Tools for monitoring of data exchange in real-time avionics systems

V.V. Balashov, V.A. Balakhanov, A.G. Bakhmurov, M.V. Chistolinov, P.E. Shestov, R.L. Smeliansky, N.V. Youshchenko

Lomonosov Moscow State University, Dept. of Computational Mathematics and Cybernetics, Laboratory of Computer Systems

e-mail: {hbd,baldis,bahmurov,mike,osmin,smel,yoush}@lvk.cs.msu.su

Abstract

In this paper we present a toolset for monitoring of data exchange through onboard channels of real-time avionics (RTA) systems. The toolset is applicable to different stages of RTA system development, from purely-software simulation to field testing. Checking correctness of data exchange schedule and correctness of transferred data is supported. The toolset uses project database as the source of information on data exchange schedule and on messages structure. It is applied on practice to development and testing of aircraft RTA systems.

1. Introduction

Modern real-time avionics (RTA) systems contain dozens of data exchange channels connecting multiple devices. Data sets transferred through these channels must have correct values and timings. Data exchange, real or simulated, takes place on following phases of simulation-based development of RTA systems [1]:

1) purely-software simulation;
2) hardware-in-the-loop (HITL) simulation and integration;
3) prototype evaluation;
4) field testing.

On phase 1 of development process proposed in [1], data exchange is performed via software models of data exchange channels, in particular MIL STD-1553B and ARINC 429. These channel models simulate data exchange transactions between attached onboard device models, with correct transfer timings. Device model can include source code of target RTA device's application and system software, which enables simulation-based software development. Realistic simulation of channel operation along with using real software for data exchange control enable full-featured data exchange workout and verification. This activity requires monitoring of simulated data exchange and analysis of monitoring results.

On phase 2 step-by-step integration and verification of RTA system is performed, with gradual replacement of software models by hardware units, up to a fully integrated RTA system or its subsystem. During this phase, data exchange takes place both on simulated channels and real hardware channels. It is necessary to verify both correctness of data exchange between subscribers of hardware channels *and* matching of data exchange characteristics for simulated channels and real channels which replace them. Absence of such matching might mean that transition from simulation models to real devices introduced a problem, or that the models were incorrect. To perform a smooth transition from simulation models to real devices, it is necessary to monitor and analyze data exchange for real and simulated channels in a uniform way. Furthermore, a uniform representation of data exchange for different channel types is necessary, for example, to check if data received by one type of channel and sent farther by a different type of channel have coherent values.

On phase 3, a complete RTA system (or its subsystem) is evaluated and verified. This includes full-scale testing of RTA devices operation, including monitoring and verification of data exchange. This phase includes iterative upgrades of RTA devices software, and may coexist with phase 4.

Both phases 2 and 3 typically involve an integration/testing bench which includes computers responsible for channel monitoring. Full-scale monitoring and verification of data exchange requires simultaneous monitoring of most channels, so multiple computers are necessary for monitoring of data exchange. Computers with multiple onboard interface adapters, responsible for generation of test data traffic, are attached to channels in the testbench, and it makes a benefit to use monitoring features of these adapters (if present) instead of installing separate computers and adapters solely for monitoring purposes.

On phase 4, a real RTA system installed on a (prototype of) controlled system, e.g. an aircraft, is tested. A mobile monitoring solution is necessary to examine the data exchange. Such examination is essential as no technological software stubs are allowed to provide extra information on what is going on inside the RTA devices. Such solution can be farther used during field operation phase in case the controlled system does not have tight constraints on mass and size of “extra” load; for instance, it is acceptable to take a compact mobile monitoring device onboard a ship or a heavy transport aircraft. As RTA system developers are not typically available on-site during field operation, it is necessary to support long-lasting monitoring process (for several days at minimum).

On all phases of RTA system development process mentioned above, data exchange specifications (message formats, schedules etc) are taken from a project database.

A single solution is necessary to support data exchange monitoring and analysis on all four phases of the process. Requirements to this solution are as follows:

1) support for monitoring of different types of channels present in RTA system, with uniform representation of monitoring results and unified capabilities for analysis of these results;
2) support for monitoring of both real and simulated channels;
3) integration with project database as a source of data exchange specifications;
4) support for following configurations:
   - software only installation for working with a purely software simulation model of RTA system on early development phases;
   - stationary multi-computer system (a part of testbench) controlled from a single workstation; sharing of channel adapters with test traffic generating computers is a favorable feature;
   - compact mobile platform (e.g. a rugged notebook) for use during field testing and field operation.

This paper presents a software toolset for data exchange monitoring which suits all the requirements listed above and provides a wide range of features to support data exchange monitoring and analysis. This toolset is developed in the Computer Systems Laboratory (CS Lab) of Computational Mathematics and Cybernetics department of the Moscow State University.

The rest of the paper is organized as follows. Section 2 presents an overview of several existing monitoring solutions, including the presented toolset, and compares their feature sets. In particular the toolsets are checked for conformance to requirements 1-4. Section 3 describes structure of the presented toolset. Section 4 presents the workflow for application of the toolset. Section 5 contains two case studies. In the last section, future directions of work are proposed.

2. Related work

In this section we list several examples of monitoring toolsets provided by different vendors and assess their feature sets with special attention to support of requirements 1 – 4 from Section 1. The scope of analysis is limited to MIL STD-1553B and ARINC 429 channels as they are most widely used in today's military avionics [2].

The toolsets of interest are as follows:

- **PBA.pro** from AIM GmbH [3];
- **CoPilot** from Ballard Technology [4];
- **DataSIMS** from DDC [5];
- **MIL-1553 Tester** from Elcus [6];
- **Flight Simulyzer** from AIT [7];
- **ADS2** from TechSAT GmbH [8];
- **Luthier** from Sital Technology [9];
- **BusTools** from General Electric [10];
- **Exalt+** from Excalibur Systems [11];
- **IMUX G2** from Wyle [12];
- **MIL STD-1553B and ARINC 429 Analyzer**, introduced in this paper.

Overview results are summarized in Table 1. Analysis of feature sets reveals following main features of monitoring tools, in addition to listed in Section 1:

- Unpacking parameters from recorded data blocks ("Par" column in Table 1);
- MIL STD-1553B terminal devices management, including setting/viewing subaddress data ("RT" column);
- MIL STD-1553B bus controller (and ARINC 429 sender) management, including exchange sequence specification and execution ("BC" column);
- Recording and display of data exchange traces ("Rec" column);
- Replay of registered exchange ("Rpl" column);
- Fault injection into channel ("FI" column);

- Recording start/stop on specified events during data exchange ("Ev" column).

Support for a mobile platform is typical for the reviewed tools (provided that the computer is powerful enough, and there are extension slots for adapter cards). If a monitoring toolset supports both MIL STD-1553B and ARINC 429, it usually represents monitoring results in a uniform way for both channel types. Considering this, specific features related to requirements 1-4 from Section 1 are as follows:

- support for monitoring of both real and simulated channels ("Sim" column); the latter implies support for software only configurations;
- integration with project database ("DB" column);
- support for a stationary multi-computer system (a part of testbench) controlled from a single workstation ("MCS" column);
- sharing of channel adapters with test traffic generating computers of a testbench ("SHR" column).

Table 1. Monitoring toolsets capabilities

Toolset name	Supported channel types	Par	RT	BC	Rec	Rpl	FI	Ev	Sim	DB	MCS	SHR
PBA.pro	**M1553**, **A429**, FC-AE, ADFX, CAN, Panavia	+	+/-	+	+	-	+	+	-	-	-	+/-
CoPilot	**M1553**, **A429**, AFDX, A708	+	+	+	+	+	+	-	-	-	-	-
DataSIMS	**M1553**, **A429**	+	+	+	+	+	+	+	-	-	-	-
MIL-1553 Tester	**M1553**	-	-	-	+	-	-	-	-	-	-	-
Flight Simulyzer	**M1553**, **A429**	-	+	+	+	-	+	-	-	-	+	-
ADS2	**M1553**, **A429**, AFDX, CAN, …	+	+	+	+	-	+	+	-	+	+	+/-
Luthier	**M1553**	-	+	+	+	-	-	-	-	-	-	-
BusTools	**M1553**, **A429**, AFDX	+	+	+	+	-	+	+	-	-	-	-
Exalt+	**M1553**, **A429**, A708,AFDX,...	+	+/-	+	+	-	+	+	-	-	-	-
IMUX G2	**M1553**, **A429**, A624, FC-AE, ...	+	-	-	+	-	-	-	-	+	+	+/-
MIL STD-1553B and ARINC 429 Analyzer	**M1553, A429**	*****	**+**	**+**	**+**	-	-	-	**+**	*****	**+**	**+**

Notes for Table 1.

- "+/-" for RT management feature means that only RT and subaddress status flags management is supported, but not setting up data for RT subaddresses;
- "+/-" for hardware adapter sharing between testing and monitoring tools means that this toolset supports both testing and monitoring functions, but it is unclear from available documentation whether adapter sharing is supported;
- "*" means that the feature implementation is on schedule.

The overview shows that the most full-featured toolsets like PBA.Pro, DataSIMS, ADS2 "as is" cannot support simulation-based development of RTA systems [1] on phases 1 and 2 which involve data exchange through simulated channels, and most toolsets do not support multiple computer configurations controlled from a single workstation. The proposed toolset lacks some of "common" features but is designed for full support of all four phases of the process [1] (see Section 1).

3. Monitoring toolset structure

Figure 1 show the structure of the presented monitoring toolset in multiple computer configuration.

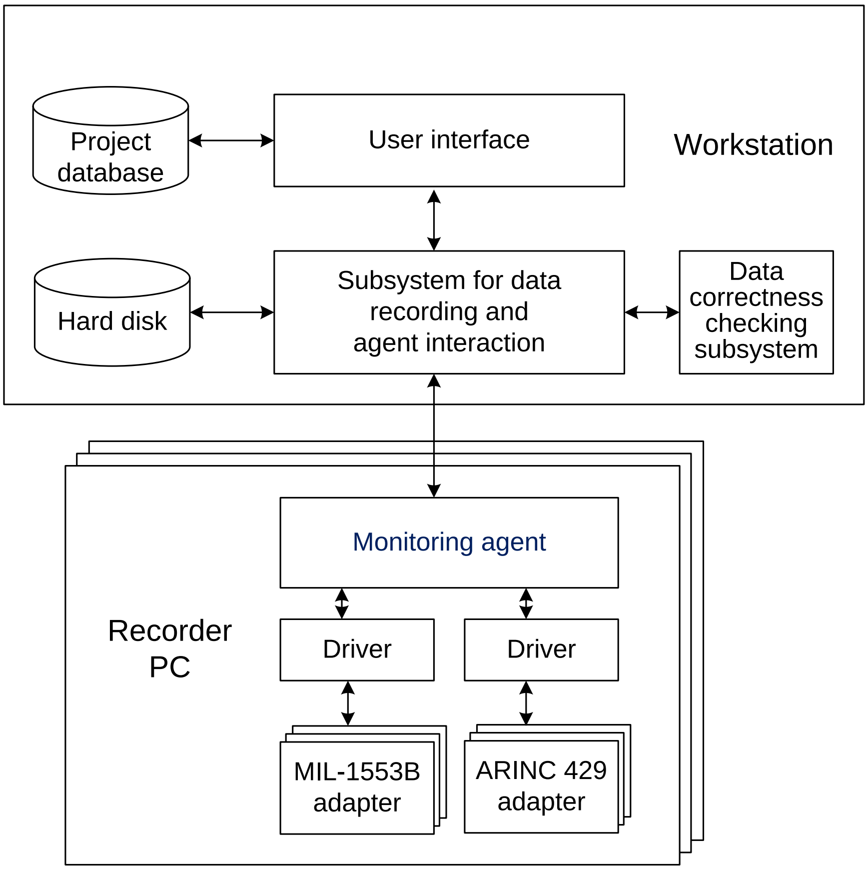

Figure 1. Monitoring toolset structure

Resident module of the toolset runs on a recorder PC (REC PC) and includes:

- adapter drivers;
- monitoring agent responsible for interaction between user-controlled workstation module and adapter drivers.

REC PC includes channel adapters supporting sender/receiver/monitor functions (ARINC 429), bus controller/remote terminal(s)/bus monitor functions (MIL STD-1553B); for each channel type, the adapter may support one or several functions at once. Monitoring toolset is optimized for specific channel adapter cards produced by Elcus company and Space Research Institute, Russia.

Adapter drivers are built to enable multiple non-blocking access to adapters performing receive-only functions (channels monitors, ARINC 429 receivers), and independent (though blocking) use of remote terminals (RT) on multi-RT MIL STD-1553B adapters and of output channels on ARINC 429 channels with many such channels. This enables cooperative use of PCs and adapters by monitoring tools and by hardware-in-the-loop integration/testing toolset [1]. Drivers also perform pre-filtering of received data according to user-specified criteria in order to optimize traffic to workstation and recorded trace size (which is crucial for long-run recording). Simulation of MIL STD-1553B and ARINC 429 channels is implemented by specialized drivers of "virtual" channel adapters.

Monitoring agent, in addition to interaction support functions, supports execution of complex data exchange schedules, for instance those constructed by Scheduler CAD tool [13]. As adapter cards support end-to-end execution for single exchange chain only, the monitoring agent performs real-time reloading of exchange chains to bus controller cards.

Workstation module of the toolset runs on a workstation PC (WS PC). A single instance of this module running on a WS PC can control monitoring agents on several REC PCs. Workstation module includes:

- subsystem for recording of data received from agents, and for interaction with agents;
- subsystem for checking correctness of recorded data;

- user interface.

Data recording subsystem writes the received data to a hard disk (splitting them into chunks of specified duration) and reads the previously recorded data to be displayed in GUI. During online monitoring, data bypass the recording phase and are displayed in GUI in real time (writing to a disk is performed concurrently).

Data correctness checking subsystem supports on-the-fly testing of received data against correctness constraints, such as belonging to specified ranges, conformance to smoothness requirements, correlation of data values transferred through duplicated channels etc. Data correctness check is performed on parameter values unpacked from recorded messages; unpacking is performed according to message structure specification which is entered by the user or imported from the project database. There is also an option to check the recorded exchange sequence for conformance to a specified exchange schedule.

User interface represents the monitoring results in following forms:

- parameter-oriented views, displaying unpacked parameters in table and graph forms;
- exchange-oriented views:
  - exchange log;
  - exchange statistics (including error statistics), calculated for different addresses and subaddresses separately;
  - last recorded exchange for each sender-receiver pair (MIL STD-1553B) or word address (ARINC 429);
- user controls for operation with:
  - MIL STD-1553B bus controller and ARINC 429 data sender, including exchange schedule specification;
  - MIL STD-1553B remote terminals, including setting up and viewing data for subaddresses;
- tools for setting up filters for data recording and display;
- tools for data search.

Integration of workstation module of the toolset with project database is in progress. Database integration enables import of messages structure and exchange schedule specifications from the database.

In mobile installation of the toolset, workstation PC and recorder PC is the same computer (a rugged notebook).

4. Workflow for toolset application

In this section we describe the workflow for application of the presented monitoring toolset as a part of simulation-based integration workflow proposed in [1]. The workflow from [1] includes following steps:

1) filling the RTA system project database with data on the system structure, on protocols and formats of data exchange between devices;
2) automated generation of interface sections of the RTA system device models (including input and output parameters, interfaces of models with channels, interconnections between models);
3) implementation of the functionality logic for models of the devices that are not yet available in hardware, on one of the levels of detail:
   a) detailed implementation that includes source code of device’s software;
   b) simplified implementation, imitating external behaviour of the device;
4) automatic construction of schedules of data exchange for MIL STD-1553B channels (by means of Scheduler CAD);
5) automatic generation of code for schedule definition in the following formats:
   a) unified format for target devices and device models, recognizable by the code of system tasks running either on models or on real devices;
   b) specialized format for simplified models which do not contain code of system tasks;
6) automatic generation of code for message packing and unpacking in the following formats:
   a) unified format for target devices and device models;
   b) specialized format for simplified models;
7) integration of generated code into the models and available real RTA system devices;
8) preparation of the testbench hardware, in particular connecting instrumental computers and available RTA system devices to the data exchange channels;
9) defining the configuration of the testbench: distribution of models to instrumental computers, settings for channel monitoring and for registration of simulation events;
10) performing the simulation with a given set of hardware RTA system devices and device models;
11) analysis of simulation results, including automated verification of conformance of the recorded data exchange sequences to reference exchange schedules from the project database.

Monitoring toolset is involved at following steps:

- steps 1 and 4: input data for the toolset are entered into the project database;
- step 8: hardware (including REC PCs and adapters) is set up for use by resident module of the monitoring toolset;
- step 9: binding of “logical” channels to specific adapters on REC PCs is defined; data exchange specifications are loaded from the project database into the workstation module of the toolset;
- step 10: during simulation, the monitoring tools record and analyze the data exchange through real and simulated channels;
- step 11: the user performs offline analysis of monitoring results.

If there are no hardware devices available on the current stage of RTA system development, steps 7-11 involve only simulation models of the devices and constitute a process of “virtual” integration. During this process, real source code for the devices and real exchange schedules are validated via testbench and monitoring tools.
Application of monitoring toolset during in-field testing and operation of RTA system is generally the same, however on all steps involving monitoring toolset a real RTA system and a mobile monitoring solution are used. For in-field operation, step 10 may be long-lasting, and step 11 may require delivery of collected recording results to an engineering laboratory for analysis.

5. Case studies

Two industrial case studies for monitoring toolset application are considered below.
Stationary monitoring solution for integration/testing bench. In 2009, a testbench for integration and testing of aircraft RTA systems was created and accepted for operation. This testbench includes several instrumental computers equipped with MIL STD-1553B and ARINC 429 adapters, and workstations. Instrumental computers perform functional and integration testing activities under control from workstations, generating test data traffic and checking responses from RTA system devices. Instrumental computers are also capable of running simulation models of unavailable RTA system devices. Monitoring toolset's resident modules are installed on all instrumental computers, and onboard interface adapters are shared between testing and monitoring tools. Monitoring tools can be used either as a source of information on data exchange between RTA system devices and instrumental computers (e.g. for test or model debugging purposes), or as a standalone facility for generation of simple traffic for RTA system devices in course of development of devices' source code. In both cases, the online monitoring functions are mostly used. The testbench is connected to a server which hosts the project database to enable automatic import of data from the database.
Mobile monitoring solution for in-field testing. This solution is currently under development. It is based on a rugged notebook with several USB-attached MIL STD-1553B adapters and intended for long-run recording of data exchange for naval RTA systems. The focus is on detecting exchange errors and deviation of transferred parameter values from given specifications. The user performs mainly offline analysis activities.

6. Conclusion

In this paper we presented a toolset for monitoring of data exchange on MIL STD-1553B and ARINC 429 channels in real-time avionics systems. This toolset supports different phases of simulation-based RTA system development process proposed in [1]. Two industrial case studies of toolset application were considered.
Directions for future development of the monitoring toolset include:

- completion and delivery for operation of the mobile monitoring solution;
- development of monitoring solution for high-speed Fibre Channel bus;
- development of scripting subsystem for specification of user-defined constraints on correctness of transferred data.

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