Generic Reconstruction and Analysis for Simulations or Live Exercises

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ABSTRACT: *A detailed After Action Review (AAR) is essential to get the most out of a live exercise or training simulation. An effective AAR requires an overall picture of all the actions and events that took place during the exercise. Compiling such an overall picture is often a complicated task, because the different participants all perform their own data logging, resulting in many separate data logs, often in different data formats.*

TNO's Generic Reconstruction And Computing Environment (GRACE) has been developed for quickly compiling the overall picture of a live exercise or training simulation. GRACE can process various data formats and provides various tools for the analysis, integration, and visualization of logged data, making it possible to create a complete reconstruction of an exercise. Its flexible architecture allows the addition of new data formats or new analysis tools. GRACE has been proven successful during several live firings.

This paper describes the innovative architecture and ideas behind GRACE. We will discuss how GRACE handles, interprets and combines data, how the framework was designed to be generic and flexible for extensions, and we will give examples of our experiences with the tool.

1. Introduction

Analysis of live firings has always been of great importance to the Royal Netherlands Navy (RNLN). This analysis is done by the RNLN's Maritime Doctrine and Tactics Centre (MDTC). In the past, the MDTC used several custom made tools for analyzing the various data logs produced during live firings. The introduction of the new Air Defence and Command Frigates (ADCFs) in 2002, however, meant both an increase in live firings (to test the new combat management systems) and an increase in the amount of logged data. This resulted in the need for a new, better analysis tool.

Since TNO (the Netherlands Organization for Applied Scientific Research) had already years of experience with the onboard logging and analysis on the Dutch Walrus submarines, we were asked by the RNLN to build this new tool. The result is GRACE, which stands for Generic Reconstruction And Computing Environment. GRACE allows both a *quick onboard* After Action Review (AAR), giving the crew a 3D reconstruction of the exercise, and a *detailed* AAR (usually ashore at the MDTC), in which the actual data can be analyzed using a combination of charts, tables, 3D visualization, and audio and video recordings.

In this paper, we will first describe how RNLN exercises were analyzed in the past and which problems were encountered in doing this. Then we explain GRACE's architecture, focusing on how we created a generic and flexible framework that could fulfil the RNLN's needs. Finally, we show how GRACE has already been used for

analyzing live firings, and highlight some of the other purposes for which GRACE is currently used.

2. Analyzing Exercises

Analysis of data collected during exercises or live experiments requires that the logged data is made available and that data from different sources is combined and processed.

In the past, the data of an exercise was often available only on paper print-outs (telemetry data) or on dedicated hardware with dedicated software. This made it difficult to make the data available for other applications on other platforms. Processing the data was a labour-intensive process, because the processing of could not be computerized.

In the current situation, a lot of data is logged during an exercise. The different kinds of data are now easier accessible because more and more standard hardware (PC platforms), standard software (such as Linux, Unix, and Microsoft Windows), and standard protocols (like TCP/IP) are used. Also the analyzing facilities have improved: 3D visualization is normal and the data can be processed in tools like MATLAB and Microsoft Excel.

2.1 Challenges

A lot of data can be logged for analyzing purposes, but as a consequence, a lot of data also needs to be processed and stored. The storage and processing of this data needs to be robust, because the data of the expensive exercise needs to be saved carefully.

The logged data is easier accessible, but is still stored in different formats by the different sources. Although the data can be read, the meaning of each detail of the data of a certain format is not always known, and each detail does not need to be known always.

Logged data from the different sources needs to be aligned to each other: the data in different data logs may have different positional offsets or time offsets. These offsets problems need to be detected and solved.

Another problem are data gaps: sometimes some information in a data log is missing, for example due to temporary loss of telemetry links.

Different sources may log the same kind of data, for example the GPS location. One source needs to be chosen to be used as the “master” to integrate the data logs. Sometimes, the different sources use a different precision, which can be the selection criterion in such cases.

If all these problems can be solved, data reconstruction after an exercise can provide a mixed reality opportunity to the analysts and participants. For instance, a combination of data from a live-firing and the simulation of a live-firing can create more analysis results and can also create new and deeper insights.

3. Architecture Aspects of GRACE

There are two main architecture aspects we want to discuss in this paper. The first aspect concerns the software design, which makes use of a plug-in structure. The second aspect is the way in which we handle the data within GRACE.

As said, GRACE uses a plug-in structure (see Figure 3.1). The framework of GRACE provides only the basic aspects, such as a database connection and the layout of the user interface. All other functionality is placed into plug-ins. We decided to use a plug-in structure because it allows bug fixing existing functionality, or adding support for a new data format, without the need to update the whole application. Especially during an actual exercise, this can be an important issue. Plug-ins also ease the distribution of GRACE with an appropriate set of data format plug-ins.

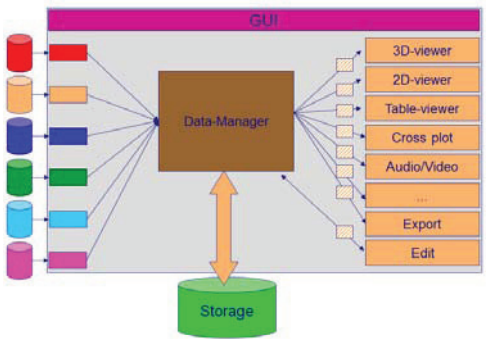

Figure 3.1: The architecture of GRACE

There are two kinds of plug-ins in GRACE: data format plug-ins and user interface plug-ins. A data format plug-in contains the knowledge required for importing and interpreting a data log in a certain data format, for example GPS data. A user interface plug-in contains a user interface module, allowing a user to perform actions like editing, visualizing, managing, or exporting data. The user interface plug-ins use the data format plug-ins for interpreting all data.

The data handling in GRACE is based on two principles: all data from a data log is imported, even if some parts of the data cannot be interpreted (yet) by GRACE, and all data are imported into a fixed data structure.

Before discussing the data import, we first want to explain how GRACE's data structure is built up. This data structure consists of projects, groups, and tables. A project is supposed to contain all data relating to a single live firing or training exercise. Within a project, there are groups. A group is a set of all data relating to (or originating from) one participating entity, like a ship or a drone. A group consists of tables. A table is a set of similar data, dependent on the kind of the original data log.

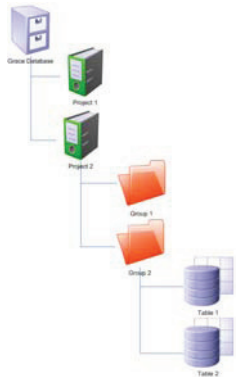

Figure 3.2: Organization of data

Importing a data log in GRACE consists of two steps: placing the data into GRACE's database in the described data structure, and actually interpreting the data. For the first step, it is only required that the input data can be split into records, where each record must contain a time stamp. All records are stored in the database with their time stamps as keys. Records may be divided over different tables, based on a key field in the record (if the input contains multiple types of data lines).

Note that the contents (other than time stamp and possible key) of the records are not interpreted at this stage. The records are stored in the database as raw data (BLOBs, Binary Large OBjects), even if the data is pure text. The reason for using BLOBs is that in this way all data can be stored, even if some parts of the records cannot be interpreted (yet).

Currently, GRACE has plug-in support for importing data logs in about 15 formats. These formats were added based on the needs of the RNLN on the one hand, and the needs of several projects within TNO on the other hand. Although GRACE has the flexibility to be extended easily with support for new data formats, this cannot be done by a user. Therefore we have recently added a "Generic Importer", allowing users to import text and Microsoft Excel data logs for which no data format plug-in is available. Users can specify how fields should be interpreted, for example as date, time, position, heading, or speed.

GRACE has originally been designed to work with a database developed at TNO. The reasons for choosing this database were its good performance and easy of use. Recently, we have added support for connecting to an arbitrary SQL database.

4. The Use of GRACE in Practice

All user interface modules of GRACE are plug-ins. Figure 4.1, which is a screenshot of GRACE, shows the following user interface modules:

- Workspace Viewer;
- 2D Viewer;
- Clock;
- Attribute Chart;
- Gantt Chart;
- Calculator.

Other user interface modules are:

- SIMDIS Exporter;
- Excel Exporter;
- Data Fixer.

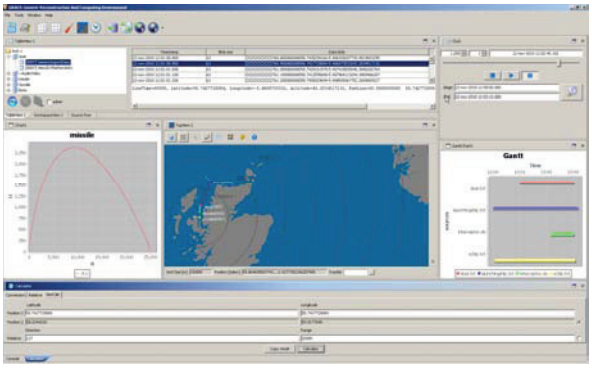

Figure 4.1: Screenshot of GRACE

4.1 Workspace Viewer

The Workspace Viewer allows browsing through all projects, groups, and data. It is similar to the Microsoft Windows Explorer: folders are similar to projects and groups, and files are similar to tables. Each table consists of records.

Next to examining the data, commands (provided by plug-ins) can be performed on selected elements in the workspace viewer, for example “Export to Excel”.

4.2 2D Viewer

Using the 2D Viewer, showing a top view and a selectable side view, it is possible to get a quick impression of the total situation, and to align the data (in position and/or time) from the different sources into one coherent picture.

4.3 Clock

When opening a project in GRACE, a session is created. A session is the combination of a project and a “current time”. Several user interface modules (such as the Workspace Viewer and 2D Viewer) are synchronized to that current time. The Clock module allows changing the current time or playing over the period that is covered by the data. It is even possible to keep the clocks of GRACE sessions on different computer synchronized.

4.4 Attribute Chart

The Attribute Chart allows plotting one or more data values against time (*time plot*) or against each other (*XY plot*). The data values do not necessarily have to be from the same data source.

An Attribute Chart can be useful for visual inspection of the data and for detecting anomalies in the data (some data formats also support automated anomaly detection).

4.5 Gantt Chart

For time synchronization, a Gantt Chart is used. It shows which period of time the data in each data source (or other selected elements) cover. This allows for an easy visual detection of timing errors.

4.6 Calculator

The Calculator can be used for date/time calculations and for geographical calculations in WGS84.

Date/time calculations include dealing with time zones, and conversion between date/time and “milliseconds since 1970”.

The geographical calculations can be used to determine bearing and range between two positions, or the other way around (compute the current position based on a given starting position, a bearing, and a range). All calculations are WGS84-based.

4.7 SIMDIS Exporter

For 3D visualization, GRACE supports the use of SIMDIS™. SIMDIS is a set of software tools for the 3D analysis and display of simulation data, test data, and operational data. It has been developed by the Naval Research Laboratory [1]. It allows for replay in 3D, synchronized with XY plots, and replay of audio/video files.

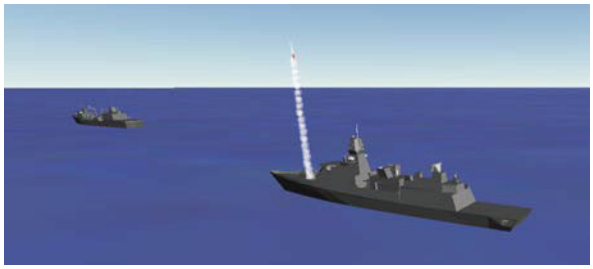

Figure 4.2: Screenshot of 3D visualization in SIMDIS

4.8 Excel Exporter

Using the Excel Exporter, any part of the data can be exported to Microsoft Excel, for further processing.

4.9 Data Fixer

For each data format, a separate Data Fixer module is provided. The Data Fixers allow changing data format specific settings, such as the time offset or position offset. For the Generic Importer, it allows defining the structure and meaning of the data.

5. Examples of the Use of GRACE

Currently, GRACE is mainly used by the Royal Netherlands Navy, for reconstructing live missile firing exercises. Firing a missile is costly, so an exercise should be thoroughly evaluated and analyzed to get the most out of it.

In such an exercise, one or more missiles are fired against an incoming threat, which can be either another missile or a drone. Data logs are made of the ship’s GPS, the Combat Management System, the own missile telemetry, target trajectory, and air surveillance (to clear the area). In addition, audio and video recordings are made, and sometimes other system specific technical data logs are made.

Usually, a first reconstruction and analysis is given to the ship's crew within 24 hours after the exercise. A more thorough analysis is done later by the MDTC. Aspects that are addressed are for instance:

- The chain of events, and the response of the crew and systems to these events. Examples of such events are: detection of the threat, recognizing the detected object is a threat, assigning the weapon system to engage it, launch of the own missile(s), the several phases in the own missile's flight, intercept, and kill assessment.
- The target trajectory: did it correspond with the requirements (speed, altitude)?
- 3D reconstruction.
- Probable causes of things that went wrong or caused problems (if any).

The successful application of GRACE by the RNLN had as a side effect that the awareness of the importance of logging, reconstruction, and analysis was increased. The result is that this subject now has a more prominent place in exercises and in requirements for technological developments.

Figure 5.1: Live firing launch

Another application is the analysis of radio communication in an exercise. The radio communication itself, and data on who is talking/listening to whom are logged. GRACE can then be used to analyze whether or not the expected or required lines of communication were followed.

In addition to its use in live exercises, GRACE can also be used for reconstruction and analysis of simulation runs. GRACE has been used to visualize high fidelity missile simulations, and compare them to logged data of real missiles. This was useful for obtaining insight in the missile's behaviour (visualization of trajectory, sensor beams, etc.), validation of the simulation, and for analysis of a real missile firing.

GRACE has also been used for visualization by several simulation models, such as a ground based simulation model (in which many tanks, trucks, and men were moving around in the terrain) and an advanced sensor data fusion algorithm linked to an air defence simulation model (where the algorithm combined information from sensors on different platforms, to generate a common picture).

GRACE can be used for logging and replay of DIS events (Distributed Interactive Simulation; a protocol for distributed simulations). This was useful for a JPOW exercise [2][3][4] (a large military simulation exercise on air and missile defence), where TNO analyzed the DIS and Link-16 traffic using our JoiNT tool [5], which is based on GRACE. In JoiNT, the simulation traffic (DIS) was compared with the tactical data link (Link-16), and a real time analysis was shown on screen.

6. Future Plans

For logging of DIS and HLA there are already dedicated tools on the market. Instead of doing all logging internally in GRACE, we intend to link GRACE to an external logging tool, the Pitch Data Recorder [6].

Although JoiNT was based on GRACE, it is a separate tool now. We intend to integrate it into GRACE, which will make maintenance easier, and will enable the use of other GRACE functionality while analysing Link-16 in a simulation (DIS/HLA) or live exercise.

GRACE will possibly also be linked to TNO's simulation models JROADS [4] and the Underwater Warfare Testbed (UWT; [7]). These models can be used (amongst others) for pre-exercise planning or for the analysis of exercises. The combination of GRACE and a simulation model allows the comparison of a real exercise with a simulation of the same exercise. GRACE can then also support LVC (Live, Virtual, and Constructive) exercises, by integrating live data and simulation data.

7. Conclusion

GRACE is a reconstruction and analysis tool that has been successfully used by both the Royal Netherlands Navy and TNO. Although it has been primarily developed for certain defence applications, its flexible and modular architecture makes is easily applicable to other areas that involve analyses of live exercises and simulations. The use of GRACE did not only directly contribute to the success of exercises, but the reconstructions made with the use of GRACE also contributed to the awareness of the importance of a good logging, reconstruction and analysis policy.

8. References

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Author Biographies

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PASCAL ORDELMANS joined the RNLN in 1990. He sailed on submarines, frigates and flew on helicopters. He worked in the operations branch and therefore has a broad working experience with sonars, radars and weapon systems. In 2010, he got a bachelor degree in computer science. For the last 4 years, he worked for the MDTC department. After a recent promotion he became head of the analysis and reconstruction team, and project leader for GRACE.