MORTICIA, a statistical analysis software package for determining optical surveillance system effectiveness.

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Abstract. Surveillance modelling in terms of the standard Detect, Recognise and Identify (DRI) thresholds remains a key requirement for determining the effectiveness of surveillance sensors. With readily available computational resources it has become feasible to perform statistically representative evaluations of the effectiveness of these sensors. A new capability for performing this Monte-Carlo type analysis is demonstrated in the MORTICIA (Monte-Carlo Optical Rendering for Theatre Investigations of Capability under the Influence of the Atmosphere) software package developed at the Council for Scientific and Industrial Research (CSIR). This first generation, python-based open-source integrated software package, currently in the alpha stage of development aims to provide all the functionality required to perform statistical investigations of the effectiveness of optical surveillance systems in specific or generic deployment theatres. This includes modelling of the mathematical and physical processes that govern amongst other components of a surveillance system; a sensor's detector and optical components, a target and its background as well as the intervening atmospheric influences. In this paper we discuss integral aspects of the bespoke framework that are critical to the longevity of all subsequent modelling efforts. Additionally, some preliminary results are presented.

1. Introduction

The expected performance of an electro-optical sensor system is often uncertain due to the large number of factors that influence it. Range prediction for these surveillance sensors involves many dimensions of variability, both those under design control as well as environmental factors which can often be modelled with varying degrees of physical fidelity, but which lie outside engineering control. The MORTICIA (Monte-Carlo Optical Rendering for Theatre Investigations of Capability under the Influence of the Atmosphere) software framework has been developed to produce a statistical representation of the range capabilities of surveillance sensors in both generic and specific deployment theatres. This platform independent tool currently in the alpha stage of development, when complete, would be of particular use in the hands of commanders, providing knowledge of what the current surveillance capability is, both for own and opposing forces. The operational tool could show the current DRI range capability based at least partly on local, in situ, measurements of the prevailing conditions. However, the in situ measurements would likely have to be supplemented with relevant parameters that have been predicted using models or measured by remote sensing e.g. weather satellite observations. The greatest value would be achieved through dynamic integration of in situ measurements, model outputs and real-time or near real-time satellite observations.

In the sections to come, the image quality metric used for DRI predictions will be explored followed by a description of a typical Monte Carlo simulation run. Initial results and concluding remarks round off the paper.

2. Johnson's Criteria and Targeting Task Performance Metric

The probability of DRI for a particular target set can be quantified in terms of a threshold image quality metric. One of the oldest sets of such metrics is known as "Johnson's criteria" [1], which simply states that the surveillance system must resolve a certain number of spatial cycles over a certain critical target spatial dimension in order to execute the task with 50% probability of success. While useful as a ballpark estimate, there are many deficiencies in the original method and many improvements to surveillance tasking probability prediction have arisen. One of the latest image quality metrics for DRI that has been published is known as the Targeting Task Performance (TTP) metric [2]. The TTP metric is similar to Johnson's criteria in that thresholds for task performance, denoted V^{50} for a particular, target set are determined, preferably by experiment. These V^{50} thresholds, which essentially express the task difficulty, can then be used to predict performance in other conditions and with other sensors operating in the same spectral band. The equivalent thresholds for Johnson's criteria are denoted N^{50}.

A number of published studies have been consulted [2], [3] and [4] in order to establish reasonable V^{50} task cycle criteria.

3. Statistical Modelling

The surveillance problem is usefully conceived as a chain of elements from light source (chiefly the sun in the shortwave spectrum) via atmosphere and target, then back through the atmosphere to the surveillance sensor and onwards ultimately to the human observer. Each element in the surveillance chain generates spectral, spatial and temporal modulations in the optical signal received by the observer. For sake of brevity only some of the considerations for each of these elements are discussed below.

3.1. Target

The high fidelity implementation of target generation in MORTICIA utilises 3D synthetic scene generation using hyperspectral or band Radiance Environment Maps (REM) and raytracing of a target model. This is achieved primarily through the use of libRadtran [5], a collection of tools for atmospheric radiative transfer computation.

The default synthetic target used for modelling efforts is a lambertian sphere or ellipsoid with latitude and longitude spokes, creating what is essentially a 3D Siemens star, referred to in prose as a "beachball" target. An example of which is shown below in Figure 1.

Figure 1. Rendered Image of Beachball Target

The "beachball" target has been selected as a generic target that is fast and easy to render and whose only definitive properties in pure lambertian form are the spectral reflectance values for the light and dark sector spokes and the number of light/dark spoke pairs. For realistic simulations, the modelled diameter of the sphere as well as the mean and modulation of spectral reflectance must be representative of the target or set of targets for which it is to be a generic surrogate.

3.2. Background

Currently MORTICIA only caters for vegetative backgrounds. This model assumes a uniform background, but future efforts plan to use a more comprehensive approach such as the synthesising of backgrounds using statistical methods, further even, would be to use aerial photography of the deployment theatre. Since detection depends quite strongly on background spatial structure, the detection thresholds alluded to in the section on performance metrics are regarded as the least reliable of the DRI metrics. The field of view of the sensors utilised for these applications is assumed sufficiently narrow that the background has no spatial variation carried over from the REM either.

3.3. Environment

The emphasis here is on geophysical environmental variables that have most impact on the radiant environment i.e. the amount of light traveling in different directions at different wavelengths (spectral radiance).

3.4. Atmospheric Profile

It is necessary to specify the atmospheric profile with respect to height above ground as an input to the RTC. The libRadtran suite provides a number of standard profiles as well the option to customise a profile using site specific aerosol data.

3.5. Clouds

The latest version of MORTICIA makes use of only a single water cloud model and vertical distribution. This is potentially a significant shortcoming, but the real impact on DRI has not been assessed. Only the Cloud Optical Depth (COD) and Cloud Cover Fraction (CCF) can be manipulated in the simulation, while the vertical distribution and effective droplet remain fixed for all MC sample points.

3.6. Aerosols

Cumulative frequency distributions for total Aerosol Optical Depth (AOD) and aerosol phase function data representative of the theatre of interest are required for modelling the effects of aerosols on overall image quality. Through narrow-angle scatter, aerosols introduce blur into the image. The other effects of aerosols are to scatter and absorb desired photons from the target and to scatter undesirable photons into the sensor Field of View (FOV), referred to as path radiance. For longer ranges and higher scattering optical depth, exacerbated by high absorption optical depth, all of which tend to go together, aerosol Modulation Transfer Function (MTF) can become a significant or even dominant contributor to the overall atmospheric MTF [7]. The model used in this work does not currently have an aerosol MTF component and this is possibly a significant shortcoming.

3.7. Atmospheric Turbulence

With respect to optical imaging along sightlines of substantial length passing through the atmospheric surface layer, atmospheric turbulence is quite often the limiting factor on DRI range performance. Atmospheric turbulence is simulated based on a peak C_n^2 value at a user-defined reference height above ground, where C_n^2 is a measure of the variation in refractive index between two points in space. The time dependent C_n^2 at the reference height is computed based on the empirically observed variation between the times of sunrise and sunset. The variation of C_n^2 with height is based on a simple power law decay. The coherence diameter and corresponding Fried parameter for each sightline zenith angle at a specific time of day is then computed by performing a simple integration of C_n^2 over the height from target to sensor. With growing interest in elevated surveillance platforms, such as aerostats and Unmanned Aerial Vehicles (UAV), the reliable knowledge of vertical distribution of turbulence and aerosols becomes a vital consideration. This is elaborated on in work by Sprung et al.[8].

3.8. Sensor and Platform

Once the at-target radiance is known as well as the atmospheric path (sightline between sensor and target) transmittance, radiance and Fried coherence length, the at-sensor radiance and path MTF can be computed. What remains is to compute the image data from the sensor based on knowledge of the optics, detector and platform induced vibration and smear. These tasks are performed by the python translated Basic Optical Sensor Model (BOSM), code based on a Swedish Defense Research Agency (FOI) report by Kopeika [7] and Winzell [9] amongst others.

4. Implementing the simulation

The implementation described here has adopted the statistical approach in which data sources for a number of key theatre environment variables have been exploited. The surveillance theatre is defined by a single quadrilateral for which adequate sampling of climatological conditions is required. The overall strategy is to sample the climatology at a random day/time point and compute a REM for every date/time sample inside the simulation loop. The MC loop process runs through each of the engineering options and computes DRI metrics for samples of the environment covering the broadest possible range of system operating conditions. The loop continues until the task probability is 50%. At this point the ground range for the viewing zenith angle is computed and logged together with all MC sample data and relevant metadata.

5. Applications

MORTICIA is primarily concerned with determining the effectiveness of a specific surveillance system within a particular environment. However, once effectiveness modelling is in place, it becomes possible to do simple trade-off studies i.e. deciding which surveillance system from a limited choice of possibilities will be more effective in a particular application. Taking this one step further opens the possibility of performing optimization studies.

6. Results

The main results of the Monte Carlo simulation are written to a table containing all or most parameters on which results may be aggregated for graphical display or further statistical analysis. One of the most important result summaries is the polar DRI range plot. This polar graph shows the threshold (50% probability of success) ground range for the targets and tasks defined for the simulation as a function of Solar relative View Azimuth Angle (SVAZ). Results can also be also be aggregated over true azimuth (relative to north) or with respect to any other input or output model parameter. This allows for exploration of possible relationships and mining for insights contained within the model results.

Figure 2 below provides typical range plots for a task in which six separate sensors were required to detect a human target from a platform height of 500m above ground level. Relative daytime is used where 0 is sunrise and 1 is sunset. Local noon is at relative daytime of 0.5. The plots are all relative to solar azimuth, where looking into the sun is azimuth 90° and looking away from the sun is azimuth 270°. Threshold range is seen to be reduced when viewing into the solar azimuth, particularly early and late in the day when the sun is low, and atmospheric turbulence is reduced. This is due to a reduction in apparent target contrast because of the scattering of sunlight into the sensor FOV.
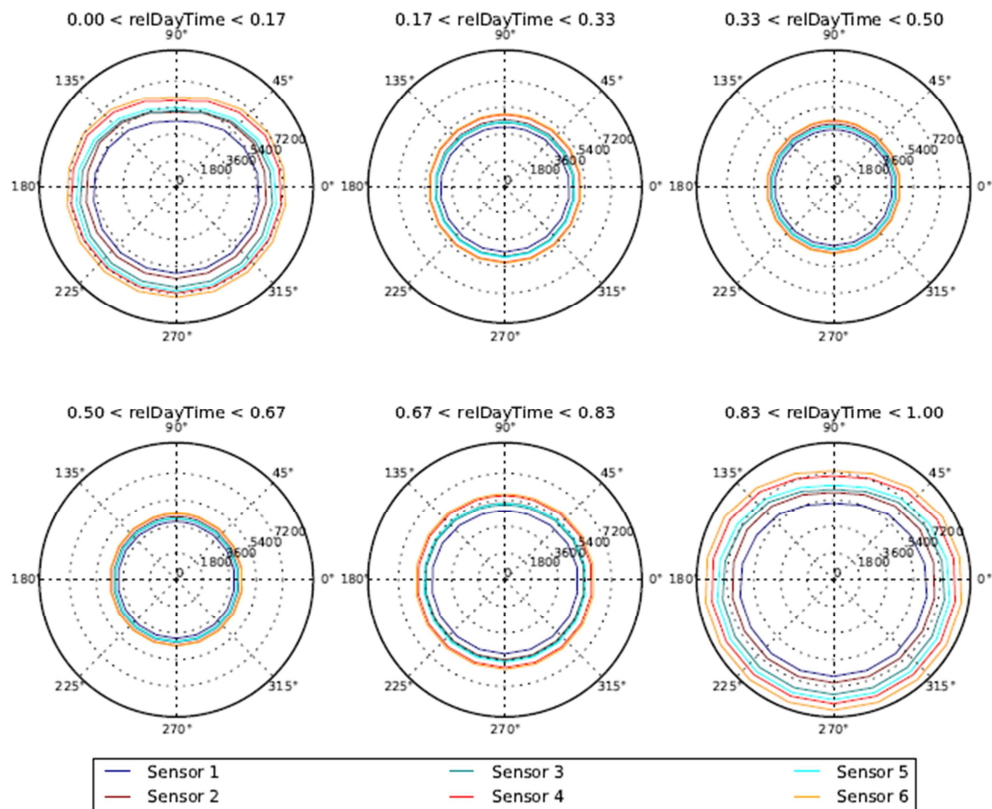

Figure 2 Ground Range Threshold for Target Task at Platform Height of 500m

7. Conclusion

While surveillance modelling in general has a rich body of literature, there is little coverage of the statistical approach attempted with MORTICIA. The proof of concept of statistical, theatre-orientated surveillance modelling has been successfully demonstrated in this study. A number of refinements and optimisations to the code base are underway. In addition, validation exercises are planned for the immediate future.

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