University Defence Research Collaboration in Signal Processing

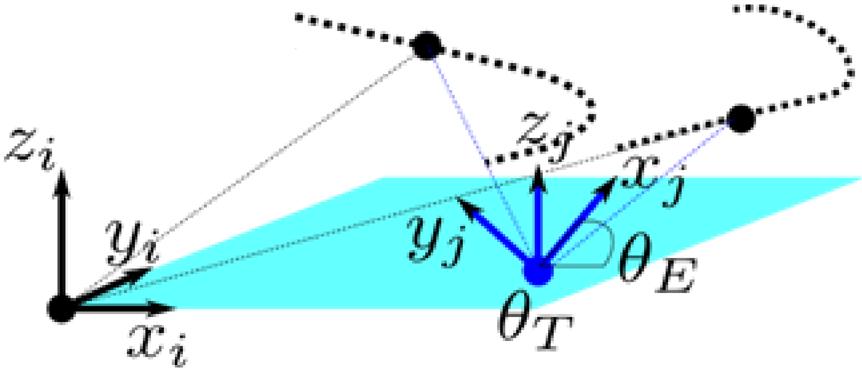
Edinburgh Consortium White Paper

A Scalable Sensor Localisation/Calibration Algorithm Using Objects of Opportunity in Wide Area Surveillance

Introduction

Wide area surveillance in defence and security contexts involves developing and enhancing situation awareness in which the required information is obtained using a large volume of data collected by several sensors (Figure 1). Typically, a common picture of the surveillance region is built by detecting entities, for example, vehicles and other objects of interest, and finding their trajectories over time. Enabling technologies facilitate exploitation of a large number of sensors by connecting them through a communication network, organising the sensor nodes for sensing tasks, and, efficiently processing the vast amount of data collected across the network.

Figure 1. Multi-sensor exploitation and collaborative signal processing for situation awareness (picture courtesy of IEEE Signal Processing Magazine)



An important step in network organisation is to find the locations and orientations of the sensor platforms which is known as sensor registration, or, calibration. This information is a pre-requisite for integrating the local sensor views into the common picture the network maintains (Figure 2). This is a crucial step for sensor integration or fusion as small orientation errors can result in large uncertainties in the fused output.

Figure 2. Illustration of the sensor registration problem: Two sensors have a view of two objects in their own coordinate system. In order to integrate these local views into a common picture of the surveillance region, one needs to know the respective locations (θ_T) and orientations (θ_E) of these sensors, which is known as the sensor registration problem.

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One way of solving the registration problem in these networks is to mount additional equipment on the platforms such as gyroscopes for measuring orientation angles and Global Positioning System (GPS) receivers for finding locations. Such solutions, however, are not always viable. For example, GPS systems cannot be used in underwater surveillance networks (Figure 3). Existing solutions often resort to use of anchor nodes with known location and beacons such as cooperative vehicles which necessitates a degree of human intervention. These undermine the ease-of-deployment, flexibility and robustness requirements from such networks. Such difficulties need to be considered even where GPS is available, due to its vulnerability to deception or jamming.

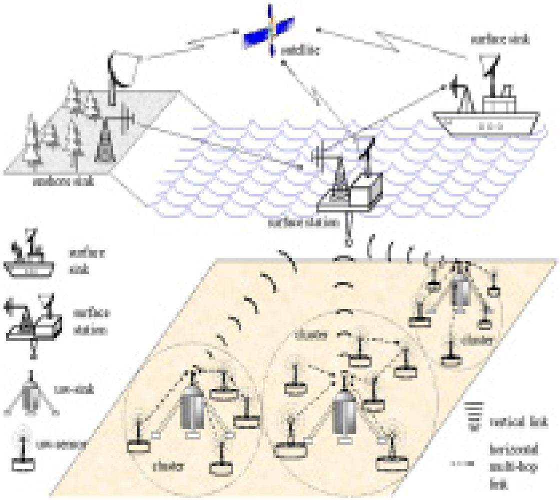

Figure 3. An underwater surveillance network (Akyildiz et. al. 2002).

Method

An alternative is to exploit the sensor measurements collected from the surveillance region. These consist of noisy measurements from the objects of interest as well as measurements from the surroundings which are referred to as “clutter”. In principle, these measurements can be used to locate all the nodes in the network, with respect to a selected platform as the origin of a network coordinate system. If all sensor measurements were to be routed to a centre for localisation, the network services would be at risk of failure, however, because of the high data rate. Not less importantly, the computational complexity of processing multiple sensor data in the case of multiple objects and high clutter rates is prohibitively high. Therefore, attention has to be paid to ensure that the resource constraints of the network such as limited communication bandwidth and processing power are taken into account, when designing processing algorithms for such networks.

With these considerations, we developed an algorithm [1] using a distributed processing paradigm. Our approach decomposes the global calibration problem across the network into smaller sub-problems and then combines solutions to these sub-problems in a consistent manner [2,3]. The computational structure of the algorithm consists of iterative message passing operations in which pairs of sensors assess the likelihood of their respective locations (or, orientations) and combine the results obtained for other nodes over the network.

Our algorithm combines the probabilistic graphical models and message passing algorithms framework with linear complexity multi-object tracking algorithms using a novel concept we refer to as “separable likelihoods”. Separable likelihoods lead to very accurate approximations to the original localisation problem while keeping the computational complexity linear in the number of sensors. This scalability feature together with the message passing structure makes it amenable for a distributed operation, as well as a parallel implementation at a fusion centre in the case of a centralised processing paradigm. Furthermore, it is capable of tackling with measurement noise and clutter. In a simulated distributed self-localisation scenario with noisy and cluttered measurements from a surveillance region, we have achieved an error margin of approximately 1% of the neighbouring platform distances. As a result, our algorithm stands out as a unique alternative to solve sensor localisation problems in GPS denied environments.

References:

[1] Murat Uney, Bernard Mulgrew, Daniel Clark, “A cooperative approach to sensor localisation in distributed fusion networks,” IEEE Transactions on Signal Processing, accepted for publication.

[2] Murat Uney, Bernard Mulgrew, Daniel Clark, “Cooperative sensor localisation in distributed fusion networks by exploiting non-cooperative targets,” IEEE Workshop on Stat.Signal Proc. 2014.

[3] Murat Uney, Bernard Mulgrew, Daniel Clark, “Target aided online sensor localisation for bearing only clusters,” SSPD 2014.