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A new method for ground vehicle access control and situation awareness: experiences from a real-life implementation at an airport

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Abstract

To improve safety in complex traffic situations, access control can be applied. This paper presents a generic vehicle access control method for improved situation awareness. The method concerns three main steps (i) zones definition (ii) rules to manage access and (iii) situation awareness based on real-time position monitoring. The proposed system consists of a server where the access zones and rules are stored and mobile units providing position data to the server and information to the driver. At the control center a client control unit is used to provide improved situation awareness by monitoring and visualizing the positions of the clients in the vehicles. The client in the control center is also utilized to give access to the clients in the vehicles that request access. The system has been demonstrated at an airport to grant access for ground vehicles to enter the runway and has since been developed into a commercial product by an industrial supplier. It was introduced at the World ATM Congress in Madrid in March of 2017. The server system is implemented as a cloud service in Microsoft Azure, the control client uses a WACOM CINTIQ touch screen computer for interaction and the vehicle clients are off-the-shelf Samsung Android units paired with Trimble R1GNSS receiver and 4G mobile communication between the server and the clients.

KEYWORDS: Ground access control, C-ITS, Traffic management

Introduction

Recently a new EU regulation (CS ADR-DSN.M.770 Road-holding position lights) regarding ground vehicle access control on airport was introduced. All access roads onto a runway will need to have traffic signaling controlled by Air Traffic Control (ATC) to indicate that the vehicles are granted access to the runway. Installations of such infrastructure for all access roads will be too costly for many small airports and the risk is that instead of installing the traffic lights, access roads will be removed to cut cost. Fewer access roads introduce a higher risk level since it makes it more difficult for Ground Vehicles (GV) to leave the runway in an emergency situation.

At an airport, movements of all vehicles on the ground are controlled by the ATC. The movements of GVs and aircrafts are very similar that of vehicles in a city environment, with safety-critical, complex and unpredictable traffic situations, where much of the responsibility lies on the driver to resolve upcoming situations.

To improve safety at the airports, the control tower uses various systems to keep track of both ground vehicles and airplanes. Generally, an advanced surface movement guidance and control system (A-SMGCS) is used to control the movements to avoid any conflicts between vehicles at the runway [1,2]. Controlling traffic at airports is a great challenge due to the huge risks. Rigorous safety requirements call for advanced sensor technologies, e.g. ground radar, lidar or camera systems [3,4]. In [5] a system for ground vehicle monitoring is proposed based on wireless communication and GPS. The system requires a network infrastructure to be able to communicate with the devices through 802.11a (5GHz) wireless communication. To have high reliability within the network an overlap between the wireless cells is required.

With inspiration from road traffic, this paper presents a generic vehicle access control method based on 4G mobile communication, mobile devices inside vehicles and a cloud-based system of rules
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where the access rules stored. A demonstrator system (DRIWS – Digital Runway Incursion Warning System) has been developed and demonstrated at Umeå Airport in Sweden. The proposed system is built to fulfill the EU regulatory requirements by means of modern technology such as geo-fencing and connected vehicles, thus placing the traffic signaling inside the vehicle.

A general term in this field of research is advanced surface movement guidance and control system (A-SMGCS). In [2], an Integrated Airport Apron Safety Fleet Management (AAS) was developed that can provide location awareness by combining map-based and location-based information. Communication between the mobile objects and the central server is achieved through an IEEE 802.11a wireless network and a GPRS mobile network was available as alternative communication. This approach was successfully used to deploy a geo-fencing mechanism that detected if any vehicles were causing security infringements or safety incursions. In [1], a runway incursion detection method was developed based on monitoring multiple protected areas and a flight status mechanism. The results from this work indicate that the proposed system has the potential to improve runway safety by early detection and warning of runway incursions. In [4] a simulation study of an A-SMGCS system is presented, showing the potential of A-SMGCS.

In the current study a location-based access control and situation awareness system is proposed and demonstrated. The system uses 4G mobile communication to connect the mobile units with a central cloud server that maintains the overall situation awareness, controls the geo-fencing mechanisms that grant access to the vehicles to enter the runway and issues warnings if necessary.

The rest of the paper is organized as follows. The next Section describes the problem to be solved followed by a Section describing the system. Then the results are presented followed by a Section containing a discussion regarding the relation to the development of C-ITS and automated vehicles. The final Section concludes the findings of the paper.

Problem formulation

**Airport**

Ground vehicle drivers have been the cause of 45% of all Runway incursions (RWYI) reported over the past 10-year period, Figure 1a.

![Figure 1a Causes of RWYI 2007-2016](image)

![Figure 1b Number of RWYI per year 2007 – 2016](image)

**Figure 1 (a) Causes of RWYI 2007-2016, (b) - Number of RWYI per year 2007 – 2016. (Source: Eccairs)**

While incidents caused by persons remain constant over time, the number of RWYI occurrences caused by aircraft (pilot) and ground vehicles (driver) have almost doubled over the period. Since 2011 the ground vehicles represent the majority of incidents (Fig. 1b).

For larger airports, GV movements are controlled by designated controllers. However, with large numbers of GVs moving in intricate and complex patterns most of the responsibility remains in the
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hands of the individual drivers. Adding low visibility (fog, darkness, snow) leaves at hand a risk for human error yet to be resolved.

Proposed solution

The approach for DRIWS builds on establishing zones by means of geo-fencing and connected vehicles that continuously report their geographical positions. This way reminders can be transmitted to the drivers of GVs as well as to the ATC. The system architecture is depicted in Fig. 2. Fig. 3a below shows the layout of Umeå Airport (>1 M passengers/year), currently the test-site. The proposed solution is scalable and planning is ongoing to expand the system to cover not only runway incursion but also taxiways and other critical areas at Stockholm Arlanda airport (> 24 M passengers/year). The cloud server is implemented in Microsoft Azure.

Figure 2 Schematic illustration of the proposed solution.

Zones definition

The airport is divided into geographical zones with different features. These zones are tailored for the requirements of each individual airport. For the demonstration system, the airport is divided into 3 individual zones, see Fig. 3a.

- Airside – where vehicles can be traced by the system but where no grant is necessary for GV movements. This would normally cover the entire airport area.
- Callzone – where GV drivers are reminded to request grant for access to runway or must report leaving the restricted area. This zone is flexible and based on individual airport requirements.
- Restricted zone – where a runway incursion will be registered if access has not been granted by ATC. This zone is defined by regulation based on distance from the center line of the RWY.

Figure 3 (a) Illustration of the access zones in ATC and (3b) Illustration of HMI of the vehicle application. Left view indicates when a vehicle is granted access to the runway and the right view indicates when a vehicle has caused a RWYI.
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The zones can be defined by mouse input using a dedicated configuration mode in the control client application. In this mode, the rules for access control are also defined.

Situation awareness - vehicles

With the system in full operation, all vehicles will be equipped with a screen to provide information to the driver. For the demonstrator system, see Fig. 3a, the screen provides notifications to remind the driver to contact the ATC when the GV approaches, or leaves, any restricted zone. Some additional information is also provided, e.g. regarding Low Visibility Procedures (LVP), communication- and position status and if any RWYI is detected. Sound and light signals alert the driver if necessary. For the demonstrator, an Android smartphone was used, see Fig. 3b.

Situation awareness - control center

The ATC manages the access control. It monitors the position and the status of all vehicles that are active, in relation to the restricted zones. Fig. 4a shows a screenshot of the demonstrator implementation where 2 GVs, one with granted access (green) and one where the driver is alerted that grant is required (red) to proceed. The control client is operated from a 22” WACOM CINTIQ touch screen computer showing all vehicles (excluding those inside any garage) and their status, see Fig. 4b. Grant is permitted by ATC by pointing at the symbol for each vehicle, which then changes to green or vice versa. In this example, the ATC has also introduced LVP procedures. Additional functions, above the legislative requirements, include option to start Low Visibility Procedures (LVP) from the tower and indications if a GV performs a RWYI, which is then automatically logged by the system.

Communication

To connect the server and the vehicle clients, mobile 4G communication was used. The protocol used was TCP/IP. All vehicles send their position, time and status (granted or not granted access) at the rate of 1 Hz to the server. The server client, operated by the air-traffic controller or the dedicated ground vehicle traffic controller, can follow the vehicles on the 22” WACOM screen. The access requests are received over wireless two-way radio communication, hence following airport safety regulations, and the reply is sent both over the two-way radio and the visual interface from the control client to the vehicle client, see above. Enabled by communication the system allows improved situation awareness since the control client updates all vehicles about the current position and status of all other vehicles.

Positioning

To detect RWYI the server needs to have accurate position of the vehicles. The accuracy of the satellite navigation system in a smartphone is not enough for this application and therefore a high-fidelity system was used. This system utilizes a Trimble R1 GNSS (Global Navigation Satellite Systems) receiver and provides positioning accuracy of 2RMS<1m. This corresponds to a probability of 95% for the values to fall into the RMS circle.
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Logging of safety violations
Given the large amount of movements and with only visual verification it is likely that many runway
incursions or safety incidents today go un-reported. With improved control, this could then imply that
the number of reported incidents initially will increase with the introduction of DRIWS. When the
system detects a safety violation it is automatically logged in a database, available for reporting and
analysis from airport management and authorities. Hence the system ends the potential discussion
regarding if an incident indeed was a safety violation, and instead provides detailed information
regarding vehicle position and speed, which in combination with the recorded voice communication,
serves as support for future improvements of processes and training for GV drivers and ATC staff.

Additional safety net
All current, local and global, regulations regarding access to the runway remain at the airport,
with the system in place. Apart from continuous status and position for each vehicle the system provides
reminders and warnings to the driver and messages regarding communication and positioning are
monitored. Instead the system is designed to act as an additional safety net with focus on situation
awareness for ATC and drivers.

Results
The system was demonstrated at two separate occasions at Umeå Airport in Sweden, in September
2016. Functions presented in the demonstrated version are strictly related to the legal requirements
from the Swedish Transportation Agency to achieve a formal approval of the system as a viable
alternative to the physical infrastructure proposed in the EU regulation (CS ADR-DSN.M.770 Road-
holding position lights).

HMI
The control client has two modes, operation and configuration mode. In configuration mode, the
access zones can be created and the associated rules and access privileges are associated to the
different zones. In operation mode, the HMI provides three different functionalities. Granting and
retrieving runway access and to activate (and indicate) Low Visibility Procedures (LVP). Inside the
vehicle, the HMI consists of an Android device with the main purpose to alert the GV driver to contact
ATM when approaching the restricted zone. It can also be used to send various messages to all
vehicles, such as LVP indication. Hence the GV device is used for one-way communication with the
driver.

User comments on usability
The response from the airports was very positive, including feedback related both to the
implementation cost of the required functionally and not the least to the added safety features of the
system. Some comments from airport management:
• “An excellent alternative solution to resolve the new legislation…”
• “More safety added at less cost for all airports…."
• “The system is a dream for any flight safety coordinator…”

Communication reliability
The system uses 4G mobile communication to share information between the server and the vehicle
clients. Communication between the control client and the server is established via Ethernet LAN and
from the server to the cloud service, where the zones and rules are stored, is established using 4G
mobile communication. Fig. 5a illustrates the packet delay for 13 brake tests (runway friction
estimation) made when the system was tested in January 2017. The speed of the vehicle reaches 100
km/h in some parts of the test. In Fig. 5a, the bars indicate the fraction of packets that were delayed in
each of the brake tests. Overall, 99,2 % of the packets were delivered on time. Fig. 5b illustrates the
trace of the vehicle performing a brake test (Brake test #3). The blue markers indicate packets
delivered on time and the red markers indicate the delayed packets (3 out of 174 samples).
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Position accuracy

For the demonstrator, a GNSS unit (Trimble R1 GNSS receiver) was used for tracking vehicle movements, giving an accuracy of < 1 meter. This accuracy is sufficient for the scenarios demonstrated in the current DRIWS system, but can be upgraded for planned future application areas such as automated or autonomous driving, where < 0.1 meter may be required. At hand, there is no Real Time Kinematic (RTK) Global Positioning System (GPS) to verify the positioning accuracy. Instead we estimate the deviation from the assumed straight line that the vehicle was driving while performing the brake test in Fig. 5b. The $RMS = \sqrt{\frac{1}{N} \sum_{i=1}^{N} d_i^2}$ where d is the distance in meters from the line to the measurement and N is the number of samples (in this case 67) is used to obtain an estimate of the performance of the GNSS device.

![Figure 5a](image1.png) ![Figure 5b](image2.png)

Figure 5 (a) Statistics of packet delayed between vehicle and server (b) shows the trace of a vehicle performing a brake test.

The GNSS provides an acceptable RMS of 0.16. It was found that the GNSS device sometimes had problems with updating the position, and reported the last known position. This error could be dealt with by adding a Kalman filter that can predict the next position based on the previous samples [6].

Discussion

By digitizing the airport, by introducing DRIWS as an information platform that provides increased situation awareness, a natural next step is to introduce automated vehicle functions that make use of the DRIWS technology. As a restricted area, the airport is attractive for testing and implementing automated vehicle functions. Other areas for early introduction of live vehicle automation applications are harbors, construction sites, mines and agriculture.

We foresee that the technology and general setup of the DRIWS project can easily be adapted to development and research regarding C-ITS in ordinary traffic situations. 4G communication and smartphones can be utilized for scenarios where accuracy and speed of communication are not crucial, e.g. emergency vehicle warning, road work warning, congestion warning, electronic brake light warning and slippery road warning. The DRIWS platform and mobile application solution can be converted into C-ITS aftermarket solutions for the road vehicle community.

For more critical traffic situations, often involving immediate risk for accidents, Dedicated Short Range Communication (DSRC) is still required, due to its low latency. However, with the upcoming 5G communication, direct peer-to-peer interaction with < 10 ms latency will be possible. Future transformation from 4G to 5G will most likely be less drastic than moving from a DSRC solution. Hence, for current development of vehicle automation solutions, the two modes for communication should be used in parallel, both for system redundancy and for future compatibility.
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Conclusion and future work

A new method for ground vehicle access control at airports is presented. Ground vehicles use a mobile phone and an attached GNSS device to communicate their position to a server where geo-fencing rules are used to detect any violations of the restricted areas. High reliability is achieved with 4G wireless communication and a high accuracy GNSS positioning device. The system was evaluated during real life tests and the users were satisfied with the ease of use and the increased situation awareness and safety it provided.

Future work includes the introduction of the DRIWS system at Stockholm Arlanda Airport (>24 M passengers/year) in 2017-2018. The introduction at Arlanda involves significantly more complex traffic structures covering not only runway access control, but all vehicle movements on the airport. Fig. 6a below shows an example of airport infrastructure to be controlled by the expanded version of DRIWS – Digital Ground Vehicle Control (DGVC).

Figure 6 (a) Illustration of an airport infrastructure and (6b) picture of an autonomous lawn mower.

With connected vehicles, the door is open to further research around AVs, including fully autonomous vehicles with the vision of “the Autonomous Airport”. Current plans include demonstrators showing unmanned airport ground maintenance such as lawn mowing, see Fig. 6b, sweeping, snow plowing, traction control and more. These projects are in progress as of September 2017.

References