and the human capital supporting their deployment and expansion. Spence writes that "the world we are entering is one in which the most powerful global flows will be ideas and digital capital, not goods, services, and traditional capital. Adapting to this will require shifts in mindsets, policies, investments (especially in human capital), and quite possibly models of employment and distribution."

Naomi Wu regards the usage of 3D printing in the Chinese classroom (where rote memorization is standard) to teach design principles and creativity as the most exciting recent development of the technology, and more generally regards 3D printing as being the next desktop publishing revolution.

3. Self-driving car

Outline

A self-driving car (also known as an autonomous car or a driverless car) is a vehicle that is capable of sensing its environment and moving with little or no human input.

Autonomous cars combine a variety of sensors to perceive their surroundings, such as radar, computer vision, Lidar, sonar, GPS, odometry and inertial measurement units. Advanced control systems interpret sensory information to identify appropriate navigation paths, as well as obstacles and relevant signage.

Potential benefits include reduced costs, increased safety, increased mobility, increased customer satisfaction and reduced crime. Safety benefits include a reduction in traffic collisions, resulting injuries and related costs, including for insurance. Automated cars are predicted to increase traffic flow; provide enhanced mobility for children, the elderly, disabled, and the poor; relieve travelers from driving and navigation chores; lower fuel consumption; significantly reduce needs for parking space; reduce crime; and facilitate business models for transportation as a service, especially via the sharing economy.

Problems include safety, technology, liability, desire by individuals to control their cars, legal framework and government regulations; risk of loss of privacy and security concerns, such as hackers or terrorism; concern about the resulting loss of driving-related jobs in the road transport industry; and risk of increased suburbanization as travel becomes more convenient.

3.1 History

General Motors' Firebird II of the 1950s was described as having an "electronic brain" that allowed it to move into a lane with a metal conductor and follow it along.

Experiments have been conducted on automating driving since at least the 1920s; trials began in the 1950s. The first truly automated car was developed in 1977, by Japan's Tsukuba Mechanical Engineering Laboratory. The vehicle tracked white street markers, which were interpreted by two cameras on the vehicle, using an analog computer for signal processing. The vehicle reached speeds up to 30 kilometres per hour (19 mph), with the support of an elevated rail.

Autonomous prototype cars appeared in the 1980s, with Carnegie Mellon University's Navlab and ALV projects funded by DARPA starting in 1984 and Mercedes-Benz and Bundeswehr University Munich's EUREKA Prometheus Project in 1987. By 1985, the ALV had demonstrated self-driving speeds on two-lane roads of 31 kilometers per hour (19 mph) with obstacle avoidance added in 1986 and off-road driving in day and nighttime conditions by 1987. From the 1960s through the second DARPA Grand Challenge in 2005, automated vehicle research in the U.S. was primarily funded by DARPA, the US Army and the U.S.

Figure 7: Waymo Chrysler Pacifica Hybrid undergoing testing in the San Francisco Bay Area.

Navy yielding incremental advances in speeds, driving competence in more complex conditions, controls and sensor systems. Companies and research organizations have developed prototypes.

The U.S. allocated $650 million in 1991 for research on the National Automated Highway System, which demonstrated automated driving through a combination of automation, embedded in the highway with automated technology in vehicles and cooperative networking between the vehicles and with the highway infrastructure. The program concluded with a successful demonstration in 1997 but without clear direction or funding to implement the system on a larger scale. Partly funded by the National Automated Highway System and DARPA, the Carnegie Mellon University Navlab drove 4,584 kilometers (2,848 mi) across America in 1995, 4,501 kilometers (2,797 mi) or 98% of it autonomously. Navlab's record achievement stood unmatched for two decades until 2015 when Delphi improved it by piloting an Audi, augmented with Delphi technology, over 5,472 kilometers (3,400 mi) through 15 states while remaining in self-driving mode 99% of the time. In 2015, the US states of Nevada, Florida, California, Virginia, and Michigan, together with Washington, D.C., allowed the testing of automated cars on public roads.

In 2017, Audi stated that its latest A8 would be automated at speeds of up to 60 kilometres per hour (37 mph) using its "Audi AI." The driver would not have to do safety checks such as frequently gripping the steering wheel. The Audi A8 was claimed to be the first production car to reach level 3 automated driving, and Audi would be the first manufacturer to use laser scanners in addition to cameras and ultrasonic sensors for their system.

In November 2017, Waymo announced that it had begun testing driverless cars without a safety driver in the driver position; however, there is still an employee in the car. In July 2018, Waymo announced that its test vehicles had traveled in automated mode for over 8,000,000 miles (13,000,000 km), increasing by 1,000,000 miles (1,600,000 kilometers) per month.

3.2 Terminology

There is some inconsistency in terminology used in the self-driving car industry. Various organizations have proposed to define an accurate and consistent vocabulary. Such confusion has been documented in SAE J3016 which states that "Some vernacular usages associate autonomous specifically with full driving automation (level 5), while other usages apply it to all levels of driving automation, and some state legislation has defined it to correspond approximately to any ADS at or above level 3 (or to any vehicle equipped with such an ADS)."

3.2.1 Words definition and safety considerations

Modern vehicles provide partly automated features such as keeping the car within its lane, speed controls or emergency braking. Nonetheless, differences remain between a fully autonomous self-driving car on one hand and driver assistance technologies on the other hand. According to the BBC, confusion between those concepts leads to deaths.

Association of British Insurers considers the usage of the word autonomous in marketing for modern cars to be dangerous, because car ads make motorists think 'autonomous' and 'autopilot' means a vehicle can drive itself, when they still rely on the driver to ensure safety. Technology alone still is not able to drive the car.

When some car makers suggest or claim vehicles are self-driving, when they are only partly automated, drivers risk becoming excessively confident, leading to crashes, while fully self-driving cars are still a long way off in the UK.

3.2.2 Autonomous vs. automated

Autonomous means self-governing. Many historical projects related to vehicle automation have been automated (made automatic) subject to a heavy reliance on artificial aids in their environment, such as magnetic strips. Autonomous control implies satisfactory performance under significant uncertainties in the environment and the ability to compensate for system failures without external intervention.

One approach is to implement communication networks both in the immediate vicinity (for collision avoidance) and farther away (for congestion management). Such outside influences in the decision process reduce an individual vehicle's autonomy, while still not requiring human intervention.

Wood et al. (2012) wrote, "This Article generally uses the term 'autonomous,' instead of the term 'automated.' " The term "autonomous" was chosen "because it is the term that is currently in more widespread use (and thus is more familiar to the general public). However, the latter term is arguably more accurate. 'Automated' connotes control or operation by a machine, while 'autonomous' connotes acting alone or independently. Most of the vehicle concepts (that we are currently aware of) have a person in the driver's seat, utilize a communication connection to the Cloud or other vehicles, and do not independently select either destinations or routes for reaching them. Thus, the term 'automated' would more accurately describe these vehicle concepts." As of 2017, most commercial projects focused on automated vehicles that did not communicate with other vehicles or with an enveloping management regime.

Put in the words of one Nissan engineer, "A truly autonomous car would be one where you request it to take you to work and it decides to go to the beach instead."

EuroNCAP defines autonomous in "Autonomous Emergency Braking" as: "the system acts independently of the driver to avoid or mitigate the accident." which implies the autonomous system is not the driver.

3.2.3 Autonomous versus cooperative

To make a car travel without any driver embedded within the vehicle some system makers used a remote driver.

But according to SAE J3016, some driving automation systems may indeed be autonomous if they perform all of their functions independently and self-sufficiently, but if they depend on communication and/or cooperation with outside entities, they should be considered cooperative rather than autonomous.

3.2.4 Self-driving car

Techemergence says.

> "Self-driving" is a rather vague term with a vague meaning
>
> —?Techemergence

PC mag definition is: A computer-controlled car that drives itself. Also called an "autonomous vehicle" and "driverless car," self-driving cars date back to the 1939 New York World's Fair when General Motors predicted the development of self-driving, radio-controlled electric cars.

UCSUSA definition is: Self-driving vehicles are cars or trucks in which human drivers are never required to take control to safely operate the vehicle. Also known as autonomous or "driverless" cars, they combine sensors and software to control, navigate, and drive the vehicle. Currently, there are no legally operating, fully-autonomous vehicles in the United States.

NHTSA definition is: These self-driving vehicles ultimately will integrate onto U.S. roadways by progressing through six levels of driver assistance technology advancements in the coming years. This includes everything from no automation (where a fully engaged driver is required at all times), to full autonomy (where an automated vehicle operates independently, without a human driver).

3.2.5 Classification

A classification system based on six different levels (ranging from fully manual to fully automated systems) was published in 2014 by SAE International, an automotive standardization body, as J3016, Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems. This classification system is based on the amount of driver intervention and attentiveness required, rather than the vehicle capabilities, although these are very loosely related. In the United States in 2013, the National Highway Traffic Safety Administration (NHTSA) released a formal classification system, but abandoned this system in favor of the SAE standard in 2016. Also in 2016, SAE updated its classification, called J3016_201609.

3.2.6 Levels of driving automation

In SAE's automation level definitions, "driving mode" means "a type of driving scenario with characteristic dynamic driving task requirements (e.g., expressway merging, high speed cruising, low speed traffic jam, closed-campus operations, etc.)"

Level 0: Automated system issues warnings and may momentarily intervene but has no sustained vehicle control.

Level 1 ("hands on"): The driver and the automated system share control of the vehicle. Examples are Adaptive Cruise Control (ACC), where the driver controls steering and the automated system controls speed; and Parking Assistance, where steering is automated while speed is under manual control. The driver must be ready to retake full control at any time. Lane Keeping Assistance (LKA) Type II is a further example of level 1 self-driving.

Level 2 ("hands off"): The automated system takes full control of the vehicle (accelerating, braking, and steering). The driver must monitor the driving and be prepared to intervene immediately at any time if the automated system fails to respond properly. The shorthand "hands off" is not meant to be taken literally. In fact, contact between hand and wheel is often mandatory during SAE 2 driving, to confirm that the driver is ready to intervene.

Level 3 ("eyes off"): The driver can safely turn their attention away from the driving tasks, e.g. the driver can text or watch a movie. The vehicle will handle situations that call for an immediate response, like emergency braking. The driver must still be prepared to intervene within some limited time, specified by the manufacturer, when called upon by the vehicle to do so. As an example, the 2018 Audi A8 Luxury Sedan was the first commercial car to claim to be capable of level 3 self-driving. This particular car has a so-called Traffic Jam Pilot. When activated by the human driver, the car takes full control of all aspects of driving in slow-moving traffic at up to 60 kilometers per hour (37 mph). The function works only on highways with a physical barrier separating one stream of traffic from oncoming traffic.

Level 4 ("mind off"): As level 3, but no driver attention is ever required for safety, i.e. the driver may safely go to sleep or leave the driver's seat. Self-driving is supported only in limited spatial areas (geofenced) or under special circumstances, like traffic jams. Outside of these areas or circumstances, the vehicle must be able to safely abort the trip, i.e. park the car, if the driver does not retake control.

Level 5 ("steering wheel optional"): No human intervention is required at all. An example would be a robotic taxi.

In the formal SAE definition below, note in particular what happens in the shift from SAE 2 to SAE 3: the human driver no longer has to monitor the environment. This is the final aspect of the "dynamic driving task" that is now passed over from the human to the automated system. At SAE 3, the human driver still has the responsibility to intervene when asked to do so by the automated system. At SAE 4 the human driver is relieved of that responsibility and at SAE 5 the automated system will never need to ask for an intervention.

3.2.7 Legal definition

In the district of Columbia (DC) code, "Autonomous vehicle" means a vehicle capable of navigating District roadways and interpreting traffic-control devices without a driver actively operating any of the vehicle's control systems. The term "autonomous vehicle" excludes a motor vehicle enabled with active safety systems or driver- assistance systems, including systems to provide electronic blind-spot assistance, crash avoidance, emergency braking, parking assistance, adaptive cruise control, lane-keep assistance, lane-departure warning, or traffic-jam and queuing assistance, unless the system alone or in combination with other systems enables the vehicle on which the technology is installed to drive without active control or monitoring by a human operator.

In the same district code, it is considered that:

An autonomous vehicle may operate on a public roadway; provided, that the vehicle:

(1) Has a manual override feature that allows a driver to assume control of the autonomous vehicle at any time;

(2) Has a driver seated in the control seat of the vehicle while in operation who is prepared to take control of the autonomous vehicle at any moment; and

(3) Is capable of operating in compliance with the District's applicable traffic laws and motor vehicle laws and traffic control devices.

Technical challenges

The challenge for driverless car designers is to produce control systems capable of analyzing sensory data in order to provide accurate detection of other vehicles and the road ahead. Modern self-driving cars generally use Bayesian simultaneous localization and mapping (SLAM) algorithms, which fuse data from multiple sensors and an off-line map into current location estimates and map updates. Waymo has developed a variant of SLAM with detection and tracking of other moving objects (DATMO), which also handles obstacles such as cars and pedestrians. Simpler systems may use roadside real-time locating system (RTLS) technologies to aid localization. Typical sensors include Lidar, stereo vision, GPS and IMU. Udacity is developing an open-source software stack. Control systems on automated cars may use Sensor Fusion, which is an approach that integrates information from a variety of sensors on the car to produce a more consistent, accurate, and useful view of the environment.

Driverless vehicles require some form of machine vision for the purpose of visual object recognition. Automated cars are being developed with deep neural networks, a type of deep learning architecture with many computational stages, or levels, in which neurons are simulated from the environment that activate the network. The neural network depends on an extensive amount of data extracted from real-life driving scenarios, enabling the neural network to "learn" how to execute the best course of action.

In May 2018, researchers from MIT announced that they had built an automated car that can navigate unmapped roads. Researchers at their Computer Science and Artificial Intelligence Laboratory (CSAIL) have developed a new system, called MapLite, which allows self-driving cars to drive on roads that they have never been on before, without using 3D maps. The system combines the GPS position of the vehicle, a "sparse topological map" such as OpenStreetMap, (i.e. having 2D features of the roads only), and a series of sensors that observe the road conditions.

3.2.8 Human factor challenges

Alongside the many technical challenges that autonomous cars face, there exist many human and social factors that may impede upon the wider uptake of the technology. As things become more automated, the human users need to have trust in the automation, which can be a challenge in itself.

Testing

Testing vehicles with varying degrees of automation can be done physically, in closed environments, on public roads (where permitted, typically with a license or permit or adhering to a specific set of operating principles) or virtually, i.e. in computer simulations. When driven on public roads, automated vehicles require a person to monitor their proper operation and "take over" when needed. Apple is currently testing self-driven cars, and has increased the number of test vehicles from 3 to 27 in January 2018, and to 45 in March 2018.

One way to assess the progress of automated vehicles is to compute the average distance driven between "disengagements", when the automated system is turned off, typically by a human driver. In 2017, Waymo reported 63 disengagements over 352,545 miles (567,366 km) of testing, or 5,596 miles (9,006 km) on average, the highest among companies reporting such figures. Waymo also traveled more distance in total than any other. Their 2017 rate of 0.18 disengagements per 1,000 miles (1,600 km) was an improvement from 0.2 disengagements per 1,000 miles (1,600 km) in 2016 and 0.8 in 2015. In March, 2017, Uber reported an average of 0.67 miles (1.08 km) per disengagement. In the final three months of 2017, Cruise Automation (now owned by GM) averaged 5,224 miles (8,407 km) per disruption over 62,689 miles (100,888 km). In July 2018, the first electric driverless racing car "Robocar" completed 1.8 kilometers track, using its navigation system and artificial intelligence. (Table 1). Source: Wang, Brian (25 March 2018). "Uber' self-driving system was still

Maker	Distance between disengagements	Distance
BMW	638 miles (1027 km)	638 miles (1027 km)
Bosch	0.68 miles (1.09 km)	983 miles (1582 km)
Delphi Automotive Systems	14.9 miles (24.0 km)	2658 miles (4278 km)
Ford	196.6 miles (316.4 km)	590 miles (950 km)
General Motors	54.7 miles (88.0 km)	8156 miles (13126 km)
Mercedes Benz	2 miles (3.2 km)	673 miles (1083 km)
Nissan	263.3 miles (423.7 km)	6056 miles (9746 km)
Tesla	2.9 miles (4.7 km)	550 miles (890 km)
Waymo	5127.9 miles (8252.6 km)	635868 miles (1023330 km)

Table 1: Self-driving cartesting results.

400 times worse [than] Waymo in 2018 on key distance intervention metric". NextBigFuture.com. Retrieved 25 March 2018.

3.3 Fields of application

3.3.1 Automated trucks

Several companies are said to be testing automated technology in semi trucks. Otto, a self-driving trucking company that was acquired by Uber in August 2016, demonstrated their trucks on the highway before being acquired. In May 2017, San Francisco-based startup Embark announced a partnership with truck manufacturer Peterbilt to test and deploy automated technology in Peterbilt's vehicles. Waymo has also said to be testing automated technology in trucks, however no timeline has been given for the project.

In March 2018, Starsky Robotics, the San Francisco-based automated truck company, completed a 7-mile (11 km) fully driverless trip in Florida without a single human in the truck. Starsky Robotics became the first player in the self-driving truck game to drive in fully automated mode on a public road without a person in the cab. In Europe, the truck Platooning is considered with the Safe Road Trains for the Environment approach.Vehicular automation also covers other kinds of vehicles such as Buses, Trains, Trucks. Lockheed Martin with funding from the U.S. Army developed an automated truck convoying system that uses a lead truck operated by a human driver with a number of trucks following autonomously. Developed as part of the Army's Autonomous Mobility Applique System (AMAS), the system consists of an automated driving package that has been installed on more than nine types of vehicles and has completed more than 55,000 hours of driving at speeds up to 64 kilometres per hour (40 mph) as of 2014. As of 2017 the Army was planning to field 100-200 trucks as part of a rapid-fielding program.

3.3.2 Transport systems

In Europe, cities in Belgium, France, Italy and the UK are planning to operate transport systems for automated cars, and Germany, the Netherlands, and Spain have allowed public testing in traffic. In 2015, the UK launched public trials of the LUTZ Pathfinder automated pod in Milton Keynes. Beginning in summer 2015, the French government allowed PSA Peugeot-Citroen to make trials in real conditions in the Paris area. The experiments were planned to be extended to other cities such as Bordeaux and Strasbourg by 2016. The alliance between French companies THALES and Valeo (provider of the first self-parking car system that equips Audi and Mercedes premi) is testing its own system. New Zealand is planning to use automated vehicles for public transport in Tauranga and Christchurch.

In China, Baidu and King Long produce automated minibus, a vehicle with 14 seats, but without driving seat. With 100 vehicles produced, 2018 will be the first year with commercial automated service in China.

Those minibuses should be at level 4, that is driverless in closed roads.

3.4 Potential advantages

3.4.1 Safety

Driving safety experts predict that once driverless technology has been fully developed, traffic collisions (and resulting deaths and injuries and costs), caused by human error, such as delayed reaction time, tailgating, rubbernecking, and other forms of distracted or aggressive driving should be substantially reduced. Consulting firm McKinsey & Company estimated that widespread use of autonomous vehicles could "eliminate 90% of all auto accidents in the United States, prevent up to US$190 billion in damages and health-costs annually and save thousands of lives."

According to motorist website "TheDrive.com" operated by Time magazine, none of the driving safety experts they were able to contact were able to rank driving under an autopilot system at the time (2017) as having achieved a greater level of safety than traditional fully hands-on driving, so the degree to which these benefits asserted by proponents will manifest in practice cannot be assessed. Confounding factors that could reduce the net effect on safety may include unexpected interactions between humans and partly or fully automated vehicles, or between different types of vehicle system; complications at the boundaries of functionality at each automation level (such as handover when the vehicle reaches the limit of its capacity); the effect of the bugs and flaws that inevitably occur in complex interdependent software systems; sensor or data shortcomings; and successful compromise by malicious interveners.

3.4.2 Welfare

Automated cars could reduce labor costs; relieve travelers from driving and navigation chores, thereby replacing behind-the-wheel commuting hours with more time for leisure or work; and also would lift constraints on occupant ability to drive, distracted and texting while driving, intoxicated, prone to seizures, or otherwise impaired. For the young, the elderly, people with disabilities, and low-income citizens, automated cars could provide enhanced mobility. The removal of the steering wheel—along with the remaining driver interface and the requirement for any occupant to assume a forward-facing position—would give the interior of the cabin greater ergonomic flexibility. Large vehicles, such as motorhomes, would attain appreciably enhanced ease of use.

3.4.3 Traffic

Additional advantages could include higher speed limits; smoother rides; and increased roadway capacity; and minimized traffic congestion, due to decreased need for safety gaps and higher speeds. Currently, maximum controlled-access highway throughput or capacity according to the U.S. Highway Capacity Manual is about 2,200 passenger vehicles per hour per lane, with about 5% of the available road space is taken up by cars. One study estimated that automated cars could increase capacity by 273% (˜8,200 cars per hour per lane). The study also estimated that with 100% connected vehicles using vehicle-to-vehicle communication, capacity could reach 12,000 passenger vehicles per hour (up 445% from 2,200 pc/h per lane) traveling safely at 120 km/h (75 mph) with a following gap of about 6 m (20 ft) of each other. Currently, at highway speeds drivers keep between 40 to 50 m (130 to 160 ft) away from the car in front. These increases in highway capacity could have a significant impact in traffic congestion, particularly in urban areas, and even effectively end highway congestion in some places. The ability for authorities to manage traffic flow would increase, given the extra data and driving behavior predictability combined with less need for traffic police and even road signage.

3.4.4 Lower costs

Safer driving is expected to reduce the costs of vehicle insurance. Reduced traffic congestion and the improvements in traffic flow due to widespread use of automated cars will also translate into better fuel efficiency. Additionally, self-driving cars will be able to accelerate and brake more efficiently, meaning higher fuel economy from reducing wasted energy typically associated with inefficient changes to speed (energy typically lost due to friction, in the form of heat and sound).

3.4.5 Parking space

Manually driven vehicles are reported to be used only 4-5% time, and being parked and unused for the remaining 95-96% of the time. Autonomous vehicles could, on the other hand, be used continuously after it has reached its destination. This could dramatically reduce the need for parking space. For example, in Los Angeles, 14% of the land is used for parking alone, equivalent to some 17,020,594 square meters. This combined with the potential reduced need for road space due to improved traffic flow, could free up tremendous amounts of land in urban areas, which could then be used for parks, recreational areas, buildings, among other uses; making cities more livable.

3.4.6 Related effects

By reducing the (labor and other) cost of mobility as a service, automated cars could reduce the number of cars that are individually owned, replaced by taxi/pooling and other car sharing services. This would also dramatically reduce the size of the automotive production industry, with corresponding environmental and economic effects. Assuming the increased efficiency is not fully offset by increases in demand, more efficient traffic flow could free roadway space for other uses such as better support for pedestrians and cyclists.

The vehicles' increased awareness could aid the police by reporting on illegal passenger behavior, while possibly enabling other crimes, such as deliberately crashing into another vehicle or a pedestrian. However, this may also lead to much expanded mass surveillance if there is wide access granted to third parties to the large data sets generated. The future of passenger rail transport in the era of automated cars is not clear.

3.4.7 Potential limits or obstacles

The sort of hoped-for potential benefits from increased vehicle automation described may be limited by foreseeable challenges, such as disputes over liability (will each company operating a vehicle accept that they are its "driver" and thus responsible for what their car does, or will some try to project this liability onto others who are not in control?), the time needed to turn over the existing stock of vehicles from non-automated to automated, and thus a long period of humans and autonomous vehicles sharing the roads, resistance by individuals to having to forfeit control of their cars, concerns about the safety of driverless in practice, and the implementation of a legal framework and consistent global government regulations for self-driving cars. Other obstacles could include de-skilling and lower levels of driver experience for dealing with potentially dangerous situations and anomalies, ethical problems where an automated vehicle's software is forced during an unavoidable crash to choose between multiple harmful courses of action ('the trolley problem'), concerns about making large numbers of people currently employed as drivers unemployed (at the same time as many other alternate blue collar occupations may be undermined by automation), the potential for more intrusive mass surveillance of location, association and travel as a result of police and intelligence agency access to large data sets generated by sensors and pattern-recognition AI (making anonymous travel difficult), and possibly insufficient understanding of verbal sounds, gestures and non-verbal cues by police, other drivers or pedestrians.

Possible technological obstacles for automated cars are:

- artificial Intelligence is still not able to function properly in chaotic inner-city environments,

- a car's computer could potentially be compromised, as could a communication system between cars,
- susceptibility of the car's sensing and navigation systems to different types of weather (such as snow) or deliberate interference, including jamming and spoofing,
- avoidance of large animals requires recognition and tracking, and Volvo found that software suited to caribou, deer, and elk was ineffective with kangaroos,
- autonomous cars may require very high-quality specialized maps to operate properly. Where these maps may be out of date, they would need to be able to fall back to reasonable behaviors,
- competition for the radio spectrum desired for the car's communication,
- field programmability for the systems will require careful evaluation of product development and the component supply chain,
- current road infrastructure may need changes for automated cars to function optimally,
- discrepancy between people's beliefs of the necessary government intervention may cause a delay in accepting automated cars on the road. Whether the public desires no change in existing laws, federal regulation, or another solution; the framework of regulation will likely result in differences of opinion,
- employment - Companies working on the technology have an increasing recruitment problem in that the available talent pool has not grown with demand. As such, education and training by third party organizations such as providers of online courses and self-taught community-driven projects such as DIY Robocars and Formula Pi have quickly grown in popularity, while university level extra-curricular programmers such as Formula Student Driverless have bolstered graduate experience. Industry is steadily increasing freely available information sources, such as code, datasets and glossaries to widen the recruitment pool.

3.4.8 Potential disadvantages

A direct impact of widespread adoption of automated vehicles is the loss of driving-related jobs in the road transport industry. There could be resistance from professional drivers and unions who are threatened by job losses. In addition, there could be job losses in public transit services and crash repair shops. The automobile insurance industry might suffer as the technology makes certain aspects of these occupations obsolete. A frequently cited paper by Michael Osborne and Carl Benedikt Frey found that automated cars would make many jobs redundant.

Privacy could be an issue when having the vehicle's location and position integrated into an interface in which other people have access to. In addition, there is the risk of automotive hacking through the sharing of information through V2V (Vehicle to Vehicle) and V2I (Vehicle to Infrastructure) protocols. There is also the risk of terrorist attacks. Self-driving cars could potentially be loaded with explosives and used as bombs.

The lack of stressful driving, more productive time during the trip, and the potential savings in travel time and cost could become an incentive to live far away from cities, where land is cheaper, and work in the city's core, thus increasing travel distances and inducing more urban sprawl, more fuel consumption and an increase in the carbon footprint of urban travel. There is also the risk that traffic congestion might increase, rather than decrease. Appropriate public policies and regulations, such as zoning, pricing, and urban design are required to avoid the negative impacts of increased suburbanization and longer distance travel.

Some believe that once automation in vehicles reaches higher levels and becomes reliable, drivers will pay less attention to the road. Research shows that drivers in automated cars react later when they have to intervene in a critical situation, compared to if they were driving manually. Depending on the capabilities of automated vehicles and the frequency with which human intervention is needed, this may counteract any increase in safety, as compared to all-human driving, that may be delivered by other factors.

Ethical and moral reasoning come into consideration when programming the software that decides what action the car takes in an unavoidable crash; whether the automated car will crash into a bus, potentially killing people inside; or swerve elsewhere, potentially killing its own passengers or nearby pedestrians. A question that programmers of AI systems find difficult to answer (as do ordinary people, and ethicists) is "what decision should the car make that causes the 'smallest' damage to people's lives?"

The ethics of automated vehicles are still being articulated, and may lead to controversy. They may also require closer consideration of the variability, context-dependency, complexity and non-deterministic nature of human ethics. Different human drivers make various ethical decisions when driving, such as avoiding harm to themselves, or putting themselves at risk to protect others. These decisions range from rare extremes such as self-sacrifice or criminal negligence, to routine decisions good enough to keep the traffic flowing but bad enough to cause accidents, road rage and stress.

Human thought and reaction time may sometimes be too slow to detect the risk of an upcoming fatal crash, think through the ethical implications of the available options, or take an action to implement an ethical choice. Whether a particular automated vehicle's capacity to correctly detect an upcoming risk, analyze the options or choose a 'good' option from among bad choices would be as good or better than a particular human's may be difficult to predict or assess. This difficulty may be in part because the level of automated vehicle system understanding of the ethical issues at play in a given road scenario, sensed for an instant from out of a continuous stream of synthetic physical predictions of the near future, and dependent on layers of pattern recognition and situational intelligence, may be opaque to human inspection because of its origins in probabilistic machine learning rather than a simple, plain English 'human values' logic of parsable rules. The depth of understanding, predictive power and ethical sophistication needed will be hard to implement, and even harder to test or assess.

The scale of this challenge may have other effects. There may be few entities able to marshal the resources and AI capacity necessary to meet it, as well as the capital necessary to take an automated vehicle system to market and sustain it operationally for the life of a vehicle, and the legal and 'government affairs' capacity to deal with the potential for liability for a significant proportion of traffic accidents. This may have the effect of narrowing the number of different system operators, and eroding the presently quite diverse global vehicle market down to a small number of system suppliers.

Drone Technology: Types, Payloads, Applications, Frequency Spectrum Issues and Future Developments

4 Drones

4.1 Introduction

The aim of this chapter is to provide an overview of the different types of drones currently used, their technical specifications, potential payloads and applications, frequency spectrum issues, and the current and near-future technological development in drone technology. Needless to say, this chapter is not exhaustive since (drone) technology evolves rapidly. Therefore, some overviews provided in this

chapter can become outdated quickly. The main characteristics of drones, however, will probably remain the same for years to come. Aspects like propulsion, autonomy, and size may change in the near future but the characteristics themselves will remain important in for the use of drones nevertheless. The first important distinction in the use of drones is between the drone itself (the platform) and the equipment attached to it (the payload). In this context, the drone itself can best be considered a flying platform which can be made suitable for different goals. These goals can be achieved in combination with the specific payload suitable for that goal. For instance, a camera can be attached to a drone to make it suitable for particular inspections. This distinction is used to define the different parts of this chapter. In Sect. 2.2, the different types of drones and their technical properties are discussed in more detail. In Sect. 2.3, an overview of the different payloads and the possible practical applications is provided. In Sect. 2.4, frequency spectrum issues are discussed. In Sect. 2.5, future developments in the drone technology are discussed. In Sect. 2.6, this chapter is concluded.

4.2 Types of Drones and Their Technical Characteristics

To get a better understanding of drones, it is important to discuss their different technical characteristics. In this section, these characteristics are discussed and, in order to further visualize these technological characteristics, examples of existing drones with these characteristics are described. The most notable characteristic is what we will call the type of drone. In this chapter, this term is used to define the difference between fixed-wing systems, multirotor systems, and other systems. Examples of other systems are so-called hybrid systems, which are both multirotor and fixed-wing systems, ornithopters, and drones that use turbo fans. The technology used to keep the drone flying defines the type of drone. This characteristic is also the determining factor in the shape and appearance of the drone. A second characteristic is the level of autonomy of the drone. The autonomy can vary from full autonomous operation to fully controlled by a remote pilot. Another noteworthy characteristic is the difference in size between drones. The size can vary from drones the size of an insect to drones the size of a commercial airplane. Weight is also an important characteristic. The weight of drones can vary from several grams to hundreds of kilograms. The final defining characteristic discussed in this section is the difference in energy source. Examples of energy sources are battery cells, solar cells, and traditional airplane fuel. The importance of characteristics lies in the fact that the different drone payloads and related applications depend on (gradations within) these characteristics. Also, drones are usually categorized using the mentioned characteristics.

4.2.1 Main Existing Drone Types

As stated above, an important technical characteristic of drones is the type of drone. The main drone types are fixed-wing systems and multirotor systems. The majority of existing drones can be defined within these two types. Other systems like hybrid systems and ornithopters are also briefly discussed. Fixed-Wing Systems Fixed-wing is a term mainly used in the aviation industry to define aircraft that use fixed, static wings in combination with forward airspeed to generate lift. Examples of this type of aircraft are traditional airplanes, kites that are attached to the surface and different sorts of gliders like hang gliders or paragliders. Even a simple paper airplane can be defined as a fixed-wing system. An example of a fixed-wing drone is the widely used Raven, which will be discussed in more detail later in this section. Multirotor Systems Multirotor systems are a subset of rotorcraft. The term rotorcraft is used in aviation to define aircraft that use rotary wings to generate lift. A popular example of a rotorcraft is the traditional helicopter. Rotorcraft can have one or multiple rotors. Drones using rotary systems are almost always equipped with multiple small rotors, which are necessary for their stability, hence the name multirotor systems. Commonly, these drones use at least four rotors to keep them flying. A popular example of these multirotor drones is the widely used Phantom drone made by the Chinese company DJI. This four-rotor drone will be discussed in more detail later in this section. Differences between fixed-wing drones and multirotor drones are important for the different applications consumers want to use the drone for. For example, multirotor drones do not need a landing strip, make less noise than their fixedwing counterparts and can hover in the air. Fixed-wing drones can fly faster and are more suitable for long distances than their multirotor counterparts. These characteristics determine which of these drone types to use for a specific application. Other Systems Some types of drones cannot be labeled as a fixed-wing or a multirotor drone. Sometimes because the drone simply is neither fixed-wing nor multirotor, sometimes because the drone has characteristics of both types. Hybrid systems are systems that have characteristics of both multirotor and fixed-wing systems. The hybrid quadcopter is an example of such a drone.1 This drone uses multiple rotors to take-off and land vertically but also has wings so it can fly longer distances. Drones that are neither fixed-wing nor multirotor systems are far less frequent. An example of such a drone is the ornithopter. These drones fly by mimicking wing motions of insects or birds. Most of these ornithopters are scaled to the birds(201, 2018a)

or insects they represent. These small drones are mostly still under development and are not widely used in practice. Examples of ornithopters include the Delfly explorer,2 a drone that mimics a dragonfly, and the micromechanical flying insect,3 a drone under development that is eventually going to represent a fly both in size and movement. Another example of drones that are neither fixed-wing nor multirotor are drones using jet engines. The T-Hawk drone is an example of such a drone.4 This drone uses a turbo fan, making the drone look more like an unmanned (hydro)jetpack than fixed-wing or multirotor.5 To give a more complete picture, unmanned balloons (filled with for example hot air, helium, or hydrogen) are mentioned here as well. These balloons can fly by heating the air inside. Unmanned balloons are a special kind of unmanned aircraft, but are not commonly seen as drones. The same goes for rockets and jetpacks.

4.2.2 Level of Autonomy

Because of the absence of a pilot, drones always have a certain level of autonomy. An important distinction within the concept of autonomy is the difference between automatic and autonomous systems. An automatic system is a fully preprogrammed system that can perform a preprogrammed assignment on its own. Automation also includes aspects like automatic flight stabilization. Autonomous systems, on the other hand, can deal with unexpected situations by using a preprogrammed ruleset to help them make choices. Automatic systems cannot exercise this 'freedom of choice.'6 In this chapter, the focus is on autonomy in flight routes and operations (i.e., focusing on drone use and applications) rather than on automation like flight stabilization (i.e., focusing on technology). The United States Department of Defense distinguishes four levels of autonomy in their roadmap for unmanned systems.7 The most basic level of autonomy is a human operated system in which a human operator makes all the decisions regarding drone operation. This system does not have any autonomous control over its environment. A higher level of autonomy is a human delegated system. This system can perform many functions independent of human control. It can perform tasks when delegated to do so, without further human input. Examples are engine controls, automatic controls, and other automation that must be activated or

deactivated by a human controller. The third level of autonomy is a human supervised system. This system can perform various tasks when it is given certain permissions and directions by a human. Both the system itself and the supervisor can initiate actions based on sensed data. However, the system can only initiate these actions within the scope of the current task. The final level of autonomy is a fully autonomous system. This system receives commands input by a human and translates these commands in specific tasks without further human interaction. In case of an emergency, a human operator can interfere with these tasks.

4.2.3 Size and Weight

Other important characteristics of a drone are its size and weight. Clarke (2014) distinguishes large drones and small drones, but divides the small drones in multiple subcategories. Clarke also adds minimum weight indicators to the drone categories. The lower weight limit of large drones is 150 kg for fixed-wing drones and 100 kg for multirotor drones. Many countries distinguish large and small (or light and heavy) drones.

For instance, the Dutch Human Environment and Transport Inspectorate (ILT) makes a distinction between light drones and heavy drones. Light drones are drones lighter than 150 kg and heavy drones are drones of 150 kg or more.8 Custers et al. (2015) make a distinction between large and small drones but with different criteria than mentioned above.9 The development of drones is currently focused on making smaller and lighter drones for the general public. Large drones are mainly used for military purposes. Therefore, a shift can be observed from large drones to smaller drones. This calls for changing the reference categories and the category parameters. Therefore, they suggest to use the term large drones for fixedwing drones between 20 and 150 kg and multirotor drones between 25 and 100 kg. Small drones are fixed-wing drones up to 20 kg and multirotor drones up to 25 kg. Within the category of small drones, they suggest to use a subcategory of mini drones. Mini drones can vary in weight from several grams up to several kilograms. These mini drones are mainly suitable for indoor applications and recreational applications. Examples of such drones are discussed later in this section. (Fig. 8)

Figure 8: Types of drones

4.2.4 Differences in Energy Source

The final drone characteristic discussed here is the energy source. There are four main energy sources: traditional airplane fuel, battery cells, fuel cells, and solar

8 ILT 2013. 9 Custers et al. 2015.

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cells.10 Airplane fuel (kerosene) is mainly used in large fixed-wing drones. An example of such a drone is the military Predator drone. This drone is used a lot by the US army and can be equipped with a number of different sensors, but also with rockets and other types of ammunition.11 Battery cells are mainly used in smaller multirotor drones. These drones are short range and require less operating time than drones using kerosene. These drones are often for recreational use, making it more practical for the drone to run on a rechargeable battery cell. An example of such a drone is the above-mentioned Phantom drone.12 A fuel cell is an electrochemical device that converts chemical energy from fuel directly into electrical energy. Because of the lack of conversions in thermic and mechanical energy, this conversion is efficient and environment friendly. Fuel cells are currently rarely used in drones. Only fixed-wing drones can be equipped with such a cell because of the cell's relatively high weight. A major advantage of using a fuel cell is the fact that drones can fly longer distances without recharging. For example, the Stalker drone which uses a fuel cell has a flight time of 8 h instead of 2 h.13 Drones using solar cells are rare in the current drone industry. Drones using solar cells are mainly fixed-wing drones. Because of the low efficiency of current solar cells, these cells are usually suitable for many multirotor drones. However, solar cells are suitable for small ornithopters. Solar cell drones attracted a lot of media attention when both Google and Facebook struck deals with manufacturers of these drones.14 Their goal was to let solar-powered drones fly in the atmosphere permanently in order to enable people to connect to the Internet more easily and massively.(Dekoulis, 2018)

4.2.5 Widely Used Drone Models

To further illustrate the drone characteristics described above, some specific drone models are described in this section. Currently, drone models are developing fast and numerous drone models already exist. Due to the increasing popularity of drone technology, new models are developed at a fast pace.

Therefore, it is impossible to describe here every drone model currently existing. Hence, only some models which have been in the media to some degree and models which are widely available for governments, industry, and citizens are described here. These are the widely used, well-known, and available drone models. The order in which these models are discussed is from small to large. Delfly Explorer The Delfly Explorer is an ornithopter drone that flies like a dragonfly and is being developed by Delft University of Technology in the Netherlands. The drone can take-off and fly fully autonomous within a closed environment. It can avoid obstacles by using two cameras. The drone has a weight of 20 g and can currently operate for only nine minutes because of the size and weight constraints of the battery. In the future, these models could be used for reconnaissance and air photography, but also for applications like greenhouse inspections to check if fruit is mature.15 The Delfly Explorer is an interesting example of current developments in the drone industry. Drones tend to get smaller and lighter. Later in this chapter, future developments in drone technology are discussed in more detail. Hubsan x4 Drone The Hubsan x4 is a small multirotor drone developed by the Chinese company Hubsan. This mini drone is fairly simple in design and operation. It has four rotors and can be operated with a controller. Some models of the x4 drone come with a built-in camera for making pictures and recording video. The drone is currently a popular and relatively cheap alternative for the more advanced drones. The drone has a weight of 30 g, a radius of around 100 m and can operate for 7 min with a fully charged battery. Unlike most of the other models discussed, this drone does not have advanced features and is mainly built for recreational purposes.16 Parrot AR Drone The Parrot is a drone mainly built for recreational purposes. It has a multirotor system that can be controlled by a smartphone or tablet. The drone can operate for 12–18 min and weighs about 400 g. Its speed is about 18 km/h and it has a range of about 50 m. The drone has two cameras, Bluetooth and WiFi technology and uses GPS-waypoints to fly a preprogrammed route. The Parrot is similar to the below-mentioned Phantom, both in applications and functions. Besides film and photography software, the drone is also equipped with gaming software, making its emphasis on recreation more clear. The gaming aspect includes a racing game and augmented reality driven shooter games in which a real-world environment is augmented by computer-generated graphics and/or sound.17 The user can preprogram the drone with a task and settings like maintaining a particular altitude, after which it carries out the given task by itself.18 The Parrot is one of the most widely

used and popular models for recreational activities at the moment.19 Surveillance and privacy issues regarding this drone have caused a lot of discussion in for example Germany.20 DJI Phantom The Phantom drone is a multirotor drone with four rotors and is mainly built for recreational purposes. The drone comes with a camera and can be controlled using a smartphone or a WiFi controller. The smartphone can also control the camera to move and make pictures or record video. The Phantom can fly at around 54 km/h and it can operate for about 25 min. Just by programming the flight altitude and certain waypoints the drone can take-off, land, make recordings, and return automatically.21 Raven The Raven is a fixed-wing drone developed in 2002. The drone was originally developed for the US Army but is frequently used by many other countries as well, making it one of the most widely used drones in the world at this moment.22 The main purpose of the Raven is surveillance and it can be controlled remotely or preprogrammed for autonomous operation. The Raven has a width of 1.4 m, weighs about 2 kg, and can stay operational for 60–90 min within a range of 10 km. It is equipped with an optic and an infrared camera. Like regular model airplanes, the Raven can be launched by throwing it in the air. It lands by gliding toward a preprogrammed landing site and can compensate for the impact when hitting the ground by falling apart.23 ScanEagle The ScanEagle is a fixed-wing drone dating from 2004 and is mainly used as a surveillance tool. It is equipped with an optic and/or infrared camera and can operate for over 20 h. It is 3.1 m in width, 1.2 m in length, weighs 18 kg and has a cruising velocity of 89 km/h. The drone can be launched by pneumatic pressure and it can land with a skyhook system, plucking it out of the air. Therefore, a landing strip is not necessary. Contrary to most fixed-wing drones, the ScanEagle needs little space to take-off or land.24 In this section, a number of core characteristics of drones were described to determine the main differences between drones and their technical properties. These characteristics are displayed schematically in

4.3 Flying cars

Today, commuting to work in a personal helicopter or private jet is something that's only really available to billionaire CEOs, hedge fund managers, and "one hit wonder" rappers who are six months away from bankruptcy. That's all going to change in the near future, however. Just like the way that cellphones used to be exclusively for the 1 percent, soon the idea of taking a personal flying machine to work is going to be a part of everyday life. Don't believe it? Check out some of the companies who are building personal drones, flying "cars,"

4.3.1 Opener Blackfly

Californian startup Opener's entrant into the flying car market is BlackFly, which the company hails as, "the world's first ultralight all-electric fixed-wing vertical take-off and landing (VTOL) aircraft." It's a single-seat aircraft/vehicle capable of travelling up to 25 miles on a charge, with a top speed of 62 miles per hour. You won't need a pilot's license to fly it, although you will have to complete vehicle training and an FAA Private Pilot written exam. As with a lot of the other vehicles on this list, no official price has been announced yet, although Opener has stressed the importance of "competitive pricing." In interviews, designer Marcus Leng has said that Opener should cost no more than an SUV. Provided he's talking about an average midsize SUV, that would suggest we'll be able to take to the skies for around $33,000.

4.3.2 Passengers Drone

Sometimes you don't need to give your product a flashy millennial marketing team name — unnecessarily frivolous and featuring lower case letters where upper case ones should be — to sell your product. That's the case with the simply named Passenger Drone (Fig **??**) : an upcoming self-driving, 16-rotor, human-sized drone. The machine will be controlled by a touchscreen, and promises to take off with just one button. Users can then draw their route on a map, and have the drone fly them there, using a range of smart autonomous technologies to do so without accidentally running into anything on the way. The company has yet to reveal how much this will all cost. While we're expecting it to be pretty pricey, the theoretical ease-of-use of such a device could certainly help make this a mainstream entity, provided it's within reach of your average consumer. And that it works, obviously.

Figure 9: Passenger Drone

4.3.3 Aston Martin's Volante Vision

We're including this one despite the fact that, yes, we realize that most people don't currently drive an Aston Martin to work. The idea that somehow one of the world's most luxurious car brands will become cheaper when it adds a new flying feature to the mix is pretty darn unlikely. But the dream of arriving at the office in a flying version of James Bond's car is too intoxicating to ignore. Aston Martin's Volante Vision flying car is a hybrid-electric aircraft with vertical take-off and landing capabilities. Although no official release date has been announced, it promises to offer sufficient space for three adults in a triangular configuration. Given that the company is sticking to its luxury market ethos, this one's probably more of a weekend hire if we're honest.

4.3.4 Uber flying taxi

Who said that you need to actually own a flying vehicle in order to enjoy all the good things it can deliver? That's what Uber has figured out, and is working toward with its flying taxi (Fig **??**)program. Uber's concept, as depicted in a promotional video, shows how we might summon UberAir flights using a smartphone app. So far, so identical to catching a regular Uber. After you've booked your flight, however, you'll then have to get to a dedicated "Uber Skyport," gain access to your vehicle with the QR code from your digital boarding code, and then take off. The tagline at the end of the video reads, "closer than you think." To this we can hopefully add, "cheaper than you fear."

4.3.5 Lilium Aviation

German aviation startup Lilium Aviation has attracted the support of high-profile investors like China's giant holding company Tencent to bring its flying car dreams to life. In 2017, Lilium carried out a demo of its two-seater VTOL vehicle at a private airfield in Bavaria. The vehicle was remotely remotely by a pilot on the ground. Lilium is also working on a five-person vehicle, which should be able to fly for up to 60 minutes on a single charge. The company hasn't announced pricing information but, like Uber, it is very

Figure 10: Uber flying taxi concept

interested in the concept of flying car taxis. CEO Remo Gerber has said that taking a ride should be no more expensive than taking a road-based taxi or buying a train ticket. That sounds promising.

4.4 Types of Payloads and Their Applications

This section will discuss the types of payloads that can be attached to drones. Virtually all kinds of payloads can be attached to drones, the only restrictions are usually the weight and size of payloads. Most drones are equipped with cameras by its manufacturer. Other payloads can be ordered at drone manufacturers, but drone users also can attach payloads to their drone themselves. In this section, we will distinguish between sensors and other types of payloads. We will describe some applications for these payloads as well. (201, 2018b)

4.4.1 Sensors

The weight, model, and energy source of a drone are major factors influencing its maximum altitude, flight duration, flight range, and maximum payload. An important category of payloads are sensors. Most drones are nowadays equipped with cameras. Cameras and microphones are the most often used payloads for drones and often come standard when buying a drone. Cameras can be regular cameras but also infrared. Such cameras may enable night vision and heat sensing. Other sensors include biological sensors that can trace microorganisms, chemical sensors ('sniffers') that can measure chemical compositions and traces of particular chemical substances including radioactive particles and meteorological sensors that can measure wind, temperature, humidity, etc.

Characteristics Delfly Explorer

Hubsan x4 Drone

Parrot A.R. Drone

DJI Phantom

Raven ScanEagle

Type of drone Fixed-wing—-X X Multirotor -XXX -OtherX —Autonomy Human operated system -XXX XX Human delegated system –XX XX Human supervised system X- – -Fully autonomous system- —Size/weight Large drone (25-150 kg)- —Small drone (2-25 kg) —- XX Mini drone (up to 2 kg)X XXXEnergy source Airplane fuel —- -X Battery cells XXXX XFuel cells —- -Solar cells —- X

Fig. 2.1 Overview characteristics

Cameras can be useful payloads for the prevention, criminal investigation, criminal prosecution, and sentencing of criminal behavior. Most applications assume drones to be flying camera surveillance. The preventive function of camera surveillance shows mixed results.25 Citizens expect more crime prevention from police presence than from camera surveillance.26 The preventive function of camera surveillance, including drones, will probably be very limited when there are not at least a substantial number of drones in the sky. However, even with a large number of drones in the sky, the preventive function may be limited as with regular camera surveillance.27 It is often assumed that live monitoring images or reviewing camera footage after a crime, may be useful to reconstruct incidents or to trace, arrest and prosecute perpetrators.28 In practice, reviewing images indeed may yield useful information for solving crime, for instance, for tracing and arresting suspects, for excluding potential suspects, identifying witnesses, finding missing persons, reconstructing incidents, and finding stolen objects and vehicles. Satisfaction about camera surveillance among law enforcement agencies is limited however.29 Camera images can be useful as steering information for the police during criminal investigations. Drones may also be useful for forensics, since drones can be used to investigate crime scenes without stepping on valuable traces. Due to the high angle under which drones record images, it is not always likely that faces can be recognized. The use of image processing software, such as image recognition and license plate recognition may be limited for the footage collected with drones. Footage collected with drones may also be used in court as evidence. In the US there are examples of this.30 Law enforcement applications for drones are not limited to the use of cameras. Other sensors may also provide opportunities. For instance, heat sensors are very useful for detecting hemp that people are growing in their attics. Chemical sensors may be useful for detecting traces of illegal drugs. Drones equipped with WiFi hotspots may provide clues about someone's position and can be used for tapping phone and Internet use. In the security domain drones are useful as observation and surveillance instruments. Webster distinguishes three mechanisms31: non-active systems, in which cameras act as a visual deterrent by using fake cameras to create the illusion of surveillance without actual monitoring or storage, reactive systems, which have recording, storage and playback facilities for footage of incidents after an event has occurred, and proactive systems with live surveillance from a dedicated control room with recording, storage and playback facilities, allowing for an

25 Taylor 2011. 26 Sparks et al. 2001; Brands and Schwanen 2013. 27 Welsh and Farrington 2008. 28 Ditton 2000; Koskela 2003. 29 Custers 2012; Custers and Vergouw 2015. 30 Sherwell 2014. 31 Webster 2009.

Maxwell's equations:

$$B' = -\nabla \times E, \tag{1a}$$

$$E' = \nabla \times B - 4\pi j, \tag{1b}$$

immediate response to incidents as they occur. Drones can be used for all three types of surveillance. However, it is unlikely that citizens will feel safer, as research has shown for live monitoring.32 In fact, people usually do not know whether camera systems are proactive, reactive, or non-active. Drones equipped with sensors may also provide useful intelligence about particular situations, such as the presence of people or buildings in a particular areas or reconnaissance surveys of areas. In case of disasters or crises, information collected with drones may contribute to improved situational awareness. Remote areas or places that are difficult to reach (e.g., because of traffic jams), may be easily accessible for drones. The higher altitude position of a drone may provide better overviews and provide images for reconstructions, evidence, and insurance claims. In the area of security, drones are also useful for purposes of crowd management, for instance, at large demonstrations, music festivals, sports games, and other events. Drones with cameras are useful for tracking people and assessing potential escalations. For instance, drones may provide information of a group of protesters heading in a particular direction or information about two groups of football fans moving toward each other. Drones may be useful for protecting VIPs, vulnerable buildings (nuclear power plants, harbors, airports), and infrastructure (water supply, internet, etc.). In case of large fires, drones may provide information about the size and development of the fire, the release of toxic particles and the direction of local winds. In case of accidents with nuclear power plants drones can trace the presence and dissemination of radioactivity. Most of these applications focus on movements; identifying individuals is much more difficult with drones. For inspections and maintenance of infrastructure, such as highways, railroads, windmills, bridges, pipelines and dams, drones may be a useful tool. Weak spots, erosion, or wear and tear may be detected with cameras. The use of infrastructure, such as the movement of vehicles, aircraft, and ships can easily be monitored. In case of traffic jams, the traffic can be rerouted and the data collected can be used for traffic analyses. Pipelines leaking gas or water may be detected. High objects like roofs, chimneys, windmills, and electricity network cables can be inspected from close distance when using drones. Drones with sensors may be useful to supervise and enforce permits, for instance, permits for building a structure, parking permits, and permits for removing trees. Drones may also be useful for purposes of cartography and geomapping. These are promising applications of drone use in the near future.33 Drones are cheaper than aerial photography from manned aircraft and also cheaper than satellite imaging. Since drones can get closer to the surface, they can also reach

32 Brands et al. 2013. 33 COM (2014) 207, A new era for aviation, opening the aviation market to the civil use of remotely piloted aircraft systems in a safe and sustainable manner. Communication from the commission to the European Parliament and the Council, European Commission, April 8, 2014.

different angles and perform other measurements like 3D terrain modeling, research on vegetation, and geomorphology (erosion, seismographic activity, volcanic activity, etc.). When equipped with particle sensors, drones are useful for detecting the emission of particulates. Concentrations and emission rates of sulfur oxides, nitrogen oxides, and ammonia can be measured. Other sensors can measure light, sound, and radiation. These applications of drones may contribute to the environment and are also less polluting than manned aircraft.34 Drones may also help monitoring illegal waste dump and transport of toxic waste. When particular animals are provided with RFID tags, drones can track migrations, biodiversity, poaching, and habitats. Images created by drones may also be useful for estimating animal populations and tracking their behavior.35 Drones with sensors are currently used in agriculture, for instance, for monitoring crop growth, estimating biomass, checking for weeds and plant diseases, and evaluating the quality and level of water. The use of drones in border surveillance is particularly useful in vast areas and areas that are difficult to reach or access. Border surveillance may prevent trafficking illegal drugs and illegal migration. The US government uses drones on the Mexican border.36 The Australian government has announced the use of drones for border surveillance, particularly for finding boat refugees. Frontex, the EU agency for border security explicitly mentions the use of drones in establishing the border surveillance system EUROSUR.37 In the field of cinematography, television, and entertainment there are wide possibilities for drones. Drones provide the opportunity to take high camera shots.38 During the 2014 Winter Olympics in Sochi, Russia drones were used to film sportsmen. Also, drones are particularly useful for providing overviews of landscapes, cities, and buildings. In movies, pursuit scenes can be recorded from an aerial perspective.39 Drones can fill the 'gap' between hoisting cranes (with limited height) and helicopters (with high costs). In what is called drone journalism, drones enable journalists to cover news, large events, and police pursuits. Citizens can easily order small drones via the internet and such drones are usually equipped with cameras. People use these cameras to record or take pictures

of their homes and their neighborhood, sometimes just for fun, sometimes

for other purposes, like neighborhood crime prevention. Other recreational

purposes in which drones are used are bird watching, sportsmen recording

$$z = \overbrace{\underbrace{x}_{\text{real}} + i \underbrace{y}_{\text{imaginary}}}^{\text{complex number}}$$

themselves40 and making selfies (self-portraits featuring the photographer).41 A typical example of a drone specifically designed for making selfies is the Nixie, a bracelet that can unfold as a drone.42 This drone is still in development, however. The use of drones in science is also a growing domain. Drones may be useful to collect all kinds of research data. For instance, in meteorology drones can collect data on humidity, pressure, temperature, wind force, radiation, etc. Apart from hurricanes, some drones can withstand severe storms.43 In case of nearing tornados or hurricanes, people can be timely evacuated. Drones can gather relevant data in places that were hitherto difficult or costly to reach—-data that may provide new scientific insights,44 increasing knowledge about the environment, the atmosphere, and the climate. Such knowledge may improve existing models and provide more accurate predictions. Drones are also becoming more common in archeology.45 Drones can survey landscapes cheaper and more detailed than satellites. From the air, patterns in landscapes can be observed, for instance, vegetation that indicates an old road or settlement. Images collected by drones can also be used to reconstruct sites and excavations. In geography, drones can be useful for estimating populations, for instance, in slums. Even in developed countries actual populations may differ from what is officially registered, as there may be significant numbers of illegal immigrants. New tribes in remote areas, like in the Amazon rainforests, may still be discovered with the use of drones. Drones may be useful in mapping and monitoring urbanization and traffic flows. Geological surveys with drones are already used in finding new sources of gas and oil.46(Wich and Koh, 2018)

4.4.2 Other Payloads

Apart from the sensors described in the previous subsection, all kinds of other payloads can be attached to drones. Most payloads that are not sensors involves cargo that needs to be delivered, i.e., mail like letters and parcels, medicines, meals, supplies, and fire extinguishers. Cargo can also be illegal, such as narcotics

40 Beckham 2014. 41 Drones, even without any payload, are popular among citizens for recreational use. In this context, drones are often referred to as remote controlled airplanes/helicopters. Some people like to participate in air racing or pylon racing, a competition in which a drone has to fly a series of prescribed figures or has to fly a route the fastest. In pylon racing the drone has to fly 10 laps around three pylons in a triangular position as fast as possible. In combat games, paper ribbons are attached to each drone and then drones have to cut off each other's paper ribbons in their flight. 42 http://www.flynixie.com. Accessed April 1, 2016. 43 Kelly 2013. 44 Richardson 2014. 45 Euronews 2013. 46 Parker 2014; Dillow 2013.

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and firearms. In some cases, the cargo is not intended for delivery; examples of such payloads are ads and WiFi hotspots. From a commercial perspective, drones are considered interesting for delivering mail, parcels, and other cargo. A typical example would be supplying oil drilling platforms or remote islands. In the US there are speculations about delivering pizzas using drones47 and in Russia pizzas are already delivered using drones.48 In China drones deliver pies.49 However, it is likely that these experiments are mainly interesting for publicity reasons, in order to draw attention to a specific company or product, rather than from an efficiency in logistics perspective, as there are obvious limits to the size and weight of the cargo that small drones currently can carry. In the US, Amazon intends to deliver its orders using drones, but the authorities have prohibited the use of drones.50 Another commercial application of drones is that of flying advertisements. Objects, banners, ticker tapes, and speakers can be attached to drones to disseminate marketing messages. Examples may be to attach a large beer can or a large shoe with a logo to a drone and fly it around. However, such applications are still in development. As mentioned above, drones in the security domain often use cameras and other sensors. Other useful payloads include, for instance, fire extinguishing materials51 and speakers and light signals for crowd control purposes.52 More controversial is the use of drones equipped with weapons, teargas, etc.53 For search and rescue operations, drones may be used to supply water, food, medicine, and AEDs to stranded mountaineers, people in the desert or people who were shipwrecked. Infrared cameras may be useful to find lost people and save them from hypothermia, dehydration, etc. After disasters like earthquakes or tsunamis, complete infrastructures may be disables, but drones may be equipped with WiFi to restore communication networks. Highly controversial is the use of drones for targeted killing.54 Drones in agriculture do not only focus on monitoring. In Japan, currently already 30 % of the rice fields are sprayed with drones.55 Pesticides and fertilizers can be used in minimum quantities by means of so-called precision farming. Drones are faster, safer, and less damaging than tractors. They may also scare

47 Pepitone 2013. 48 Daily Mail 2014. 49 Atherton 2013. 50 McNeal 2014. 51 Wells 2014. 52 Finn and Wright 2012. 53 Whitehead 2012. 54 Statman 2004; Kretzmer 2005; Gross 2006. 55 Koebler 2013.

36 B. Vergouw et al.

away birds, plant seeds, and impregnate fruit trees,56 although these applications require much more precision than is currently possible from a technological perspective. Some people use drones to make a personal statement, for instance to demonstrate or use their freedom of expression. A typical example is an incident during a soccer game between Serbia and Albania in 2014. During the game, a drone with the flag of 'Greater Albania,' flew in the stadium. Serbian players took the flag but were attacked by Albanian players. The audience became angry and ran on the field, attacking the Albanian players, who had to run for their lives. Other freedom of speech or more recreational uses may include drones equipped with projectors to spread news or images,57 for instance, by projecting live images on buildings or walls. A creative form of using drones are spaxels (pixels in space). In this application drones equipped with LED lighting fly in the night sky and draw 3D drawings, something similar to fireworks.58

4.5 Frequency Spectrum Issues

In order to perform a flight, most drones have a need for a certain amount of wireless communications with a pilot on the ground. In addition, in most cases there is a need for radio communication for the payload, like a camera or some kind of sensor. To allow radio communication to take place frequency spectrum is required. The requirements for frequency spectrum depend a on the type of drone, the flight characteristics and the payload. Since frequency spectrum does not end at national borders and manufacturers have a need for (semi) global markets, international coordination on the use of frequency spectrum is required. Within the CEPT,59 EU,60 ITU,61 and ICAO62 a number of working groups are dealing with this issue. This section will first address the legal issues on frequency spectrum usage and electronic equipment. Secondly the surveillance and compliance (enforcement of the usage of frequency spectrum and equipment requirements) will be addressed. Finally, some attention will be given to special government usage.(Sonnenberg, 2016)

4.5.1 Legal Issues on the Use of Frequency Spectrum and Electronic Equipment

The international regulation of the use of frequency spectrum is laid down in the so-called Radio Regulations (RR).63 The RR contains the complete texts as adopted by the World Radiocommunication Conferences (WRC). These conferences are organized every four years by the International Telecommunication Union (ITU), a body of the United Nations. The RR contains, besides regulations, a table which lists all the frequency allocations. All regional and national tables of frequency allocations are derived from this table. An allocation may have a primary or secondary status, meaning that a primary user may cause harmful interference to a secondary user of the frequency spectrum but not vice versa. Several countries also have the notion of a tertiary allocation which often deviates from the ITU table. Tertiary users may not cause any interference to primary and secondary users and must accept all interference from all other users. Cases of interference to those users are most often not acted upon by the national regulator. Applications that make use of license exempt bands often have a secondary or tertiary allocation. Within Europe the CEPT is tasked with the detailed allocation of frequencies and the required frequency spectrum engineering in order to investigate the compatibility between radio systems. The CEPT also drafts a European position on frequency matters for the coming World Radio Conference (WRC). A number of frequency bands are allocated to the aeronautical services. Traditionally these bands were reserved for manned aircraft operations. In the WRC-12 frequency band 5030–5091 MHz was allocated on a primary basis to be used by remotely piloted aircraft systems (RPAS), drones, but only for control and non-payload communications (CNPC). This frequency band has been allocated for commercial unmanned aircraft systems which are able to fly over large distances and may fly in controlled airspace, used by manned aircraft. ICAO has been tasked to set up a band plan to facilitate the international use of this band, however, there is no clear coordination on this work. Investigations are ongoing to indicate which are the relevant criteria to be taken into account. At this moment, June 2015, no band plan has been made. Furthermore, international discussions are ongoing about the use of the regular satellite services to be used for Command and Control of RPAS. These fixed satellite services (FSS) are not initially meant to be used for aeronautical safety services.64 Therefore, criteria need to be set to validate the possible use of FSS for safety services. (Fig. 11)

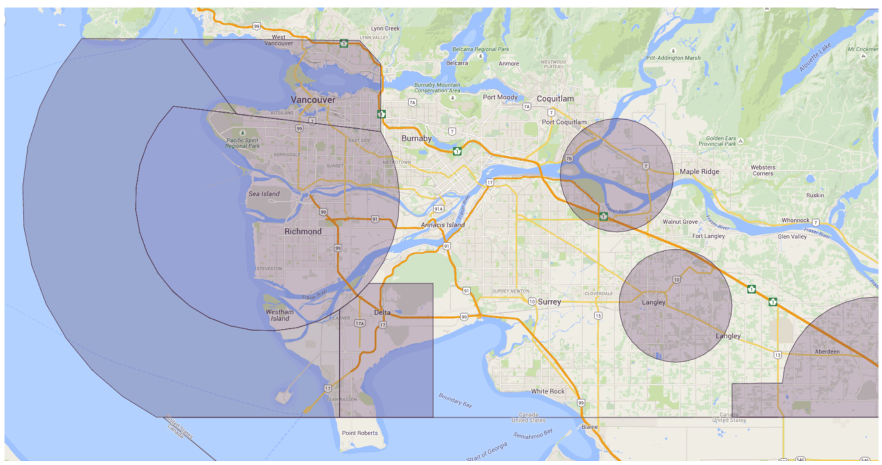

Figure 11: Drone air zones

For small drones no specific frequency allocations have been made on an international level for command and control or payload. Given the major developments in this area in the past few years, the demand for frequency spectrum is ever increasing. The lack of reserved frequency spectrum means that drones can, in most countries, only make use of generally available (license-free) frequency spectrum. Within Europe a large number of license-free frequency bands have been allocated. Several European Recommendations and decisions like ERC Rec 70-03 give a list of all these bands together with technical limitations and requirements. Since these bands are license-free the frequency band is shared with other unlicensed users on a secondary or tertiary basis. Two popular license-free bands used for drones for command and control and payload communications, the 2.4000–2.4835 MHz and 5.470–5.725 MHz bands, have to comply with the regulations that apply to broadband data transmission systems like WIFI. In Europe the band 5.725–5.875 MHz is available for non-specific short-range communication with a maximum transmission power of 25 mW effective isotropic radiated power.65 Because of the popularity of WIFI, especially in the 2.4000– 2.4835 MHz, there is a reasonable chance of interference between drones and other usage in populated areas, which may lead to the loss of control over the drone. The receiver of the drone may pick up a high level of interference because of the height of its flight. Therefore, together with the low transmission power requirements, only drone flights within line of sight of the pilot and with low safety requirements can use these frequencies. For drone flights that require large flying distances, for instance for the observations of dikes, woodlands and borders, it is not realistic to make use of the license exempt bands mentioned. Special arrangements have to be made to make these flights possible. In most cases a license for the use of dedicated frequencies is required, which is the competence of the national regulating authority (NRA). The frequencies which may be used for command and control and payload communications, if required, will in most cases not be in the low frequency ranges. For instance in the Netherlands it is expected that a part of the 7 GHz band, which is also in use for ENG/OB,66 may be used for these purposes. Using these high frequencies requires a line of sight connection between the ground transmitter/ receiver and the drone. Together with often low flying altitudes of the drone it requires careful preflight planning to preserve line of sight conditions throughout the whole flight. In future the internationally reserved frequency range between 5030 and 5091 MHz for CNPC may be used for flights beyond line of sight. If during a flight payload communication is required, for instance, in cases of fire or border control, other additional frequencies are needed.

4.5.1.2 European System of Standardization

Drones require radio systems to allow communication between the drone and the pilot. European Aviation Safety Agency (EASA) directive 216 is only applicable for drones with a weight above 150 kg67 and only for control and non-payload communications. In the European Economic Area68 the radio equipment on board drones up to 150 kg therefore need to comply with the essential requirements of the R&TTE69 and EMC70 directives for command and control communications. All pure payload communications in drones need to comply with these directives. The R&TTE directive will be replaced by the RED71 directive by June 2016. Manufacturers and importers have the responsibility for compliance of their drones before placing them on the market. If the drone complies with the essential requirements a CE marking has to be affixed to the drone or eventually to the packaging or the accompanying documents. Furthermore, a declaration of conformity has to be published.

4.5.2.1 Use of Frequencies

Drones use frequencies that may cause harmful interference for a number of reasons. These can be * Drones bought outside the European Union and used in Europe might well use frequencies intended for other use in Europe and interfere with that other usage. * The use of a particular frequency requires a license because other users also make use of those frequencies. If no license is issued no planning has taken place and interference can occur. * The combination of emitting equipment might unintentionally cause interference. * Radio equipment in a drone may malfunction. * The use of high transmission power may not be in accordance with regulations. In cases of reported interference the NRA may start a surveillance to resolve the issue. Due to the relative short flight time of drones interference may have ceased to exist when the reported interference case is investigated. In severe cases and reoccurrence of interference administrative fines may be issued.

67 This may change in the future. 68 All EU countries, Lichtenstein, Norway and Iceland. 69 Radio and Telecommunications Terminal Equipment. 70 Electro Magnetic Compatibility. 71 Radio Equipment Directive.

40 B. Vergouw et al.

2.4.2.2 Electronic Equipment

National regulating authorities have the responsibility to verify the compliance of radio equipment to the R&TTE72 and the EMC directives. Within Europe, the national regulating authorities coordinate their efforts within ADCO.73 Based on risk analysis the national regulating authorities take samples of radio equipment entering the European market. If severe noncompliance to the EMC or R&TTE/ RED directives is established the radio equipment may be taken off the national and European market. Since drones require radio equipment this procedure also applies to them.

4.5.3 Government Usage

In most countries the frequencies for drones used by the government is regulated differently than commercial or private use. The government, or parts of it like the Ministry of Defense, can make use of dedicated frequency bands which they use for their entrusted tasks. Additionally a number of governmental organizations can make use of (military) satellites to command and control their drones even outside their own territories. This, however, does not mean that all ministries within a government have sufficient frequency spectrum available for drones. In most countries special legal arrangements exist to allow (parts of) the government to increase or release their rights on the use of frequencies. For instance, in the Netherlands the government has to substantiate its claim for frequencies in a dedicated plan in which they describe in detail their current and future frequency needs. In the UK the principal of frequency spectrum pricing is used, in which the price for spectrum is used as an important mechanism to ensure that those resources are used efficiently by the users.74 In Europe drones used by the government, if they are not commercially of the shelf, do not need to comply with the EMC and R&TTE/RED directives. As mentioned before this does not mean that they can use any frequency they like or may cause harmful interference to other users with the same ore higher status.

2.4.4 Conclusions on Frequency Spectrum Issues

No dedicated 'drone-only' spectrum is available. The current spectrum usage by drones can be facilitated by license-free spectrum or, on a national basis, licensed (Table 2.)

spectrum. To accommodate international usage and future needs, efforts have to be made to make spectrum available for the use of drones. The availability of spectrum is essential for the operation of RPAS. Several organizations are dealing with the spectrum requirements for the drone market. Distinctions within the drone market by weight classes, the application of safety services and the different types of payloads lead to complexity. Intentions of the regulating authorities are to enable safe operation of unmanned aircraft on a large scale in segregated and nonsegregated airspace, used for a broad range of services. Harmonization and the development of standards must contribute to a competitive worldwide market of radio equipment, which is not causing interference to other services or suffering interference from those services.

4.6 Future Developments

There are three major developments in drone technology: miniaturization, autonomy, and swarms. The first development, miniaturization, is the most incremental development. As in most areas of robotics, each new generation of drones is a bit smaller, lighter, and cheaper than the previous generation. For instance, new materials and lighter and more efficient batteries create better trade-offs between the drone and its flight range, maximum altitude, and maximum payload. The limits of miniaturization are unknown. The smallest commercially available drones are more or less the size of credit cards, but experts indicate that within a few years we can expect drones the size of insects. Cheaper and smaller drones are also likely to result in the ubiquity of drones. Whereas drones may now still be a rare sight in the sky, it is expected that within a few years, there will be plenty of drones available among the general public. This expectation is based on the rate at which drones are manufactured and sold. Drones are popular birthday and Christmas presents for teenagers, they are popular among photographers and sportsmen and there is an increase in small companies that offer drones services. A second major development is the further increasing autonomy of drones. Drones are often seen as remote control aircraft, but there are technologies that enable autonomous

Table 3.1: RPAS Market Segmentation by Size

Size	Approximate weight	Current and potential applications	Price and quantity
Small (¡20kg)	Micro/ Nano/ miniature/ 'toy' RPAS (few hundred grams)	* Leisure use	* Available to buy on the high street and online
		* Commercial use (surveillance and inspection of hard to reach areas)	* £100 for leisure use
		* Limited flight capability due to poor battery life	* £10000 for specialised use
			* Estimated to be tens of thousands of toy-like RPAS in the UK
	Small RPAS (¡ 2kg)	* Leisure use	* £100–PS900
		* Commercial use (photography)	* Estimated to be thousands in the UK
	Small RPAS (2–7kg)	* Mainly commercial use (photography, aerial surveying and inspection)	* £500–PS4000
		* Large recreational models also available	* 360 units used commercially
	Small RPAS (7–20kg)	* Mainly commercial use (photography, aerial surveying and inspection)	* £4000–PS20000
		* Some specialist recreational models produced	* 150 units used commercially
Light (20-150kg)	Light RPAS (20–50kg)	* Potential to inspect pipelines/power cables, spray crops, search and rescue	* £40000–PS100000 depending on endurance and technology
			* 2 units used commercially
	Light RPAS (50–150kg)	* Potential for border surveillance; forest fire Monitoring	* Few for commercial use
			* ¡ £300000 depending on airworthiness certification requirements
Large (¿150kg)	Large RPAS (¿ 150kg)	* Potential for cargo transport	* ¿ £500000
		* Potential to remain airborne for days, if not months, and travel thousands of miles	* None used commercially at present, though some may be in testing

Table 2: Drones

operations, in which the remote control by a human operator is partially of completely excluded.75 Most drones that are commercially available are remotely controlled, but at the same time they already contain elements of autonomy, mostly software for flight stabilization. More professional drones offer the possibility to pre-program flights. In the near future, more autonomy is expected with regard to determining flight routes, sense and avoid systems76 for

75 USDoD 2013. 76 Finn and Wright 2012.

performing evasive maneuvers (e.g., birds, airplanes), adapting to changing weather conditions and defensive reactions when drones are under attack. A third major development is the use of drones in swarms.77 The increasing autonomy of drones enables the cooperation between drones in so-called swarms. The use of swarms may widen the range, flight duration, and maximum payload for particular applications. For instance, using drones in swarms, one drone may take over a task from another drone with an exhausted battery. In this way, the flight range can be extended beyond the range of the first drone. Drones that fly beyond the reach of control signals or are damaged during their flight can be replaced by other drones. Heavy payloads may in some cases be distributed over several drones, exceeding the payload of only one drone. Swarms of drones may be used as sensor networks.78 When drones are used to follow several persons, a problem may arise when they split up. When using swarms, each drone may follow an individual instead of having to choose whom to follow. A technological difficulty to overcome concerns the fact that drones in swarms have to communicate with each other besides communication with ground control, which requires many more communication channels.

4.7 Conclusions

This chapter provided an overview of the different technological aspects of drones. This overview includes the different types of drones currently used and their technical specifications, potential payloads and applications, frequency spectrum issues and the current and near-future technological development in drone technology. The first important distinction made is that between the actual drone (the platform) and the attached equipment (the payload). The different types of drones can be differentiated by the type (whether it is fixed-wing, multirotor or something else), the degree of autonomy, the size, weight, and the power source. These technical specifications are determining factors for the drone's capabilities, for example it's range, flight duration, and loading capacity. The payload can consist of almost anything. Some examples include all sorts of sensors (like cameras, sniffers, and meteorological sensors) and different kinds of freight (like parcels, medicine, fire extinguishing powder, and flyers). In this chapter, we also described a number of applications for drones and their different payloads. These applications illustrate the potential of drones and of their payloads. More examples of drone use are discussed in Part II of this book. In order to be able to control a drone, communication between the user and the drone and/or its payload is required. For this communication frequency spectrum

is required. At this moment, there is no spectrum available dedicated to drones only. Currently, the spectrum usage by drones can be facilitated by license-free spectrum or licensed spectrum on a national basis. Efforts have to be made to make spectrum available specifically for drone usage in order to accommodate the international usage of drones. Since frequency spectrum does not end at national borders, international coordination of its use is required. This is an essential part in the operation of drones. Therefore, standards have to be developed in order to create a feasible worldwide market which is not causing interference to other services or suffers from interference from other services. Future developments of drone technology include drones becoming smaller, lighter, more efficient, and cheaper. Therefore, drones will become increasingly widely available to the general public and they will be used for an increasing scope of applications. It is to be expected that drones will become more autonomous and more capable of operating in swarms in the near future.

Things you need to know about drones

UAVs, first developed by the military in the 1990s, are a mind-blowing innovation. They spark curiosity and wonder. Quadcopter Arena presents a few myths and debunks them with a few drone facts.

Interesting drone myths

There are many things about UAVs that you may believe, but they are myths. It can be quite difficult for you to separate fiction from reality. These interesting facts about drones will help you debunk long-standing myths, and put things in perspective.

1. A Model Airplane is a Drone

One of them is that a model airplane is a drone. Drones are machines that fly without a pilot controlling them. In contrast, pilots fly model airplanes within their line of sight. A model airplane cannot move out of a pilot's periphery of vision, which disqualifies it as a drone.

2. Drones are like surveillance cameras

Drones may seem like street cameras because they have the same functions. Both survey and record images (Fig. 12)

Figure 12: Drones Camera

Contrary to this belief, they are not like surveillance cameras because they take to the air. They fly, and can follow a person's movements wherever they go.

You may have to merge the feeds taken by surveillance cameras. Drones have a continuous live feed, and can capture images without interruption.

3. Only the police and the military use drones

Drone uses have expanded. Many civilians fly them these days. Modern ones like the DJI Phantom 3 or the Nano QX bring joy to many avid hobbyists.

4. Police need a warrant if they are flying a drone below 400 ft

The police often use aerial vehicles to survey backyards for marijuana. You may think that they need a warrant if they fly a drone below 400 feet.

The US Supreme Court has found that it is not a violation of constitutional rights to fly a drone at a low altitude. The ruling enables the police to use such devices to fight crime.

5. The police cannot use the footage delivered by drones

Using drone footage is not a violation of constitutional rights either. As long as an officer has the right to be at a crime scene, he can use the evidence he collects. The same applies to drones. The police can use the footage drones record, as long as it this is not done in a restricted area.

6. Flying drones does not take skill

Contrary to what you may believe, achieving control of a drone's pitch and yaw takes practice. Experienced pilots can make a drone dance in the air.

7. All drones have weapons

Not all drones do. Drones help people in many ways. While some drones have military uses, others are used for photography and other purposes.

8. Drones cannot stay in the air for long

Lightweight drones like the Blade Nano QX or the Hubsan X4 cannot remain in the air for more than 10 minutes.

Not all drones are mini-drones. The DJi Phantom drones can stay in the air for about half an hour. US military drones can hover for many hours at a time.

9. There are more downsides than upsides to using drones

You may have heard horror stories of low durability, crashes and short flight time. But the advantages of using drones outweigh their disadvantages.

Manufacturers are blending robotics, airframe design and sensors in many ways. These innovations have created jobs and increased the competitiveness of companies.

15 Surprising facts about drones There are many fun facts about drones waiting for you to discover. Many of them are historical in nature. Others are simply frightening. In all, they will definitely floor you.

1. The first drones targeted terrorists

The first military drone, the Predator, targeted Osama Bin Laden.

The United States built the first drone before the 9/11 attacks, but it was not ready for deployment.The first drone killing was in 2001 when UAVs shot Muhammed Atel, an Al Qaeda commander.

2. Military uses for drones are increasing

Drones do not just track and survey the enemy. They bear powerful weapons and are lethal devices.

3. Attack drones need people to man them

That all drones are autonomous is a misconception. The higher the attack capability of a drone, the more people need to man it.

4. Israel was the first country to build drones

The first country to manufacture drones was Israel. Israel Aerospace Industries has production facilities about 24 countries around the world.

5. Drones have taken many lives

According to the Federal Bureau of Investigation, attack drones have killed about 4756 people. Many were children.

6. Drones help humanity

There are many things a drone can do. Besides having military uses, they enable communication in inaccessible areas. They also survey land for real estate purposes.

7. Drones fight crime

The police use them for tracking purposes. The aerial footage they capture serves as evidence to convict criminals.

8. Drones deliver food and medicine

You may not realize how helpful drones are. Many bring food and medicine to people in war-torn areas. (Fig. 13)

Figure 13: Drones in the medical supply

9. They are excellent farming tools

Drones are great farming assistants. They survey crops, and their footage will show farmers the damaged ones.

10. Drones cover important events from the air

Drones can help you to record important sports games or celebrations from the air. With a drone, you will never miss a fireworks display. (Tab. 3)

	GoPro Karma	DJI Phantom 4
Weight	1380g	1280g
Max Speed	35 MPH	45 MPH
Camera	Hero 5, Session	4K, 30 fps
Flight Time	20 mins	28 mins

Table 3: comparison of drones

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