An integrated GPS-GIS surface movement ground control system

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Abstract

The need to guarantee a high safety level in airport areas and the high congestion at the airports, due both to the increase of air traffic demand and the lack of significant intervention on the infrastructures, ask for more intensive studies concerning the problem of the ground circulation in an airport area. In particular, high traffic airport areas must be continuously monitored in order to know at each time the position of all the moving objects (land vehicles and aircrafts) on the ground (aprons, taxiways, runways). Recent solutions used to resolve the problem of object positioning move towards the use of GPS apparatus. In this work, an integrated GPS-GIS system is proposed for monitoring the airport areas, following the new requirements of Intelligent Transport System (ITS) applications.

Keywords: airport ground movements; land vehicles and aircrafts location; GIS and GPS technologies.

1 Introduction

The development of the air transport system in the last decades, due to a more and more increasing transport demand level, has a constraint in the bounded capacity of the system, that depends on the air control system and the actual specific set of rules.

The bottlenecks of the system can be identified in the finite capacity of both airways and airports, these latter even more constraining.

The ground movement control system plays an important role for the estimation of the airport capacity; in fact, it establishes the time and/or space
minimum separations that has to be guaranteed between two aircrafts during the landing/take-off operations.

With reference to the take-off operations (similar considerations can be made for the landing operations), the management of ground movements requires the exact position of the aircraft to be known by the tower operators during the movement from the taxiway to the runway as well as its waiting point before the take-off. In order to guarantee safety conditions during the ground vehicle movements (not only aircrafts, but also land vehicles as bus for passenger transfers, luggage and refuelling vehicles, and so on) suitable separations has to be ensured among them as during the flight.

With reference to this aspect, the FAA (Federal Aviation Administration) defines the runway incursion at an airport as “any occurrence at an airport involving an aircraft, vehicle, person or object on the ground that creates a collision hazard or results in a loss of separation reduction with an aircraft taking-off, intending to take-off, landing or intending to land” [1]. A similar definition has been developed by the European Organization for the Safety of the Air Navigation (within Eurocontrol, the European organization that deals with the air traffic management and control), that defines the runway incursion as “any unauthorized presence on a runway of an aircraft, vehicle person that creates a collision hazard or results in a potential loss of separation” [1].

Even of the air transport system can be considered a safe system [7], however, the risk linked to interferences among aircrafts and/or vehicles during ground movements is still high with respect to the suitable standards for the system. The safety problem of the ground operations has been studied also by means of a simulation approach [9], in order to verify the incidence of the airport configuration on the ground movement operations.

To assure safety conditions to the operations occurring in the airport area (as landing, take-off, ground circulation) different systems have been proposed and partly realized; they are known as Surface Movement Ground Control Systems, (SMGCS). They can be used not only to control the ground circulation in order to guarantee suitable safety standards, but also to optimal manage the ground movements. In fact, the exact knowledge of the actual position of the aircrafts (as well as the land vehicles) in real time could allow the system be managed in order to increase the airport capacity, particularly by both reducing possible excessive spaces among aircrafts and addressing the moving vehicles along the best path in order to optimise the whole system in terms of capacity.

At this time, the systems used to control the ground aircraft movement are based mainly on radar systems and/or underground detectors. Limits of radar systems are linked to the wave propagation system and to the reflections generated by adverse meteorological conditions that reduce their efficacy; as regards the detector systems, they can detect the movements of the vehicles (both aircrafts ad land vehicles) only at specific points, because they are located in prefixed points on the ground.

Even if technological progresses have given a good support to the management of the airport ground movements, the problem of the aircraft and land vehicle surveillance cannot be resolved by means of only one kind of
technology given the continuous occurring of accidents due to insufficiency of the technological systems and wrong communications between pilots and tower operators.

In fact, the actual system cannot neither locate and identify the moving vehicles with the needed accuracy nor convert the signals acquired by detectors in analogical data to be used in an automatic computing system.

For this reason different systems have been studied in order to integrate the radar control with other apparatus, also by using completely different technologies to guarantee both the ground movement safety and the airport capacity increase.

In this paper, an integrated approach GPS-GIS will be describer; its goal is to provide a surveillance and guidance system for the airport ground movement; the GPS component is used to establish the aircrafts/vehicles position in real time while the GIS component is used to manage and depict the geographical information of the aircrafts/vehicles position.

The paper is organized as follows: in section 2 the ground movement control problem is discussed as well as the benefits deriving from an optimal management of the ground movements; in section 3 the GPS technology is briefly described; in section 4 the GPS-GIS system for the airport ground movement control is discussed, with particular reference to the needed apparatus and the data transmission system. Finally, section 5 reports some short conclusions.

2 Ground air traffic control system

The Advanced Surface Ground Movement Control System (A-SMGCS), as defined by ICAO [6], is a modular system able to support the ground movements of land vehicles and aircrafts at the airport area in a safe, orderly and quick way, whichever the meteorological conditions, traffic density and airport complexity are.

The need to have an A-SMGCS arises from the observation of the increasing number of accidents occurring in an airport area, the augmented complexity of the airport structure, the increased number of operations and the desire to ensure the operative capacity in all weather conditions.

Functions required to an A-SMGCS can be synthesised as follows:
- surveillance function
- routing function
- guidance function
- control function.

The surveillance function must be directed to the identification and location of aircrafts and land vehicles within the airport area. In most cases, the surveillance procedures are based on the criterion "see and be seen", in the sense that the separations among all the moving vehicles are visual and are directly managed by the pilots or by the land vehicle drivers. This procedure should be unsafe when the external conditions do not permit a good visibility (e.g., in presence of fog) or the traffic density is quite high. In these situations there is a
real need for systems able to support or substitute the procedure "see and be seen", whichever the whether conditions are, in order to locate moving/stationary vehicles and verify the absence of interferences among moving vehicles.

The routing function must be directed to plan and assign a path to each moving aircraft and land vehicles in the airport area in order to assure a safe, quick and efficient movement from its current position (origin) to its final position (destination). At this time, the routing is provided via radio communications to pilots (or to drivers of land vehicles) in terms of sequence of taxiways that must be run to move from the origin position to the destination position.

The usual procedure is based on the use of a standard terminology (in order to avoid wrong interpretations) and confirmation in terms of message repetition by pilots. Paths are established by the tower operators (Air Traffic Control, ATC), on the basis of the visual observations from the tower and the knowledge of the airport landside. An advanced function of routing must consider the opportunity to change the path at each time, plan all the paths for aircrafts and land vehicles for each traffic condition, interact with the tower to minimize all possible conflicts at the intersections, answer quickly to all users path requests.

The guidance function must be directed to provide pilots (and drivers) with suitable, unequivocal and continuous information about the path to be followed and the speed to be maintained to continue safely. At this time, the control function is realized by means of visual aids, in other words the pilot moves along taxiways and aprons following the painted markings (particularly the centerlines) and in-pavement lights. Furthermore, pilots have got airport maps that can be used to have additional information. Sometimes, ATC operators can provide pilots with information or instructions about the taxiways. An A-SMGCS must provide guidance for all possible assigned paths, give clear and unambiguous information to pilots and drivers such that they can follow the assigned path, make them aware of their position along the assigned path, accept path modifications at any time.

Finally, the control function must guarantee from each possible collision and runway incursion, and assure safe, quick and efficient movements in the airport surface area. At this time, the control function is under the responsibility of both pilots and controllers; in fact, the pilot moves following the rule "see and avoid", while the controller reduces the number of movements in order to avoid possible conflicts. An advanced control function must be able to support the ground movements in any traffic condition and to support the required movements for up to one hour; it must be able to find conflicts and to provide fast solutions to avoid them; it must be able to verify that the required safety distances are kept and advise if they reduce by a minimum value. Similarly, it must advise in case of runway or other restricted area incursions by means of suitable alarm systems; it must coordinate driver and pilot actions; spacing aircrafts to ensure minimum delay and maximum utilization of the airport capacity; finally, it must separate movements from obstacles, secure areas and restricted areas.

Till today, the most used systems to control the surface air traffic refer to two projects, identified by the acronyms ASDE-3 (Airport Surface Detection
Equipment) and AMASS (Airport Movement Area Safety System), based on the use of radars to locate aircrafts (Ground Movement Radar systems). The first one is formed by a GMR system whose aim is to help the tower operators to identify the surface aircraft position. The second one is a development of the first one and it is addressed to send alarm signals when possible surface conflicts can develop.

As known, the radar working principle is based on the following: radio-waves, generally impulse modulated, are sent towards the object to be looked for and then the waves reflected by the objects itself (radar echo) are received by the apparatus. The object distance can be deduced as a measure of the time length between the emission and reception of the wave; in other words, the time spent by a radio-frequency impulse, generated by the radar transmitter, to reach the object, be reflected by it and then return to the receiver can be used to measure the distance between the radar position and the object. The orientation of the electromagnetic beam generated by the transmitter gives the direction of the object.

Generally, only one transmitter is used both as transmitter and receiver; the reception is temporarily interrupted during the impulse generation and then it is suddenly activated to capture echoes. The apparatus used to this aim is a kind of switch activated by the transmitted impulses. The radar antenna generally spins with a constant speed in order to explore the whole horizon; this kind of exploration is called azimuthal because it allows the angle between the reflecting object and the local meridian (azimuth angle) to be identified.

An optimization of the system is due to the visualization of the object on a screen. In fact, the reflected signal, captured by the received and suitably amplified, is transformed in a video impulse on a screen where the signal is reproduced as a high brilliance trace and its position with respect to the screen centre reproduces, in the given scale, the distance between the radar (supposed located at the centre of the screen) and the object that generated the radar echo. At each time the angular direction with which the electron beam realizes the scanning corresponds to the direction of the radar electromagnetic beam.

Other systems used to follow the surface movements of aircrafts are under-pavement detectors whose aim is to control the high traffic density airport areas (Airport Surface Monitoring Equipment, ASME). Among these, ASME-4 assures the following four main functions: surveillance, control, guidance and assistance. The network of under-pavement detectors can distinguish different kinds of traffic by identifying the moving vehicles. A further detector network on the outside of the paved areas allows a possible aircraft out-of-way to be quickly located and assisted. The system can also be connected to the way lights, so, following the acquired information and those introduced by the operators using the keyboard, a suitable system activates the lights preceding the aircraft and switches off those behind it, in order to generate a light path that guides the pilot from the taxi/run-way to the assigned apron and vice versa.

Detectors that can be used refer mainly to three classes:
- magnetic turns under-pavement, that use the physical principle of the magnetic induction on metallic wire;
- piezoelectric detectors, that use the physical principle of the pressure forces generated over the ways;
- pyroelectric detectors, that use the physical principle of the infra-red radiation emitted by hot bodies.

Among these, the pyroelectric detectors are not intrusive because they do not require the pavement perforation and the following rebuilding of the pavement as for the first two systems.

3 Global Positioning System (GPS)

The NavSTAR GPS (Navigation Satellite Timing And Ranging Global Positioning System) system was originally borne in USA for military purposes; it allows the three-dimensional positioning of objects (also moving) to be identified by means of information coming from a geostationary satellite system by using distance-measuring spatial intersections (ground receiver - orbit satellite).

Even if the new European satellite system GALILEO is coming, for the next ten years the GPS will be still the dominant system in the application field including the dynamic control of the territory, the emergency and above all the navigation, the goods positioning in terms of container vehicle fleet, goods wagon and anti-collision systems.

Mainly two kinds of GPS measures can be used [2], [3], [5], [8]: the pseudo-range and phase measures. The first ones are used above all for navigation assistance, while the second ones are used in all applications for which a greater accuracy is required, as the land deformation control.

The differential (RT-DGPS) and relative (RTK) positioning are particularly useful to continuously control in real time the moving means of transport (cinematic GPS); in this case, the measure (Cartesian coordinates of the baseline vector between the known master station and the rover station referred to the vehicle to be positioned) must be initialized and the satellite visibility must be guaranteed (by means of the monitoring of the DOP value) during all the time of the positioning measure. The acquisition system must be equipped with a firmware for the on-the-fly (OTF) initialisation, in case of temporary loss of the signal, and suitable links among the acquisition stations (master and rover) to obtain in real time the correct transmission of the data following given protocols.

4 A GPS-GIS approach for the air traffic ground control problem

In this section an integrated GPS-GIS system is proposed for monitoring the airport areas, following the new requirements of Intelligent Transport System (ITS) applications. ITS applications use telematics technologies and data processing methods to obtain an “intelligent” management of the transport system in terms of efficiency, safety and environmental aspects.

Geographical Information Systems (GIS) are an essential support to plan, manage and depict all useful information related to the examined system, and
particularly many applications have been made (and some other can be thought) also in the transport field [4].

The system proposed here involves both the GPS and GIS systems in order to obtain an efficient, safe and quick management of the vehicle movements in an airport area (both aircrafts and land vehicles), in order to cover the surveillance and control functions of an A-SMGCS for taking-off aircrafts moving from the apron along the taxiways and for vehicles operating in the airport areas.

In facts, thanks to GPS systems, the actual trace of the aircraft (or land vehicles) can be followed (by means of transmission and updating of the navigation data in real time), while the GIS system allows the geographic information and the position to be managed and visualised (by means of the implementation of suitable software functions to resolve the problems of perception and management of the information and to update in real time the acquired data).

Particularly, the proposed system considers:

- location and positioning of aircrafts and the other moving vehicles in the aprons by GPS and transfer of data referred to its position (other data measured by different sensors can also be considered);
- management and data processing operating in a GIS system;
- information re-transmission to the aircraft by local transmitters, internet and WAP systems.

This latter point is structured as follows: a master station, located in a point of known coordinates, sends positioning information to the remote station (aircrafts or vehicles, all equipped with firmware for RTK-OTF and/or DGPS) that, fixed the ambiguity flight (OTF initialization) if it is the case, processes immediately the self-acquired data and those sent by the master station giving as output its positioning in real time (it has to be noticed that the possible presence of radio repeaters and/or GSM technologies could increase the range of transmission); this positioning information is sent (via GSM transmission – Internet – radio modem) to the control centre (server) formed, for example, by the control station where a GIS tool allows the view of the monitored vehicle/aircraft (as suitable trace) in real time and continuously during the time. The GIS system has to be suitably modelled in order to transform the positioning information into geometrical coordinates in turn transformed in graphical information on a screen.

The main components of the system are:

- a master station of known coordinates (that can or cannot coincide with the control centre);
- a device (firmware RTK-OTF and/or DGPS), located on the rover (moving vehicles: aircrafts and land vehicles), that has to detect in real time their position and must be able to communicate with the master station in real time; it is equipped with a display, connected to a network of data transmission, where on a cartographic support is showed the path to be followed;
- radio transmitting and receiving the RCTM protocol or, alternatively, GSM modem;
- a control centre equipped with a data reception system, a GIS system for visualising and processing the data and with a data transmission system that returns the information to the aircraft (figures 1 and 2).

Figure 1: The GPS system to detect the moving vehicles on the ground.

Figure 2: Identification and control of moving vehicles on the ground by means of a GIS system.

The device, autonomous and fed by suitable batteries, is characterized by a system able to receive and apply a real-time correction in terms of code range and/or phase (DGPS), initialize the measure (OTF firmware to initialize quickly or during the movement), compute the object position in real time, memorize and store the coordinates and transmit the memorized data to the control centre according to international protocols (NMEA).
The control centre, whose aim is the real-time view of the movements of the vehicles/aircrafts on ground, is characterized by a GIS modulus realized to manage the monitored information; it works on a cartographic map that reproduces the airport ground area and is equipped in order to acquire, re-process, return and re-transmit positioning information on a digital base.

The system is then based on a client-server type, with moving clients (aircrafts and vehicles) and a control centre as server able to measure in real time the client position, showing the position to the server, re-transmit the view to the client. The system architecture is characterized by the following technologies:

- local technology: GPS system;
- commercial technology: GSM, Internet, radio modem;
- memorizing technology;
- view and analysis technology: GIS

Specific attention should be addressed to the transmission modalities of the positioning information. The radio-modem transmission, given the actual legal rules, does not allow the radio signal transmission with high power and then the range is limited to few kilometres; it is also dependent on the obstacles in the zone. Generally, the used radio modem apparatus transmit at 400-500 Mhz, that correspond to a 2-2.5 Km range.

To reduce these inconvenients, a repeater could be added to the master and rover stations (figure 1), according to two possible systems:
- radio repeater in a fixed location on the ground;
- mobile radio repeater on the ground.

The presence of the repeater increases the range of the RTK system and if there is a mobile repeater also the system flexibility increases. The repeater allows more precise positioning measures to be obtained than in the case where it is not considered; furthermore, more rover stations linked to the same master station could work at the same time.

Alternatively, the correction signal can be sent by using the GSM technology (phone system). The GSM transmission system is reliable in terms of signal transmission, provided that the signal is covered and the passage between two cells does not involve the telephonic link interruption. For both systems it is convenient operate in a range of 15-20 Km.

The last solution could be considered the most advantageous; in fact, the control unit of the RTK system, equipped with a firmware able to dial the phone number of the master station, while dialling the rover opens the telephonic link with the master station itself and receive the data of the differential correction. The monetary cost of the phone call is charged on the rover station suitable equipped with a special SIM card. The master station is equipped with a data transmission SIM card. The data transmission speed is 9600 bit/sec.

5 Conclusions

The system described before has been tested using a small private aeroplane, during the taking-off operations. Even if it is still under test, because more moving vehicles, higher taking-off speeds and different solutions to
communicate data between the different apparatus are now testing, however the results are very encouraging.

Some problems could verify during the landing operations, given the possible GPS signal latency due to the high involved speeds and then the impossibility to visualize the aircraft in real time.

In any case, more tests and more work need in this field due to the importance of the topic involving the human safety.

References