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A multi-agent system for meteorological radar data management and decision support☆,☆☆

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ABSTRACT

The continuous processing and evaluation of meteorological radar data require significant efforts by scientists, both for data processing, storage, and maintenance, and for data interpretation and visualization. To assist meteorologists and to automate a large part of these tasks, we have designed and developed Abacus, a multi-agent system for managing radar data and providing decision support. Abacus' agents undertake data management and visualization tasks, while they are also responsible for extracting statistical indicators and assessing current weather conditions. Abacus agent system identifies potentially hazardous incidents, disseminates preprocessed information over the web, and enables warning services provided via email notifications. In this paper, Abacus' agent architecture is detailed and agent communication for information diffusion is presented. Focus is also given on the customizable logical rule-bases for agent reasoning required in decision support. The platform has been tested with real-world data from the Meteorological Service of Cyprus.

1. Introduction

Environmental data management and surveillance, especially for hazard identification and forecasting, require significant efforts for the operational integration of environmental monitoring devices, such as sensor networks, radars and satellites. Information technology contribution is essential for overcoming interoperability obstacles and disseminating environmental information effectively and accurately. Existing monitoring devices and networks need to be coupled with software applications that enable open services, making recordings available to wider audiences. Issues of transparency, interoperability and reusability are at stake. To achieve these objectives, legacy environmental monitoring infrastructure require to be extended with modular, flexible software interfac es that provide with inputs to Environmental Decision-Support Systems for hazard identification and incident forecasting.

In this background, this paper presents the development of a software system, called Abacus, that effectively captures, processes and delivers data recorded by a meteorological Doppler radar. Abacus has been developed as a multi-agent software tool for meteorological radar data management and decision support. Agent-based computing has been selected as a means for achieving modularity and service-orientation properties.

Cross-disciplinary innovations related to both software agent technology and meteorology are presented in the paper. Section 2 gives the background of the meteorological radar 'Kykkos' of the Meteorological Service of Cyprus, and the common problems in its daily operation. In Section 3, Abacus system requirements are specified and the adoption of an agent-oriented approach is discussed. Next, Section 4 specifies the architectural design and details Abacus' generic agent types, each one of which undertakes specific tasks. Of particular interest is a community of artificial 'meteorologist' agents that take over decision-making responsibility for parts of the radar scan. Each member of the community is assessing the weather in its own niche. Both local and global decision making of Abacus' agents using rules is detailed as well. Section 5 presents agent communication and the ontology of the system, along with

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☆☆ Abacus software is available for free for academic use. Please contact authors to obtain a copy.
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system implementation details and the demonstration, using actual recordings from 'Kykkos' radar. Finally, the paper concludes with discussing the main findings of the reported work, gives pointers to related work and raises issues for future work.

2. The meteorological radar Kykkos

2.1. Meteorological radar details

The Doppler radar of the Meteorological Service of Cyprus is installed on the northwestern mountainous region of the island. The radar is established near Kykkos medieval monastery; hence, it is named after it. The radar *Kykkos*' characteristics are comprehensively shown in Table 1. Kykkos' antenna is able to execute a complete rotation of 360° on the horizontal plane, while changes its vertical target for distinct elevation levels. Kykkos' beam is reflected by the clouds or other obstacles within its range. In this manner, Kykkos radar scans provide a three-dimensional overview of the atmosphere around the island. Kykkos is operated remotely from Larnaka Airport, where the Weather Forecasting Office of the Meteorological Service of Cyprus is located. The radar may operate in two modes: In the surveillance mode, radar scans are projected on a terminal monitor in real time, while in the off-line mode, radar data volumes are acquired, according to predefined scan strategies and consequently are stored in a local hard disk.

2.2. Radar use and limitations

Kykkos radar operates in order to assist the weather forecasters of the Meteorological Service of Cyprus in very short term forecasting practices. More specifically, radar data are used for:

(a) the surveillance of the weather conditions in real time;
(b) the identification of precipitation patterns within the area covered by the radar; and
(c) the forecasting of extreme events and the issue of related warnings.

These activities require the engagement of meteorological scientists, who are responsible for acquiring radar's data, preprocessing them appropriately, and ultimately making decisions. This process involves data filtering and restoration activities, as radar's reflections are disturbed by natural obstacles that cause beam's occultation and ground clutter problems (Golz et al., 2006).

Beam Occultation is observed when the radar beam is blocked by the presence of obstacles (mountains or hills). This causes the alteration of the reflection value of the beam. The beam can be blocked totally or partially. In the latter case the radar beam can pass over the mountain, but the measurement is disturbed.

Ground Clutter is the disturbance that is caused when the radar beam hits the terrain, and an echo occurs. This echo can be considered as rain signal by mistake. The only characteristic that makes the Ground Clutter reflections differ from real reflections is their time permanency (zero velocity). Thus, in order to minimize the effect of this phenomenon zero velocity echoes must be neglected. Ground clutter is the reason that the radar detects strong echoes both when the sky is clear and when heavy rainfall occurs.

Beam occultation and ground clutter phenomena depend on the surrounding terrain morphology. Fig. 1 illustrates a segment of radar reflections, where areas of zero velocity echoes due to some mountains in the region that destruct beam reflections are apparent. These disturbances have been taken into consideration through the design of the Abacus system, so as to reduce their negative side-effects in the decision-making process.

The current settlement of Kykkos radar requires an operator (a human expert) that continuously monitors the radar's reflections and decides upon interesting events (incidents). Either operating in the surveillance, or in the off-line mode, the continuous evaluation of radar data requires significant efforts by the meteorologists, for data processing, storage, and maintenance, along with data interpretation and visualization.

Table 1
Kykkos' radar parameters.

Transmitter–receiver	
Peak power	158 kW
Frequency	5.7 GHz
PRF	250 Hz and 1180 Hz
Pulse duration	2 μs and 0.7 μs
Antenna	
Diameter	2.5 m
Beam width at half power	1.1°
Power gain	44 dB
Polarization	Horizontal
Data features	
Maximum range used	120 km
Radial resolution	500 m
Number of power levels	80 (−15 dBz to 65 dBz)

3. System requirements and methodology

3.1. System goals

For supporting meteorologists in their activities, we developed a software agent-based system for managing radar data and decision support, called *Abacus*. Abacus constitutes a middleware software system that intervenes between Kykkos radar and the meteorologists and provides advanced services to the Meteorological Service of Cyprus. Abacus system is envisioned as a platform of autonomous, artificial 'meteorologist agents' that undertake Kykkos radar data management and exploit appropriately all information that it produces. Specifically, the system's main objectives concern:

(a) the data review, transformation and preprocessing of radar's scans;
(b) the identification of weather conditions at real time and their evolution through time;

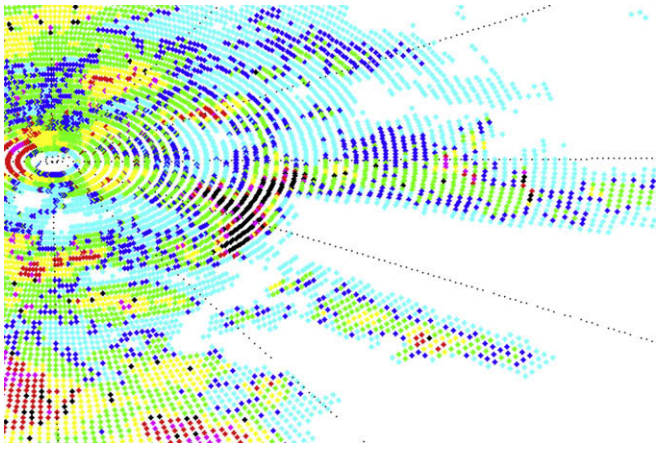

Fig. 1. Radar reflections are disturbed by natural obstacles, therefore some measurements are distracted or missing.