Runway Safety: Technologies for Debris Detection

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Background

This paper has been provided instead of copies of the slides to be presented at the Runway Safety Conference. The slides do not have much text; they are predominantly colour images that may not reproduce clearly for the handouts.

Roke Manor Research Limited has a contract from EUROCONTROL, the European Organisation for the Safety of Air Navigation, to study technologies for the detection of debris on airport runways. This paper is an overview of the results to date; it was written before completion of the work, so the conclusions of the study will not be given.

The study is part of EUROCONTROL’s CARE programme, which promotes, inter alia, innovation in Air Traffic Management research. The EUROCONTROL web site has details of this initiative at:

[http://www.eurocontrol.int/care/innovative/index.html](http://www.eurocontrol.int/care/innovative/index.html)

Brief descriptions of the studies funded in 2001, including that of the Airport Runway Debris Detection study, can be found at:

[http://www.eurocontrol.int/care/innovative/studies2001/prelim_studies.htm](http://www.eurocontrol.int/care/innovative/studies2001/prelim_studies.htm)

Of course, debris detection is important throughout the manoeuvring areas of an airport, not just the runway. We have chosen to concentrate on the active runway because that presents the most demanding environment, from both the physical and regulatory viewpoints. For example, there can be severe acoustic vibration and the sensor mountings must be less than ninety centimetres tall; both of which make debris detection and location more difficult.

Note: There is scope for further development of a runway debris sensor to provide warnings of runway incursions by vehicles or intruders. It is a less straightforward task to develop an incursion sensor to detect debris.

Debris?

The word debris, which is from an Old French word meaning to break, implies parts of something broken. A lot of what we are required to detect is in this category, for example a castor broken from a catering trolley, a part fallen off an aircraft, a detached runway light fitting, or part of the pavement itself. Not all the objects for which we are searching are of this nature, however. There are misplaced tools or equipment; objects
that have been blown by weather or jet blast; and, of course, some “debris” has fur, or feathers.

Foreign object damage due to debris on the pavement can occur anywhere in the aircraft manoeuvring areas of an airport. Damage can be caused by jet blast from one aircraft blowing debris onto another, or onto people, or onto logistics and infrastructure items. Damage can also occur directly to an aircraft striking debris on the pavement.

A major event in which an aircraft sustains significant damage can cause delay to, or cancellation of, its flight, with the consequent knock-on effects of re-scheduling, increased workloads for airport and airline personnel, and loss of Customer satisfaction. The major cost items will be repair and third-party liability claims. If debris is ingested by a jet engine, repair costs can exceed one million euro; the airline or its insurer will be looking to recover these costs.

On the active runway, the consequence of a foreign object damage event can be more severe than elsewhere on the airport due to the higher kinetic energies involved; it can even lead to loss of the aircraft, and consequent loss of life. Takeoff accidents are likely to be particularly severe due to the large fuel load. Such an event on the airport is likely to result in closure for a significant period, causing knock-on effects throughout the Air Navigation System of the region, which may increase the likelihood of further accidents elsewhere.

Risk

Debris on the runway poses a hazard to operations. One attribute of a hazard is the risk; this parameter can be used to compare hazards. Risk is a two-dimensional quantity; it represents the likelihood that the hazard will lead to an accident, and the severity of the consequences of the accident should it occur. Conventionally a hazard is well defined and so can be represented by a small area of uncertainty on a two dimensional graph. For example a hazard could be expressed in terms of a specified failure mode of a system resulting in a particular accident. The severity of the consequences in this case is known by definition, and an accurate estimate of the likelihood could be made with a high degree of confidence.

Debris on the runway is not a hazard in the formal sense; it is too loosely defined. There is uncertainty as there is a range of different accidents that may result from the same piece of debris. A stone on the runway may not impact an aircraft at all, or it may dent the skin, or it may get into an engine, and so on. This range of outcomes has an associated range of likelihoods. There is in fact a range of hazards. The hazards should be expressed in terms like “debris on the runway causes loss of aircraft”. The severity is defined; the likelihood is a combination of sequential factors including the likelihood of actually striking an object, the likelihood of it causing damage of this severity, etc.

But which are the highest risks? Unfortunately, there does not seem to be a common standard of data recording and sharing on what has been found where on airports, and what incidents, if any, resulted. Many operators have their own systems, but there are no statistics available combining these data.

We could expect that the severity of the consequences of striking some debris to be related to the size of the item; a large stone can cause more damage than a small one.
We can also assume that shape has an effect, a sharp object can cause more damage to a tyre, say, than a flat one.

The likelihood of striking an object and causing damage depends not only on size, but also position. For example, it could be expected that landing on an object would cause more damage than running into it during the deceleration phase. This suggests that the debris sensors should be concentrated on the area upon which most landings occur. It could be argued that it is here that debris fallen from aircraft is most likely to be found.

For take-offs, greatest damage would be expected at the point of greatest speed, i.e. the sensors should perhaps concentrate around the point of lifting off, but this is a less well-defined area, depending upon aircraft type, loading and the weather.

These arguments seem reasonable; a small stone causes less damage than a larger item such as a misplaced tool and, considering its size, it is less likely to be struck. But consider the example, from August 1970, of a DC-8 Freighter taking off from New York JFK. It climbed to about four hundred feet, rolled twenty degrees to the left, crashed and caught fire. The investigation report cited the probable cause as “Loss of pitch control caused by the entrapment of a pointed, asphalt-covered, object between the leading edge of the right elevator and the right horizontal spar web access door in the aft part of the stabilizer.”

Just because an event is very unlikely, it does not mean that it will not happen.

**Mitigation**

The best defence is ‘good housekeeping’. At present, the risk of foreign object damage is mitigated solely by observation and ‘sweeping’ activities. However, the area where the risk is highest, the active runway of a busy airport, cannot be swept on a periodic and frequent basis without reducing the number of aircraft movements, i.e. adversely affecting airport capacity. What is required is an on-condition runway maintenance concept. Periodic sweeping activities would be less frequent, and the runway would be continuously monitored by automatic sensors to warn of the appearance of significant pieces of debris. But whom should it warn?

The Operational Concept has to be defined and it may differ from airport to airport. Clearly it is impractical to have someone continuously watching a video monitor. It would be difficult to remain alert for extended periods, and who can afford to employ a group of screen watchers on a continuous roster?

Where debris detection is concerned, we expect there to be at least three ‘stakeholders’; the operations people who actually go and perform the sweeps of the runway, the pilots who use the runway, and the air traffic control operators responsible for coordinating runway use. Off the runway there are other “actors” involved in debris control, such as the baggage handlers, catering services and construction workers; they should be made very aware of the need for ‘good housekeeping’.

Operations will have a timetable of inspection activities. They are not just interested in finding debris; they need to check for damage of, or contaminants on, the pavement. Additional inspections will be carried out when prompted by air traffic control, who will be either passing on a pilot’s observation of debris, or requesting an additional sweep when an aircraft has landed after declaring an emergency, for example.
With effective sensors the number of scheduled sweeps can be reduced to the minimum required by regulations or company policy, whilst the number of initiated sweeps is likely to increase, being now dependent, not only upon prompts from the pilots and air traffic control, but also the sensor suite. This places Integrity requirements upon the sensors; they must not generate many false alarms but, of course, they are also required to detect all significant items of debris. Assistance is required from airport operators, et alia, to define what is meant by “significant debris”, i.e. where should the thresholds be set on the risk graph?

Continuity of Service is also an important parameter; the sensors are required to operate all the time that the airport is required to operate, e.g. at night and in severe weather conditions.

Even though the Integrity and Continuity of Service requirements have yet to be specified in detail, it is thought unlikely that a single sensor type can be found to fulfil them. This is because, apart from the need to operate continuously whilst minimising false alarms, it is a difficult sensing task. “Debris” is not a neatly defined set of objects to sense. Different sensors excel in different conditions; their outputs need to be combined to give adequate performance over all expected conditions and types of object.

**Fusion**

The term “Sensor Fusion” is one of those engineering terms that mean different things to different people. It can be used for the case in which sensors augment each other, for example, one sensor may raise an alarm causing another of a diverse type to be tasked to check the findings of the first. The more common use of the term is where the outputs of a number of diverse sensors are combined to form the quantity that is checked for alarm conditions.

An example of the first type would be a combination of the two sensors presented at the Runway Safety Conference; alerts from the millimetre wave radar could require the duty officer in Operations to view the equivalent visual sensor image before deciding whether anything need be done, and vice versa. Note that three sensor systems are actually involved here, the duty officer being the third.

The combination of sensor signals to form a composite quantity technique has been applied, inter alia, to aircraft identification. In that application it is typically preceded by an association stage, i.e. the position estimates made by all the sensors are examined first to see which are likely to be information on a common target. Thereafter the position information is tracked, but used as little more than a label. For debris detection the position information can be used to assist in the detection process itself, for example if all sensors are giving out low confidence indications of debris, but agree on the location, there is likely to be something there, albeit small. If one sensor gives a strong response at a location and the others report nothing, it may be something benign to which the sensor is particularly sensitive, like a quarter wavelength sized piece of metalised foil. If a large number of detection events are made all over the runway, it is likely to be a hailstorm.

To take best advantage of the position information it is necessary to ascertain for each point in the area of interest, and for each sensor, the probabilities of false positives or
false negatives and, where a sensor can correctly identify that there is a piece of debris, the distribution of location accuracy.

Some sensors may be very good at detecting the existence of debris, but poor at specifying the exact location, others may be the other way around. Note that the distribution may be location dependent, e.g. sensors would in general be expected to be more accurate at close range. Armed with this information each sensor can now be used to produce a map of the whole area of interest with the probability of the presence of debris at every point. All these maps may be combined into one map by using one of a number of established techniques, including Bayesian Filtering; Neural Networks; or Fuzzy Logic based Expert Systems.

Unfortunately all of these techniques have been over-hyped at one time or another, none is the universal panacea that some people perceive them to be. However, they do work given appropriate initial training data and good quality sensor data. What would be produced is a single map with an indication for the entire coverage area of the presence or absence of debris. The different techniques produce different outputs, e.g. a “weight” related to confidence of the presence of debris, or a probability that an indication is not a false alarm.

The map data should be masked with the runway area of interest. Comparisons of the data against pre-defined thresholds can then be used to raise an alarm. The thresholds could be defined to be different in different areas to increase sensitivity in areas of greatest threat. They could also be adjusted for different ambient conditions, visibility, for example. The nature of the alarm, or rather the detailed specification of the user interface, is another area in which we welcome input from airport operators.

Sensors

The preceding material has been written implying a fixed installation, but the sensors need not be mounted on posts or be embedded in the runway. They can be mounted on an inspection vehicle to increase the effectiveness of its operation. Indeed, this may prove the most cost-effective solution for some airports. Although it is expected that the majority will require a fixed installation, a combination of fixed and mobile sensors may be found to be the optimum solution for some operators.

It may be thought odd that a paper ostensibly examining the different technologies for debris detection can get to page five without actually doing so. This is a pragmatic approach; if we can get the operational concept, the data combination strategy and the method of alarm presentation correct, the actual sensors types employed are relatively unimportant as long as they can, in combination, achieve the Integrity and Continuity of Service requirements for the airport of application.

Sensors can be classified as active or passive; the former emit a reference signal and perform their sensing function by measuring some aspect of the reflected signal, the latter are receive-only. Active sensors present more problems for the designer in terms of the requirements for installation at an airport. The reference signal must not interfere with other systems, such as navigational aids; neither can it be of such strength as to cause damage or injury. For example, one solution to the problem of detecting debris at night could be the provision of infrared illuminators to augment the visual sensors; these
must be eye-safe. Such lamps have a range that is more than adequate when considering the width of a typical runway, but leaves a bit to be desired when length is considered.

A familiar active sensor type is the radar, this works by emitting a, for example, microwave signal and receiving the echo from an object. If the signal is pulsed, or otherwise structured such that round trip time can be measured, the distance to the object can be derived. The sensors could use small wavelengths and high pulse repetition frequencies to achieve high resolution in range, which would minimise the effect of background clutter (enabling small changes to be detected from the background). Another contributor to this conference will cover a particular example of millimetre wave radar in detail. A device that is similar in concept is the lidar, which is a device that is similar in operation to radar but emits pulsed laser light instead of radio frequencies. Even better measurement resolution could be expected from such a device.

Alternatively, synthetic-aperture radar systems, where high angular resolution is achieved via the movement of a small and relatively low cost sensor, could be employed. The synthetic aperture approach uses signal-processing techniques to achieve equivalent performance to a large single antenna system. The required motion could be achieved by running a sensor on rails alongside the runway or by fitting it to the vehicles currently used for runway patrol. In this latter case, the system would provide enhanced capability over the existing survey system (particularly in poor weather).

Multi-static radar techniques are also being examined. This involves the installation of receivers, operating in the radar band, to detect energy from existing airport radar systems and to note changes in received levels, which may be caused by scattering from objects on the runway. The radar cross section of typical debris is being measured to help in assessment of this method, which has the advantage of exploiting existing assets and, in principle, could be a very low cost adjunct to already installed radar equipment. In an ideal world, these receivers would operate in a coherent manner but unfortunately most airfield radar systems use incoherent magnetron-based transmitters, and do not have the stability for coherent processing to be performed over the multi-static array.

Roke Manor Research has produced miniature short-range radar sensors. Such devices could be used to instrument a runway and then function as a co-operative radar network. It is not clear if these sensors would have the ability to detect small targets in the presence of clutter. However, given that such sensors have been contemplated for deployment on airports, it is worth exploring enhancements to them to enable the debris detection rôle to be taken on.

The most familiar passive sensor is the surveillance camera system. These cameras would need to operate through large telephoto zoom lenses in order to achieve ranges of two to three hundred metres. In its least sophisticated form, this would be an automatic scanning stereo camera system, with the stereo aspect used to determine the range of the detected object. Behind this system would be a change detector that would note significant changes between the average, or normal, runway condition and the current condition. These changes would then be flagged to an operator for closer inspection before remedial action was taken. Although ranges much greater than three hundred metres could be considered, it is thought that atmospheric conditions, e.g. turbulence, would make such a system ineffective over longer ranges. This solution could thus require a number of camera systems to cover a single complete runway. It is more practical to have a number of simpler cameras mounted close to the runway using vision
processing techniques to detect debris, as described by another contributor to the Conference.

Radio frequency or infrared Radiometers could be used to survey the runway to detect, in particular, cold metal on a warm runway surface. This technique has been used to detect road vehicles but, at present, it is unknown whether sufficient thermal contrast can be detected between non-metallic objects and a runway; this remains an area of investigation. Like the camera system, it is anticipated that a number of these sensors would be required to cover an entire runway.

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The samples of debris for characterisation, photographs of which are included in the presentation, were supplied by BAA plc, who must also be thanked for providing airside access to witness debris-monitoring operations.