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Editorial

Distributed Mobile Sensor Networks for Hazardous Applications

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1. Introduction

A key justification for the use of robotic systems is for applications that are dull, dirty, or dangerous, where the use of robotic systems may reduce or eliminate the danger to humans working in an environment known to be hazardous.

Hazards may include nuclear, biological, or chemical contaminants, flood, fire, or earthquake damage as well as underwater, under-ice, down mines, and space exploration.

Hazardous applications include rescue missions, dealing with hostile targets, addressing potential terrorist threats, or any operation performed in a hazardous environment.

Distributed networks of robots may be deployed in such hazardous environments to effectively perform missions such as reconnaissance, surveillance, search and recovery, or resource harvesting. When mobile robots are used to host sensor and communication nodes for a distributed sensing network, the sensor network may achieve improved capabilities for detection and classification of potential targets and other objects of interest.

Intervention begins with gathering information about the nature of the problem. Sensor fusion in the context of distributed sensor networks has emerged as a leading method for implementing robust and efficient surveillance.

The “designer” of such distributed sensing systems has simple rules for the behavior of individual team members on one end and the overall objective function of the entire team at the other end. Observed in biological swarms, emergent behaviors are able to link these two ends, as also engineering approaches for the design of “Systems of Systems” can do.

For hazardous environments and applications, this special issue contains papers describing concepts, simulations, and real applications. The focus lies on sensor networks that have the additional features of control parameters in order to optimize the sensor and fused data quality. Implementing the resulting adaptive behavior into the robots lets the network advance towards its high-level goal.

2. Fusion and Performance Evaluation

S. Jiang et al. propose a new Linear Decision Fusion Algorithm under the Control of Constrained-PSO for WSNs. They state that a major application of a distributed WSN (Wireless Sensor Network) is to monitor a specific area for detecting some events such as disasters and enemies. In order to achieve this objective, each sensor in the network is required to collect local observations which are probably corrupted by noise, make a local decision regarding the presence or absence of an event, and then send its local decision to a fusion center. After that, the fusion center makes the final decision depending on these local decisions and a decision fusion rule, so an efficient decision fusion rule is extremely critical. It is obvious that the decision-making capability of each node is different owing to the dissimilar signal noise ratios and some other factors, so it is easy to understand that a specific sensor’s contribution to the global decision should be constrained by this sensor’s decision-making capability, and based on this idea, we establish a novel linear decision fusion model for WSNs. The authors employ the constrained particle swarm optimization (constrained-PSO) algorithm to control the parameters of this model. They also apply the typical penalty function to solve the constrained-PSO problem. The emulation results indicate that their design is capable to achieve a very high accuracy.

A. Skvortsov and B. Ristic discuss the modelling and performance analysis of a network of chemical sensors with dynamic collaboration. The problem of environmental monitoring using a wireless network of chemical sensors with a limited energy supply is considered. Since the conventional chemical sensors in active mode consume vast amounts of energy, an optimisation problem arises in the context of a balance between the energy consumption and the detection capabilities of such a network. A protocol based on "dynamic sensor collaboration" is employed: in the absence of any pollutant, majority of sensors are in the sleep (passive) mode; a sensor is invoked (activated) by wakeup messages from its neighbors only when more information is required. The authors propose a mathematical model of a network of chemical sensors using this protocol. The model provides valuable insights into the network behavior and near optimal capacity design (energy consumption against detection). An analytical model of the environment, using turbulent mixing to capture chaotic fluctuations, intermittency and nonhomogeneity of the pollutant distribution, is employed in their study. A binary model of a chemical sensor is assumed (a device with threshold detection). The outcome of their study is a set of simple analytical tools for sensor network design, optimisation, and performance analysis.

X. Sun and E. J. Coyle address the effects of motion on distributed detection in mobile ad hoc sensor networks. A large set of mobile wireless sensors observe their environment as they move about. The authors consider the subset of these sensors that each made observations about a brief, localized event at the time when near that location. As the sensors continue to move, one of them eventually finishes processing its observations, decides that an event of interest occurred, and wants to determine if other sensors confirm its results. This sensor thus assumes the role of a Cluster-Head (CH) and requests that all other sensors that collected observations at that time/location reply to it with their decisions. The motion of the sensors since the observation time determines how many wireless hops their decision must cross to reach the CH. The authors analyze the effect of this motion in the 1D case by modeling each sensor's motion as a Correlated Random Walk (CRW), which can account for realistic transient behavior, geographical restrictions, and nonzero drift. The authors also account for observation errors and errors in each hop in the wireless channel. Quantities, such as the error probability of the final decision at the CH and the minimum energy required to collect the local decisions from all relevant sensors, can then be directly calculated as functions of time and the parameters of the CRW, the measurement noise, and the channel noise. These results thus allow a rapid characterization of the time dependence of distributed detection algorithms that are being executed in realistic mobile sensor networks.

3. Energy and Topology Optimization

J. Jia et al. present theoretical analysis and simulations of energy balanced density control to avoid energy hole for wireless sensor networks. Density control is of great relevance for wireless sensor networks monitoring hazardous applications where sensors are deployed with high density. Due to the multihop relay communication and many-to-one traffic characters in wireless sensor networks, the nodes closer to the sink tend to die faster, causing a bottleneck for improving the network lifetime. The authors investigate systematically the theoretical aspects of the network load and the node density. Furthermore, the authors prove the accessibility condition to satisfy that all the working sensors exhaust their energy with the same ratio. By introducing the concept of the equivalent sensing radius, a novel algorithm for density control to achieve balanced energy consumption per node is thus proposed. Different from other methods in the literatures, a new pixel-based transmission mechanism is adopted, to reduce the duplication of the same messages. Combined with the accessibility condition, nodes on different energy layers are activated with a nonuniform distribution, so as to balance the energy depletion and enhance the survival of the network effectively. Extensive simulation results are presented to demonstrate the effectiveness of the new algorithm.

A. Jawahar et al. present a new capacity-preserved, energy-enhanced hybrid topology management scheme in wireless sensor networks for hazardous applications. A wireless sensor network is composed of large number of sensor nodes which are densely deployed in the field. These nodes monitor the environment, collect the data, and route it to a sink. The main constraint is that the nodes in such a network have a battery of limited stored energy, and if the nodes start to die, the network lifetime gets reduced. There are various topology management schemes such as SPAN, STEM, GAF, and BEES, for improving network parameters such as capacity, lifetime, coverage, and latency. None of these schemes will improve all the mentioned network parameters. In Sustainable Physical Activity in Neighbourhood (SPAN), some of the nodes become coordinators to form the backbone path and can only forward messages. A noncoordinator will check periodically whether it should become coordinator. SPAN preserves network capacity, decreases latency but provides less energy savings. Sparse Topology and Energy Management scheme (STEM) improves network lifetime by putting the sensor nodes either in monitoring state or in transfer state. STEM does not try to preserve capacity resulting in great energy savings and high latency. In the scheme proposed by the authors, a new coordinator rule is implemented in SPAN, and then integrated with STEM. The authors observe that the energy conserved increases by about 3.18% to 4.17% without sacrificing network capacity. Due to definite path in the proposed scheme the latency is reduced by almost half the latency of STEM scheme.

4. Applications

X. Dai et al. apply techniques for wireless communication networks for gas turbine engine testing. A new trend in the field of aeronautical engine health monitoring is the implementation of wireless sensor networks (WSNs) for data acquisition and condition monitoring to partially replace heavy and complex wiring harnesses, which limit the versatility of the monitoring process as well as creating practical deployment issues. Augmenting wired with wireless technologies will fuel opportunities for reduced cabling, faster sensor and network deployment, increased data acquisition flexibility, and reduced cable maintenance costs. However, embedding wireless technology into an aero engine (even in the ground testing application considered here) presents some very significant challenges, for example, a harsh environment with a complex RF transmission channel, high sensor density, and high data rate. The authors discuss the results of the Wireless Data Acquisition in Gas Turbine Engine Testing (WIDAGATE) project, which aimed to design and simulate such a network to estimate network performance and de risk the wireless techniques before the deployment.

S. Petillo et al. investigate the construction of a distributed AUV network for underwater plume-tracking operations. In recent years, there has been significant concern about the impacts of offshore oil spill plumes and harmful algal blooms on the coastal ocean environment and biology as well as on the human populations adjacent to these coastal regions. Thus, it has become increasingly important to determine the 3D extent of these ocean features ("plumes") and how they evolve over time. The ocean environment is largely inaccessible to sensing directly by humans, motivating the need for robots to intelligently sense the ocean for us. The authors propose the use of an autonomous underwater vehicle (AUV) network to track and predict plume shape and motion, discussing solutions to the challenges of spatiotemporal data aliasing (coverage versus resolution), underwater communication, AUV autonomy, data fusion, and coordination of multiple AUVs. A plume simulation is also developed as the first step toward implementing behaviors for autonomous, adaptive plume tracking with AUVs, modeling a plume as a sum of Fourier orders, and examining the resulting errors. This is then extended to include plume forecasting based on time variations, and future improvements and implementation are discussed.

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