Investigation of Runway Incursion Prevention Systems

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II. Glossary

air traffic control (ATC): the department of an airport responsible for aircraft/ground vehicle traffic management

automatic dependent surveillance – broadcast (ADS-B): a modern aviation format of positional data encoding and transmission, such that airborne systems directly communicate their position and status to other airborne systems

classification and tracking component (CTC): a computer processor in the inductive loop sensor subsystem that matches inductance variance signals with a target aircraft and plots the target position on a display

cockpit display of traffic information (CDTI): a monitor unit located in the cockpit of an aircraft that displays aircraft traffic information being broadcast by such systems as ADS-B and TIS-B

global positioning system (GPS): a system of satellites orbiting the earth that can be used to triangulate and report the position of a specified target

incursion: the act of entering or running into†

inductance: the property of an electric circuit by which an electromotive force is induced in it as the result of a changing magnetic flux‡

inductive loop sensor subsystem (LSS): a full runway incursion prevention system that utilizes inductive loop technology to track aircraft on an airport surface

inductive loop technology (LOT): an aircraft-detection technology placed below the runway surface; particularly useful in blind-spot areas of surface radar coverage

local area augmentation system (LAAS): a differential GPS-based precision approach and landing system

loop detection component (LDC): a stationary unit in the inductive loop sensor subsystem that receives inductance variance signals from inductive loops and transmits them to a classification and tracking component system
<table>
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<th>Term</th>
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<td>multilateration</td>
<td>a positioning method that uses a mathematical concept known as time difference of arrival to triangulate the position of a target</td>
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<tr>
<td>multistatic dependent surveillance (MDS)</td>
<td>a system of three or more remote sensor units that use multilateration to triangulate the position of a target</td>
</tr>
<tr>
<td>PathProx alerting system</td>
<td>an on-board surveillance system designed to identify early conditions for runway incursions and provide aircraft pilots and ground vehicle operators with sufficient time to avoid runway incursions and collisions</td>
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<tr>
<td>remote unit (RU)</td>
<td>a technology capable of receiving signals being transmitted from a target aircraft</td>
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<tr>
<td>RS-232 interface</td>
<td>a serial modem datalink between two systems</td>
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<td>runway conflict alert (RCA)</td>
<td>a PathProx system alert generated when an actual runway incursion has occurred and there is potential for the pilot’s aircraft to collide with it</td>
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<tr>
<td>runway traffic alert (RTA)</td>
<td>a PathProx system alert generated when a pilot’s own aircraft has the potential to be involved in a runway incursion with other traffic</td>
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<tr>
<td>target processor (TP)</td>
<td>a computer processor that receives and processes timestamped messages from the remote units of a multistatic dependent surveillance system</td>
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<tr>
<td>taxi</td>
<td>to move slowly on the ground or on the surface of the water before takeoff or after landing</td>
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<tr>
<td>time difference of arrival (TDOA)</td>
<td>a mathematical concept used to solve for an unknown set of target coordinates based on the time it took a signal sent from the target to reach each member of a set of remote sensor units</td>
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</table>
timestamp: the act of assigning a number to a received signal, signifying the time that the signal was received by the given remote unit

traffic information service – broadcast (TIS-B): a broadcast surveillance service in which data from ordinary ground radar systems is transmitted from a ground station to airborne systems

transponder: a technology capable of sending encoded position messages from an aircraft

VHF data broadcast (VDB): a type of equipment capable of transmitting signals and encoded messages at very high frequencies

† see Works Cited section, entry 9.

III. List of Symbols and Abbreviations

Symbols

d      the distance between two points with coordinates \((x_1, y_1, z_1)\) and \((x_2, y_2, z_2)\)

c      the speed of light \((3*10^8 \text{ m/s})\)

t_{i, j, k}      the time that it takes a signal emitted from a target to reach each of the remote units in a multistatic dependent surveillance system

x/y/z      the set of coordinates for the unknown target aircraft

x/y/z_{i, j, k}      the set of coordinates for each remote unit in a 3-remote unit multistatic dependent surveillance system

x/y/z_1      the set of coordinates for the first point used in the distance formula

x/y/z_2      the set of coordinates for the second point used in the distance formula
<table>
<thead>
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<th>Abbreviations</th>
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<tr>
<td>ADS-B</td>
<td>Automatic Dependent Surveillance–Broadcast</td>
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<td>ATC</td>
<td>Air Traffic Control</td>
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<tr>
<td>CDTI</td>
<td>Cockpit Display of Traffic Information</td>
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<td>CTC</td>
<td>Classification and Tracking Component</td>
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<td>DGPS</td>
<td>Differential Global Positioning System</td>
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<td>FAA</td>
<td>Federal Aviation Administration</td>
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<td>GNSS</td>
<td>Global Navigational Satellite System</td>
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<td>GPS</td>
<td>Global Positioning System</td>
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<td>LAAS</td>
<td>Local Area Augmentation System</td>
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<td>LDC</td>
<td>Loop Detection Component</td>
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<td>LOT</td>
<td>Inductive Loop Technology</td>
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<td>LSS</td>
<td>Loop Sensor Subsystem</td>
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<td>MDS</td>
<td>Multistatic Dependent Surveillance</td>
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<td>NASA</td>
<td>National Air and Space Administration</td>
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<tr>
<td>RCA</td>
<td>Runway Conflict Alert</td>
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<td>RF</td>
<td>Radio-Frequency</td>
</tr>
<tr>
<td>RTA</td>
<td>Runway Traffic Alert</td>
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<tr>
<td>RU</td>
<td>Remote Unit</td>
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<tr>
<td>TDOA</td>
<td>Time Difference of Arrival</td>
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<tr>
<td>TIS-B</td>
<td>Traffic Information Service–Broadcast</td>
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<tr>
<td>TP</td>
<td>Target Processor</td>
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<tr>
<td>VDB</td>
<td>VHF Data Broadcast</td>
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<td>VHF</td>
<td>Very High Frequency</td>
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IV. Introduction

The Federal Aviation Administration (FAA) defines a runway incursion 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 (as dictated by air traffic requirements) with an aircraft taking off, intending to takeoff, landing or intending to land” (R&ED Subcommittee, 1998, p. 1). Such incidents are incredibly costly for airlines and, more importantly, have a high risk of causing fatalities. Over the past decade, the number of nationwide runway incursions has nearly doubled, rising from 187 incursions in 1988 to 337 incursions in 2002 (Federal Aviation Administration, 2002, p. 1). According to comparative data analysis results, this significant increase in runway incursions has come “without a commensurate system-wide increase in the number of flight operations” (R&ED Subcommittee, 1998, p. 1). Thus, without a significant national increase in the number of taxiing aircraft at airports, runway incursions have continued to steadily increase, presenting a major problem to the air traffic control (ATC) world.

As a response to the rapid increase of such accidents, the National Air and Space Administration (NASA) and the FAA have begun to develop theories and systems to prevent them. These subsystems range from optical data and moving-map displays in the cockpits of runway-taxiing aircraft to sensor systems that send aircraft location data to airport communications towers.

The purpose of my research was to investigate a variety of such runway incursion prevention systems. I mainly focused on the technical functionality of the systems and the ways that they help to prevent runway incursions.

V. Sources

For my research, I was most successful using the *IEEE Xplore*, INSPEC, and *Web of Science* online journal databases. These databases often directed me to articles in the *Digital Avionics Systems Conference* paper compilations. I also found a number of useful articles using the *Yahoo!* and *Google.com* search engines. During the Fall 2002 semester, I participated in the Cornell University Engineering Co-op Program at Sensis Corporation,
an engineering company that specializes in air traffic control and air defense systems. While working at Sensis Corporation, I had 4 months of “hands-on” experience with the Multistatic Dependant Surveillance system, one of the forefront technologies in runway incursion prevention. Also during this Co-op assignment, I met many engineers who had been heavily involved in the development of runway incursion prevention systems. One of these engineers at Sensis Corporation, Ed Valovage, directed me to a number of useful resources and projects located on the Federal Aviation Administration (FAA) website.

VI. Discussion

A. Runway Incursion Scenarios

The FAA has broken down the potential for runways incursion into four general scenarios (Mead, 1997). They are:

1. **Pilot Deviations** – An action of a pilot that results in violation of a Federal Aviation Regulation.

2. **Operational Errors** – An occurrence attributable to an element of the Air Traffic Control (ATC) system which results in:
   - Less than the applicable separation minima between two or more aircraft, or between an aircraft and terrain or obstacles, as required by FAA Order 7110.65, ATC, and supplemental instructions. Obstacles include vehicles/equipment/personnel on runways; or
   - An aircraft landing or departing on a runway closed to aircraft operations after receiving air traffic authorization.

3. **Operational Deviations** – Controlled occurrences where applicable separation minima, as referenced in the definition of operational error (see above) are maintained, but
   - Less than the applicable separation minima existed between an aircraft and protected airspace without prior approval, or
   - An aircraft penetrated airspace that was delegated to another position of operation or another facility without prior coordination and approval.

4. **Vehicle/Pedestrian Deviations** – Incursions resulting from a vehicle operator, non-pilot operator of an aircraft, or a pedestrian who deviates onto the movement area (including the runway) without ATC authorization. (Cassell, 2000, 7.D.3-1 – 7.D.3-2)

In other words, a pilot deviation occurs when a pilot makes a maneuver that results in a deviation from an established flight plan or course change without ATC notification or clearance (Hawes, 2001, 2.E.2-1). Operational error occurs when an aircraft accidentally “loses separation” (causes a collision or comes very close to causing a collision) with an-
other plane while taxiing on a runway or when an aircraft attempts to land on or take off from a runway that has been closed. Operational deviation occurs when an aircraft enters a protected airspace without approval. Finally, a vehicle or pedestrian deviation occurs when outside vehicles or people enter an aircraft traffic area without proper authorization and cause a potential incursion. See Figure 2 for examples of common runway incursion situations. The picture in the upper-left of the figure depicts an aircraft taxiing onto a runway that another aircraft is attempting to land on. The picture in the upper-right of the figure shows an aircraft taxiing onto a runway that another aircraft is attempting to take off from. The picture in the lower-left of the figure depicts an aircraft attempting to land on a runway that another aircraft is attempting to take off from. Finally, the picture in the lower-right of the figure depicts two aircraft attempting to land on or take off from intersecting runways.

The four FAA-defined runway incursion scenarios listed above are mainly caused by two problems:

1. A lack of clear, absolute knowledge on the part of both the pilots and the ATC personnel involved of where all aircraft and ground vehicles are located on an airport surface at a given time.

2. A lack of an efficient and effective means of communications and coordination between ATC and taxiing, taking off, and landing aircraft.

A number of solutions to these problems have been and are currently being developed by the FAA, NASA, and subcontracted companies. The following subsections detail a variety of these runway incursion prevention subsystems.
B. Runway Incursion Prevention Systems

1. Multistatic Dependent Surveillance System

A number of solutions to airport runway surveillance have already been developed and are currently being implemented around airports worldwide. These solutions include stationary ground radar systems on airport surfaces, which independent track taxiing aircraft, and Global Positioning System (GPS) units inside the aircraft itself, which use a cluster of orbiting satellites to pinpoint the position of the aircraft to an accuracy of less than 1-2 meters. However, in the case that either of these systems fails, aircraft pilots and ATC personnel could receive erroneous data and thus, the likelihood of a runway incursion could actually be higher in this situation than if the systems were not in use at all. In response to the need for a secondary aircraft-tracking solution for such a circumstance, the multistatic dependent surveillance (MDS) system has been developed. This system is exceptionally powerful because it utilizes the highly accurate technique of GPS positioning as well as a positioning technique known as multilateration. Although multilateration is not as accurate as tracking techniques such as GPS (positional accuracy to approximately 5-10 meters as opposed to positional accuracy of less than 1-2 meters), it is quite effective as a secondary airport surveillance technique because it tracks aircraft completely independently from the GPS system.

The MDS system is comprised of three or more stationary remote sensor units (RUs) that are placed around an airport surface and detect certain radio frequency (RF) emissions from taxiing, landing, and taking-off aircraft. See Figure 2 for an illustration of a 3-remote unit MDS system setup. All aircraft operating on or near an airport surface are equipped with a transponder unit that sends out an RF signal once per second at a frequency of 1090 MHz. These signals are typically encoded as Automatic Dependent Surveillance – Broadcast (ADS-B) messages. ADS-B is a modern format of aviation positional data-encoding and transmission that allows aircraft to frequently transmit their position and status directly to other surrounding aircraft. These messages contain such information as the encoded latitude and longitude of the aircraft (determined from an on-board GPS unit), as well as the aircraft’s velocity and altitude. Each RU receives and decodes these signals and individually timestamps them with a time-of-reception value, ac-
According to an internal clock that is synchronized among all the RUs in the system. Each RU then attaches this timestamp value to the end of the decoded message and transmits the message back to a central target processor (TP), usually located in a nearby ATC tower. In this way, the MDS system acquires a highly accurate GPS solution from a target aircraft and also acquires the information needed to independently triangulate its position using multilateration.

Multilateration is a positioning technique that uses a mathematical concept known as Time Difference of Arrival (TDOA) to estimate the position of a target. The crux of the TDOA concept is the basic formula for the distance between two points, \((x_1, y_1, z_1)\) and \((x_2, y_2, z_2)\):

\[
d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}
\]  

(1)

Using equation (1), a system of equations (one equation for each RU in the system) can be developed. For the case of three RUs, these are the resulting equations (Bucher, 2001):

\[
c \times t_i = \sqrt{(x_i - x)^2 + (y_i - y)^2 + (z_i - z)^2}
\]  

(2)

\[
c \times t_j = \sqrt{(x_j - x)^2 + (y_j - y)^2 + (z_j - z)^2}
\]  

(3)

\[
c \times t_k = \sqrt{(x_k - x)^2 + (y_k - y)^2 + (z_k - z)^2}
\]  

(4)

On the right-hand side of equations (2) – (4), the coordinates \((x_i, y_i, z_i)\), \((x_j, y_j, z_j)\), and \((x_k, y_k, z_k)\) are the known positions of each of the three stationary RUs in the system. The coordinates \((x, y, z)\) are those of the origin of the signal that each RU received (the target
position) and are the unknown values that must be solved for. On the left-hand side of
equations (2) – (4), the variable ‘c’ represents the speed of the received signal, assumed
to be the speed of light, $3 \times 10^8$ m/s. The variables $t_i$, $t_j$, and $t_k$ represent the time that it
took the signal to reach each respective RU and are unknown. However, the time difference
between when the signal arrived at one RU as opposed to another is known, since
the signal is timestamped by each RU upon reception. Thus, $t_i$, $t_j$, and $t_k$ can represent the
timestamp values of the signal for each RU if and only if they are being used in TDOA
equations. Taking the time difference between the equations above results in the follow-
ing (Bucher, 2001):

$$c \cdot t_i - c \cdot t_j = \sqrt{(x_i - x)^2 + (y_i - y)^2 + (z_i - z)^2} - \sqrt{(x_j - x)^2 + (y_j - y)^2 + (z_j - z)^2}$$  \hspace{1cm} (5)

$$c \cdot t_i - c \cdot t_k = \sqrt{(x_i - x)^2 + (y_i - y)^2 + (z_i - z)^2} - \sqrt{(x_k - x)^2 + (y_k - y)^2 + (z_k - z)^2}$$  \hspace{1cm} (6)

$$c \cdot t_j - c \cdot t_k = \sqrt{(x_j - x)^2 + (y_j - y)^2 + (z_j - z)^2} - \sqrt{(x_k - x)^2 + (y_k - y)^2 + (z_k - z)^2}$$  \hspace{1cm} (7)

When each of these equations (5) – (7) is solved, a hyperbolic arc solution is produced.
The point at which all of these hyperbolic arcs approximately intersect is the estimated
position of the target. An example of this can be seen in Figure 2. While only a 3-RU
system is discussed here, the MDS system can be implemented with any number of RUs.
The more RUs that receive a signal and offer data for hyperbolic arc solutions, the more
accurate the estimated target position will be.

Once an estimated multilateration position is calculated by the TP, this position data is
fused with the GPS position data (decoded from the ADS-B message) using a special data
fusion algorithm. A highly accurate position of the target is then displayed on a monitor.
See Appendix A for an example of this display output. Individual RUs can be seen la-
beled in grey as ‘ru4’, ‘ru5’, and ‘ru2’. Targets can be seen labeled in green with unique
IDs, such as ‘N4322B’. These units and targets are all plotted over a virtual map of the
airport surface, giving ATC personnel a highly accurate and reliable means of tracking
taxiing, landing, and departing aircraft.
2. **Inductive Loop Technology**

The existing radar-based and GPS solutions to runway incursion prevention have proven to be quite effective at tracking aircraft along much of the airport surface. However, virtually all airport surfaces contain large hangers, ATC towers, and terminals. The large size of these structures causes two problems: the disruption of the accuracy of the radar-based systems due to RF signal reflections off of the large structures, and the hindrance of the ability of ATC personnel to visually scan the full airport surface and accurately track any taxiing aircraft. In order to solve this problem, inductive loop technology systems are being developed and implemented on a variety of airport surfaces.

The LOT system (also known as the inductive loop sensor subsystem, or LSS) is one example of an inductive loop system, consisting of a sensor, a loop detection component, and a classification and tracking component. Four 135’ x 10’ inductive loops are placed under the airport surface in rectangular saw cuts and provide the sensing element of the system (Edwards, 2000, 7.D.6-3). See Figure 3 for a cross-sectional layout of these inductive loop placements. Each loop consists of three turns of encapsulated stranded wire placed under the runway in a rut ~1.5’ deep and ~0.25’ wide. The loops are then covered with a backer rod and finally, the rut is sealed with epoxy. See Appendix C for a general layout of the LOT/LSS system.

The loop detection component (LDC) is located within a controller cabinet, usually located within 500-1000 ft. of the loop itself. A lead-in cable connects the LDC with each loop. When an aircraft/vehicle passes over a loop, an inductance variance occurs within the loop and creates a shape-based signal “signature”. This signal is unique for all varieties of aircraft. When the time-varying inductance signal exceeds the loop detector detection threshold value,
the LDC declares a target detection (Edwards, 1999, 5.D.1-3). See Appendix B for an example of this time-varying inductance signal.

The LDC sends this time-varying signal to a Classification and Tracking Component (CTC) host computer over an RS-232 interface with a spread spectrum radio frequency (RF) communications link (Edwards, 2000, 7.D.6-3). The CTC, programmed with a large set of aircraft and vehicles signatures, then proceeds to identify the target based on the detected inductive signal. Using a variety of target-tracking algorithms, the CTC then continuously displays the movement of the target on an output display screen as it passes over subsequent inductive loops, integrating the tracking results from other sensor input systems (such as radar units, MDS system etc.) to display a highly accurate tracking of the aircraft.

Technically, LOT can provide full runway tracking coverage, if units are placed all around the airport surface. However, “a more cost-effective implementation is a limited system installation that addresses the immediate and localized safety needs of the airport.” (Edwards, 1999, 5.D.1-1) See Figure 4 for detailed diagrams on such an implementation. As described earlier, hangars and towers often block the view of ATC personnel and interfere with accurate radar tracking along an airport surface. One highly effective way to implement the LOT system would be to pinpoint such areas on an airport and place inductive loop sensors around them. This implementation can be seen on the left-hand side of Figure 4. Also, regardless of view/radar blockage, it would be advantageous to place a LOT system around airport “trouble spots”, such as selected runway intersections. This would ensure that such areas
receive extra surveillance coverage and could potentially decrease the chances of an actual runway incursion.

3. Local Area Augmentation System

While many runway incursions occur due to insufficient tracking coverage of the airport surface, they can also occur due to inaccurate position and approach data when an aircraft is attempting to land on a runway. In order to minimize this problem, the Local Area Augmentation System (LAAS) is being developed.

LAAS is a differential GPS-based (DGPS) precision approach and landing system consisting of three subsystems: a GPS satellite subsystem, a grounded subsystem with reference antennas placed around the airport runway surface, and a data processing subsystem onboard the aircraft (Hawes, 2001, 2.E.2-2). See Figure 5 for an illustration of the three LAAS subsystems and how they interact with each other. The GPS receivers in the aircraft and in each of the reference antennas use a cluster of GPS satellites to pinpoint their respective position. The position data determined by the antennas in the grounded subsystem is then analyzed by a computer system to obtain differential correction and integrity information for the current runway approach being assigned to the aircraft. This correction and integrity information is then transmitted back to the processing subsystem onboard the aircraft by means of VHF (Very High Frequency) Data Broadcast (VDB) equipment. Once the processing subsystem aboard the aircraft receives this differential
correction and integrity information, it uses this data combined with its own position information (obtained directly from the GPS subsystem) in order to calculate differentially corrected position estimates of the runway approach (Hawes, 2001, 2.E.2-2). Using this technique, the potential for inaccurate position and approach data is significantly decreased and landing aircraft have much more precise runway approach instructions.

4. PathProx System

The various surveillance systems that actively track targets along airport surfaces (radar, LOT/LSS, MDS etc.) all undoubtedly help to prevent runway incursions. Most notably, they significantly enhance the abilities of ATC personnel to quickly and accurately identify potential runway incursions and notify the involved parties before the incursion occurs. However, in the time that it takes ATC personnel to identify a potential incursion, valuable seconds are lost that could be crucial to actually preventing the accident from happening. A solution to this issue is proposed with the PathProx system.

PathProx is “an on-board surveillance system designed to identify early conditions for runway incursions and provide aircraft pilots and ground vehicle operators with sufficient time to avoid runway incursions and collisions.” (Cassell, 2000, 7.D.3-3) The system utilizes air traffic location information broadcasts (provided by either the Traffic Information Service – Broadcast system, TIS-B, or the Automatic Dependent Surveillance – Broadcast system, ADS-B, which both get their traffic information from outside surveillance sources, such as radar systems and the MDS system) along with its own Global Positioning System (GPS) to continuously keep track of potential runway incursions. See Figure 6 for a block diagram of this system. The PathProx system is designed to handle over forty different runway incursion situations (Cassell, 2000, 7.D.3-4).
for four common situations that the PathProx system is programmed to recognize. By comparing its own pinpointed position, using its GPS/GNSS (Global Navigational Satellite System) unit, to the positions of other aircraft in the area, transmitted by either the TIS-B or ADS-B radio systems, the PathProx alerting logic system can continuously determine the potential for incursion conflicts. Once a potential runway incursion is identified, the PathProx system provides an alert to the on-board Cockpit Display of Traffic Information (CDTI). As shown in the diagram, the GPS/GNSS system involved with the PathProx alerting system also has the ability to fuse differential runway approach correction information from the aircraft’s LAAS receiver to obtain an even more accurate personal position.

There are two different alerts that the PathProx can send to the CDTI. The first is a Runway Traffic Alert (RTA), which is generated when a pilot’s own aircraft has the potential to be involved in a runway incursion with other traffic. The second is a Runway Conflict Alert (RCA), which is generated when an actual runway incursion has occurred and there is potential for the pilot’s aircraft to collide with it. Detailed instructions on how to avoid the incursion is not provided with the alert, but valuable information including “identification of the incurring aircraft (or vehicle), the runway associated with the aircraft, the separation distance and the time to conflict” all are provided in real-time in the aircraft cockpit (Cassell, 2000, 7.D.3-5). Thus, using the PathProx alerting system, potential runway incursion warning delays are circumvented and the involved vehicles are given more time to take the proper evasive actions.

VII. Conclusion

Currently, a number of highly effective aircraft-tracking and runway incursion alerting systems are being implemented at airports worldwide. With such useful developments as the MDS system, inductive loop technology, the LAAS precision approach and landing system, and the PathProx alerting system, ATC personnel and aircraft pilots should be better informed of airport traffic locations and of potential runway incursions.
While major advances have been made towards the prevention of runway incursions, especially in the area of precise and continuous aircraft-tracking, the system is far from ideal and certainly could use improvement. Specifically, more research should be spent on ways to quickly and effectively predict runway incursion scenarios and transmit warnings and collision-avoidance instructions to the pilots of the involved aircraft. The Path-Prox system is a step in the right direction towards this goal, but major enhancements can still be developed. The more time that pilots have to acknowledge potential runway incursions and take the proper steps to avoid them, the more likely it is that they will actually be successful in avoiding them. Thus, a critical factor of runway incursion prevention that deserves a great deal of focus is the reduction in the time that passes between when a potential runway incursion is detected and when the involved pilot(s) are actually warned of the situation. If such advances continue to be made in the area of runway incursion prevention, the future certainly looks promising for the world of airport traffic management.
VIII. Works Cited

IX. Appendices

Appendix A: Illustration of a 3-Remote Unit MDS System

(Adapted from Bussolari, 2000)
Appendix B: Examples of LOT Inductance Variance Output

Appendix C: General Layout of the LOT/LSS System

(Adapted from Edwards, 2000, 7.D.6-4)