Unmanned Aerial Photogrammetric Systems in the Service of Engineering Geodesy

Mateo Gašparović, PhD [1], Assist. Prof. Dubravko Gajski, PhD [2]

[1] *Faculty of Geodesy, Kačićeva 26, Zagreb, Croatia, mgasparovic@geof.hr*
[2] *Faculty of Geodesy, Kačićeva 26, Zagreb, Croatia, dgajski@geof.hr*

Abstract. *The development and price reduction of unmanned aerial systems enables their wider use. Using unmanned aerial systems the Earth' surface and objects on it can be documented from new perspectives, simpler, quicker and with better quality. Also, the development of computers and automatic correlation algorithms has enabled the automatic acquisition of large amounts of data per unit time. Drones are equipped with technology that has been used in geodesy for years, e.g. camera, GPS, INS and, of course, the RF device to transmit signals to Earth. Such aircrafts can be controlled from the ground by the operator or it can be completely autonomous and do the survey automatically after a predefined flight plan. This method is extremely useful for documenting large areas or longer linear objects like bridges, embankments, buildings etc. Choosing a predefined path allows photogrammetric survey in the constant scale, which guarantees constant measurement accuracy. It is necessary to modernize the existing regulations and to harmonize the legislation with the trends and the market needs, so that this new area of geodesy could develop accordingly. Also, it is important to clearly define the required accuracy and the quality of data for both, licensed engineers and end users alike.*

Keywords*: engineering geodesy, legal frameworks, photogrammetry, unmanned aerial systems*

1. Introduction

Today we are witnessing the growing use of unmanned aerial photogrammetric aircrafts for the measuring purposes. These types of aircrafts represent an ideal platform for a variety of tasks. Unmanned aircrafts due to their construction solutions and flexibility solve capturing problems such as large area capturing or capturing of high buildings otherwise inaccessible for terrestrial survey. The flexibility of photogrammetric surveying methods along with choosing the adequate cameras and lenses, result in adapting of the measuring platform (unmanned aerial vehicle – UAV) to the needs of the tasks. Furthermore, if we add the possibility of an autonomous recording, aircrafts become independent devices for gathering a large number of high-quality data of the field or object with appropriate accuracy. They can capture the terrain at high speed by a predefined flight plan that has all the parameters adjusted to the required accuracy of the survey.

This paper will give an overview of the technological development of the unmanned aircrafts used for the purposes of photogrammetric measurements in the engineering geodesy. The main classification of unmanned aerial vehicles is listed and explained as well as the advantages and disadvantages of each category. One of the chapters in the paper refers to the legal regulations in the Republic of Croatia and to the most important rules for flying the unmanned aircrafts and capturing images with them.

Unmanned Aerial Vehicles are composed of many devices and sensors necessary for the flight, navigation and recording. The paper shows and explains the sensors required and used for the operation of the unmanned aircraft, as well as the implementation of the aerial survey. For the needs of this paper, a model of integration of sensor data for the purposes of the photogrammetric survey was developed and is explained.

2. The development of unmanned aerial vehicles

The main initiator of the development of unmanned aircraft was the military. Unmanned aircrafts were mostly used as offensive or defensive weapons and for the reconnaissance and espionage purposes. For the first time, UAVs were used in the first half of the 19th century when the Austrians attacked the Italian city of Venice with unmanned balloons loaded with explosives. Balloons do not generally meet today's definition of a UAV, because the flight was not controllable.

The first pilotless aircrafts were built during and shortly after World War I. Leading the way, using Archibald Montgomery Low's radio control techniques, was the Ruston Proctor Aerial Target of 1916 [Taylor and Munson 1977]. Soon after, on September 12, the Hewitt-Sperry Automatic Airplane, also known as the "flying bomb", made its first flight, demonstrating the concept of an unmanned aircraft. They were intended for use as "aerial torpedoes", an early version of today's cruise missiles. Control was achieved using gyroscopes developed by Elmer Sperry of the Sperry Gyroscope Company [Pearson 1969].

Since mid-1930s aircrafts were used as an important combat tool for training exercises in air defense. Examples of such aircrafts are British DH.82B Queen Bee and American Radioplanes. Queen Bee is the first return and reusable UAV, making it practical and more cost effective than previous [URL 1]. World War II further encouraged the development of UAVs. Although the main form of propulsion at the time was piston engines, certain manufacturers were also developing aircrafts powered by pulse jet engines. The most important representatives of this period were the V-1 (Germany) and the T2D2-1 (USA). During the Vietnam War UAVs had assumed the role of devices for espionage. Representatives from that period would be AQM-34 Firebee Ryan (USA) and D-21 (USA).

Since the 1970s UAV systems have greatly enhanced in the field of aircraft propulsion with the aim to increase the autonomy of the flight. From the 1990s to nowadays the role of the observer of the environment on Earth has crystallized and the representatives are Firebird 2001 (Israel), the RQ-1 Predator (USA), Helios (USA). NASA's unmanned aircraft Helios is currently in the process of development and will have a system of fuel cells to store energy for power to fly overnight. In the next 10 years the Helios aircraft is expected to be widespread as broadband communications platform providing a unique cost-effective complement to the satellite and the terrestrial communications systems [Pavlik *et al.* 2014].

3. Legal regulations

According to the International Civil Aviation Organization (ICAO) unmanned aircrafts are divided into [ICAO 2015]:

- Autonomous aircrafts,
- Remotely piloted aircrafts (RPA).

Autonomous aircrafts are based on advanced systems for dynamic guidance and are currently considered to be inappropriate for regulation because of legal issues and questions of liability. Remotely controlled aircrafts are subject to legal regulations by the International Civil Aviation Organization and the regulations and laws of the national civil aviation agencies.

In Croatia there are two key documents concerning unmanned aircrafts and their use in photogrammetric purposes, and those are:

- Ordinance on unmanned aircraft systems [NN 49/15] and
- Regulation on aerial surveying [NN 130/12].

Croatian Civil Aviation Agency (CCAA) with its Ordinance on unmanned aircraft systems regulates UAV flight based on the regulations of the International Civil Aviation Organization. State Geodetic Agency regulates aerial surveying and the use of taken images with its Regulation on aerial surveying.

3.1. Ordinance on unmanned aircraft systems

According to the Ordinance, unmanned aircraft is an aircraft designed for carrying out flights without a pilot on board, while an airline model is unmanned aircraft designed exclusively for the purposes of recreation and sport.

This regulation does not cover unmanned aircrafts heavier than 150 kilograms. Aircrafts that cannot achieve the kinetic energy of more than 79 J and all aircrafts indoors are permitted for using.

Due to their operating mass, Ordinance classifies unmanned aircrafts into three categories: <5 kg, 5-25 kg and 25-150 kg., while the flight areas are divided into 4 categories: unbuilt, built uninhabited, populated and densely populated areas. Based on the classifications above, Ordinance defines the flight operation categories [Table 3.1] and the conditions for the aircraft and the operator, so that the operations in a particular category would be approved.

Ordinance clearly defines that the flight operations of A and B categories can be performed by the operator that has submitted a corresponding statement to CCAA. C category can be performed by the operator that has made an operational manual and also submitted a previously mentioned statement while for the D category areas the operator must previously obtain an approval from the CCAA.

Table 3.1 Categories of flight operations [NN 49/15]

Class of unmanned aircraft system	Class of the flight field			
	I Unbuilt area	II Built uninhabited area	III Populated area	IV Densely populated area
<5kg	A	A	B	C
5-25kg	A	B	C	D
25-150kg	B	C	D	D

3.2. Regulation on aerial surveying

This Regulation defines that aerial surveying in the Republic of Croatia could be performed by physical and juridical persons who are registered for aerial photography, for the purpose of land surveying, research, physical planning and other economic and scientific needs. The aircraft operator must have a valid certificate and an indicated approval, for the aerial survey or other authorization issued by the CCAA, to perform the operations.

More information on the topic of the legal framework related to unmanned aircrafts can be found in the research [Gašparović and Gajski 2015].

4. Technology of unmanned aerial vehicles

Today, UAV's are increasingly used for the photogrammetric survey of small areas or high buildings. Those aircrafts according to Unmanned Aerial Vehicle Systems Association can be divided into several categories [

Table 4.1 Classification of UAV’s according to Unmanned Aerial Vehicle Systems Association [Bendea *et al.* 2008]].

Table 4.1 Classification of UAV’s according to Unmanned Aerial Vehicle Systems Association [Bendea *et al.* 2008]

UAV Categories	Acronym	Range (km)	Climb rate (m)	Endurance (hours)	Mass (kg)
Micro	μ (Micro)	< 10	250	1	< 5
Mini	Mini	< 10	150-300	< 2	150
Close Range	CR	10-30	3000	2-4	150
Short Range	SR	30-70	3000	3-6	200
Medium Range	MR	70-200	5000	6-10	1250
Medium Range Endurance	MRE	> 500	8000	10-18	1250
Low Altitude Deep Penetration	LADP	> 250	50-9000	0,5-1	350
Low Altitude Long Endurance	LALE	> 500	3000	> 24	< 30
Medium Altitude Long Endurance	MALE	> 500	14000	24-48	1500

Ideal UAVs for applications in engineering geodesy are mini and micro category aircrafts. Such aircrafts are made up of a number of sensors that can be divided into three categories:

- Sensors necessary for the functioning of the platform (power supply, motors, central unit, RF, etc.),
- Navigation sensors (GNSS - Global Navigation Satellite System, RTK - Real Time Kinematic, IMU - Inertial Measurement Unit, compass, barometer, etc.) and
- Sensors for aerial photogrammetry (digital camera, multi and/or hyper spectral sensors, thermal cameras, laser scanner, etc.).

Multi-rotor Octocopter UAV platform with the vibration isolated sensor frame, carrying the laser scanner, MEMS based IMU, GNSS receiver with antenna and video camera is shown below [Figure 4.1. The multi-rotor Octocopter UAV platform with the vibration isolated sensor frame, carrying the laser scanner, MEMS based IMU, GPS receiver with antenna and video camera [Wallace *et al.* 2012]].

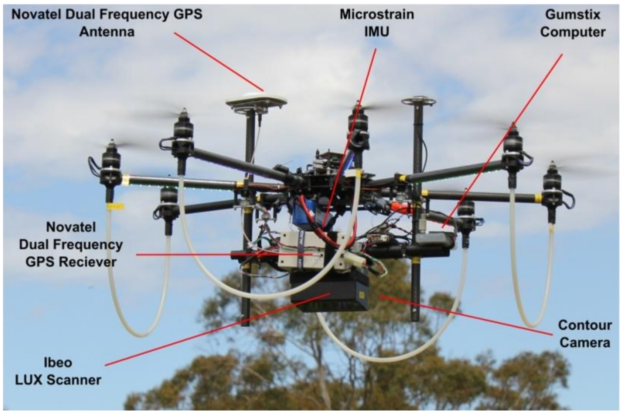

Figure 4.1. The multi-rotor Octocopter UAV platform with the vibration isolated sensor frame, carrying the laser scanner, MEMS based IMU, GPS receiver with antenna and video camera [Wallace *et al.* 2012]

It is necessary to properly integrate all sensors with each other so that the results would be satisfactory. Possibilities of such systems are numerous. Firstly, the possibility of quality determination of the external orientation to initial elements of each image taken, and each point recorded with laser scanner, should be noted.

An example of the sensor integration for the purpose of photogrammetric measurements with unmanned aircrafts was developed for the needs of this research and it is shown below [Figure 4.2. The integration of sensor data on the aircraft for the purposes of photogrammetric survey]. The developed model of sensor integration is based on data obtained from multiple sensors: GNSS and/or GNSS RTK receiver, IMU and the images from a digital camera and the point clouds obtained by laser scanner. The need for the integration of data lies in the fact that GNSS device measures absolute location of the aircraft in space with frequency <1 Hz, while the IMU provides information often >100 Hz. Therefore, data integration of GNSS/RTK with IMU primarily determines the spatial location of the aircraft in each unit of a second (e.g. >100 Hz). Also, with mutual integration of these data we achieve higher, spatial accuracy of the path. Such integration is usually based on the Kalman filter [Caron *et al.* 2006]:

$$x(k+1) = Fx(k) + w(k) \tag{1}$$

where $x(k) \in \mathbf{R}^n$ is the state vector, $w(k) \in \mathbf{R}^n$ is a sequence of zero mean white Gaussian noise of assumed known covariance matrix $Q(k) = E\left[w(k)w(k)^{\mathbf{T}}\right]$. $F(k) \in \mathbf{R}^{n \times n}$ is the known state transition matrix. In the simplest case, measurements are expressed as a linear relation with respect to the state space variables and are corrupted by noise. The following relation (2) describes the measurements for a set of N sensors [Caron *et al.* 2006]:

$$z_i(k) = H_i x(k) + b_i(k), \quad i = 1,\dots, N \tag{2}$$

with $z_i(k) \in \mathbf{R}^l$ the measurement vector of the sensor *i*, $b_i(k) \in \mathbf{R}^l$ the white Gaussian observation noise for the sensor *i* with zero mean and with assumed known covariance matrix $R_i(k) = E\left[b_i(k)b_i(k)^{\mathbf{T}}\right]$, $H_i \in \mathbf{R}^{l \times n}$ is the measurement matrix associated to the sensor *i* and *N* is the number of sensors. More about the procedure can be found in the work [Caron *et al.* 2006] and [Benzerrouk *et al.* 2013]. Further in the process, the bundle block adjustment (BBA) with the initial parameters taken after GNSS/IMU integration follows. Finally, the transformation of the point cloud in the referent coordinate system in which external orientation elements of images calculated by BBA method are set, creates a precondition for the independent creation of digital surface models (DSM) with the photogrammetric method and laser scanning.

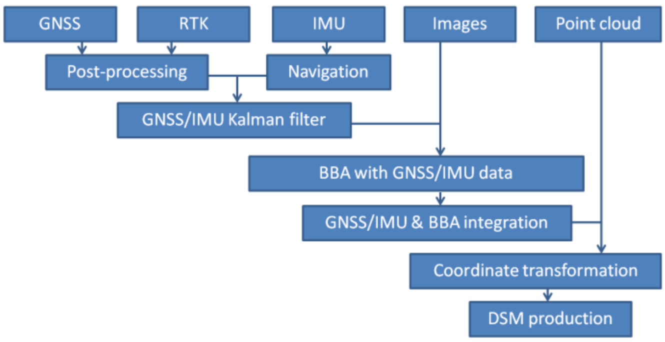

Figure 4.2. The integration of sensor data on the aircraft for the purposes of photogrammetric survey

5. Application in engineering geodesy

The camera axis can be vertical, horizontal or slope, depending on the characteristics of the terrain and the size and characteristics of the object of interest for the photogrammetric surveying, consequently adapting the structure of the unmanned aircraft. There are several types of unmanned aerial vehicles: [McGlone 2013] and [Luhmann *et al.* 2014]:

- Rotary wing (multicopter, helicopter) [Figure 5.1 a) Norwegian University of Science and Technology's X8 fixed wing UAV [Skulstad *et al.* 2015], b) Rotary wing UAV [Mancini *et al.* 2013]b]
- Fixed wing (aircraft, glider) [Figure 5.1 a) Norwegian University of Science and Technology's X8 fixed wing UAV [Skulstad *et al.* 2015], b) Rotary wing UAV [Mancini *et al.* 2013]a].

a) b)

Figure 5.1 a) Norwegian University of Science and Technology's X8 fixed wing UAV [Skulstad *et al.* 2015], b) Rotary wing UAV [Mancini *et al.* 2013]

5.1. Fixed wing UAVs

The main advantage of a fixed wing UAV is that it consists of a much simpler structure in comparison with a rotary wing. The simpler structure provides less complicated maintenance and repair process, thus allowing the user more operational time at a lower cost. More importantly, the simple structure ensures more efficient aerodynamics that provides the advantage of longer flight durations at higher speeds, thus enabling larger survey areas per given flight.

Another advantage of fixed wing UAVs is their natural gliding capability. The possibility of stopping the engine at the time of recording contributes to the quality of the photogrammetric recording.

Also worth considering is the fact that fixed-wing aircrafts are able to carry greater payloads for longer distances on less power, allowing you to carry some of the bigger (more expensive) sensors as well as twin sensor configurations.

The only disadvantage of a fixed wing solution is the need for a runway or launcher for takeoff and landing. However, VTOL (vertical takeoff/landing) and STOL (short takeoff/landing) solutions are very popular to help eradicate this issue. Nevertheless, fixed wing aircrafts require air moving over their wings to generate lift and they must stay in a constant forward motion, which means they can't stay stationary the same way a rotary wing UAVs can. This means fixed wing solutions are not best suited for stationary applications like inspection work.

From the above explained characteristics of fixed wing aircrafts, it is evident a large possibility of their application in engineering geodesy. Those aircrafts are ideal for recording large areas for engineering tasks such as:

• Making the geodetic basis for the planning of large objects for example roads, viaducts, etc.

• Monitoring the movement of large objects on a wide area for the purpose of spatial temporal analysis.

• Detecting the changes in the environment and land-use change on a large area [Figure 5.2. a) Flight plan example of surveying with fixed wing UAV [Xue *et al.* 2015]a].

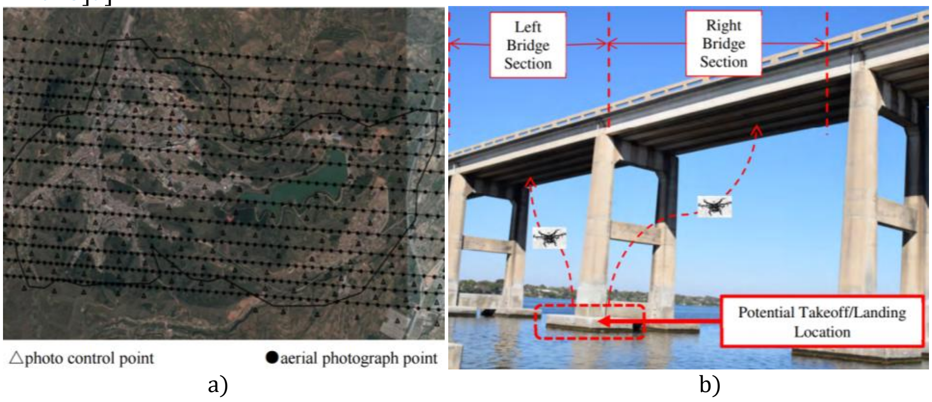

Figure 5.2. a) Flight plan example of surveying with fixed wing UAV [Xue *et al.* 2015], b) Example of bridge inspection with rotary wing UAV [Otero *et al.* 2015]

5.2. Rotary wing UAVs

The biggest advantage of rotary UAVs is the ability for taking off and landing vertically. This allows the user to operate within smaller vicinity with no substantial landing/takeoff area required. Their capacity to hover and perform agile maneuvering makes rotary wing UAVs well suited to applications like inspections where precision maneuvering and the ability to maintain a visual on a single target for extended periods of time is required.

On the flip side rotary wing aircraft involve greater mechanical and electronic complexity which translates generally to more complicated maintenance and repair processes, implicating that the user's operational time can be decreased, which can cause increases in operational costs.

Finally, due to their lower speeds and shorter flight ranges the operator will require more additional flights to survey significant areas, meaning increase in time and operational costs.

Definitely, one of the main advantages is the possibility of horizontal and slanted axis capturing, as with fixed wing aircraft this is not possible. Due to these characteristics rotary wing aircrafts are inevitable when capturing high objects such as bridges, skyscrapers, chimneys or vertical rocks and landslides.

From the above explained characteristics of rotary wing aircrafts, it is evident a large possibility of their application in engineering geodesy. One of the biggest advantages of those aircrafts compared to fixed wing UAVs is the ability to capture the object with horizontal axis of the surveying as well as the ability to hover. Thus, those aircrafts are ideal for capturing small objects for engineering tasks such as:

• Making the geodetic basis for the planning of smaller inaccessible and/or topographic developed areas.

• Monitoring movement and inspection of objects from all perspectives, such as bridges, skyscrapers, towers, industrial chimneys, etc. [Figure 5.2. a) Flight plan example of surveying with fixed wing UAV [Xue *et al.* 2015]b].

6. Conclusion

The development of technology allows new areas of work, and it most certainly accelerates and simplifies carrying out current jobs in engineering geodesy. With the application of unmanned aerial vehicles from flying platforms, photogrammetric survey can be done very quickly and with a significantly reduced cost. This kind of unmanned platform for photogrammetric survey is adaptable to the needs of the task and the required accuracy of the survey.

To conclude, the biggest advantages of each type of unmanned aerial aircrafts should be repeated. Fixed wing aircrafts compared to the rotary wing have greater autonomy and speed of the flight and are therefore suitable for capturing larger areas. On the other hand the biggest advantages of rotary wing aircrafts are the ability of hovering, vertical takeoff and capturing with horizontal axes. Therefore, rotary wing aircrafts are better suited to capture small objects and/or indented areas.

To properly apply the new surveying technology in engineering geodesy it is necessary that the legislation follows its development. It has to be pointed out that the legislation consistency with the time and the current technology, or preferably independent of both, is of great importance. If the unmanned aircraft is used in engineering geodesy it is necessary to take into account the quality of the final data, and thus the quality of the sensor on which the collected data is based on.

References

Bendea, H.; Boccardo, P.; Dequal, S.; Giulio Tonolo, F.; Marenchino, D.; Piras, M. (2008). Low Cost UAV for Post-Disaster Aassessment, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 37(Part B), 1373-1379.

Benzerrouk, H.; Salhi, H.; Nebylov, A. (2013). Adaptive “Cubature and Sigma Points” Kalman Filtering Applied to MEMS IMU/GNSS Data Fusion during Measurement Outlier, Journal of Sensor Technology, 3(04), 115-125.

Caron, F.; Duflos, E.; Pomorski, D.; Vanheeghe, P. (2006). GPS/IMU Data Fusion Using Multisensor Kalman Filtering: Introduction of Contextual Aspects, Information Fusion, 7(2), 221-230.

Gašparović, M.; Gajski, D. (2015). Bespilotni sustavi za zračno snimanje - propisi i regulativa, Zbornik radova - 8. simpozij ovlaštenih inženjera geodezije.(Unmanned Systems for Aerial Survey – Legislative and Regulations The Proceedings 8. Symposium on Authorised Engineers)

ICAO (2015). Unmanned Aircraft Systems (UAS), Cir 328.

Luhmann, T.; Robson, S.; Kyle, S.; Boehm, J. (2014). Close-range Photogrammetry and 3D imaging. Walter de Gruyter, Berlin.

Mancini, F.; Dubbini, M.; Gattelli, M.; Stecchi, F.; Fabbri, S.; Gabbianelli, G. (2013). Using Unmanned Aerial Vehicles (UAV) for High-Resolution Reconstruction of Topography: The Structure from Motion Approach on Coastal Environments, Remote Sensing, 5(12), 6880-6898.

McGlone, J. C. (2013). Manual of Photogrammetry, 6th edition, American Society for Photogrammetry and Remote Sensing, Bethesda.

Narodne novine (2015). Pravilnik o sustavima bespilotnih zrakoplova (NN 49/15).(Legal Regulations on Systems of Unmanned Aircrafts (National Gazzete 49/15)

Narodne novine (2012). Uredba o snimanju iz zraka (NN 130/12).(National Gazzete (2012) Law on Air Surveying) NG 130/12)

Otero, L. D.; Gagliardo, N.; Dalli, D.; Huang, W. H.; Cosentino, P. (2015). Proof of Concept for Using Unmanned Aerial Vehicles for High Mast Pole and Bridge Inspections, Contract BDV28, 977-02.

Pearson, L. (1969). Developing the Flying Bomb, Naval Aviation in World War I, 70-73.

Pavlik, D.; Popčević, I.; Rumora, A. (2014). Bespilotne letjelice podržane INS i GNSS senzorima, Ekscentar, br. 17, 65-70. (Unmanned Aircrafts Supported by INS and GNNS Sensors, Ekscentar, no. 17 pp. 65 70)

Skulstad, R.; Syversen, C.; Merz, M.; Sokolova, N.; Fossen, T.; Johansen, T. (2015). Autonomous Net Recovery of Fixed-Wing UAV with Single-Frequency Carrier-Phase Differential GNSS, Aerospace and Electronic Systems Magazine, IEEE, 30(5), 18-27.

Taylor, J. W. R.; Munson, K. (1977). Jane's Pocket Book of Remotely Piloted Vehicles: Robot Aircraft Today, Collier Books, New York.

Wallace, L.; Lucieer, A.; Watson, C.; Turner, D. (2012). Development of a UAV-LiDAR System with Application to Forest Inventory, Remote Sensing, 4(6), 1519-1543.

Xue, T.; Tian, X.; Wang, J. (2015). Application of Unmanned Aerial Vehicle remote sensing image to large-scale surveying and mapping of the hilly area in Qinghai Tibet Plateau, Advanced Science and Technology Letters, 80, 30-34.

URL 1: UAV universe, https://sites.google.com/site/uavuni/1920s-1930s, (17.2.2016.)

URL 2: TD2D Katydid, http://www.designation-systems.net/dusrm/app1/kdh.html, (18.2.2016.)

URL 3: Monash University, http://www.ctie.monash.edu, (19.2.2016.)