Block Occupancy Based Surface Surveillance

Dr. Vilas Nene, Dr. Ronald Chong, Dr. Emily Stelzer, Ronald Stevens
Center for Advanced Aviation Systems Development
The MITRE Corporation
McLean, Virginia, USA
vnene@mitre.org

Abstract—The proposed surface surveillance concept divides airport runways and taxiways into a number of operationally suitable, discrete, and contiguous sections called blocks. The system uses magnetometers or other suitable sensors positioned at each of the block boundaries to monitor aircraft and vehicle movements into and out of these blocks. The system then indicates the block occupancy information for tower controllers on a two-dimensional (2-D) display of an airport map. This surveillance information is envisioned to improve controller situational awareness of surface operations, particularly in reduced visibility.

Keywords—surface surveillance; block occupancy; magnetometers

I. INTRODUCTION

Integrated surface surveillance systems using Surface Movement Radar (SMR), multilateration (MLAT) and Automated Dependent Surveillance – Broadcast (ADS-B) have been in use for years at large airports around the world. Such systems track and indicate the location of all aircraft and other vehicles on the airport surface and provide the controller with the necessary situational awareness of surface operations. As a result, safety of surface operations has significantly improved at these airports. Small and medium sized airports, however, find these systems to be cost prohibitive and have been looking for some low cost alternatives. The MITRE Corporation (MITRE) has developed a new concept of surface surveillance that is expected to enhance safety at an affordable cost to airport operators of small and medium facilities.

Under current operations at small and medium towered airports, controllers sit in a tower cab at the top of an airport control tower situated on the airport property. Within the United States, the Federal Aviation Administration (FAA) presently requires controllers to visually scan the runways using the out-the-window (OTW) view, confirming when an arriving aircraft has exited the runway, a departing aircraft is actually airborne, and that all runways are clear of aircraft or ground vehicles. The OTW view is used to support situational awareness, maintain required aircraft separation on the runways, and formulate clearances and instructions to ensure safety and promote efficiency.

The OTW view is of limited use during night-time and poor-visibility operations. Under these conditions, controllers must solicit position reports from pilots to supplement visual surveillance. This process can slow airport operations, increase controller workload, and compromise situational awareness. When visibility is particularly poor, pilots can become disoriented, and pilot self-reports of location on the airport surface can be flawed or incorrect. With a compromised OTW view and no surveillance capability to validate pilot reports, controller situational awareness can be limited. As a result, surface safety can be adversely impacted.

II. DESCRIPTION OF THE CONCEPT [1]

The proposed block occupancy based surface surveillance system is envisioned to provide controllers with enhanced situational awareness of airport surface operations. Under this concept [1], the runways and taxiways at the airport will be divided into a number of blocks based on operational and procedural considerations. Sensors installed at block boundaries will detect the presence of an aircraft or a ground vehicle in the proximity of sensor locations. The system will then process the sensor signals and determine when aircraft or vehicles cross the block boundaries. When a boundary is crossed, the system will infer that the block that is adjacent to the boundary is occupied and that the previous adjoining block has been vacated and now is unoccupied. The proposed system will not determine the location or behavior of aircraft or vehicles within the occupied blocks. The system will also not automatically identify the aircraft or vehicles occupying a block, unless a controller takes a manual action to provide that information.

The occupancy of the blocks will be presented to tower controller on a two-dimensional map display. A notional display is shown in Fig. 1. Within the figure, block boundaries are indicated with grey lines. An occupied block is shown in light grey as illustrated near the top center of the display. The identity and some operationally valuable data related to the occupying aircraft or ground vehicle will also be presented for an occupied block. The OTW view and no surveillance capability to validate pilot reports, controller situational awareness can be limited. As a result, surface safety can be adversely impacted.

The identity and some operationally valuable data related to the occupying aircraft or ground vehicle will also be presented for an occupied block. Fig. 2 provides a depiction of an occupied block, which has been tagged by the controller with aircraft identity. The block occupancy system can then use associated aircraft identity to provide additional information (e.g., aircraft type). As an aircraft or vehicle moves from one block to the next adjacent block, the data associated with the block will progress. For departing flights, the surveillance
system will obtain flight plan information from flight plan data, if available, or through manual controller entry. For arriving flights, the system will obtain flight plan information from the enroute automation system, from the terminal automation system (for tower enroute flights), or from controller manual entry.

**A. Concept Assumptions and Constraints**

The proposed block occupancy concept is based on certain basic assumptions as follows:

- The volume of traffic at the airport will be low so that there will only be a few aircraft operating simultaneously on the airport surface at any time.
- The airport will have terminal radar coverage.
- Aircraft will not be required to carry a transponder.
- Only transponder-equipped arrival aircraft will be automatically identified with the help of terminal radar.
- The tower controller can identify occupied blocks for all airport vehicles, departures, and unequipped arrivals, if it is operationally helpful to do so. The tower controller is not required to identify aircraft or vehicles within occupied blocks.
- The tower controller will confirm that an aircraft is airborne and reset or clear the occupancy status of the block where the arrival has taken off.

**B. Description of Operations with the Proposed Surveillance**

The proposed surface surveillance concept is envisioned to be based on primary surveillance sensors that will indicate the occupancy status of individual blocks of runways and taxiways. Although block occupancy could be determined with a range of sensors, this description of the concept focuses largely on a magnetometer-based system. If the system is designed with any other type of sensor, the operations may have to be modified as necessary.

A magnetic sensor can be used at a block boundary to indicate when an aircraft or a ground vehicle crosses over the sensor location. As an aircraft moves on a taxiway or runway, it will successively cross over sensors at the block boundaries and the display will depict the progress of the flight. When an aircraft takes off and becomes airborne, however, the aircraft will not cross over the sensor located at the end of the block. Consequently, the surface surveillance system will not detect that the aircraft is airborne and it will continue depict the block as occupied. When the aircraft reaches an altitude of 300 feet above ground level, however, the terminal radar system will receive the transmissions of the aircraft transponder and inform the surveillance system. The system will, in turn, mark the block as unoccupied. Alternatively, if the aircraft has not been equipped with a transponder, the controller must clear the block via an interaction with the tower display.

While the targeted airport environment for this concept is likely to have low levels of traffic, there may be instances where a taxiway block is occupied by more than one aircraft or ground vehicle. When an aircraft leaves a block previously occupied by more than one aircraft or vehicle, the block occupancy system will require the controller to reidentify the aircraft occupying the blocks, if he or she chooses, with their associated flight information.

Tower operations with the block occupancy-based surface surveillance display will be similar to those of today. Controllers will use visual surveillance via the OTW view as the primary source of information for maintaining required separation on the runways and situation awareness of surface movements. This information will be augmented with block occupancy-based surface surveillance information, depicted on the tower display. Under low visibility conditions, block occupancy information will be particularly helpful in identifying occupied runways, detecting pilot deviations and safety-critical events on the surface.

**C. Operational Scenarios**

The use of the proposed surveillance system is described here in two basic scenarios. Both of these scenarios describe the use of the block occupancy surveillance system at towered airports. The first scenario describes the routine sequential departure of two general aviation aircraft. The second scenario provides an example of a sequential arrival and departure operation; however, a pilot deviation produces an unusual
event that is detected and resolved through the controller’s use of the block occupancy display.

1) Sequential Departure of Two General Aviation Aircraft. The pilot of the first aircraft, N100TP, has received a pre-flight briefing from the Flight Service Station specialist. The pilot has filed an Instrument Flight Rules (IFR) flight plan, due to reduced visibility in the area. The aircraft leaves the hanger area and begins to move to the entry point to the movement area. As the aircraft approaches the movement area, the pilot calls the ground controller, tells him that the aircraft is approaching taxiway Echo, and asks for taxi instructions. The ground controller issues taxi instructions to the departure runway: November One Zero Zero Tango Papa, Runway One Six Right, taxi via Echo, Bravo, Bravo One. The pilot reads back the taxi instructions and enters the movement area.

As the aircraft enters the movement area, the surveillance system shows the first block as occupied by coloring the block grey; it also adds a data block showing the flight identification, the runway assignment, and the destination airport. The aircraft enters the next block of the taxiway. The surveillance system indicates that the next block is occupied and that the previous block is unoccupied. As the aircraft continues to taxi, the system continues to show its progress on the tower display and the associated data block continues to move with the occupied blocks.

As flight N100TP taxis to the runway, the ground controller observes the flight’s location on the block occupancy-based surface surveillance display, rather than relying on the pilot’s verbal report of location that is typically required under low visibility conditions. When the ground controller identifies from the display that the aircraft has reached the runway edge, the ground controller instructs the pilot to contact the local controller. The pilot performs an engine run up before departure.

Aircraft N300PD has already filed an Instrument Flight Rules (IFR) flight plan. The ground controller has the flight strip for the flight displayed on the electronic flight strip display. Before taxi, the pilot contacts the ground controller, who is providing clearance delivery services, and requests and is issued his IFR clearance. As the aircraft begins to move towards the movement area, the pilot calls the ground controller and requests a clearance. The ground controller issues taxi instructions: November Three Zero Zero Papa Delta, Runway One Six Right, taxi via Delta, Charlie, Bravo. The pilot reads back the taxi instructions and enters the movement area. As the aircraft taxis, the block occupancy display performs as described above.

The aircraft arrives at the runway behind N100TP and contacts the local controller to request departure clearance. The local controller issues the instruction: November Three Zero Zero, Papa Delta hold short, number two for departure. The aircraft waits at the runway for N100TP to takeoff.

The pilot of N100TP calls the local controller and requests takeoff clearance. The local controller issues a takeoff clearance. The pilot acknowledges the takeoff clearance and begins to roll down the runway.

Because the OTW is somewhat degraded, the local controller uses the block occupancy display in conjunction with the OTW to confirm that N100TP is airborne. The aircraft climbs to an altitude of about 300 feet above ground level, and the terminal radar picks up the responses of its transponder. The terminal automation system sends information to the surface surveillance system, indicating that N100TP is off the runway, and the surveillance system indicates that Runway 16R is unoccupied. The local controller now clears N300PD for takeoff. The aircraft begins to roll, becomes airborne, and the terminal radar receives its transponder response. Terminal radar sends information to the surface surveillance system, indicating that the flight is airborne; the system, in turn, now indicates that the Runway 16R is unoccupied.

2) Sequential Arrival and Departure Operation with Pilot Deviation. An aircraft, N200TT, is approaching the airport. The flight data for the aircraft has been sent from the En Route Automation Modernization (ERAM) system to the surface surveillance display, and a strip is shown on the display. The pilot calls the local controller and asks for a clearance to land on Runway 16R. The local controller, using the surveillance display, determines that the runway is not occupied and confirms this assessment with the OTW view. The local controller then issues the landing clearance to N200TT.

As N200TT is on final for Runway 16R, the pilot of departure aircraft N201DP radios the tower for taxi instructions for departure on Runway 16R. ERAM has sent the relevant flight data to the surveillance system, so the ground controller is able to access and view the flight strip for N201DP. The ground controller issues taxi instructions to N201DP, and the pilot taxis the aircraft towards the runway. As the aircraft nears the runway, the pilot fails to make a turn on the assigned taxiway and begins heading towards Runway 16R. While visibility is somewhat reduced OTW, the controller observes the pilot deviation on the block occupancy-based surveillance display. The controller provides a corrective taxi instruction to reroute the aircraft on a taxiway to the end of Runway 16R. As the aircraft approaches the runway, the pilot contacts the local controller and requests a takeoff clearance. The local controller instructs the pilot to hold short of Runway 16R for landing traffic.

As N200TT lands on Runway 16R, the surface surveillance display indicates its progress by showing block occupancy along the runway. As N200TT slows down, the local controller issues instructions to taxi off the runway and to contact the ground controller. The display indicates that the aircraft has exited the runway. The pilot of N200TT radios the ground controller, who issues instructions to the pilot to the parking area.
The local controller views the surface surveillance display and looks out the window to confirm that Runway 16R is unoccupied. He then issues a departure clearance for N201DP. The aircraft begins its takeoff roll and is airborne. When the aircraft reaches an altitude of about 300 feet above ground level, the terminal radar picks up its transponder responses and informs the system that the runway is unoccupied.

III. USE OF MAGNETOMETERS

As aircraft and ground vehicles move around on the airport surface, their ferromagnetic components modify Earth’s magnetic field in their vicinity. Depending on the amount and distribution of the ferromagnetic material, therefore, every aircraft and vehicle creates a specific magnetic signature in its vicinity. It is, therefore, possible to detect and track aircraft/vehicle movement along runways and taxiways at an airport by measuring the Earth’s magnetic field on the airport surface with the help of magnetometers. Such use of magnetometers has been explored extensively under the European Union’s Framework 6 project ISMAEL [2]; magnetic signatures of some aircraft measured with Votronic’s MagTrace [3] are illustrated in Figure 3 [4].

These measurements show that a magnetometer installed along the runway centerline would be able to detect GA aircraft even if it does move away from the centerline. If, however, a runway is wider than 150 ft. and a GA aircraft operates near the edge of the runway, even the centerline magnetometers will not be able to track the movement of the aircraft.

B. Airports with Edge Light and Significant GA Traffic

If the airport uses only runway/taxiway edge lights, it will be prohibitively expensive to install magnetometers along the runway/taxiway centerline. MITRE examined the possibility of installing high-sensitivity magnetometers at both edges of the runway to cover the entire width of the runway. As a part of this effort, an Applied Physics System fluxgate sensor (Model 1540) [5], and a Geometrics optically pumped Cesium sensor (Model 824-A) [6] were selected to conduct a limited number of field trials during normal operations at Manassas Regional Airport (KHEF) and Washington Dulles International Airport (KIAD). MITRE also examined the use of advanced signal processing techniques [7, 8] to improve target detection.

At KHEF, the sensors were placed at the edge of the 50 ft. wide Taxiway C; the sensors were about 27 ft. away from the centerline. KHEF traffic consisted primarily of GA aircraft. Tests at KHEF indicated that all of the small aircraft could be consistently detected at this distance by Model 824-A but not by Model 1540 sensor. At KIAD, the traffic consisted primarily of large commercial aircraft. The sensors were placed at the 150 ft. wide Taxiway Q; the sensors were almost 78 ft. away from the centerline. The Applied Physics Model 1540 could not detect these aircraft consistently at this distance.
distance but the Geometrics 824-A was able to detect all aircraft at this distance. It must be noted that presently both these sensors are prohibitively expensive for this application and cannot be considered as viable options.

If the airport has runway widths of 100 ft. or more and operates a significant level of GA traffic, the proposed block occupancy based surveillance system cannot be implemented by using magnetometers at runway edges. As mentioned earlier, the concept is agnostic about a specific sensor, and thermal IR sensors may be useful for such wide runways; all IR sensors operate well under low visibility conditions, but the thermal IR sensors are especially suited for fog conditions often found at airports. MITRE is presently examining the use of such a camera for implementing the proposed surveillance system.

A number of small and medium airports, however, have runways and taxiways with the width of 75 ft. or less. It is not clear at this time if the proposed system can be implemented in the future at these airports with the sensors placed at the runway/taxiway edges. High-sensitivity magnetometers are presently prohibitively expensive for the proposed application. If the demand for these sensors increases over the future and cost of these sensors comes down significantly, it may be possible to economically implement the proposed system for these airports.

IV. INITIAL VALIDATION OF THE CONCEPT

This concept was validated through a simulation of operations at Manassas Regional Airport (HEF) at MITRE’s Integration Demonstration Experimentation in Aviation (IDEA) Laboratory. The tower simulator, a medium-fidelity simulation capability, provided a 180 degree view from the tower of HEF. HEF is a medium-sized airport located in northern Virginia within the Washington, DC metropolitan area. HEF has two parallel runways and operates a moderate level of general aviation and business jet traffic.

Ground simulation capabilities were used to generate surface traffic, as well as arrival and departure traffic. This traffic was shown in the OTW view, as well as in the surface display. An electronic flight strip capability was also integrated with the surveillance display. Simulated traffic was selected to represent the traffic mix generally observed at HEF. In this human-in-the-loop simulation, after getting familiarity with HEF operations and the proposed controller display, eleven controllers—a mix of current and retired—were asked to control simulated HEF traffic with and without the use of the block occupancy surface surveillance display. Participants completed two groups of four scenarios, evaluating the baseline performance with no surface surveillance display and performance with the block occupancy surveillance display. The maximum simulated traffic level was 60 movements per hour. In some scenarios, pilot deviations, in which pilots became disoriented and unintentionally entered the runway without clearance to do so, were introduced.

All controllers generally agreed with the statement that the block occupancy display was useful in high visibility conditions (On a scale of 1 to 7, M = 4.67), though the magnitude of the agreement was relatively weak. However, controllers strongly agreed with the statement that the block occupancy was useful in low visibility conditions (M = 6.55), suggesting that the surveillance capability is particularly helpful when the view from the tower cab window is compromised. For low visibility conditions, participants agreed with the statement that they employed a different strategy in the simulation than used to control real operational traffic (M = 5.10); they also strongly agreed (M = 6.10) that the change in strategy was due to the presence of the block occupancy display. As another significant benefit, controllers were able to detect a blunder onto the runway much faster with the use of block occupancy display than just with the out-the-window view out of the cab window; the blunder detection time was reduced by 6.31 s (from 41 s to 34.7 s) irrespective of the visibility conditions.

V. POSSIBLE DISPLAY INTEGRATION FOR THE FUTURE

For the past several years, several organizations around the world have been developing capabilities to support remote tower operations. Within these research efforts, the remote operations use camera view(s) in place of the OTW view at a towered airport. In addition to camera views, electronic flight strip (EFS) systems are also used commonly at airports outside of the United States to manage and track surface operations. In order to capture the block occupancy display in the context of these additional tools, an integrated controller display was also designed as a part of the proposed surveillance system. This integrated display is illustrated in Fig. 5.

The block occupancy is presented at the center of the display and other data is presented around this central depiction. In the top right corner, traffic in the terminal airspace is presented as provided by the terminal radar surveillance. In the lower right corner, electronic flight strips are arranged either by runway or by arrivals and departures. The lower left corner presents a local camera view as selected by the controller. It is envisioned that airport may install either a pan-tilt-zoom...
(PTZ) camera or a number of fixed cameras on the airport surface. In towered operations, controllers may select a camera view to be presented as shown. However, in remote operation, controllers may use a panoramic view in addition to the above display.

VI. CONCLUSIONS

A number of conclusions can be drawn in reference to the proposed surveillance system:

1. The proposed block occupancy based surface surveillance will enhance the safety of surface operations, especially in low visibility conditions.

2. If aircraft are constrained to move along the runway/taxiway centerline, as commercial passenger aircraft typically do, an inexpensive AMR type of magnetometer such as the Votronic’s MagTrace installed along the centerline will provide sufficient sensitivity to detect aircraft and ground vehicles on these runways and taxiways. Also, if an airport uses centerline lights on its runways and taxiways, it may be possible to install these sensors within the light fixtures.

3. If some aircraft such as small general aviation aircraft cannot be constrained to move along the centerline, the aircraft must be detected on the entire surface of the runway. For runway widths of 75 ft, or possibly of 100 ft., it may be possible to provide such coverage with the use of high-sensitivity magnetometers on the centerline and/or the runway edges and the use of effective signal processing techniques. However, presently such magnetometers are prohibitively expensive and cannot be recommended for this application.

4. For runway widths of 150 ft. or more, different types of thermal IR sensors may be better suited than magnetometers for implementing the proposed surveillance system.

VII. RECOMMENDATIONS

A full or partial magnetometer-based system should be installed at a small airport that has centerline lights on runways and taxiways and its performance be tested under normal operations for an extended period. Also, research and development should continue in the use of IR sensors for implementing the proposed surface surveillance system.

NOTICE

This work was produced for the U.S. Government under Contract DTFAWA-10-C-00080 and is subject to Federal Aviation Administration Acquisition Management System Clause 3.5-13, Rights In Data-General, Alt. III and Alt. IV (Oct. 1996).

The contents of this document reflect the views of the author and The MITRE Corporation and do not necessarily reflect the views of the Federal Aviation Administration (FAA) or the Department of Transportation (DOT). Neither the FAA nor the DOT makes any warranty or guarantee, expressed or implied, concerning the content or accuracy of these views.

Approved for Public Release; Distribution Unlimited. Case Number 14-2068

REFERENCES