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Structural Monitoring with Distributed-Regional and Event-based NN-Decision Tree Learning using Mobile Multi-Agent Systems and common JavaScript platforms

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Abstract

Among the Internet-of-Things, one major field of application deploying agent-based sensor and information processing is Structural Load and Structural Health Monitoring (SLM/SHM) of mechanical structures. This work investigates a data processing approach for material-integrated and mobile ubiquitous SHM and SLM systems by using self-organizing mobile multi-agent systems (MAS), executed on a highly portable JavaScript-based Agent Processing Platform (APP), and optimized Machine Learning (ML) methods providing load class recognition from a set of sensors embedded in the technical structure. Machine learning approaches usually require a large amount of computational power and storage resources and ML is commonly performed off-line, not suitable for resource constrained sensor network implementations. Instead, a novel distributed-regional on-line learning is applied, with on-line distributed sensor processing and learning performed by the agent system. The APP provides ML as a service, and the agent itself only collects training and analysis data passed to the APP, finally returning a learned model that is saved by the agent in a compact format (and is available on any other location). A case study shows that the learning algorithm is suitable (stable) for noisy and time varying sensor data. Spatial global learning is reduced and mapped on local region learning with global voting.

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1. Introduction

One major field of application deploying agent-based sensor and information processing is Structural and Structural Health Monitoring (SM/SHM) of mechanical structures. Structural monitoring derive not just loads, but also their effects to the structure, its safety, and its functioning from sensor data. A load monitoring system (LM) can be considered as a sub-class of SHM, which provides spatial resolved information about loads (forces, moments, etc.) applied to a technical structure. The integration of SM systems in and the composition of SM systems with devices from the Internet-of-Things (IoT) is a breakthrough in future cloud-based sensor and information processing (see Fig. **1**), with mobile agents as an enabling technology.

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One of the major challenges in SHM and LM is the derivation of meaningful information from sensor input. The sensor output of a SHM or LM system reflects the lowest level of information. Beside technical aspects of sensor integration the main issue in those applications is the derivation of a mapping function $F_m(S)$ which basically maps the raw sensor data input S, an n-dimensional vector consisting of n sensor values, to the desired information I, an m-dimensional result vector.

Basically there are two different information extraction approaches:(I.) First those methods based on a mechanical and numerical model of the technical structure, the device under test (DUT), and the sensor, and (II.) second those without any or with a partial physical model. The latter class can profit from artificial intelligence which usually bases on classification algorithms derived from supervised machine learning or pattern recognition using, for example, self-organizing systems like multi-agent systems with less or no a-priori knowledge of the environment.

Agents are already deployed successfully for scheduling tasks in production and manufacturing processes **[4]**, and newer trends poses the suitability of distributed agent-based systems for the control of manufacturing processes **[5]**, facing not only manufacturing, but maintenance, evolvable assembly systems, quality control, and energy management aspects, finally introducing the paradigm of industrial agents meeting the requirements of modern industrial applications by integrating sensor networks. Self-organization and adaptivity are central behaviours of complex distributed MAS. Mobile Multi-agent systems are already successfully deployed in sensing applications, e.g., structural load and health monitoring, with a partition in off- and online computations **[2]**. Distributed data mining and Map-Reduce algorithms are well suited for self-organizing MAS. Cloud-based computing with MAS, as a base for cloud-based design and manufacturing, means the virtualization of resources, i.e., storage, processing platforms, sensing data or generic information. Mobile Agents reflect a mobile service architecture.

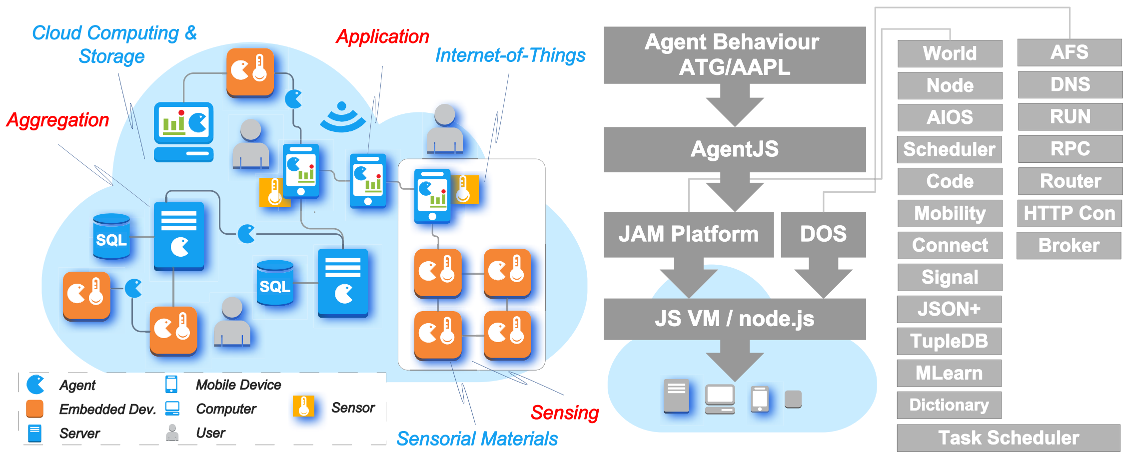

Figure 1: (Left) Distributed Structural Monitoring, Perception, and Information processing, finally integrating SM networks in the IoT using Multi-agent Systems as a unified processing model. (Right) Components of the JavaScript Agent Machine (JAM), explained in Section 3..

The scalability of complex industrial applications and ubiquitous systems, e.g., networks of smart phones, using such large-scale cloud-based and wide area distributed networks deals with systems deploying thousands up to million agents. But the majority of current laboratory prototypes of MAS deal with less than 1000 agents **[5]**. Currently, many traditional processing platforms cannot yet handle a big number of agents with the robustness and efficiency required by the industry **[5]**. In the past decade the capabilities and the scalability of agent-based systems have increased substantially, especially addressing efficient processing of mobile agents. The integration of sensor networks in generic computer networks and the Internet raises communication and operational barriers which must be overcome by a unified agent processing architecture and framework, discussed in this work.

Multi-agent systems can be used for a decentralized and self-organizing approach of data processing in a distributed system like a sensor network, enabling information extraction, for example, based on pattern recognition, decomposing complex tasks in simpler cooperative agents