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DRONE SYSTEMS FOR FACTORY SECURITY AND SURVEILLANCE

Péter Miksa Hell and Péter János Varga*

Óbuda University, Doctoral School on Safety and Security Sciences
Budapest, Hungary

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ABSTRACT

Nowadays, when preparations and implementations are under way for smart cities, the use of drone systems in the safety of factories has come to the fore. Factories and industrial areas are complex systems. Physical control is essential for their optimal and safe operation. Most of the inspections can be performed with the use of human resources. However, efforts should be made to minimize the human factor in order to make the system as automated and optimized as possible. Pre-programmed routine tasks can be performed by drones, both indoors and outdoors. Dedicated drones are already in use around industrial facilities, primarily for facility protection. However, in enclosed halls, it is not easy to provide these tools with routine tasks, because indoor labor – material handling, reconnaissance, and accident-free transport – requires orientation. Besides the production lines and inside warehouse buildings, drones are already commonly used to perform smaller tasks, but the goal is to ensure the right ratio in the human-machine relationship. In their technical implementation, modern drones are assisted by various sensor systems (lidar, ultrasound, camera) that they are equipped with. This article presents the application of task-specific drones in industrial areas, both indoors and outdoors.

KEY WORDS

drone, smart city, factory, security, surveillance, indoor environment

CLASSIFICATION

JEL: L63, L92

*Corresponding authors, η: varga.peter@kvk.uni-obuda.hu; -;
Óbuda University, Tavaszmező u. 15-17., H – 1084 Budapest

INTRODUCTION

We have seen many examples of outdoor use of drones in recent years. From hobby flight systems to special drone systems, the field of application is very wide. Nowadays, the issue of outdoors orienteering has already been resolved and is supported by GPS, but in the framework of the Industry 4.0 concept, there has been an increased demand for indoor navigation of drones. When it comes to indoor use, you have to face the limitations that are not encountered during outdoor use. One of the biggest problems when trying to ensure safe indoors flight is to determine the appropriate position and reference points [1, 2].

INDUSTRY 4.0 AND DRONES

The Fourth Industrial Revolution directs us towards intelligent manufacturing, that uses information technology to change the way products are produced and reduce costs, and by doing so, it is focusing on efficiency [3, 4]. By accessing real-time data, companies can respond more quickly to customer interactions and product use interactions. Industry 4.0 is primarily about new technology and new innovative business models. During production, a single drone can be used in complex systems as a mobile sensor that transfers data from physical production processes to production control. Manufacturing companies have already used autonomous robots in the production and handling of products. Autonomous entities become more and more widespread [5-7]. A specially equipped drone works like a flying robot. Such a device can be integrated into assembly and manufacturing workflows to enable companies to operate more easily, efficiently and safely. Integrating drone technology into industrial manufacturing and control processes is becoming increasingly important. Figure 1 shows the rate of use of drones in the current market [8, 9].

Drones can become an integral part of industrial controls, as they can perform a task without human intervention for long periods of time in difficult to access or unsafe locations. Using high-definition cameras and Internet of Things (IoT) tools, drones can quickly identify key control points and provide information about the target being checked. Thanks to bidirectional

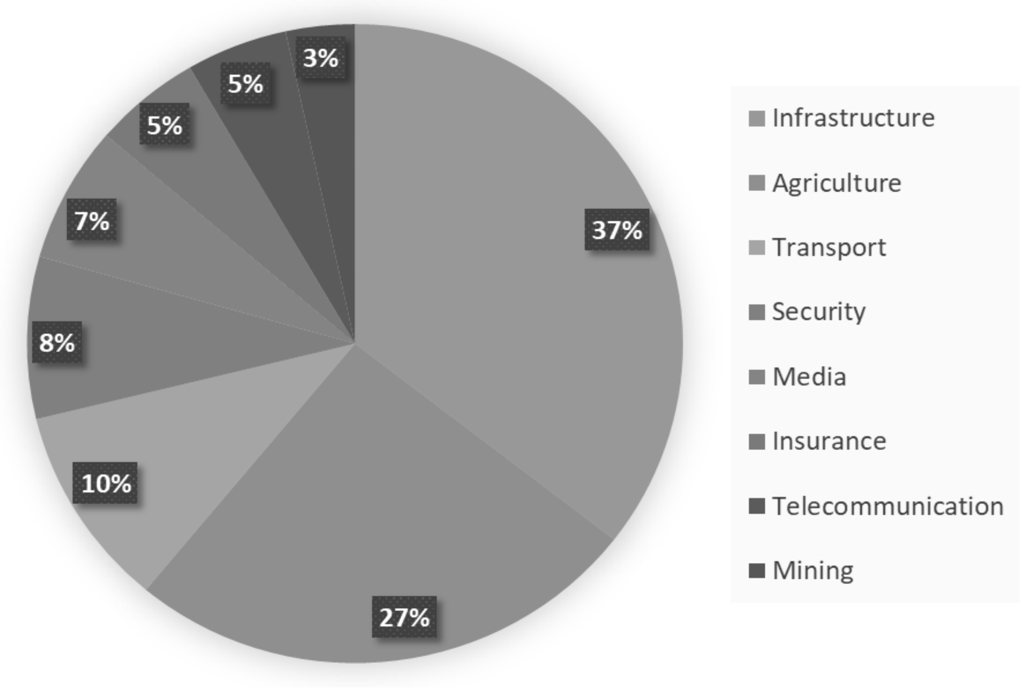

Figure 1. Drones in construction 2018 [10].

communication, the IoT platform provides an opportunity to analyze data immediately and identify problems. This autonomous drone, created with this knowledge and insight, is a preprogrammed aircraft that is capable of self-handling without operator intervention [11].

Hardware and software conditions required for fully safe collaboration of people and drones and the integration of drones in the production process:

- secure flight in an indoor, enclosed area with sensors, cameras, and intelligent object recognition and collision prevention algorithms,
- immediate situation recognition and real-time response to unexpected situations and obstacles ,
- the ability of drones to connect and communicate with other drones, machines, devices and people via IoT devices mounted on board,
- recognition and identification of the assigned markers,
- ability to make decisions independent of the pilot using artificial intelligence,
- automatic data upload and synchronization with a cloud-based database,
- flight time – battery capacity optimization,
- modularity. Drone configurations should be plug-and-play configurable to work as a module that can be added to existing processes.

OUTDOORS ORIENTATION

When it comes to outdoors, orientation is perfectly solved nowadays with Global Positioning System (GPS) and Global Navigation Satellite Systems (GNSS). Satellite positioning allows us to determine the right position via different kinds of GPS and Glonass. The accuracy is only a few centimeters. This can be further enhanced by a combination of Real Time Kinematic (RTK) systems. GPS is sufficient for outdoors orientation and positioning, but not for recognizing obstacles in the flight path. There is a simple reason behind this. When it comes to GPS and GNSS, the codes transmitted from satellites do not contain any land-based feature information. Also, the GPS receiver's map database does not include the exact location of the features. GPSes work reliably, but their operation depends on outside organizations. If for some reason these systems do not broadcast information or deliberately send incorrect information to the GPS receivers, then the whole system becomes inoperative. Figure 2 shows a flight route plan around a factory. The observation drone keeps track of the landmarks in a safe height and distance along the route only with the help of GPS. This can be combined with a sensor system placed on the drone.

GPS cannot help drones to perform tasks without collision in an industrial facility or within a building. Only various proximity sensors mounted on the drone are a solution for detecting and responding to various obstacles in the flight path. The real-time data from the sensors is processed by the flight controller, which then either corrects the flight path for accident avoidance or entirely stops the drone. In premium category drones, the default setting for the Security Proximity Sensor is to override the pre-written flight plan or the drone pilot command in case of a possible collision [12, 13]. These sensors operate on a variety of measurement principles, ranging from a simple ultrasonic Doppler-effect rangefinder to the intelligent object recognition algorithm of today's state-of-the-art 3D camera image analyzer [14-16].

On-board sensors for supporting drone stability and autonomy

Autonomous sensors ensure the stable flight and floating of the drones. These sensors are not connected to a global system such as GPS. The drone's flight controller processes and evaluates the data sent by the sensors then decides based on a pre-written or learned algorithm. The sensor data can only be sent for monitoring to the drone pilot or the drone control

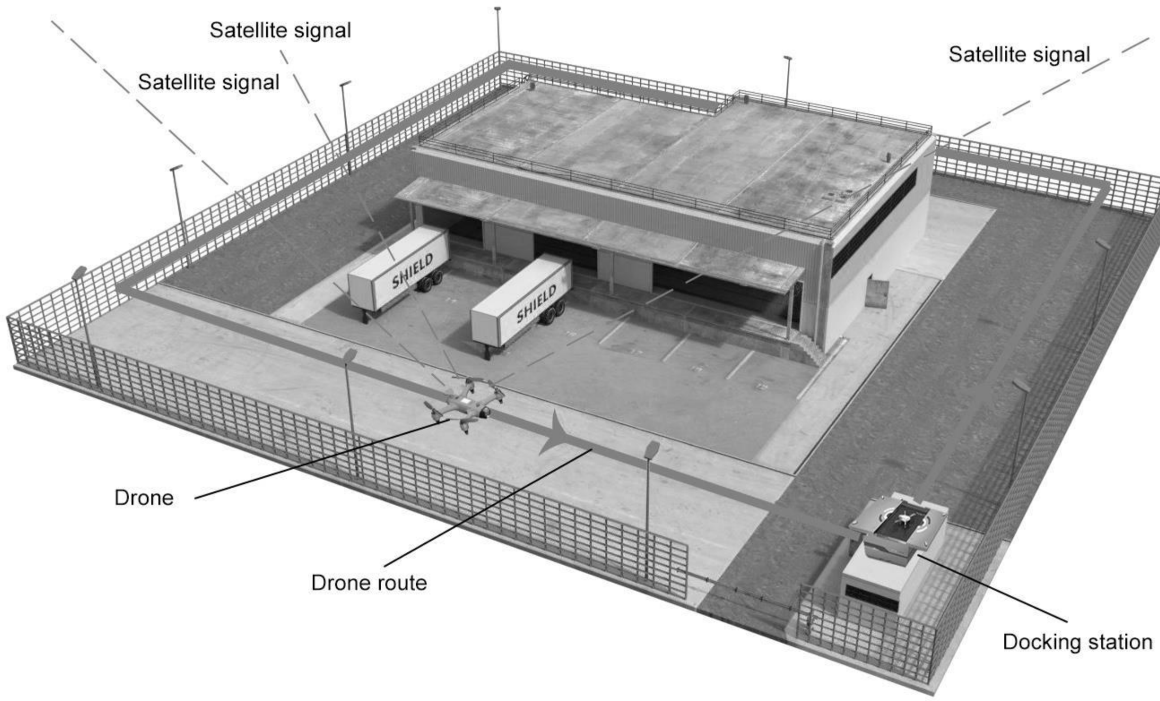

Figure 2. Drone performing a routine task using GPS.

control system. Even the simplest drone requires simultaneous processing and evaluation of multiple sensor signals for air retention and positioning [17].

Gyroscope

There are many gyroscopes that use different physical phenomena, such as rotation speed. To date, these devices have been completely replaced by the most common microelectromechanical systems (MEMS-systems) created by the combination of small microelectronics and mechanics. MEMS-type gyroscopes keep a small mass in constant vibration and regularly measure the deviation for the initial vibration plane. The differences are measured by the determination of the Coriolis force known in physics.

Accelerometer

The geometric size of the MEMS accelerometer sensors allows us to combine the sensor with other sensors for more accurate positioning. Their operation is very similar to the operation of a gyroscope. Inside the sensor, there are two comb structures that form a series of capacitors. When the sensor detects acceleration, the mass moves and causes a change in the capacitance of the capacitor.

Magnetometers

The principle of MEMS magnetometers is based on the Hall-effect. If a current flows in a conductor or a semiconductor and is placed in a magnetic field, the Lorentz force acts on the particles carrying the current, so there is a potential difference on both sides of the conductor. This potential difference can be measured.

Barometer

Most barometers used in drones are piezoelectric barometers (based on the MEMS system). A piezoelectric insert is located behind an opening in a cavity, completely blocked from its surroundings. In this cavity, an air mass value is recorded as a reference value. With the change of height, the air pressure also changes, which deforms the piezo tile and results in a measurable electrical potential difference proportional to the air pressure.

Ultrasonic distance meter

The ultrasonic distance meter operates on the principle of the Doppler effect. The transmitter of the device transmits in the ultrasound range (40 kHz), which is reflected from the objects into the receiver. The electronics calculate the subject distance based on the timing of the reflected signals. In drones, these sensors are usually used as a ground-level altimeter or to avoid large obstacles such as walls or ceilings. This is one of the most important elements of indoor orientation. The advantage of the ultrasonic distance meter is that it is accurate even in poor visibility due to its operating principle. Its disadvantage is that its operation is only reliable for a few meters, and smaller, thinner objects such as electric wires are not noticed by it.

Optical flow

Continuous images recorded with the camera enable the speed of the drones to be measured. Their operation is very similar to that of a computer mouse. A low-resolution camera (below 1 MP) produces images at a very high refresh rate and produces a difference image using an algorithm. The two consecutive images and the change in time determine the horizontal speed of the aircraft. The accuracy, in this case, is determined by the processing algorithm, the quality of the images and the refresh time.

Stereoscopic cameras

With the advancement of technology, not only high-resolution cameras are available to be mounted on board, but also special recording cameras. They analyze images with artificial intelligence algorithms and directly help with navigation. Two-camera distance measurement is based on photogrammetric principles. By highlighting the common characteristic points of the two images, an algorithm can be used to determine the distance between the objects in the image. The quality of the finished dot net is the same as that of the cameras. This technological element is usually used to avoid obstacles, although it can also be used for 3D mapping of the environment.

LIDAR

LIDAR (Light Detection and Ranging) is an optical space mapping technology that lets you determine the distance of objects. Laser light consists of a pulse emitting transmitter and an optical sensor facing in the same direction that reads the reflected laser pulses. The measurement works on the principle of the Doppler effect. The narrow opening combined with a 360-degree rotating motion allows LIDAR to construct a complete panoramic image of its environment.

LEDDAR

The LEDDAR (Light-Emitting Diode Detection And Ranging) sensor is a further developed version of LiDAR technology, without the complex rotating mechanics. There is a great future ahead for this new generation device in Geographical Information System. Due to its size and price, it could be the most reliable sensor for drones. The angle of view depends on the optics. The sensor device can detect multiple objects simultaneously and determine their distance with millimeter accuracy. Depending on the angle of view, it detects objects up to 100 meters away. Obstructive objects nearby are illuminated by the built-in infrared, so the sensor can also be used in the dark.

Flight modes

Table 1 shows the general flight modes of advanced drones, outdoors and indoors [18].

Table 1. Flight modes for drones for outdoors and indoors. Light shaded – flight is not dangerous, dark shaded – flight is dangerous, flight mode is not optimized for the location.

Manual mode	Outdoors	Indoors
Full manual mode		
Manual mode with proximity sensor data		
Manual mode - except for No-fly Zone		
Automatic mode		
Automatic mode based on route plan, no proximity sensor		
Automatic mode based on sensor data		
Emergency flight mode		
Return on the shortest route with Ascension and Go Home function		
Return due to deviation from automatic travel direction		
Return due to a technical problem		

Positioning and navigation within buildings

GPS systems are well known in the determination of outdoor location. However, positioning inside buildings is a major challenge. The satellites usually do not reach the covered areas and the system would be unusable anyway due to interference. For these reasons, indoor positioning systems have received increasing attention over the past decades. The safe operation of indoor forklift trucks, such as servo robots and controlled trucks, is based on sophisticated technology. Due to the two-dimensional space of maneuver and the low speed of robots, the number of unexpected incidents causing accidents is negligible. However, this is not always the case for drones. In addition to the horizontal two-dimensional movement, these devices can move in a vertical direction, and are also faster, so, the security requirements for indoor drones are much higher [19, 20].

Indoors, task-specific drones use a particular, dedicated path to perform their task. Tasks may include taking pictures or videos of objects, material handling, workflow, and people. In order for the drone to safely perform its assigned task, the control system must continuously know the current position of the device with centimeter accuracy. An unexpected event may occur at any time on the assigned route, to which the drone must respond immediately. For indoor flight planning, we need to be aware of all the landmarks (such as walls, furniture, machinery, conveyor belt) that are present where the drone system is being implemented. The location of landmarks greatly influences flight operations (eg material handling, tracing). In order to avoid a collision between drones and landmarks, zones in which the airplane can move freely, and zones where the flight is prohibited must be selected during the training phase. If the path of the starting point and the point of arrival or route alternatives are unknown during task completion, route optimization cannot be performed in advance. In addition, if an unexpected obstacle also affects the direction, then the execution schedule of the planned tasks will also change [21].

For these reasons, indoor positioning systems have received increasing attention over the past decades. The position of an object placed in a three-dimensional space can basically be determined by two principles. Either the object determines its own position in space, or we determine the position of the object from the outside. The first version is ideal for drone systems because coordinate information must be processed directly on the drone. Figure 3 shows

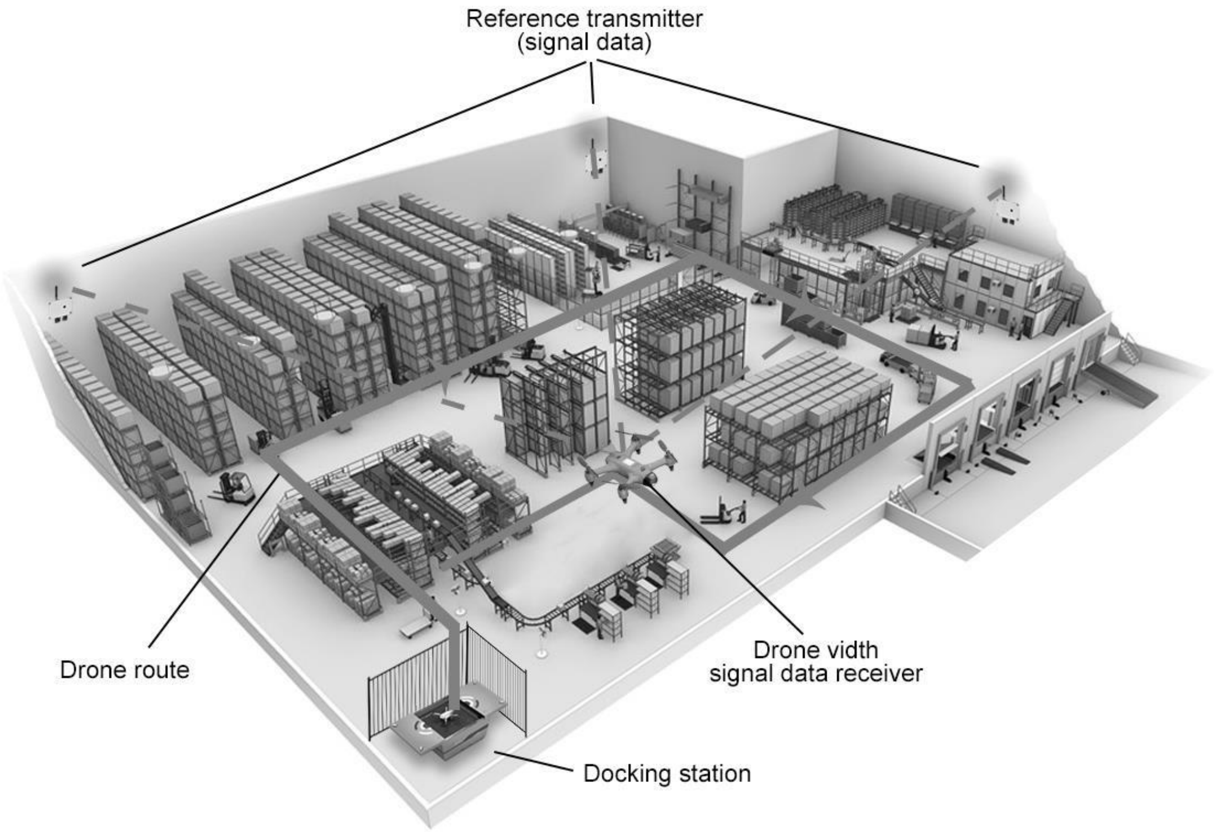

Figure 3. Drone performing a task based on a roadmap using indoor positioning [10].

the elements of an indoor location system. In a confined space, fixed transmitters emit a unique code sequence into the space that the drone sensor receives and the device calculates the exact position of the receiver unit (drone) based on an algorithm [22].

There are many different positioning systems based on infrared, ultrasound, RFID, ZigBee, and Bluetooth technology, each with its advantages and disadvantages. Of these standard systems, Bluetooth 5.1 is the one capable of positioning with centimeter accuracy, but the range of technology does not allow stable operation in an industrial-scale environment. The most commonly known radio frequency positioning generally uses the Received Signal Strength Indication (RSSI) method, which determines the position of the devices by triangulation based on the strength of the detected signals [23]. However, these measurement procedures are unreliable in terms of accuracy. The exact positioning can be solved by the so-called Angle of Arrival (AoA) and Angle of Departure (AoD) measurement procedure shown in Figure 4. The essence of AoA is that the transmitter device first uses a single antenna to send a directional data packet that the receiver detects with multiple antennas. The system algorithms calculate the arrival angle and direction of the signal based on the minimal delay the packets arrive with to the antennas.

AoD is the opposite of AoA. Here, a sending device works with several antennas, from which it simultaneously sends signals to the receiver with one antenna, for positioning purposes. The signals arrive at the receiver with a delay, so an algorithm can calculate the direction from which the received signal was received. This principle is the most similar one to satellite positioning. The clearer the view of the transceivers and receivers, the more accurately the technology works. Objects and walls in the path may cause interference, impairing accuracy [24].

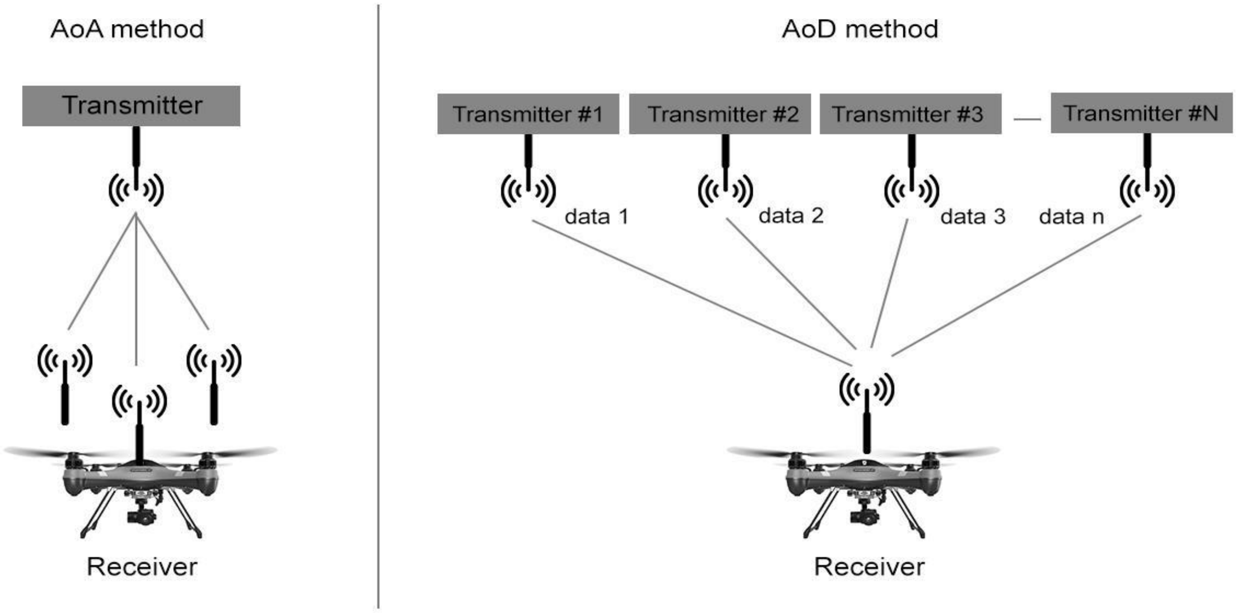

Figure 4. AoA and AoD system positioning.

Systems for flight support and data acquisition

The drone sensor system assists in the safe execution of tasks, both indoors and outdoors. To achieve this goal, it is necessary to create a hardware and software environment that is responsible for flight planning - determining routes, turning points, and altitude. The system is able to stay in constant communication. With the help of an operator, a so-called work management option can be implemented, which ensures that the flight plan is modified on the move. The operator can track the changes and the current position of the drones on a properly designed graphical interface. It also makes it possible to monitor drone sensor data - eg. distance detection, speed, charge level, flight altitude. In these systems, the data is processed continuously, so that the operator can be informed about the measurement results even during the task completion, and, if necessary, can intervene manually.

CONCLUSION

The drones need to become smarter in order to optimize industrial processes, maximize their utility and be widely accepted in future factories. If all these criteria are realized, they can be applied in engineering, maintenance, critical infrastructure management, and asset management operations. The use of drone systems in the industry clearly offers new opportunities and new innovative business models. To accelerate manufacturing processes, companies are trying to implement these new innovative technologies into their systems to make their processes safer, more reliable, and more predictable. The drones appear as a new alternative in this area (eg.: swarms of autonomous drones). From an industry standpoint, the implementation of this technology can be ideal in the automotive industry. This is projected by test plants in car parts manufacturing (eg Subi-Ker 2000 Ltd. factory and innovation center) [25-30].

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