# Visualisation of Surveillance Coverage by Latency Mapping

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## Abstract

This paper introduces *latency mapping* as a technique for visualising surveillance coverage. Built on a concept for modelling the total effort by a surveillance force, latency mapping provides an understanding of the collective sensor coverage against a region of interest, in space and time. Latency mapping has been used to support the analysis of maritime surveillance operations in Australia's northern waters, and has been proposed for integration into Australia's Joint Command Support System (JCSS).

*Keywords*: latency, surveillance, operations analysis.

## 1 Introduction

The visualisation of surveillance coverage is of both practical and theoretical interest. Surveillance operations can entail the deployment of limited assets against truly vast areas of responsibility, challenging the commander in the field. The acquisition process is equally daunting, with ever-present budget drivers coupled to an explosion in possibilities from new sensor technologies (radar, sonar, optical), new platforms (surface-wave radar, uninhabited aerial vehicles, satellites) and new concepts of use (network-enabled operations). The ability to see how all these issues come together in context is thus of immense value to operators and decision-makers.

This paper introduces *latency mapping* as a method for visualising surveillance coverage. Built on a concept for modelling the total effort by a surveillance force, latency mapping provides an understanding of the collective sensor coverage against a region of interest, in space and time. The next section provides some of the wider background to the work, and then the methodology is formulated mathematically. The paper concludes with a discussion of application to operations analysis and command support.

## 2 Background

During 2001, the Defence Science and Technology Organisation (DSTO) was commissioned by Australia's Northern Command (NORCOM) to provide advice on the effectiveness of its maritime surveillance operations, and on concepts for tools to support its operational planning. NORCOM is responsible for military operations across a broad portion of Australia's northern air, land and waters, drawing upon and supporting surveillance assets including the JORN over-the-horizon radar network, flights by Coastwatch aircraft and surface inspections by Royal Australian Navy patrol boats.

Surveillance is defined thus (DOD Dictionary 2002)

> **surveillance**
>
> The systematic observation of aerospace, surface, or subsurface areas, places, persons, or things, by visual, aural, electronic, photographic, or other means. …

While methodologies for estimating the effectiveness of surveillance operational planning options date back to the 1950s and earlier (Morse and Kimball 1970) (Koopman 1980), these tended to be built around abstractions of operations; useful for predicting effect, but less useful for studying operations once conducted. In parallel, the methodologies tended to centre on proportions of targets that were detected and subsequently responded to. Since the ground-truth of actual targets is unknown, this made the methodologies very difficult to apply in practice; moreover, they missed the operational value of sweeping a region, and hence knowing that no targets were present.

In response to this, a new methodology was developed, based on modelling and understanding the surveillance effort made against a region of operations. As will be discussed, *latency mapping* was one particular outcome. The methodology was implemented in a MATLAB Toolbox, and a complete discussion including the software may be found in (Hew 2003).

## 3 Methodology

The *latency mapping* methodology uses two constructs: *swaths* and *scan history*. These concepts capture relevant aspects of surveillance assets, capabilities and operations.

### 3.1 Swaths

A *swath* is defined to be a geographic region $R$ monitored over some time interval $T = [t_S, t_E)$. This concept extends "cookie cutter" modelling to include both space and time, so the size and shape of $R$ is implicitly tied to sensor performance against some class of targets within the sensor environment of $T$. The extension is that swaths have the added aspect of "smearing" over time; specifically, the *instantaneous* coverage provided during $T$ is accumulated into *continuous* coverage of region $R$ over $T$. The "smearing" process is thus similar to a moving average, but instead of taking the average of the instantaneous coverages, smearing takes the union. As Figure 1 shows, the degree of smearing is a modelling parameter: 3 min in the first example and 5 min in the second.

Swaths can be used to model both active and passive sensors; as examples: the swath from an active radar system would be the region scanned by the radar beam, while the swath from a passive sonar array would be the region over which interesting signals can be distinguished from background noise. Crucially, swath modelling inherently requires modelling of the surveillance targets, due to their impact on detection distances. As an example, a radar system could well detect bulk carriers at 50 km but might only detect sailboats at 10 km, so the swaths for the radar system against bulk carriers would be much larger than the swaths for sailboats. The point also extends to the question of how the sensor system is affected by environmental conditions; a person with binoculars might see an object at 5 km on a clear day, but might barely see the same object at 50 m at night.

The modelling to generate swaths for a sensor system may thus range from simple horizon line-of-sight calculations through to sophisticated system models calibrated by field trials. Nonetheless, every sensor system aims to provide some kind of space-time coverage, and hence all sensor systems can be considered in terms of swaths. Swaths are thus building blocks towards unified appreciation of sensor systems and the way that they complement each other.

### 3.2 Scan History

The definition of *scan history* begins with the *scan history at a point* $x$. This can be represented through functions $f_x : \Re \to \{0,1\}$ where $f_x(t) = 1$ means "A sensor is scanning point $x$ at time $t$", and conversely for $f_x(t) = 0$, as illustrated by Figure 2. It is then possible to consider the *scan history over a region*, by having $x$ range over some region of interest $A$, recording for each $x$ a sequence $[t_1, t_2)$, $[t_3, t_4)$, $[t_5, t_6)$, … of intervals for the *durations* over which the point $x$ is scanned. From here on, *scan history* will mean the scan history over some region.

A scan history can be can be considered in concept through a chart with time on the horizontal axis and space on the vertical. Figure 3 shows the concept, plotting a notional scan history over a region A, in which a sub-region B was scanned by one sensor, and then sub-region C was scanned by another. By encapsulating sensors, locations and time, the scan history captures the total surveillance effort against region A.

The framework for generating scan histories is summarised by Figure 4. The surveillance assets are modelled for their swaths, which are then projected onto the surveillance region through *grid sampling* The projection process centres on testing of points on the grid for enclosure within the swath polygons, and thus recording the scan histories at each point. The sampling grid needs to be fine enough to capture the presence or otherwise of the smallest swath, and should use equal-area sampling between points to account for the curvature of the Earth's surface.

### 3.3 Latency Mapping

*Latency mapping* is a particular way of analysing and visualising the scan history over a region. As Figure 5, shows, the idea is to periodically consider the time since points were scanned – the *latency*. Formally, a *latency history* takes a *scan history*, and for each sampling time $t_0$, $t_1$, $t_2$, … generates a *latency slice* recording the latency at each point on the grid. The sampling times must be equally spaced, at a resolution tight enough to capture the degradation in latency as it occurs.

Latency can be visualised through colour fading from solid to transparent as time passes and latency grows, embedding a visual key of a region being dominated by a force (for instance Blue for Friendly or Red for Hostile). Colour maps can be built in Hue-Saturation-ColourValue (HSV) colour space by setting an initial Hue for zero latency, and linearly degrading the Saturation component to zero and the ColorValue component to light gray (intensity = 0.1 say) over some *fade-away time*. The full latency history can then be displayed through animation, as illustrated by the snap-shot in Figure 6, or accumulated into still plots such as average or maximum latency.

The *fade-away time* is a key parameter, driven by command judgement and the performance of the targets being sought. As an illustrative example: suppose the targets were slow-moving sailboats. The knowledge that a given point was scanned would retain its value for a long time, since the presence or otherwise of a sailboat at that point will not change rapidly. Conversely, if the targets are fast-moving speedboats, then the knowledge about a point will degrade rapidly. This is intuitively believable – if the targets move quickly, then rate of scanning will need to be fast too – and visually reflected by rapid fading in colour if fast targets are expected, against slower fading for slow targets.

Overall, it is possible to see how a set of swaths is projected in space to yield a scan history, which is then projected in time to yield a latency history. In general, the computations and display are far too intensive to do by hand, but are readily implemented through commercially available scientific software on modern hardware.

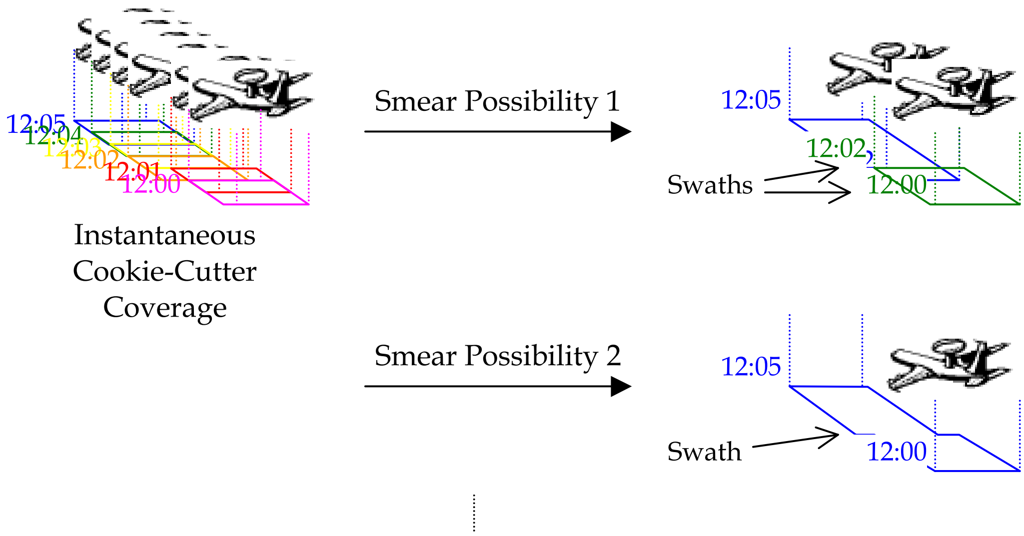


**Figure 1: Smear Instantaneous Coverage into Swaths.**

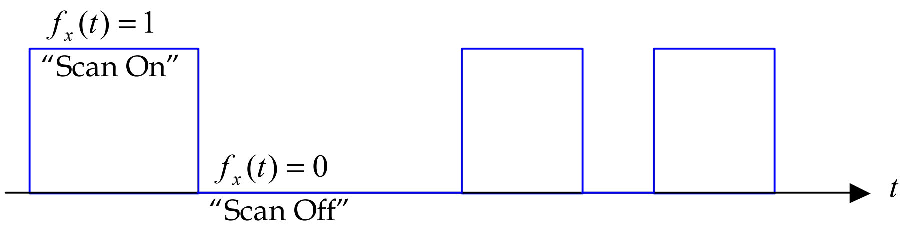


**Figure 2: Sample Scan History at a point.**

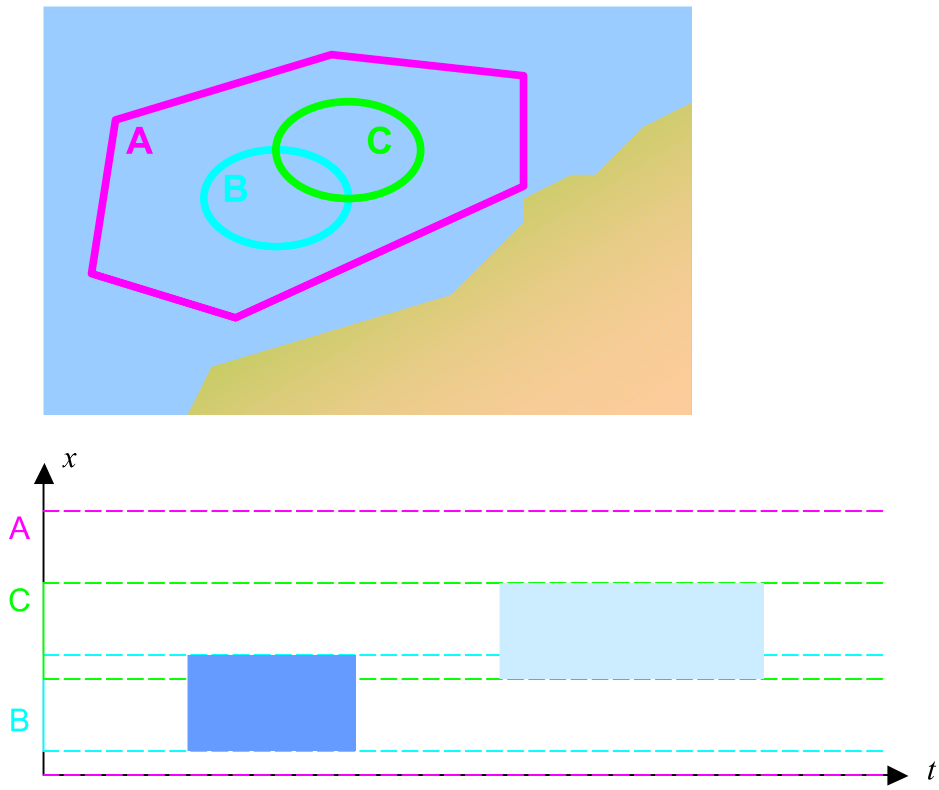


**Figure 3: Sample Scan History over regions.**

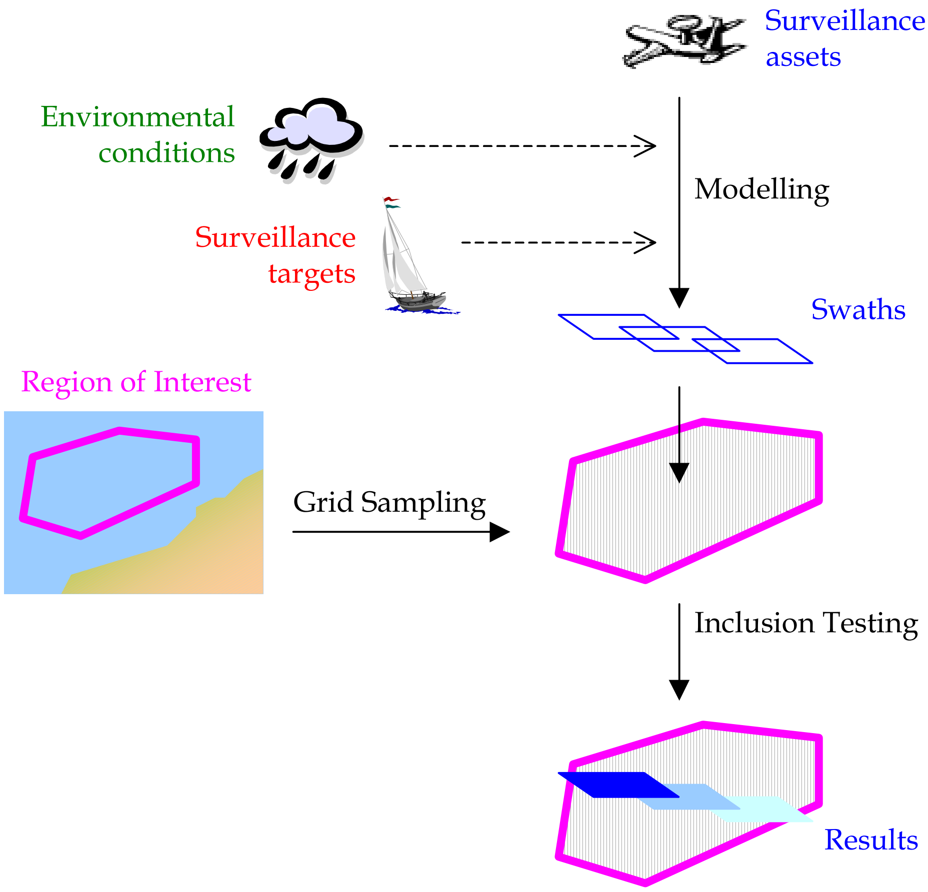


**Figure 4: Framework for generating Scan Histories.**

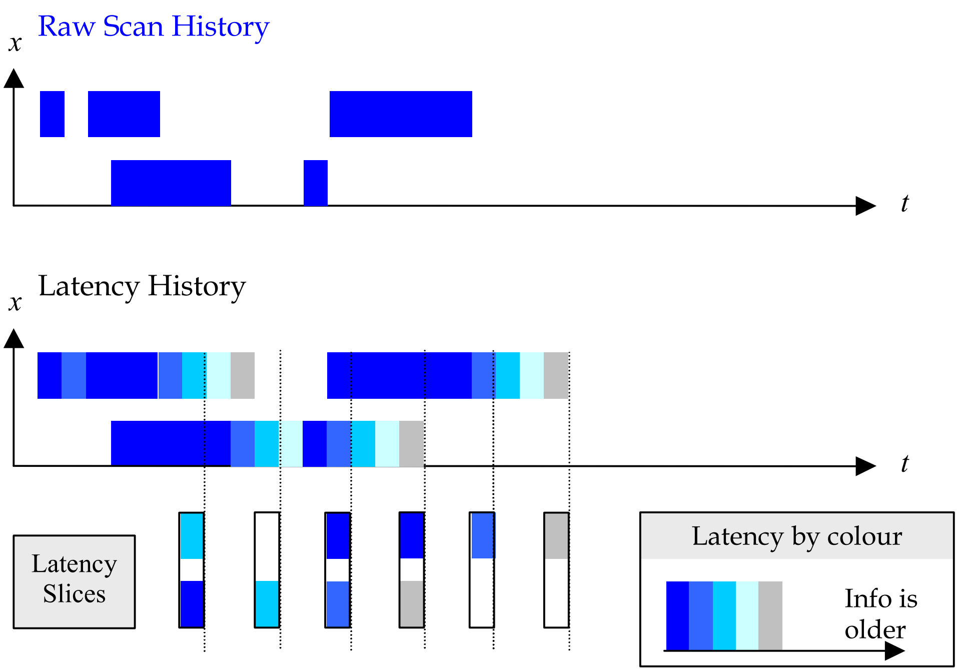


**Figure 5: Scan History analysis through Latency.**

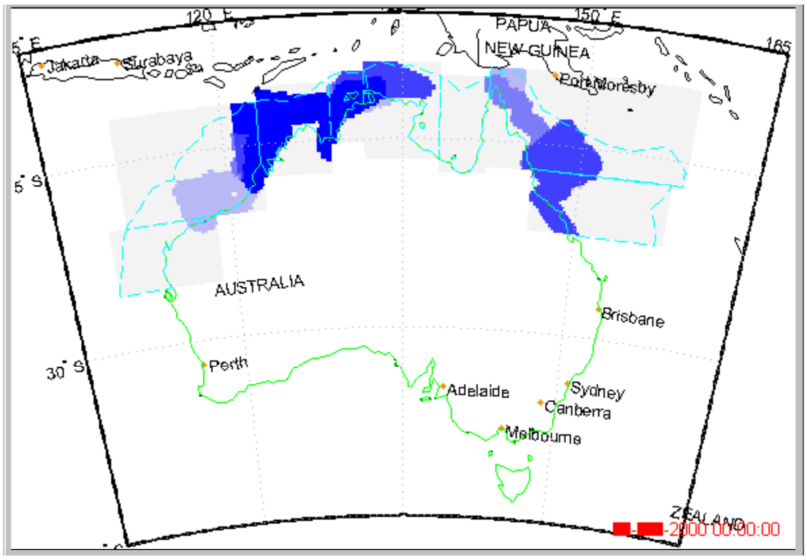


**Figure 6: Latency Mapping Example.**

# 4 Application

## 4.1 Support to Operations Analysis

Latency mapping can aid the provision of operations analysis advice, as was found with the DSTO experience with NORCOM. Its value derives from the way it captures sensor and platform detail – among them: range, detection likelihood, revisit rate and persistence – in a single scale detailing the implications to the field commander. The underlying scan and latency histories are also amenable to statistical analysis; examples include the average time between visits to some region, or the average duration of such visits.

While of interest to a field commander considering asset employment, latency mapping also has application to advice on capability development and equipment acquisition. The reasons are similar – sensor and platform details are factored out, yielding their outputs that can be explored in terms of complementarity, value and cost.

Importantly, analysis of this kind requires corporate recording of operational plans; the DSTO work at NORCOM, for example, drew heavily on Post-Flight Reports from Coastwatch. However, given the investment being made in Knowledge Management and the ready availability of powerful computing, techniques like latency mapping can complement the ability of current operations analysis to *predict* effectiveness with an ability to *assess* operations once conducted.

## 4.2 Command Support

Latency mapping has been proposed for integration into command support suites like Australia's Joint Command Support System, with the goal of improving the field commander's situation awareness. Like other command support, latency mapping does *not* replace the commander's judgement; rather, through timely understanding of the latency in coverage over a region of surveillance responsibility, the commander is able to make more rapid and better informed decisions.

In proposing latency mapping for situation awareness, it is necessary to be cognizant of the command environment into which it must integrate. On this score, latency mapping builds on the familiar map paradigm, but in turn requires the command environment to take in and process timely information about the conduct of operations. Screen clutter is also an issue, since the colouring of regions by latency can block out target tracks or terrain features. The ability to see both target tracks and latency is quite important: target tracks will show where targets have been found *in regions that have been searched*, while latency mapping highlights regions where the searching is out of date.

# 5 Summary

This paper introduced *latency mapping* for visualising surveillance coverage. The technique provides insight into the collective latency of a surveillance force against a region of responsibility over time, and builds on existing methods by its study of operations as conducted, rather than of abstract predictions. Further, the process behind latency mapping factors out the technological details of individual surveillance assets, and brings out the way that multiple assets complement each other.

Latency mapping is built on the modelling of surveillance assets through *swaths*, geographic regions monitored over intervals of time. These swaths are projected in space to generate a *scan history*, which is then projected in time to generate a *latency history*. The latency history is viewed through animation, with short latency degrading to long latency by solid colours fading to transparent.

The Defence Science and Technology Organisation has used latency mapping in operations analysis support to Australia's Northern Command, has suggested it for support to decision-making on equipment acquisition, and has proposed it for integration into Australia's Joint Command Support System to boost situation awareness. Latency mapping is software intensive and requires good operational data, and thus draws on ongoing advances in scientific software and Knowledge Management.

## 6 Acknowledgments

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## 7 References

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