A Summary of the RGS$^{\oplus}$ System: an RDF Graph Synchronization System for Collaborative Robotics

JAAMAS Track

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ABSTRACT

In the context of collaborative robotics, distributed situation awareness is essential for supporting collective intelligence in teams of robots and human agents, where it can be used for both individual and collective decision support. This is particularly important in applications pertaining to emergency rescue and crisis management. During operational missions, data and knowledge is gathered incrementally and in different ways by heterogeneous robots and humans. This paper aims to describe an RDF Graph Synchronization System called RGS$^{\oplus}$. It is assumed that a dynamic set of agents provide or retrieve knowledge stored in their local RDF Graphs which are continuously synchronized between agents. The RGS$^{\oplus}$ System was designed to handle unreliable communication and does not depend on a static centralized infrastructure.

KEYWORDS

RDF graph synchronization; multi-robot collaboration

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1 INTRODUCTION

This extended abstract briefly summarizes the work described in [5], where we address the issue of efficient data and knowledge sharing between multiple autonomous agents operating in the field. An example application targets providing support in coordinating rescue operations after natural or human-made disasters. In such scenarios, autonomous agents provide a means to quickly acquire situation awareness in the affected regions through maps, images, victim locations, etc. Such information is essential to increase the efficiency of rescue teams in time-critical life-saving activities [20]. Based on the collected information, a rescue operation can be planned to provide medical aid by professionals or deliver supplies using robotic platforms to where they are needed most. Because such operations rely on large volumes of data, agents normally do not have access to a full view of the collective situational awareness.

Generally, each team agent collects information contributing to local knowledge about the surrounding environment. Agents need to share their information with other team members to provide a globally consistent view of the entire environment. The data collected during a rescue operation ranges from low-level raw sensor data, such as images, to high-level semantic data, such as the location and status of victims. These data types have distinct properties and requirements when considering information sharing. The low-level raw sensor data usually has a very large volume and is acquired at high frequencies, while the volume of symbolic data is relatively small and has a lower update rate. The summarised article focuses on information with a symbolic representation that can be stored as Resource Description Framework (RDF) Graphs [17]. This is one of the components of a larger infrastructural multi-agent-based knowledge framework being developed to leverage heterogeneous teams of human agents and autonomous robotic platforms [12–15], which also covers bandwidth-intensive low-level data exchange.

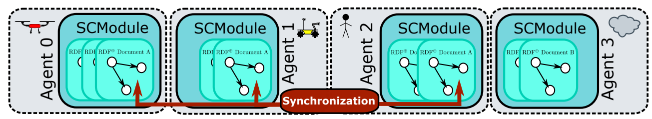

Figure 1: RDF Graph synchronization between four agents.

The purpose of the proposed RGS$^{\oplus}$ System is to ensure that all agents in a team have access to identical RDF Graphs for selected knowledge published by each agent. Consequently, all team agents have the same view of collective high-level knowledge after the synchronization process and can use it for reasoning and decision-making, allowing them to accomplish their goals. Fig. 1 depicts an example RDF Graph synchronization scenario among four agents. Agents advertise the availability of the knowledge stored locally as RDF Graphs to the RGS$^{\oplus}$ System, which synchronizes the advertised graphs automatically among the interested agents. The

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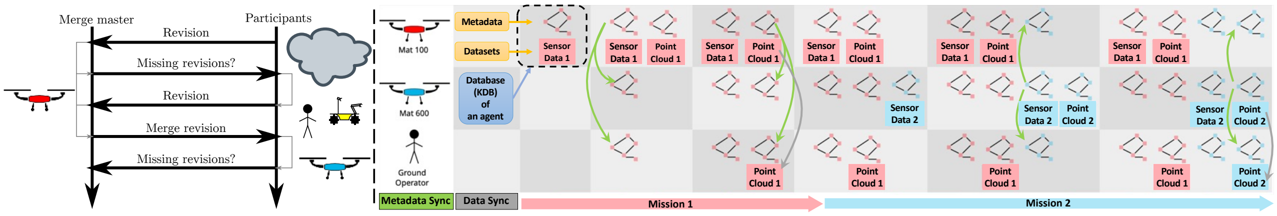

Figure 2: Left: RGS$^{\oplus}$ synchronization protocol. Right: Field robotics experiment timeline for dataset creation and exchange.

design of the proposed system has been driven by constraints and practical requirements of in-the-field search and rescue operations, namely, unreliable communication and a dynamic, changing population of agents. Thus, the proposed synchronization approach is fully automatic and does not rely on any human intervention. The RDF Graph synchronization problem and its aspects has been considered in previous works in different contexts to various extents: synchronization [3, 19], versioning [2, 6, 21], federated database systems [4, 18], and semantic web [1, 7, 16]. However, none of these approaches are applicable to collaborative robotics scenarios considered in this paper with the aforementioned practical constraints.

2 APPROACH

The RGS$^{\oplus}$ System comprises several algorithms with the synchronization approach inspired by concepts used in traditional code-versioning systems, such as Git. RDF Graphs created and stored by agents are encoded as RDF Documents [8]. To facilitate RDF Graph synchronization, the proposed system introduces the concept of an RDF$^{\oplus}$Document that includes the current instance of an RDF Graph and its history of changes. This history is represented using a *Graph of Revisions*, where vertices represent particular RDF Graph *revisions* and edges represent incremental differences (RDF *deltas*) between revisions. The RGS$^{\oplus}$ System uses custom *merge* and *rebase* algorithms to facilitate the RDF$^{\oplus}$Document synchronization between agents. The process is coordinated by a decentralized synchronization protocol (Fig. 2 left) where agents exchange information contained in RDF *deltas*, optimizing the amount of data that needs to be transmitted.

The system builds and retains a history of changes in RDF Graphs with cryptographic authentication of authorship. The decentralized approach relies on the dynamic selection of a master node among a set of available agents. The approach allows efficient synchronization among agents while propagating knowledge promptly, allowing for frequent updates to RDF Graphs. It also provides a general platform for future extensions, for example, reasoning about information sources to address issues of trust and providing a means to allow for selective access control to knowledge. The RGS$^{\oplus}$ System extends existing synchronization approaches by providing a discovery mechanism that allows handling changes to the team of agents, whether they come online, go offline, or lose communication.

3 RESULTS AND CONCLUSIONS

The proposed system has been implemented and integrated into actual robotic systems. Several empirical evaluations have been conducted to validate the performance, scalability, and applicability of the approach. These evaluations pertain to the proposed algorithms and the system behavior as a whole and include (1) a complexity analysis of synchronization algorithms, (2) an empirical validation of that analysis, (3) a simulation of the behavior of the system in realistic circumstances, and (4) a field robotic experiment. The two main algorithms (*merge* and *rebase*) used during the synchronization process have been shown to have quadratic complexity.

The field robotics experiment involves three agents: two Unmanned Aerial Vehicles (UAVs) and a Ground Operator (GOP). The GOP requests a 3D model (a point cloud) for two overlapping areas. This requires the exploration of two regions and the fusion of the acquired LIDAR data into a single point cloud. Exploration missions are executed using the two UAVs. Fig. 2 (right) shows the timeline for dataset creation, exchange, and the RGS$^{\oplus}$ System graph synchronization. In the first mission, the GOP selects an area in the user interface (UI) and executes a point cloud data request query. The system checks for existing data in the metadata RDF Graph. Since no existing data is available to answer the operator's request, a scanning mission for the region is automatically generated and delegated to a DJI Matrice 100 UAV [10] to acquire raw LIDAR data, which is then saved in the UAV's knowledge database. After the mission, the data is combined into a point cloud covering the requested area. The data is then synchronized between the UAV and the GOP and displayed in the UI. In the second mission, the GOP selects another area in the UI and executes a point cloud data request query. As existing data in the overlapping region is available to answer the request partially, some results can be reused and shown directly to the user. A scanning mission for the missing part of the newly requested area is automatically generated and delegated to a DJI Matrice 600 Pro UAV [11]. After this mission, the data is combined into a point cloud covering the newly selected area, including data previously gathered. The data is then synchronized between the UAV and the GOP and displayed in the UI.

The RGS$^{\oplus}$ System has been developed as the basis for a pragmatic knowledge management system for synchronizing RDF Graphs among a dynamic set of agents. Results of empirical evaluations in simulation and field robotics experiments show the performance and scalability of the proposed RGS$^{\oplus}$ System and its applicability to realistic real-world deployments. The implementation of the proposed algorithms has been released as an open-source project [9].

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