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The Evolution of Disaster Early Warning Systems in the TRIDEC Project

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ABSTRACT

The TRIDEC project (Collaborative, Complex, and Critical Decision Processes in Evolving Crises) focuses on real-time intelligent information management in the Earth management domain and its long-term applications. It is funded under the European Union's seventh Framework Programme (FP7). The TRIDEC software framework is applied in two application environments, which include industrial subsurface drilling (ISD) and natural crisis management (NCM).
For each domain, three consecutive demonstrators with extended capabilities are developed and field-tested during the projects lifespan. This article focuses on the technical advances achieved by the light-, mid- and heavyweight NCM demonstrators for Tsunami Early Warning.

KEY WORDS: Tsunami Early Warning System; TRIDEC; System of Systems; Mediterranean Sea, critical decision-support.

INTRODUCTION

Early warning of natural or man-made disasters is a major element of disaster risk reduction and decision-support. Its overall objective is the prevention of loss of life and the reduction of economic losses to a minimum.

TRIDEC is a IT Research Project in the European Union's Framework Programme (FP7) focusing on new approaches and technologies for intelligent information management in collaborative, complex and critical decision processes in earth management.

The goal of TRIDEC is to develop a software framework for Collaborative, Complex and Critical Decision-Support in Evolving Crises. For this, the key objective is the design and implementation of a collaboration infrastructure of interoperable services through which intelligent management of dynamically increasing volumes and dimensionality of information and data is efficiently supported thus enabling multiple decision makers to respond quickly to the developing crisis situation via a collaborative decision-support environment. Collaborative computing is used to establish a decision-support enterprise system of services which can timely deliver critical information to decision makers during environmental crises such as tsunamis or during the drilling processes of an exploration well. This TRIDEC software framework is applied in two distinct application environments. These are industrial subsurface drilling (ISD) and natural crisis management (NCM).

This article focuses on the technical and functional advances achieved by the three consecutive TRIDEC NCM demonstrators and their installations for Tsunami Early Warning in the Mediterranean.

BACKGROUND

The natural disaster of the Boxing Day Tsunami of 2004 was followed by a communications-related catastrophe as crucial early warning information could not be delivered to communities under imminent threats. This tragedy triggered various international efforts for the implementation of a tsunami early warning infrastructure, coordinated by the UNESCO/IOC (ICG/NEAMTWS, 2009; ICG/NEAMTWS, 2011; TOWS-WG, 2011; UNESCO, 2011). While significant advances were accomplished, recent events, like the Chile 2010 and the Tohoku 2011 tsunami demonstrate that the key technical challenge for Tsunami Early Warning research on the international scale still lies in the timely issuing of status information and reliable early warning messages.

In addition, there is also the second challenge concerning the integration of national Tsunami Early Warning Systems (TEWS) towards ocean-wide networks: Each of the increasing number of integrated Tsunami Early Warning Centres has to cope with the continuing evolution of sensors, hardware, software and increase of data volumes, while having to maintain reliable inter-center information exchange services.

TSUNAMI EARLY WARNING SYSTEMS (TEWS)

TEWS are distributed software and hardware systems which support the reliable detection of imminent tsunami hazards, the rapid situation assessment and the targeted dissemination of customised warning messages. TEWS infrastructures consist of national and regional warning centres (NTWC: National Tsunami Warning Centre; RTWC: Regional Tsunami Watch Centre). RTWCs operate as a hub for several NTWCs and coordinate the exchange of regional tsunami related information. NTWCs are responsible on the national level according to respective national legal frameworks and provide warnings, watches and advisories to their citizens, public and private agencies (ICG/NEAMTWS, 2009). TEWS are long evolving: New sensor- systems and types will be developed and deployed, sensors replaced or redeployed and the functionality of analysing software improved. To ensure continuous operability a system's architecture must be enabled to scale and perform despite the increase in information volume and complexities.

PREDECESSOR PROJECTS

The GITEWS project (German Indonesian Tsunami Early Warning System), funded by the German Federal Ministry of Education and Research (BMBF) addressed the challenges of early warning for near-field Tsunami with limited reaction times (Lauterjung et al. 2010; Fleischer, 2010). This was complemented by the DEWS project (Distant Early Warning System), funded under the European Union's sixth Framework Programme (FP6), which focussed on both the multi-channel warning dissemination in a multi-lingual environment and the communication between warning centres in South East Asia (Hammitzsch *et al.,* 2009). Both projects took on the task to develop an overall generic architecture for TEWS based on best practices and the results of international standardisation activities in the geospatial domain and the information and communication technology (ICT) community. This included both service-oriented architecture design based principles and specifications from the Open Geospatial Consortium (OGC) for geodata sensors and measurements (Percivall, 2010). The projects also laid the foundation for the design of collaborative decision-support environments such as those investigated in the TRIDEC project.

THE TRIDEC PROJECT: RESEARCH AND DEVELOPMENT STRATEGY

The TRIDEC project (Collaborative, Complex, and Critical Decision Processes in Evolving Crises) funded under the European Union's seventh Framework Programme (FP7) continues on the line of work of its predecessors, as it focusses on real-time intelligent information management in the Earth management domain together with its long-term application (Sabeur *et al., 2011).* Progress in the field of Earth management and especially natural crisis management (NCM) results on the one hand from advances concerning the scientific understanding of natural phenomena combined with improved scientific modelling approaches. On the other hand, all practical advancements are closely related to the rapid development of Information and Communication Technology (ICT): From the perspective of ICT, TEWS are perceived as integrated software- and hardware systems for data acquisition, decision making and information dissemination which support the detection and analyses of imminent hazards and the customised related warnings. So the strategy of TRIDEC is to foster innovation in the integration and enhancement of state-of-the-art technologies with the aid of semantic technologies which provide flexible and integrated Decision Support Services (DSS) in the TRIDEC application scenarios, on collaborative, complex and evolving decision-support.

THE TRIDEC SYSTEM ARCHITECTURE

Incremental Architecture

The research and development activities of TRIDEC follow a spiral approach consisting of three cycles in total. Each cycle comprises requirement analysis, design and development activities followed by test phases so that the results of the project can be repeatedly validated against the requirements of the respective user domains.

System of System - Approach

The build-up of Tsunami warning infrastructures for ocean basins depends on the capability to integrate national and local TEWS into a System-of-Systems (SoS). Each of the systems is developed and operated independently. In a SoS, a set of independent loosely-coupled systems cooperate to realize complex collaborative tasks, bridging organizational, national and technological barriers (Häner *et al.,* 2012). For TRIDEC, the SoS-related challenge is on real-time crisis management to fulfil common and complex tasks in crisis management in a basin-wide TEWS. Therefore, the overall TRIDEC architecture was planned with an emphasis on the federated nature of the overall system. The interoperability between components in one TEWS as well as the interaction between different TEWS as part of the SoS is determined by the degree of the standardisation of interfaces, data exchange formats and protocols. Building a SoS requires a scalable and resilient communication layer as its basis. Core component in such a loosely-coupled system-of-systems are message- and event-oriented brokers. TRIDEC advances the current state of the art for TEWS Reference Models to accommodate for such basin-wide warning infrastructures (Moßgraber *et al.*, 2012).

Messaging Infrastructure / Message Oriented Middleware

To enable distributed applications and distributed systems in heterogeneous environments to communicate with each other a resilient Message-oriented middleware (MOM) was put in place. Subsystems are designed and implemented with different programming languages (e.g., Java, C#) and deployed on different operating systems (e.g., Linux, Windows). Such heterogeneity requires a standard and open communication layer that allows loosely-coupled and asynchronous communication between the heterogeneous sources.

Data Management

For the handling of federated multi-domain heterogeneous data TRIDEC adopted a broker-based mediation design pattern for access and transformation of data between domains, focussing on scalability over raw performance. The mediation pattern is a scalable approach, allowing domain brokers to be added incrementally but suffers from a performance penalty by adding an extra 'hop' to the information workflow.

Semantic Registry

The management of resources is generally the responsibility of local, in parts very heterogeneous stakeholders. Therefore, in evolving crises it is essential to be able to discover and permanently keep track of all potential and factually available geo-distributed resources at all times based on metadata descriptions of their purpose and capabilities. This is essential for planning and disposition purposes. As a solution, the architectural approach is based on multiple semantic registries hosted by the stakeholders, who manage the resources in their responsibility. Each semantic registry provides a number of human and programmatic interfaces (frontends) and a local ontology store based on standards.

Business Process Management for workflow orchestration

Coordination of work between spatially distributed systems for crises management implies providing support to a potentially high number of stakeholders and actors who play different and changing roles within a crisis and who require individual access to a multitude of resources – including other actors – in order to be able to make timely and well-founded decisions.

Events via the MOM trigger standard or locally adapted workflows and rule sets on each of the nodes of the network. This kind of message-based event processing allows for complex and rich choreographies where each node can react specifically in accordance with local rules as well as on global constraints. The encoding of rule sets and the adaptation of workflows is carried out by the domain experts.

NATURAL CRISIS MANAGEMENT (NCM) DEMONSTRATORS

The TRIDEC Natural Crisis Management (NCM) demonstrators address collaborative information management and decision-support processes in a hypothetical natural crisis situation caused by a tsunami in the North East Atlantic/ Mediterranean (NEAM) regions. The quality levels, functionality and complexity of the NCM system and application demonstrators are increasing step by step and are driven by the cyclic development process. In addition to the task to provide early warning on a national scale, it is paramount to provide such service also on a supra-national scale for the affected ocean basin. This requires a collaborative regional infrastructure, integrating the differing national infrastructures and decision taking approaches, to enable appropriate and reliable early warning dissemination for affected nations. Once a crisis situation occurs, incoming observations and situation assessments must be shared among the involved national and regional crisis management systems. This iterative process assures that an evolving crisis cannot go unnoticed. Specifically, national-scale systems shall be enabled to deliver observations and measurements for regional systems thus providing additional input for the successful handling of the crisis situation. Furthermore, if a single system fails or is taken out, this can be compensated by the remaining systems by either partially or fully taking over the crisis-related decision-support services.

First Phase: Light-weight Demonstrator

The first phase of TRIDEC focused on requirements engineering, core system architecture, the knowledge base, the orchestration and workflow components customized decision-support as well as the development of the TRIDEC demonstrators. Foundational research explored new approaches for the TRIDEC system of systems architecture, services integration and the design of intelligent storage and retrieval of data and information from the TRIDEC knowledge-base.

The TRIDEC knowledge base services specialized in two major components. They are:

1- Structured data fusion services for situation awareness
2- Semantic services for context awareness

Software development focused on requirements engineering, core system architecture, the knowledge base and the orchestration and workflow components. The outcome was a **light-weight system** consisting of the core common components, integrated with a simple Decision Support System (DSS), knowledge base (KB) and basic user information access, and also supporting an event bus and a simple version of the service bus, and a resource, component and service repository. The development of applications included the implementation of collaborative user interfaces and enabled the adoption of legacy systems. The preparation of realistic test bed environments resulted in the first light-weight TRIDEC demonstrator, which was released in October 2011.

Second Phase: Mid-weight Demonstrator

During the second phase of TRIDEC development cycle, research and development activities focused on the middleware, the knowledge base and the decision support components to enhance scalability and resilience: The light-weight TRIDEC system was extended towards a **mid-weight system**, including a shift of focus from a message-oriented-middleware (MoM) towards a more general system of systems (SoS) perspective. Consequently, enhanced core components, like the knowledge-base and decision support, were integrated as sub-systems to the TRIDEC MoM. Also, a full enterprise service bus and security services were implemented to allow operators of the data acquisition sites to help protect the confidentiality and integrity of their data. Additionally, prescribed work-flows for more extensive thematic services are supported.

For the NCM mid-weight application demonstrator, the key objectives were the enhancement of the sensor integration platform (SSB) and the Command and Control User Interface (CCUI) to comply with the MOM and greater SoS concept and to investigate in the application of new sensors. Design changes necessitated by the performance, resilience and scalability modeling were included. For information logistics and dissemination, the dissemination channel adapter and the Affected Area Identification Service (AAI) were re-implemented, and a message template engine for NEAMTEWS warning dissemination was added. The overall workflow of the mid-weight demonstrator adheres to the NEAMTEWS specifications and includes the NEAMTEWS decision matrix knowledge-base. Another key objective for the NCM mid-weight demonstrator was the deployment of installations to gain real-world experience: TRIDEC NCM software instances were installed at the Meteorological, Climatological and Geophysical Agency (BMKG) in Jakarta, Indonesia, the Kandilli Observatory and Earthquake Research Institute of the Bogazici University in Istanbul (KOERI), Turkey and the Instituto Portugues do Mar e Atmosfera (IPMA) in Lisbon, Portugal. The latter two installations were successfully used in the context of the NEAMWave 2012 exercise (Hammitzsch *et al.*, 2013).

Final Phase: Heavy-weight Demonstrator

In its third and final phase, the TRIDEC system will be extended to a **heavy-weight system** including a fully functional multi-bus supporting multimedia streaming as well as advanced DSS and KB sub-systems. The heavy-weight system is being developed to support the dynamic composition of individual work-flows and to respond to evolving conditions, which can be orchestrated and controlled at run-time. The heavy-weight semantic services, which are under development, provide the support to querying observation and measurement data and information from the knowledge using Open Geospatial Consortium (OGC) sensor web enablement (SWE). Further work is currently progressing to automate the reporting of results to regional and National Centers. The structured data fusion and modeling services are deployed to pre-process data on demand and in accord with regions of interest to support matching scenario analyses for the selection of the most appropriate tsunami wave propagation simulation. Further work is currently under completion to support the matching scenario service that is based on the automated detection of the likely tsunamigenic signals measured around a network of tide gauges in an offshore region of interest (Sabeur *et a.,l 2012).* The heavy-weight TRIDEC NCM application demonstrator will be released in August 2013.

THE ROAD AHEAD

While ICT has become the driving factor for the architectural and functional evolution of TEWS, ICT infrastructures are themselves affected by technological and economical mega-trends. Such emerging and existing trends are expected to have a growing and lasting impact on TEWS development. Among these are cloud computing, ubiquitous sensing, integration of Earth Observation (EO) systems (Löwe *et al.*, 2013) and volunteered geographic information. Especially cloud computing provides a new paradigm for TEWS applications: Data may be virtually hosted in a reliable, performing and scalable way on a pay-per-use basis by a cloud infrastructure provider. However, for any kind of early warning system, it will be critical to prove that the range of functions can also be reliably offered as cloud-based software services.

CONCLUSION

Information and communication technology (ICT) has become the driving factor for Tsunami Early Warning Systems (TEWS). IT concepts such as service-based architecture (SOA), system of systems (SoS), middleware and semantic services are being turned into the pillars of standards-based software infrastructures connecting national and regional TEWS within ocean basins. The TRIDEC project develops such a flexible software framework with one specific application field being natural crisis management (NCM) for Tsunamis in the North East Atlantic / Mediterranean (NEAM) region. The research and development activities of TRIDEC follow a spiral approach consisting of three cycles in total. Each cycle produces demonstrator NCM applications with extended functionalities. These are used as local TEWS instances to be connected in a system of systems by the end of the project. Reliability and capabilities of the current TRIDEC NCM software have been demonstrated during the NEAMWave 2012 Tsunami exercise in the Mediterranean.

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