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Statistical Modelling of Air-Ground Remotely Sensed Geo-Intelligence Information Using Naïve Bayesian Classification: A Decision-Making Approach

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Abstract

With the increasing complexity of warfighter scenarios with respect to adversarial engagement and non-traditional environments of contention, there is an increasing need to process geo-intelligence information where the aim is the optimal understanding of state for high level decision making. Bayesian statistical modelling [1] is well suited to information fusion across different information modalities supporting this need. Two problem areas suggesting a need for statistical modelling for state estimation-based decision making are air-ground information fusion between drone and satellite and assault rifle-human information fusion for hostile ground engagements. Two fictitious model problems are explored where the aim is to explore how basic Bayesian statistical information processing would occur in these geo-intelligence scenarios which could assist human decision making.

In this first problem, a satellite and drone work together as a team to classify ground structure which is relayed to and exploited by geo-intelligence leadership. Satellites orbit at altitudes on the order of miles where spatio-temporal resolution can be limited. Spatial time series along with time-of-day information are often recorded where the spatial information is an amalgamation of multiple spatial parts holding latent structural information. This latent information is important to state estimation, classification, and decision making [2] but is of little value by itself. Drones flying at a much lower altitude over the same area, on the other hand, can resolve spatial information on a finer spatial scale. By combining the information accrued by these two different remote sensing technologies, first-order classification of ground-based information is possible permitting robust management decisions. This aim is accomplished using naïve Bayesian classification [3].

Using previously calculated mean and variances processed from satellite spatial and time stamp (metadata) information, optimal time-of-day states based on subsequently acquired spatial time series by the drone can be performed. This is because satellite-based priors form a naïve Bayesian network [4] between time-of-day information (state variable) and the spatial time series information (observation variables). This prior knowledge can be used to induce time-of-day estimates in data acquired by the drone where only spatial information data is needed. Simulation results demonstrate the algorithm for a random time series containing real covariance and reveal an optimal time-of-day estimate for deployment of a ground-based soldier squadron based on Bayesian categorization of acquired ground spatial data.

With deployment of a soldier squadron based on drone time-of-day estimation, there is a desire to optimally estimate which direction the squadron should move based on enemy muzzle fire evidence emanating from four different directions. It is imagined that defence force assault rifles can detect the lethality of enemy-artillery in terms of strike distance (state) as well as the direction of fire (observations). (E.g. The more intense the acoustical signature of bullets hits registered by a sensor on a rifle are, the more lethal the artillery. Changes in light intensity from different directions measured by a sensor on a rifle provides muzzle fire information). Naïve Bayesian classification allows for understanding the conditional

relationship between observed muzzle fire flash direction and artillery hit range with respect to a soldier armed with a machine learning aided assault rifle.

A naïve Bayesian belief network (BBN) is used to estimate the state of artillery lethality conditioned on muzzle fire direction. Though the naïve BBN models lethality state as causing muzzle flash fire, which is physically untrue, the model still is useful for state calculation supporting decision making. Analysis of the mean and variances associated with low, medium, and high lethality states allows for understanding which direction has the highest variance suggesting enemy artillery fire ineptitude. This in turn suggests an optimal direction of movement in terms of incurring the least amount of casualties and damage. Simulation results using real turbulence data, which mimics the nonlinear relationship of gun fire and lethality, demonstrates how the direction associated with maximum variance of gun fire is estimated. The in-depth interpretation of the statistics for both the air-ground and ground-ground scenarios is the next stage of human machine teaming, where the machine provides statistical results, and the human interprets these results with the aim of suggesting actionable decisions.

Keywords: artillery lethality, clusters, decision making, drone, metadata, muzzle fire, naïve Bayesian belief network, naïve Bayesian classification, optimal direction, satellite, state estimation, time-of-day

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