
**КОСМИЧЕСКИЕ АППАРАТЫ,
СИСТЕМЫ И ПРОГРАММЫ ИЗК**

PRECISION DRONES – TODAY AND TOMORROW

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Described are the possibilities for increasing accuracy in determining the location of unmanned aircraft. Compared are the capabilities of different coordinate systems to increased the accuracy to 2.5 cm. The methods for transmitting coordinate correlation data are described. In conclusion, it is assumed that for the accurate determination of the coordinates of mobile objects it is most appropriate to use the transmission of Real Time Kinematics corrections by network of a mobile operator.

Keywords: GNSS, GPS, GLONASS, Galileo, BeiDou, RTK, SBAS, Drognet, UAV, SIM

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INTRODUCTION

Precision in present days is required in many different fields and industries all over the world. Starting with manufacturing up to the end customer deliveries of products. The business of UAVs (*Unmanned Aerial Vehicle* or so called “drones”) is not excluded from the list of high demanding business sectors, requiring precision and accuracy and which is more — it is one of the most technologically advanced sector of the economics and meanwhile one of the fastest growing market in the world.

The precision of the manufacturing, low tolerances of the assemblies and highest level of accuracy of the positioning during flight would be some of the most important factors for reducing the weight, increasing the flight time and as a final result — increasing the effectiveness of any of the drones designed and manufactured in present days.

When we speak about “positioning” and “accuracy” we should determine the state-of-the-art technologies, used in present days which could satisfy the needs of the highest level of accuracy and control during normal flight of the drones used today.

GNSS POSITIONING AND ACCURACY

Global Navigation Satellite System, or also known as “GNSS” is one of the most popular independent positioning and navigation system worldwide. Initially it was developed for military purposes, the GNSS technology is also available for civil usage and is one of

the most reliable and low- cost navigation technologies used in present days. Based on satellite constellation, the GNSS is available 24/7 and 365 days per year, which determines it reliability and is implemented in automotive, aerospace and UAV industries.

In nowadays there are several GNSS systems: GPS (*Global Positioning System* — developed by the USA), GLONASS (*GLObalnaya NAVigatsionnaya Sputnikovaya Sistema* — developed by Russia), Galileo (developed by the European Space Agency) and BeiDou (developed by China), as the Galileo and BeiDou GNSS systems are expected to be fully operational worldwide in 2020.

All of the current GNSS systems are based on a similar technology; however they have different post processing capabilities and different accuracy.

GPS could deliver up to 5–10 m horizontal accuracy (7.8 m horizontal accuracy with 95% probability), while GLONASS would have accuracy within the range of 4.5–7.4 m, Galileo can provide 1m horizontal accuracy and the less accurate GNSS BeiDou can provide 10m of horizontal accuracy. The vertical accuracy, however, for all of the GNSS systems is much less accurate (around 15 m), which makes the GNSS technology not suitable for precise take-off and landing and this is the main reason for looking for advanced technology for increasing the accuracy — horizontal and vertical. No matter what, using a receiver, capable of receiving correction signals from all of the GNSS systems or at least 3 of them simultaneously, would increase the horizontal accuracy significantly.

ADVANCED GNSS TECHNOLOGIES FOR INCREASED ACCURACY

There are several solutions available on the market for increasing the accuracy and providing reliable accurate positioning for military and civil applications.

Basically, the available GNSS systems can provide much higher horizontal accuracy (up to 5–10 cm) but for security and marketing reasons the additional correction is not provided for free of charge (the data is encrypted) or is not available at all for civil purposes, as the accuracy is deliberately seriously degraded (using *Selective Availability*, or *SA*). The enhancement of the GPS accuracy technology is also known as DGPS (*Differential Global Positioning System*) and the technology providing higher accuracy using DGPS is called *Satellite Based Augmentation System (SBAS)*.

In common, DGPS provides higher accuracy (up to 20 cm) using a network of fixed ground- based

reference stations all around the Globe, also known as *DGPS Stations*. The systems combining those stations are *European Geostationary Navigation Overlay Service (EGNOS)* for Europe, *Wide Area Augmentation System (WAAS)* for North and Central America, *MTSAT Satellite Augmentation System (MSAS)* for Japan and Malaysia and *GPS Aided Geo Augmented Navigation system (GAGAN)* for India (look at Image 1).

The technology of SBAS is based on the recalculations in real time of the difference of the error between the real and calculated position. The result of the recalculations is integrity (or overlay) messages which overlay the original messages of the GNSS. Then, additional correction signal (correction message) is sent to the geo- stationary satellite and from the satellite the correction signal is received from the drone GNSS receiver (rover) — Image 2, which as result provides higher accuracy of the positioning.

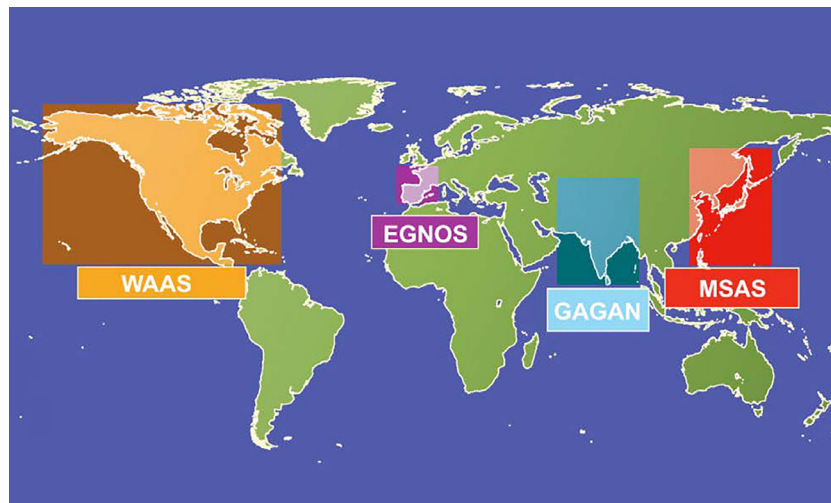


Image 1. SBAS coverage worldwide. The authors gratefully acknowledge the support of K.C. Wong Education Foundation.

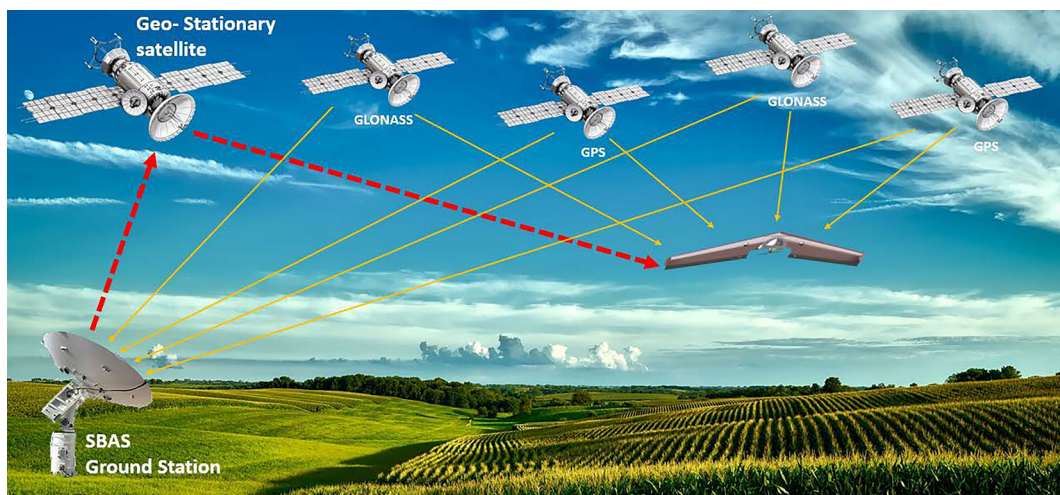


Image 2. SBAS principle diagram (Aero Vision Ltd proprietary document).

This technology, however cannot provide 20 cm accuracy all of the time because of the error accumulated with time of flight and the accuracy of DGPS degrades from 20cm up to 1m. There are some other SBAS systems available, like “RTX CenterPoint” from Trimble, providing all-of-the-time 3.8 cm accuracy or using RTK (*Real Time Kinematics*) technology, acquiring 2.5 cm accuracy. However, all of those systems are SBAS systems and the main difference between them is the *pass-to-pass* (current accuracy of positioning) and the *year-to-year* accuracy (or repeatable accuracy). The level of accuracy when using different type of correction technologies can be easily determined, looking at the Image 3.

The RTK itself is based on the same principle of the SBAS systems and it’s been known as one of the most SBAS available at present days. RTK is one of the most widely used correction technology worldwide,

when highest level of horizontal and vertical accuracy is required. Although all of the available SBAS systems are based on the same principle, there is a bit difference in the way the correction messages are generated and transferred to the rover (GNSS receiver).

The main difference between SBAS and RTK technologies is within the principle of the calculations taken. The RTK technology is based on the usage of single base station receiver and a number of mobile receivers (rovers), which station re-broadcast the single phase of the carrier signal, which receives from the GNSS constellation, while the mobile receivers (the rover receivers) compare their own phase measurement with the received one from the base station. The result is recomputed positioning and sub- centimeter accuracy (the principle of the RTK technology is visualized on Image 4).

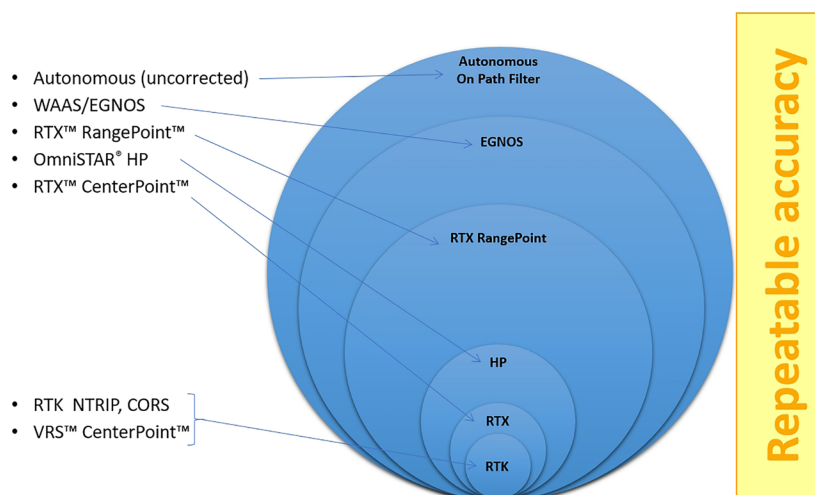


Image 3. Diagram of the level of the repeatable accuracy when using different type of correction technologies

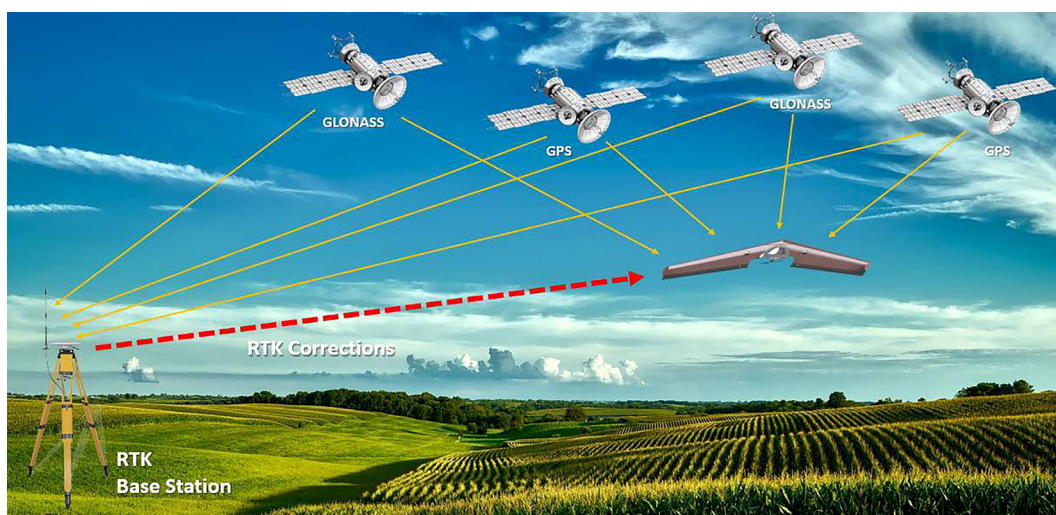


Image 4. RTK corrections via direct radio link and a single RTK Base station (Aero Vision Ltd proprietary document).

The communication between the RTK base station and the rover can be established via different methods. One of them is using direct radio link, which makes around 10 km radius of communication within the direct site between the Base and the Rover. The protocols of communication could also be different due to the numerous manufacturers of RTK equipment, as the common protocols of communication are: *CMR/CMR+* (Trimble proprietary), *NMEA* (open protocol), *RINEX/BINEX* (raw data open protocols), *RTCM 2/3* (*Radio Technical Commission for Maritime Services*) and *NTRIP* (*Networked Transport of RTCM via Internet Protocol*).

While the CMR and CMR+ can be transmitted mainly via direct radio link, RTCM and NTRIP can be easily transmitted via Internet, using different methods, as LAN, WiFi or the cell network of the local mobile operator. In present days the NTRIP protocol is widely used where more than one station is connected, as all of the data provided from the connected stations is post-processed by a NTRIP server and as a result they work as a network, not just as single connected base stations. This technology of RTK positioning is also called *CORS* – *Continuously Operating Reference Stations*. The advantages of the CORS system is that when multiple stations are connected to a server, their data is post processed simultaneously which provides higher accuracy of the positioning and extended range of operation, which can exceed 100 km main base line between two single stations. Additionally, when one base station is down (switched off) the NTRIP server can interpolate the possible error and compensate the lost station, as providing a bit less accuracy, but without affecting the covered area by the network (Image 5).

The networks established using the NTRIP services are the most widely used for RTK corrections

worldwide. The further development and improving the reliability of the GSM / mobile networks and improving their area of coverage worldwide, will make the NTRIP technology more commonly used for multiple applications – from the military industry up to the consumer grade precision drones in the next 10 years.

UAV COMMUNICATION, POSITIONING AND INTEGRATION

The possibilities for high grade accuracy positioning of UAV are quite limited. The reason for that is the cost for developing pin- point accuracy service and the limitation of the maximum Take- Off Weight (*TOW*) of the UAVs.

In present days (Q3 2017) there are not so many known solutions, provided specially for UAVs. Some of the most spread and commonly used solutions are:

Piksi RTK (provided by Swift Nav) – Swift Nav has developed some of the cheapest RTK solution for UAVs. Their electronic modules are based on the usage of RTK direct radio link with single base station. That solution provides the flexibility for the user to establish the RTK base station practically anywhere, within the direct site of view, providing high grade accuracy and meanwhile having the stand- alone integrity and autonomy of the positioning.

Here+ RTK (provided by Hex Aero) – Here+ RTK solution was specially developed for Pixhawk autopilot, which integrates open source hardware and software. It is also based on the single RTK base station and direct radio link. The main advantage of this solution is the usage of open source software, which makes it easily configurable for multiple autopilots and flight controllers, available on the market and its low price, compared to the quality (Image 6).

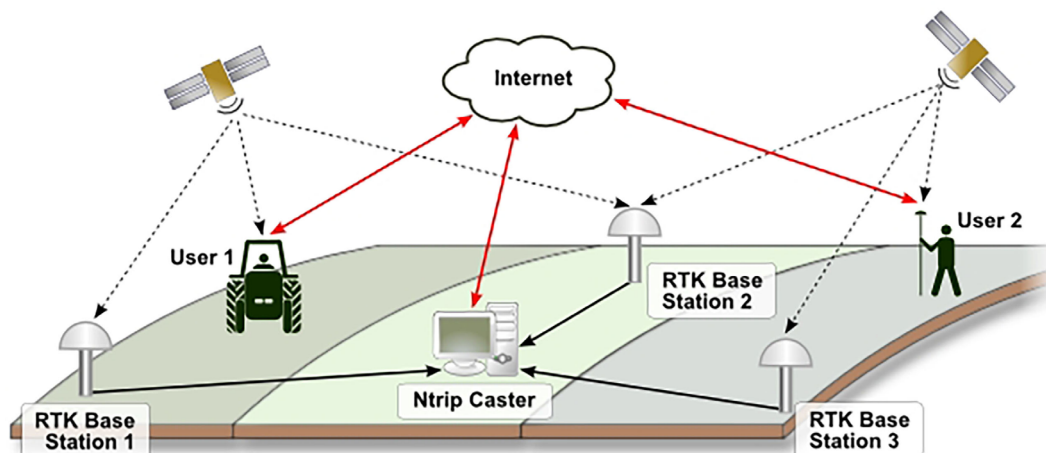


Image 5. Diagram of the principle of NTRIP network (Courtesy of Alberding GmbH solutions).



Image 6. Here + RTK, RTK solution for Pixhawk 2 Autopilot (Here+ proprietary document).

DJI D-RTK solution — The solution for RTK from DJI is quite the same as the listed above. The main difference between the solutions, provided by Here+ and Piksi from one side and the solution from DJI from the other side is the fully integrated firmware and extremely friendly user interface for the setup and configuration of DJI products, which make them very reliable and easy to use and they are very good known among the hobbyist and professionals worldwide.

These are just few of the examples for high grade accuracy solutions for UAVs available in present days worldwide. The disadvantages of all of them however are quite the same and are present to all those products. Those disadvantages could be determined with very small area of the coverage of the signal (up to 10 km), not so proven reliability (because of the radio link) and it is not suitable in urbanized areas and low-flight applications on distances over 2–3 km away from the base station.

DRAGNET INTEGRATION AND REALIZATION

The disadvantages of present RTK systems, based on direct radio-link communication, also would determine the requirements established by DARPA (*Defense Advanced Research Projects Agency*) in the document DARPA-BAA-16–55. DARPA is soliciting innovative research proposals for persistent, wide-area surveillance of small unmanned aerial systems (UASs) in urban terrain on a city-wide scale. Proposals are solicited for a scalable network of sensors on aerial platforms performing threat-agnostic UAS detection, classification, and tracking by looking over and into complex terrain, shortly classified within the *Aerial Dragnet* project for Defense UAV system. (*Proprietary document of DARPA-BAA-16–55*)

The *Aerial Dragnet* conception is based on surveillance system consisting of one or more sensors mounted on a single aerial platform. The system

will include algorithms for detecting, tracking, and classifying small UASs in urban terrain. The real-time compute engine may be located on the aircraft or on the ground connected to the platform by a high data rate link.

Performers must deploy their surveillance system on a persistent aerial platform of their choosing at a height not to exceed 1000 ft. For that reason, high-end pin-point accuracy and reliability of the positioning is required. If we consider all of the disadvantages of the positioning, exploiting the RTK correction technology, provided by the RTK via direct radio link we could say that the NTRIP technology is the best suitable option for highest grade accuracy with at least 95% of the time availability (average accuracy of 2.5 cm 100% of the time), as a positioning technology. Besides the using the NTRIP, the integration of single communication and data link in one technological solution together with the correction signal transmission is also possible.

DRAGNET COMMUNICATION, POSITIONING AND DATA LINK

The *Aerial Dragnet* concept is based on multilevel communication, analyzing and control technology, using UAVs as tool for defense of the airspace in urban areas when *intruding* drones compromise the protected area.

The conception is based on multilevel control of UAVs, covering from 20 km² up to 180 km². The goal is to achieve long range of the coverage of the *Dragnet* and at the same time to provide long endurance of flight and survivability in urban areas and *Smart Cities*.

In order to cover a neighborhood-sized area with a minimum number of platforms, a notional single surveillance node design would provide coverage and support dissemination of a COP to a small number of users over a 20 km² area.

Likewise, a networked city-wide configuration should provide coverage and support dissemination of the COP to a large number of units over a 180 km² area.

The way that could be achieved is using multiple UAVs (also called *Local UAVs*), which are performing different tasks at the same time and communicating and sharing information with the *Master UAV*, which analyzes the provided information from the *Local UAVs* and sharing the filtered information to the *Control Center*, as described on Image 7.

With other words, the entire system will be delivered by:

- *Neighborhood UVSs*;
- City UAV;
- Specialized UAVs;
- Ground Station for maintenance and servicing of UAVs;

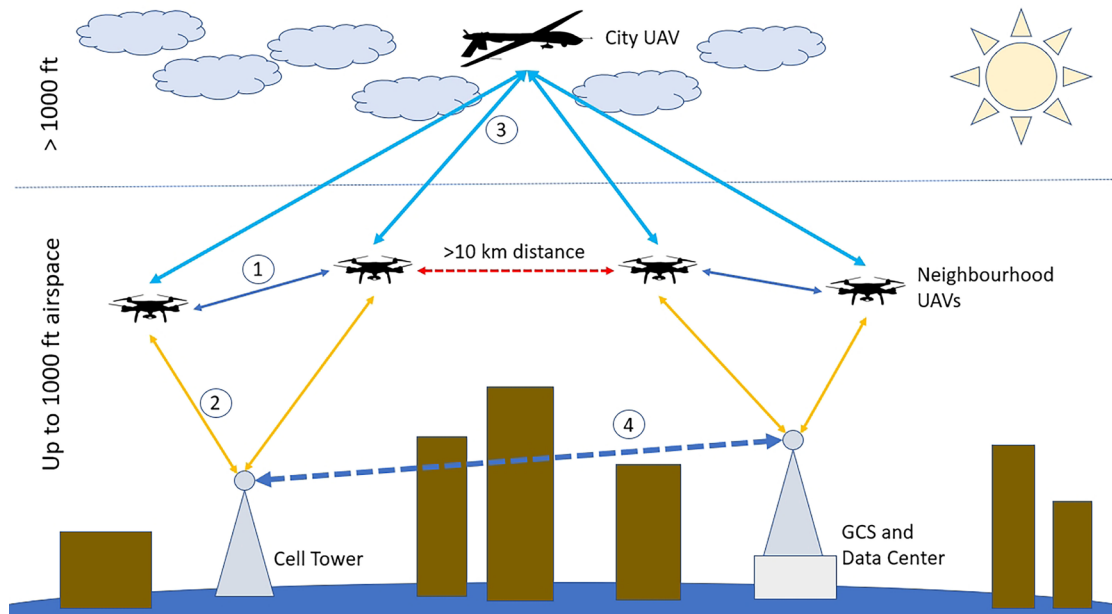


Image 7. Diagram of the control and sharing information concept (Courtesy of Aero Vision Ltd).

— Ground Control Station (GCS).

From other hands the information flow could be described by the following data types:

— *Correction data* — correction signal for the highest rate positioning accuracy (NTRIP data) — mark 2 and 4 on Img. 7;

— *Information data* — the information data from the *Neighborhood UAVs* and the *City UAV* — marks 1, 2, 3 and 4 on the Img. 7;

— *Sense and avoid data* — Data for the position, altitude, heading and speed transmitted to all of the *Neighborhood UAVs* and the Data and control center (Ground Control Station and Data Center).

The *Neighborhood UAVs* will be able to scan the area of 20 km² and they communicate to each other via encrypted and secured direct MAV radio link, which will grant at least 2–5 km reliable radio connection in urban area. The entire information then is transmitted via direct MAV radio link to the *City UAV*, where all of the info from the *Neighborhood UAVs* is recorded and analyzed. Due to the long distance between the communicating *Neighborhood UAVs*, a cell tower from the mobile operator should be used. Using the data from the GCS for the positioning (NTRIP), the correction signal is transmitted to each of the *Neighborhood UAV* and processed. The result is that each video frame recorded and picture taken on the UAVs will be geotagged with the highest positioning accuracy and precision. The result is fast and accurate locating of any intruder in the sky. Additionally, the highest accuracy of positioning would deliver accurate and safe control of the *Neighborhood UAVs* in urban

area, lower power consumption and longer flight endurance compared to standard GPS positioning.

The usage of the Cell towers of the mobile operator to transmit the data, will increase the range of the transmission within the coverage of the mobile operator network, which in urban area would be practically unlimited. Using this method for transmission of the data will provide fast, accurate and fully integration, which at the end will reduce the weight of the additional equipment used on the *City UAVs* and *Neighborhood UAVs* and will be represented with one single SIM modem, which will make possible:

— Transmission of the data from the sensors — video frames, pictures, LIDAR images; RGB/NDVI/NIR images and etc.;

— Accuracy correction, positioning and control — NTRIP positioning with 2.5 cm absolute accuracy, geotagging of images and frames;

— Transmission of the *Sense & Avoid Data* — this data will provide full information for the position of all UAVs used by the Dragnet Network, will increase the safety and will optimize the control of each particular UAV.

The *Sense & Avoid Data* is described on Image 8.

The LATAS system (*Low Altitude Tracking and Avoidance System*), developed by Precision Hawk, will increase the safety and also will take advantage of the Cell Network of the mobile operator, with redundancy and highest level of safety and security. The LATAS system from Precision Hawk works like the Transponder on the real airplanes, needed to

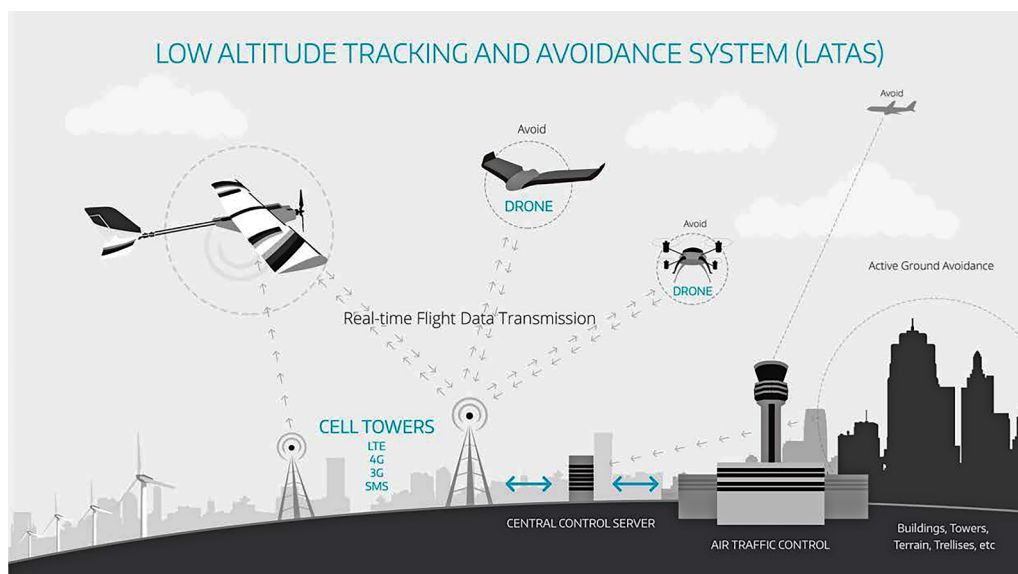


Image 8. Low Altitude Tracking and Avoidance System (LATAS).

transmit their position to the *Ground Control Station* and the other airplanes / UAVs nearby. At the end LATAS will provide highest grade of safety during the operation of the UASs and will help the ground operators to plan the flight plans and reduce the time for the flight preparations and will become absolutely mandatory equipment in the next few years, due to the increased needs for safety and the latest regulations worldwide.

CONCLUSIONS

Using the SIM modem on each UAV will provide the main advantages amongst any other technology for transmitting data and in-flight communication:

- Full integration — one unit for communication, control and positioning;
- Small dimensions and weight — based on the replacement of multiple units by a single one;
- Low rate consumption, determined by the SIM module — the same as middle class Cell phone;
- Low latency rate — less than a second within 360 km distance between the cell towers
- Practically unlimited range — restricted only by the mobile network coverage;
- High end redundancy — it can be configured to use multiple SIM cards, which will make possible the use of different service providers;
- Full control of UAV;
- Multi data transmission — it can be used to transmit all of the needed data, as:
 - RTK grade accuracy positioning (phase measurement);
 - LATAS information;
 - All information from the sensors used on board;

- control protocol of the UAV and flight plan upload/update during flight.

The technology described, as a final conclusion will be the next century technology which will make the difference and will bring high end accuracy together with all of the needed data during flight of any of the UAV in particular area, which will be the focus of all future regulations, regarding the usage of UAVs in urban areas.

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3DR Robotics (<https://3dr.com>)

Высокоточные беспилотные летательные аппараты — сегодня и завтра

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Описываются возможности повышения точности определения местоположения беспилотных летательных аппаратов. Сравниваются возможности различных систем определения координат для достижения точности 2.5 см. Описываются способы передачи данных о коррекции координат. В заключение предполагается, что наиболее целесообразно использовать трансляцию по сети мобильных операторов в режиме реального времени для точного определения координат беспилотных летательных аппаратов.

Ключевые слова: ГНСС, GPS, ГЛОНАСС, Галилео, Бэйдоу, RTK, SBAS, Dragnet, UAV, SIM