Introduction to Multicopter Design and Control

Lesson 15 Outlook

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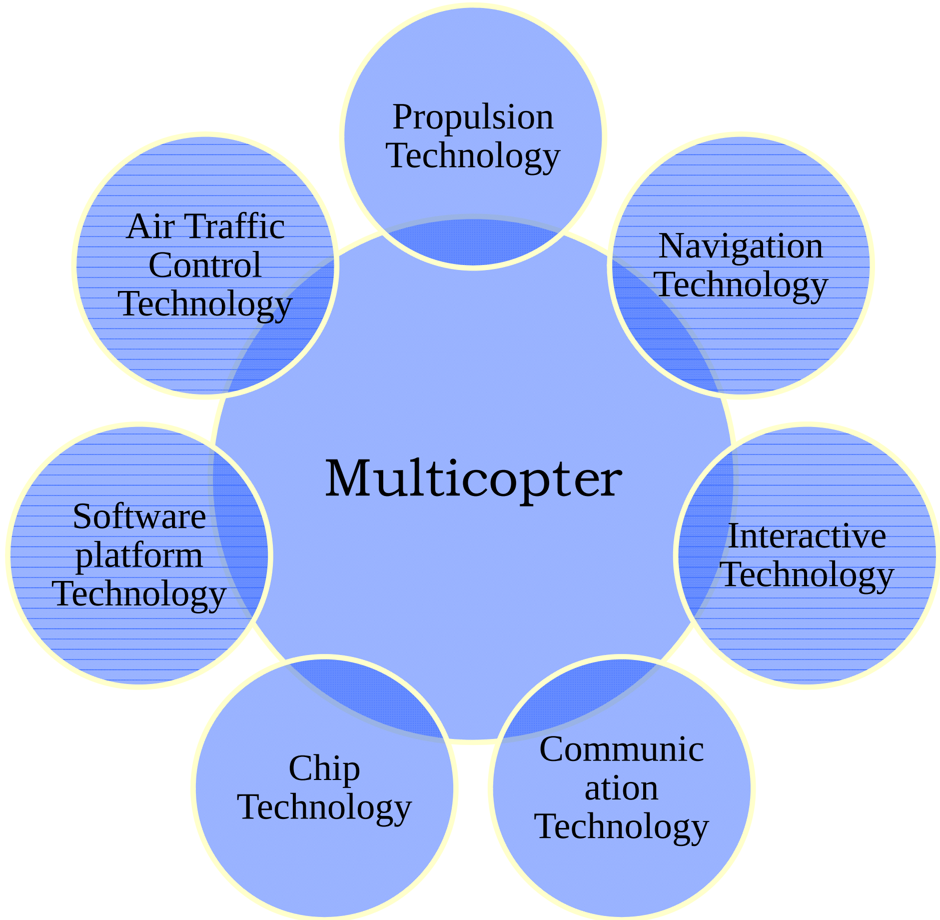
Where will multicopters go?

Outline

1. Related Technology Development
2. Demand and Technology Innovation
3. Analysis
4. Opportunities and Challenges
5. Conclusion

1.Related Technology Development



1.Related Technology Development

□ Propulsion Technology

（1） New battery

- On May 22nd, 2015, a company called EnergyOr Technologies Inc. demonstrated the world's longest multicopterflight, creating a record of 3 hours 43 minutes and 48 seconds.

Quadcopter equipped with EnergyOr fuel cell

- Potential new battery :
  - Graphene battery
  - Aluminum-Air battery
  - Nanodot battery

EnergyOr fuel cell

1.Related Technology Development

□ Propulsion Technology

（2） Hybrid power

- In 2015, a company called Top Flight Technologies created a world record that their hexacopter with1 gallon of gasoline can fly for more than two-and-a-half hours--or 160 kilometers--carrying a payload weighing 9 kilograms.
- A German company called Airstier was building a quadcopter which was powered by a combustion engine, and could stay in the air for up to 60 minutes with a payload capacity of 5 kilograms.

Top Flight Technologies hexacopter

Airstier yeair!

□ Propulsion Technology

（3） Power supply on the ground

A tethered hovering aerial system, such as HoverMast developed by a company called Sky Sapience in Israel, could be powered by the power supply on the ground via a wire in the tether.

Skysapience multicopter

1.Related Technology Development

□ Propulsion Technology

（4） Wireless charging

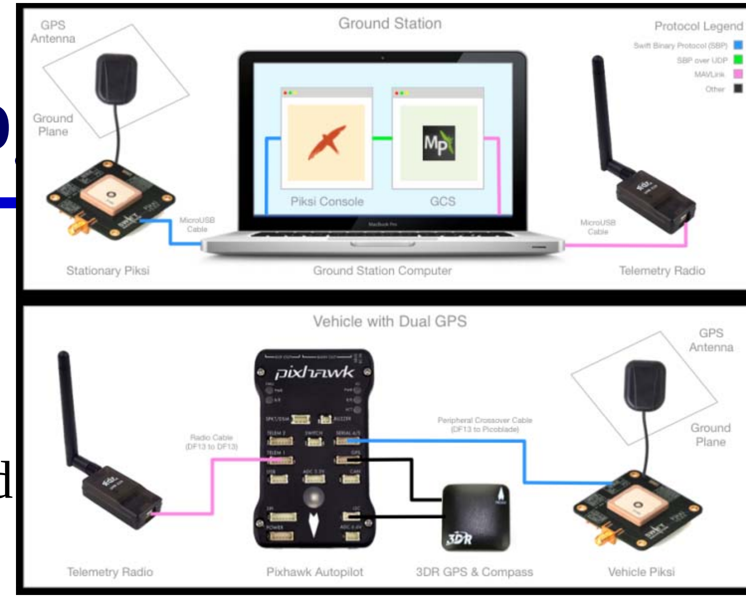
A company called Skysense in Berlin developed a landing pad with the capability as a wireless charging station. If the charging process is fast enough, then such wireless charging stations distributed over an area will ensure multicopters to fly a long distance autonomously by multiple take-off and landing.

SkySense Pad

1.Related Technolo

☐ Navigation Technology

（1） Precise positioning

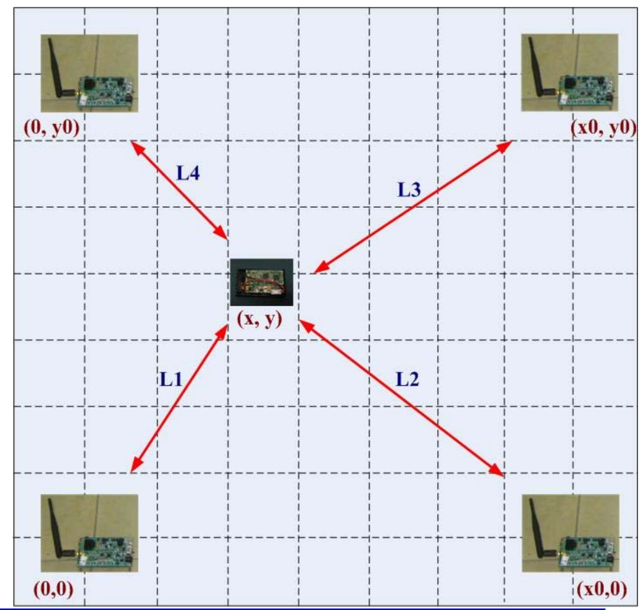


Piksi of SwiftNavigation company

1) Real Time Kinematics (RTK). A company called Swift Navigation released its first product Piksi; RTK is also supported by RTKLIB (http://www.rtklib.com/), an open source Global Navigation Satellite System (GNSS)

2) NAVigation via Signals of OPportunity (NAVSOP). U.K. defense firm BAE Systems has come up with a positioning system which uses the different signals that populate the airwaves

3) Ultra WideBand (UWB)[1].



UWB

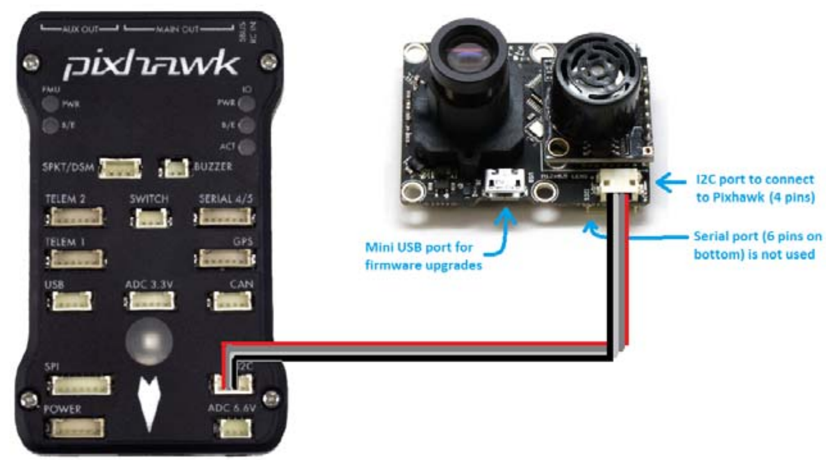
[1]J D Hol, et al. Tightly coupled UWB/IMU pose estimation. In:Proceedings of the IEEE International Conference on Ultra-Wideband. New York, USA: IEEE, 2009.

Navigation Technology

（2） Velocity measurement

A commonly-used velocity estimation method is optical flow based scheme, estimation based on the combination of optical flow, ultrasonic range finders and IMU. AR. Drone is the first product using optical flow to improve the performance, achieving a great success. PX4Flow, designed by ETH Zurich, is an optical flow smart camera. Such a sensor can help multicopter hover without GPS. Insipire and Phantom 3 proposed by DJI also use this technology.

AR. Drone sensor



PX4Flow sensor

1.Related Technology Development

□ Navigation Technology

（3） Obstacle avoidance

1） Depth camera

2） Ultrasonic range finders

3） Camera & Memristor

4） Binocular vision

5） Metamaterial Radar

6） LiDAR

7） Four-dimensional radar

RealSense sensor

Panoptes eBumper4（Sonar-based obstacle avoidance）

1.Related Technology Development

□ Navigation Technology

（4）Tracking

1) GPS-based tracking

2）Vision-based tracking

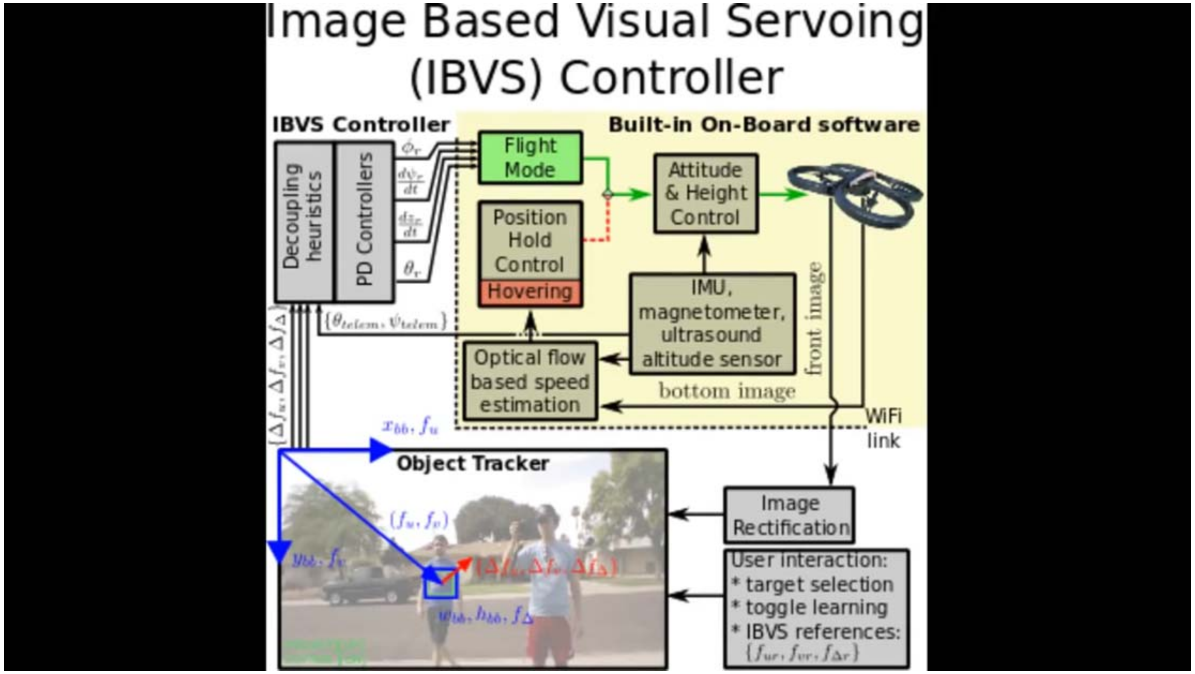


Image Based Object Tracking and Following for Quadrotor Vehicles Person running following
https://www.youtube.com/watch?v=67RXf5P7bfg

1.Related Technology Development

□ Interactive Technology

（1） Gesture control

At CES 2014, a demonstration was shown that anAR. Drone‘s tilt direction was controlled by using just one arm with a Myo gesture-control armband

Demo: Parrot AR.Drone 2.0 X Thalmic Myo armband.https://www.youtube.com/watch?v=l0sjfddk8Yo

（2） Brain-computer Interface

However, it should be pointed out such multicopters are still miles away from commercial applications due to safety considerations.

FlyingBuddy2: Brain Controls A Quadrotor for the Handicapped (Ubicomp 2012) https://www.youtube.com/watch?v=JH96O5niEnI

1.Related Technology Development

□ Communication Technology

（1） 5G/4G

On June 17th 2013, Beijing 4G Alliance and UAV Alliance organized a seminar aiming at faciliting the technology exchange between these domains. CMCC developed 4G ‘super air force’ device on 2015, which can upload aerial photography instantly. 5Gbps’ speed is 250 times than that of LTE network standard connection speed, which is a notable landmark in the wireless domain.

（2） Wi-Fi

A research team at the Karlsruhe Institute of Technology in Germany created a Wi-Fi solution to produce a constant connection speed of 40Gbit/s (5GB/s)at a distance of about 0.6 miles. This technology could offer a high-speed connection to devices on the ground through drones' video transmitters.

1.Related Technology Development

□ Chip Technology

（1） At CES 2015,based on a Qualcomm Snapdragon processor, Qualcomm Research designed the Snapdragon Cargo--a flying and rolling robot with an integrated flight controller. Brian Krzanich, CEO of INTEL, presented personally their drone. Moreover, XMOS, European processor manufacturer, announced that they will match towards the drone domain.

（2） On September 9th, 2014, the company called 3D Robotics announced that they had partnered with Intel in the development of a new microcomputer, namely Edison. This provided PC power in postage stamp size but at an acceptable price.

（3） Brain-inspired chips or termed as neuromorphic chips are also attractive. IBM unveiled a neuromorphic chip with 5.4 billion transistors designed to perform tasks such as pattern recognition, audio processing and motion control.

1.Related Technology Development

□ Software platform Technology

（1） On October 13th, 2014, the Linux Foundation announced the founding of the Dronecode Project to advance development of drones. The ultimate goal is to maximize adoption of the project‘s code for the benefit of users by developing cheaper, better and more reliable drone software. The platform has been adopted by many organizations on the forefront of drone technology.

（2） Ubuntu was recently updated to version 15.04, which is smaller and more secure than any previous Ubuntu edition. This operating system has been adopted by Snapdragon Flight from Qualcomm and the Erle-Copter Ubuntu drone

（3） A company called Airware launched its commercial drone operating system. It was claimed that this operating system could help businesses safely and reliably operate drones at scale, which moreover complied with the government and insurance requirements, and built industry-specific drone software solutions.

1.Related Technology Development

☐ Air Traffic Control Technology

(1) Airware had partnered with NASA to develop an Unmanned aerial system Traffic Management system (UTM) that will enable safe and efficient low-altitude Unmanned Aerial System (UAS) operations.

(2) SkyWard company has been developing a drone traffic control system in cooperation with Chinese drone company DJI, American company 3D Robotics and French company Parrot, aiming at proving the possibility of coexistence of abundant drones in the air.

(3) NASA has been partnering with Exelis to test a new air traffic control system called Symphony RangeVue for drone aircraft.

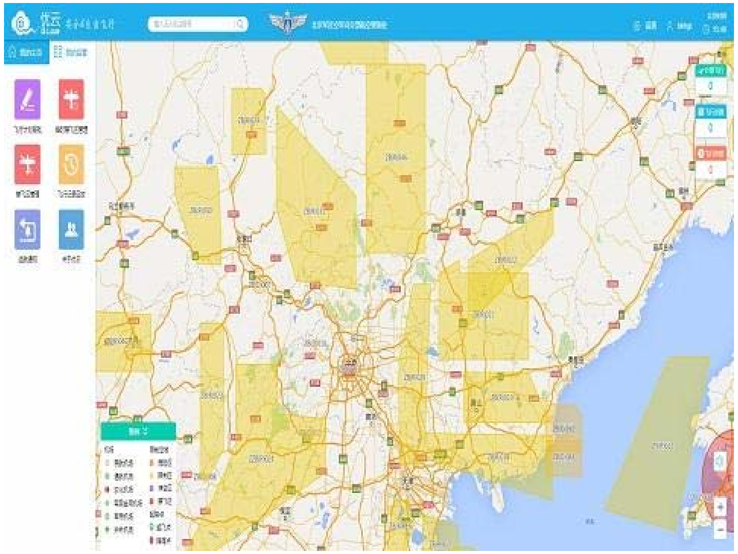
NASA's concept for a possible UTM system would safely manage diverse UAS operations in the airspace above buildings and below crewed aircraft operations in suburban and urban areas. From https://utm.arc.nasa.gov/

1.Related Technology Development

□ Air Traffic Control Technology

(4) In 2015, a company called Transtrex released the beta version of the first dynamic geospatial restriction system for UAS, at the NASA UTM Convention at Moffett Airfield. The released system can provide dynamic 3D map data, including man-made objects and operational restrictions

(5) In September, 2015, at the 3rd AOPA International Flight Training Exhibition, AOPA (Aircraft Owners and Pilots Association) China announced and launched a monitoring system called *U Cloud* for small drones.



U Cloud

2.Demand and Technology innovation

Application Innovation

- Multicopter
- Multicopter + camera
- Multicopter + pesticide
- Multicopter + parcel
- Multicopter + surveying instruments
- Multicopter + communication platform
- Multicopter + weapon
- Multicopter + light
- Multicopter + voice
- Multicopter + card reader
- Multicopter + medicine
- Multicopter + rope
- Multicopter + flamthrower

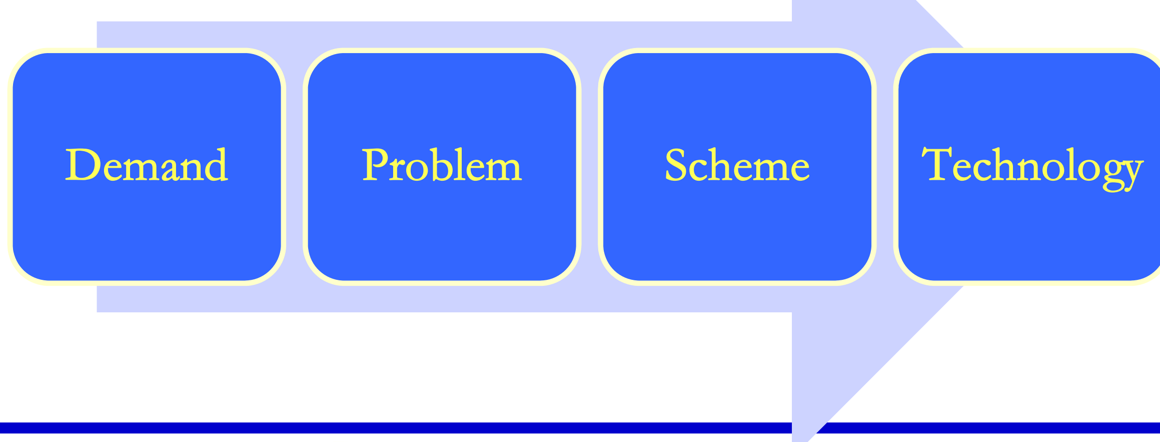
Potential domains

1) Toy & education
2) Portable quadcopter
3) Agricultural
4) Special domains

2.Demand and Technology innovation

□ Innovation level

Research and design of a multicopter start from the three levels: demand, scheme and technology. Among the three levels, finding a new demand contributes the most. Under the same demand, a good scheme is the second best. While, under the same demand and scheme, improving the technology is the last resort.



2.Demand and Technology innovation

□ Performance Innovation

Table 15.1 Relationship between performances and techniques (More “+” implies that the relationship is stronger, while “–”implies an irrelevant relationship)

Techniques / Performance	Configuration & structure design	Propulsion system	State	Controller design	Health evaluation and failsafe
Minimum noise	+++	++	+	+	-
Minimum vibration	+++	++	+	+	-
Longest hover time	+	+++	+	++	-
Longest flight distance	++	+++	+	+	-
Strongest capability of wind resistance	++	+++	+	++	-
Most precise trajectory tracking	-	-	+++	+++	-
Highest autonomy	-	-	+++	+	++
Highest safety factor	-	++	+++	+	+++

2.Demand and Technology innovation

Table 15.2 Multicopter's autonomy levels

Level	Descriptor	Decision	Perception	Control	Typical Scenario
4	Real time Obstacle/Event Detection and Path Planning	Hazard avoidance, real time path planning and re-planning, event driven decisions, robust response to mission changes.	Perception capabilities for obstacle, risks, target and environment changes detection, real time mapping.	Accurate and robust 3D trajectory tracking capability is desired.	It can fly over a long distance using camera (no GPS) and return home automatically. Moreover, a quadcopter can land safely after one propulsor failure.
3	Fault/Event Adaptation	Health diagnosis; Limited adaptation; Onboard conservative and low-level decisions; Execution of pre-programmed tasks.	Most health and status sensing; detection of hardware and software faults.	Robust flight controller; reconfigurable or adaptive control to compensate for most failures; mission and environment changes.	It can evaluate its health, and can analyze the reason that a failure arises. Moreover, a hexacopter can return home after one propulsor failure.
2	ESI (External System Independence) Navigation (e.g., Non-GPS)	Same as in Level 1	All sensing and state estimation by the multicopters (no external system such as GPS). A health assessment capabilities, can perceive failure in advance to take failsafe strategies. All perception and situation awareness by the remote pilot.	Same as in Level 1	It can rely on a camera (no GPS) to accomplish hover, landing, and tracking a target. Moreover, it can report a typical failure in advance, including RC failure, sensor failure, and propulsion system failure and so on.

2.Demand and Technology innovation

Table 15.2 Multicopter's autonomy levels (contunued)

1	Automatic Flight Control	Pre-programmed or uploaded flight plans (waypoints, reference trajectories, etc.); all analyzing, planning and decision-making by ground stations or remote pilot; Simple failsafe.	Most sensing and state estimation by multicopters, and simple health sensing. All perception and situational awareness by the remote pilot.	Control commands are computed by the flight control system.	It can hover, land, and track a target by using GPS. It can also detect the R-C failure, or GPS and electronic compass failure, or the battery power being low. Moreover, it can be switched to a mode for safe landing.
0	Remote Control	All guidance functions are mainly performed by remote pilots.	Sensing may be performed by multicopters, all data is processed and analyzed by remote pilot.	Control commands are given by a remote pilot.	It can be controlled by a remote pilot to accomplish hover, landing, and tracking a target.

From current products, most of the multicopter toys are in the autonomy Level 0. Most of the commercial products are in the autonomy Level 1. The multicopter equipped with the APM autopilot is a typical representative of this level. Both AR. Drone and DJI Phantom 3, with a capability to hover based on vision, has reached initial autonomy Level 2. Tasks in some competitions on UAVs, such as the International Aerial Robotics Competition (IARC) , have featured the characteristics of Level 4.

2.Demand and Technology innovation

□ Safety factor

(1) Model-based Systems Engineering (MBSE)

It is expected to replace the document-centric approach and further to eliminate uncertainty, ambiguity and incomputability and so on.

(2) Health evaluation

(3) Failsafe

3.Analysis

☐ Risks

（1） Personal safety

（2） Property

（3） Ethics and public risk

On January 29th 2015, a quadcopter crashed at the white house.

On April 24th 2015, a quadcopter landed on the roof of Japanese PM's office.

On June 2015, a quadcopter crashed at the Milan Cathedral.

On September 2015, a quadcopter slammed into seating area at U.S. Open.

3. Analysis

□ Suggestions

（1） For multicopter producer

1） Improve the reliability

2） Reduce the impact of falling

3） Label an ID number

4） Set the non-fly zone

5） Anti-spoofing and anti-intrusion

（2） For multicopter operators

1） Training qualified remote pilots

2） Insurance

3） Limit multicopter's flight range

4. Opportunities and Challenges

Opportunities

(1) Hardware cost is decreasing. In the recent decade, the ascending market of civil or consumer drones is inseparable from the maturity of the hardware chain and cost of hardware reduced.

(2) Human resource cost is increasing. Population aging is taking place in nearly all the countries of the world.

(3) UAS traffic management system will offer the safe and legal air space for more drones.

4.Opportunities and Challenges

□ Challenges

The greatest challenge is to integrate multicopters or drones into national airspace system. It is related to both policy and technology

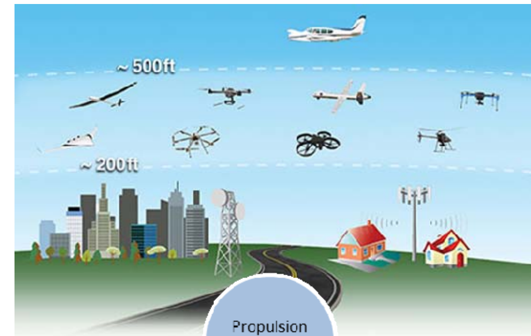
（1）Challenges caused by policy

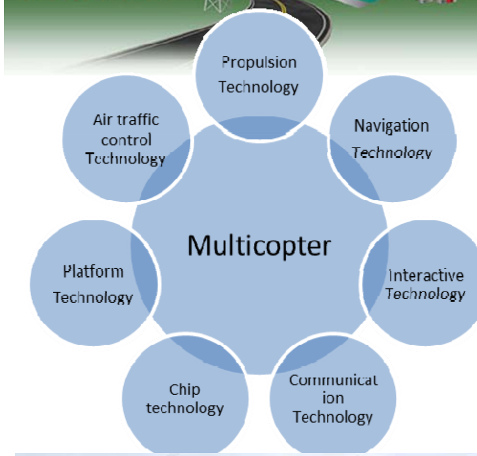
It is pending to be solved how to make a reasonable policy that can achieve a trade-off between the development of small drones and public pressure.

（2）Challenges from technical aspects

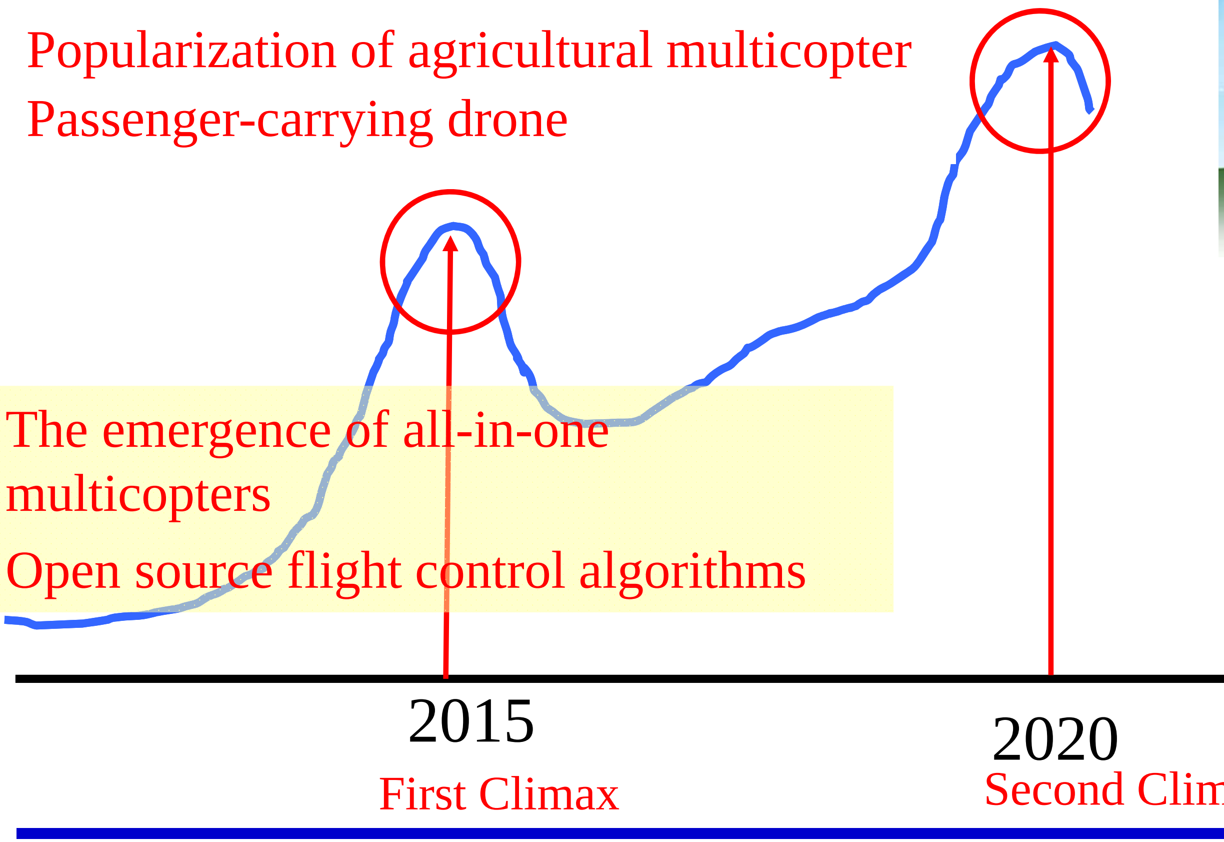
Although the development of multicopter seems fast, it is still not strong. So far, most multicopters’ reliability cannot be guaranteed. How to design a highly reliable small multicopter is the greatest technological challenge. Besides the problem of multicopter itself, technical challenge also includes the safety problem related to collisions.

- UAS traffic management system
- A mature policy
- Improvement of multicopter’s reliability
- Improvement of multicopter’s performance
- Popularization of multicopter education
- Potential demands
- Popularization of agricultural multicopter
- Passenger-carrying drone



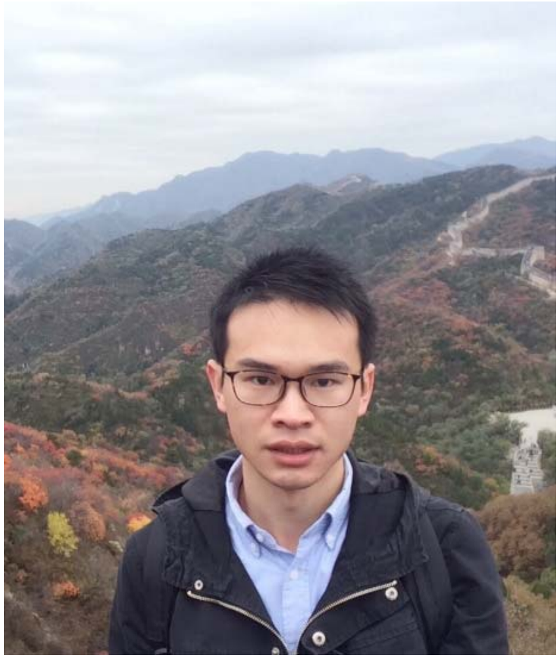


- The emergence of all-in-one multicopters
- Open source flight control algorithms



Acknowledgement

Deep thanks go to



Baihui Du

Xunhua Dai

for material preparation.

Thank you!

All course PPTs and resources can be downloaded at
http://rfly.buaa.edu.cn/course

For more detailed content, please refer to the textbook:

Quan, Quan. Introduction to Multicopter Design and Control. Springer, 2017. ISBN: 978-981-10-3382-7.

It is available now, please visit http://www.springer.com/us/book/9789811033810