Avionics Maintenance Ontology Building for Failure Diagnosis Support

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Abstract: In the aviation industry, the delay in maintaining or recovering aircrafts heavily impacts the profit of an airline company. Consequently the maintenance actions identification and planning of aircrafts is crucial. However, due to the complexity of the domain in terms of data sources, distributed systems and information availability, it is hard to provide automatic maintenance support. We propose to use semantic technologies to model the domain at a conceptual level through ontology, thus abstracting from the data sources and the maintenancers'uses and jobs. In this manner the information relevant for characterizing failures and maintenance events is encapsulated and provided to end users via an easier access, which otherwise would be inaccessible or would require expert analysis to obtain. Such a formal model of the domain can furthermore enable automated reasoning for maintenance discovery and failure causes detection by integrating a large amount of background contextual information scattering in different resources. In this paper we provide the rationale of the Avionics Maintenance ontology i.e. how we built it through expert knowledge and alignment of different sources and an ontology alignment evaluation tool.

1 INTRODUCTION

In order to profit the most out of flights an airline operates, both the airline companies as well as the aircraft manufacturers must plan at best the use of the planes. Aircraft maintenance is one of the most important topics to deal with, when referring to keep or to get back an aircraft able to fly as soon as possible. Whilst planning and optimization are topics already heavily handled by airlines, there is a need to assist in the maintenance actions, i.e. the forecast of a failure and the support to fault diagnosis. Both forecasting a maintenance task and isolating faulty components will reduce the time an aircraft is unavailable, save money and resources. In this paper we provide a model for characterizing and explaining these events.

The aviation domain is a rich, complex and technical one. As such, it involves a diversity of locations, companies, services and actors with tight interaction and interdependence. The diversity of stakeholders and its distributed nature is reflected on the systems that compose it. To automate and support actions on the aeronautic domain requires a shared and formal representation to model the domain with its interactions. However, a bottom-up data-based model is hardly possible due to the heterogeneity and the recurrence of data (redundancy of data and systems is compulsory in aeronautics for security reasons). An approach to solve this need is to provide a model at a conceptual level (not only at the data level) and then feed this model. Such a formalization of this complex domain will enable automatic reasoning to support failure forecasting and diagnosis support. Once the core maintenance ontology is designed, we will use ontology alignment techniques to enrich and validate the contents of the model, thus providing more complete and relevant answers to the final users.

We present first in this paper the aeronautics maintenance field. Then, we present the design rationale of the aeronautic maintenance ontology from several sources (operators, documentation, data, scenario) and supported by ontology alignment tool. After an overview of existing works on the field of avionics, ontology alignment and fusion and

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ontology alignment, and guided by our requirements, we present a first glance at the ontology alignment tool supporting our approach. Next, we present the needs of reasoning over the model in order to discover and refine knowledge. A set of scenarios are defined, focused on failure diagnosis, on which the end users validate the modelling.

2 AERONAUTICS MAINTENANCE

Airlines define a flight plan, which describes the usage of the aircrafts they operate. This plan has to be coordinated with other operators for shared resources and need to consider several factors as: destination demand, number of available aircrafts, state of the aircraft, maintenance, etc. The goal of the flight plan is to ensure the most efficient exploitation of the aircraft.

At the beginning/end of each flight, scheduled maintenance takes place. This is composed by a set of procedures defined in the Aircraft Maintenance Manual (AMM), given for each aircraft type by the manufacturer. External factors (like a delayed crew, or weather conditions) as well as failures (a defect in a component) may prevent the normal operation of the aircraft. Moreover, a failure will always imply unscheduled maintenance, although unscheduled maintenance may not only be caused by a failure.

Our approach focuses on modelling the latter two situations: explaining failures and unscheduled maintenance, to assist the process of ensuring the best possible exploitation for the aircraft. Such explanations provide a way to answer questions like: what are the possible causes (set of causes) of these set of symptoms, what procedures can be applied to a situation, what are the causes and effects of a specific failure, or, which undesired situations are not captured by any maintenance task. As the causes, effects, symptoms and actions taken are extensive, and because of complexity of the domain, it is difficult to establish all the cause-effect relations between the above mentioned elements.

3 LITERATURE SURVEY

3.1 Avionics & Ontologies

The avionics and avionics maintenance is largely studied in industrial research field. It is a key domain for civil as military industry. However, publication of works in the field is quite private due to the economic and safety impacts a published work could create. However, in (Danping *et al.*, 2012), authors emphasize on the importance of development of semantic information systems in avionics. Other key industries in Europe are working in the same line. They present an approach for information extraction on the domain of aviation products in order to handle the interoperability issues.

In (Putten *et al.*, 2008) a survey on ontologies oriented toward Traffic Flow Management (TFM) in aeronautics is presented, as they aim at providing a Collaborative and multi-agent TFM system. However, XCALIBR (Marshall and Morris, 2007) and AIAA Topic Database (Neff *et al.*, 2007) are of interest for the aviation domain in general. Unfortunately, these knowledge sources aim at new development of component architecture and do not handle the Maintenance part of the avionics works.

For safety and security reasons, avionics domain mainly rely on international standards and norms. As the maintenance field should comply with these requirements, we can base our ontology building on (ISO/TS 15926-8:2011, 2011) norm. This part is providing a OWL implementation. Still it deals with Industrial automation systems and integration, then on any industrial maintenance, not in avionics.

Another document of the field, which is of interest is the (NF EN 13306, 2001), giving the maintenance terminology in three languages. Again, it represents the maintenance field in any industrial domain, including maintenance maagement processes, but not especially with the terminology of avionics maintenance.

Backed by these different sources, we have to align these document contents to build an avionics maintenance ontology fitting to failure forecast and diagnosis support. For this task, we used expert knowledge and an automatic alignment tool.

3.2 Ontology Alignment

The problem of establishing the correspondence between the components of two or more ontologies is known as the Ontology Alignment or Ontology Matching problem (Euzenat and Shvaiko, 2007).. Several techniques and tools have been developed for solving it. The various techniques focus on different specific aspects of the ontology. Following (Otero-Cerdeira *et al.*, 2015) they can be classified into: lexicographic, structural, instance based and reasoning based techniques. The techniques provide correspondences between elements (concepts or relations) of different ontologies, together with a degree of confidence and the type of relation between them. A set of such correspondences is called an alignment. There can be many possible resulting alignments and many incorrect correspondences, depending on the techniques used and the ontologies to be aligned.

To establish the most relevant techniques, their weaknesses and their potential, we have developed a first prototype for evaluating a set of alignment tools with different characteristics and developed by different teams. The goal of the prototype is to have full control over the alignment process to determine the causes that lead to a(n) (in)correct correspondence, and then provide solutions or improvements for the problems found. Several tools enable (partially or fully-) automatic alignment among which we consider the following: H-Match (Castano *et al.*, 2003), S-Match (Giunchiglia *et al.*,2012), TaxoMap (Safar and Reynaud, 2009), Logmap (Jiménez-Ruiz *et al.*, 2012), (Faria *et al.*, 2013) for the complementary types of alignment they provide (Otero-Cerdeira *et al.*, 2015).

4 AVIONICS MAINTENANCE ONTOLOGY BUILDING

4.1 General Approach

It is often the case in complex domains, such as aviation, that the composing sub-systems are highly specialized and that the interaction between them is difficult. As a result, the relevant data differs for each sub-system, depending on their goals and needs. Some relevant information might not be accessible, because it is not considered by the current systems or the links to the sources of information do not exist. For instance, a shop repairing a component might focus only on repairing the components, but not on establishing the circumstances under which it has failed. Although a view on both sides allows to determine the causes and context of a failure. Additionally, the format, form and representation of the information might differ as well (text files, Excel files, XML, relational databases, etc.) moreover this information might not only be highly technical, but also the meaning may differ according to the context, thus expert knowledge is necessary to understand and evaluate it. All these factors add to the difficulty of providing a global view of the domain.

In order to support failure diagnosis, we need to understand the failure mechanism. That involves establishing the causes, context, effects and related events that lead to the failure. To this end we propose to model failure and maintenance in avionics using an ontology to provide suggestions on when and which items and events are related to a failure. These suggestions, subject to a degree of confidence, can then be presented to the user for validation and expert knowledge acquisition. These authoring process lead to knowledge discovery and revision for failure diagnosis. Likewise, rare events not considered by the maintenance procedures can be isolated and characterized for further analysis, providing support for weak signal detection. It is at this point, when an ontology is already available, that we can profit of ontology alignment techniques. Given that there exist several other sources of information (other ontologies related to the domain), aligning them to the maintenance ontology provides additional inferences, instances and axioms subject to the same validation/authoring process by the end user, thus extending the reach of the model beyond the data sources initially identified, and providing an additional mechanism for knowledge revision and ontology design.

The maintenance ontology, along with the alignment and revision processes is referred here as the maintenance ontology framework.

4.2 Avionics Maintenance Ontology

After interviewing experts, analysing manuals, procedures and documents relevant to the field (norms among others), an ontology has been designed to capture, at a conceptual level, the information relevant to failures and maintenance. That is, when they occur, why they occur and what are their consequences. In addition contextual information has been included into the model.

Once the ontology is designed, we also have to deal with the process of specifying the sources of data to populate the ontology. As mentioned before, some of the information comes from reports made by hand, others from XML files, manuals, *etc.* This process involves several considerations: the content of the sources of data is meant to be used by experts on the field, the intended information might not be found in one, but in several sources, and the availability of the sources. Regarding the latter point, this is due to the fact that the sources of data are property of the airlines, the manufacturers and the service/maintenance providers. Not only this information might be subject to privacy policies (intellectual property) but also might be subject to security policies. When avionics is tightly related to military, some of this information might not be disclosed, and thus cannot be included in the model. This represents an additional task and challenge for the approach, but also exemplifies the utility of providing a conceptual model for a domain to conciliate different sources of data.

European Standards (ISO/TS 15926-8:2011, 2011) (NF EN 13306, 2001), are used as a upper-leve ontology for building our ontology, since it provides the industry with a terminology for referring to the concepts used in maintenance in the aviation domain among others. We also use specific documents as the main sources of data for populating the ontology, like the Post Flight Report (PFR) the Flight Deck Effect (FDE) or the Electronic Log Book (ELB).

The core of our model is a subset we call the maintenance ontology, where two concepts are of special interest: *Resources* and *Services*. A *Resource* is a physical item that can be individually identified. It can be, but is not restricted to, one of the following: a hardware component, a shop-replaceable unit, a line-replaceable unit, or a set of resources. Whereas a *Service* is a function in the aircraft (e.g. heating, satellite communications, altitude measurement, etc.) that is provided by a *Resource*. These elements can present *Failures*, which are detected by the corresponding reports. A *ResourceFailure* is detected by the *PostFlightReport*, whereas a *ServiceFailure* is detected by the *FunctionReport* (FDE). Finally, because *Services* are provided by *Resources*, we establish that a *ServiceFailure* can be a *Symptom* of a *ResourceFailure*. These elements and its relations are captured in the model in figure 1:

We also know the sources of the information for the reports, which are given by some of the *MonitoringSystems* of the Aircraft. The BITE (Built-in Test) system performs tests in the components of the aircraft and reports their status. The result of these tests generates messages, known as *BiteMessages*, which are associated to a *PostFlightReport* for each *Flight*. Additionally, the Aircraft Maintenance Manual (AMM) provides one or more entries for each *BiteMessage*, where each entry is a *MaintenanceTask* designed to isolate and solve the failure. These maintenance tasks are not only related to the BITE messages but also to other events.

In the case of the *Services*, the FDE registers the status of the services during the flight, and if the interruption of any of them is detected. The absence

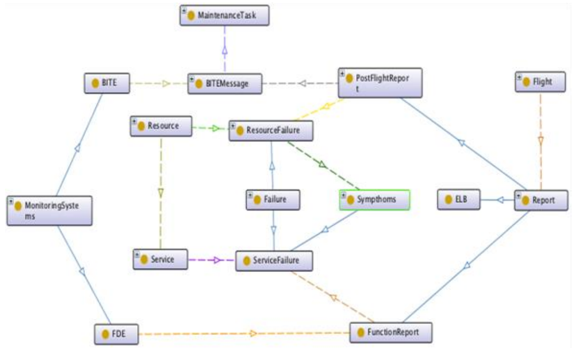

Figure 1: Core of the Avionics Maintenance Ontology.

or malfunction of a service can be as well reported by the crew.

Similarly, for each flight an Electronic Log Book (*ELB*) entry is generated that registers the status of the aircraft, its flight departure and destination, its identification information and problems/observations and the actions taken, if any. It differs from the PFR in that the cause-effect-solution process is expressed in text (as a written report) rather than related to a specific component, with a specific failure message and a specific set of tasks established for solving/isolating the failure.

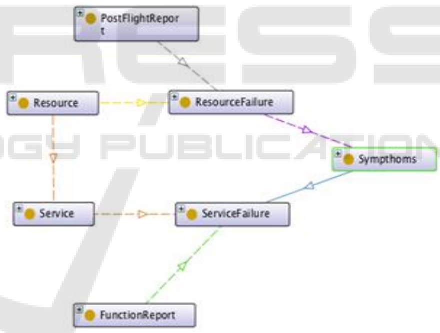

Figure 2: Failure sub-part of the Avionics Maintenance Ontology.

Finally, Maintenance takes place for each Aircraft in each Flight. Depending on the conditions this can be a *ScheduledMaintenance* or *UnscheduledMaintenance*. By adding these concepts to the ontology, we can associate causes, effects and the situations that lead to *UnscheduledMaintenance*, providing a better understanding of it (such as explanations) and thus supporting the process of diagnosis.

4.3 Ontology Alignment Tool

The creation of our own ontology for the maintenance domain is not to replace all existing ones or other pertinent ontological resources. Instead, our ontology will be used via integration with external ontologies, achieved via ontology alignment techniques, in order to explore deeper and more complete explanations for maintenance tasks.

To evaluate the alignment process and decide the relevance, accuracy and usefulness of the different techniques for our approach, we have developed a prototype integrating the different tools in a single alignment process. The process receives two ontologies in OWL (McGuinness and Van Harmelen, 2004) format as an input, allows to set the parameters for each tool, and provides the output of each tool in a unified XML format, along with the log information, for further analysis.

Figure 3 shows the workflow of the prototype and the activities of the user and the system. The user provides the input ontologies and sets the tools and respective parameters to be used in the alignment process. A timeout might also be established by the user, because an alignment process could take a long time to be completed, due to the size of ontologies. The system receives all these resources and information to first prepare the execution (loading matchers and set parameters) and then execute the alignment process. Once the results are available, they are stored and presented to the user for validation.

In the validation process the user identifies the incorrect/missing correspondences in the resulting alignment and this information is provided as an input for a subsequent iteration of the process to refine the alignment.

The goal of the tool is to explain in detail the generated alignments to discard or validate the techniques used, backed up by the results. Given the reasons why the considered techniques and tools do not capture all desired answers, we can establish improvements and algorithms to solve these issues, and validate/discard them by iterating them in the tool and running the same process.

The alignment tool consists of two components allowing us to validate the alignment process, executing them both in series and in parallel

- Configuration component: provides operations to initialize and maintain the correct configuration of the entire tool;
- Process alignment component: provides operations to create manage and control the entire alignment process between two ontologies.

Since ontologies can be large, a tool could take a long time for completing the alignment process. A component allowing us to execute the alignment process remotely was added to the prototype, exploiting the REST architectural style. Then, it can be easily replicated on different servers in order to create a distributed system, therefore to solve, at least in part, the problem about execution time.

T he alignment tool allows us to test and validate manually the selected alignment tools. The need for further extensions is considered in the design, resources and architecture of the system, providing an API to interact with the core of the tool. Validation measures based on Taxonomy Overlap (Cimiano *et al.*, 2005), Coverage, Novelty, and ExtraCoverage (Ponzetto and Strube, 2011) are planned.

4.4 Scenarios

Our experts validated several avionics maintenance scenarios, which are representative of a potential ontology use to support diagnosis and forecast failures.

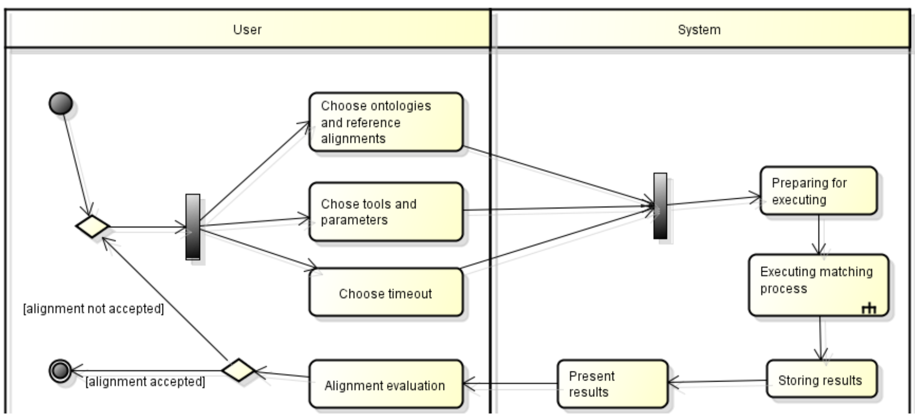

Figure 3: Alignment Tool Workflow.

- A scenario on scheduled maintenance in hangar;
- A scenario on deferred maintenance in line;
- A scenario on unscheduled maintenance in line;
- A scenario of in shop repair.

These cases picture the following concepts and processes: un/planned, un/scheduled maintenance, condition triggering maintenance (hard time, on condition, soft-time, deferred correction, condition monitoring), as well as the types of maintenance occurring: On aircraft (line or hangar maintenance), In Shop maintenance/repair (of SRU - Shop Replaceable Unit), and lastly In Shop maintenance/repair (of LRU – Line Replaceable Unit). These scenarios represent the main tasks and processes of avionics maintenance.

5 CONCLUSIONS AND FURTHER WORKS

The aeronautics domain is a large domain, in which the maintenance is unfortunately considered as a non-central topic. Then, we had to build our avionics maintenance ontology and validate it. The building is based on ontology reuse and then ontology alignment as well as expert knowledge for validation. Still we have to work automatic validation of aligned concepts and automating the ontology building based on ontology alignment.

The ontology is a basis for further reasoning works to support maintenance users in diagnosis. We plan to focus on providing the maintenance analysts with two capabilities: the discovery of links between causes and failures and the highlighting of unexplained failures. In order to provide these capabilities, we propose to use automatic pattern matching. A graphical pattern describing the observed failure is extracted from the populated maintenance ontology, and completed with generic graph structures expressing a generic link to a generic cause. We propose to use a semantic graph matching approach as in (Laudy, 2015) and relying on the use of conceptual graphs (Sowa, 1984), formalism and algorithms (Chein and Mugnier, 2008).

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