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The Power of Open-Source Tools for Satellite and Constellation Monitoring

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Operating satellites comes with several challenges that are shared with other industries. Monitoring of assets, processing large amounts of data and analyzing this data are common problems. In particular, satellite and constellation monitoring shares many similarities with other monitoring tasks, e.g. monitoring of a server infrastructure. Instead of creating bespoke software for specific problems or missions, it can be very beneficial to leverage open-source tools that are freely available and adapt them to the requirements of the mission.

I. Introduction

FOR the success of space mission operations, it is crucial to have good insights in the mission data in order to get a clear picture of the status of a system. Modern satellites produce an increasing amount of data transferred via faster communication links, e.g. from on-board sensors or more complex on-board software processes. The amount of data a satellite mission produces further increases with the usage of satellite constallations. Consequently, to get a clear picture of a mission, it is mandatory to access and assess large amounts of data. The primary approach to assess large data sets and to bring them into context is data visualisation. However, implementing systems that efficiently process and visualise data in a meaningful and easily understandable way requires special skills and know-how. Luckily, these are problems the space industry shares with other industries in the age of Big Data. This is fortunate because it means that powerful open-source tools are available that can help to tackle the challenges of spacecraft operations.

In the space industry, too often solutions are implemented for a small number of missions for very specific use cases. Instead, it can be beneficial to survey the market for tools that were created to solve generic problems like processing and storing large amounts of data. In many industries including space, the reliability of a tool is a critical metric. Popular tools used by other industries can deliver a reliability that is hard to match with custom-developed tools, as they were tested extensively by a large user base in many different scenarios.

Often, the reason for custom developments are concerns about licensing, long-term availability and maintainability, support and the desire to have a solution that fits perfectly to a given problem. Advantages commonly found when using open-source software are that it can be freely used, modified and shared. Popular tools are often maintained by a user and developer community, which does not pose additional costs to the user. As open-source software can often be modified, it can be adapted to the specific requirements of spacecraft operations. A share of the effort that was dedicated to creating custom tools can then be shifted to setting up already existing solutions and customizations.

II. Tools for Satellite and Constellation Monitoring

Over the last years, various open-source data visualisation solutions have emerged, e.g. Grafana[3] or Kibana from the Elastic Stack[4]. Often, they also contains solutions for extracting and analysing information from different sources, e.g. log files, with Logstash, saved in ElasticSearch and finally visualized in Kibana. Moreover, many of these

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solutions provide interfaces for integration with other tools, or as open-source tools they can be modified to include such interfaces.

A. Obtaining and Storing Data

The infrastructure of a mission typically consists of several systems, e.g. for planning, commanding, and receiving and analysing telemetry and reporting events. This can result in data being scattered across different systems. To obtain a clear picture of the current state of a mission, it is beneficial to have all information available at a single access point. This becomes increasingly challenging if the data is diverse, i.e. not only satellite data is considered but also the infrastructure, e.g.the health of servers on ground is monitored.

Data processing tools like Logstash ingest data from various input sources. The data to be ingested can come from files, obtained via APIs or sent to the tool via services. The input is then parsed and the optained data processed in a defined way, e.g. written in a database. Such data processing tools ideally offer means to easily configure them to define the required inputs, instructions how to parse the data and where to store the output. The standard scenario for these tools is to parse server log files and save the timestamp, severity and message in a database. However, due to this configurability, the potential is much greater than that. In space operations, this can be used to process incoming telemetry and science data and store the data in the mission data repository or to convert data from one system to the format required by a different system.

After obtaining the data, it is necessary to store it. Storing large amounts of mission data presents challenges to the database solution. The database should be fast, scalable and provide a high availability. Several solutions have emerged in the past years, for example ElasticSearch or MongoDB. These databases have the advantage of a tremendous scalability and provide easy configuration to build large database cluster. Another adavantage of the aforementioned database solutions is the long list of customers that have security, availability and performance requirements that match or exceed the requirements of typical space missions. A mission can utilize and build upon the experiences incorporated in these solutions to improve the reliability of its own services.

The trivial approach to unify all data and have it all available together is to store all data in the same repository. In practice this is often impossible. Space missions are faced with requirements that constrain which tools to use and where to store the data. The alternative is to have a central tool for monitoring that can access the data from other tools within the infrastructure. Analystical dashboards are suitable to fill the role of such a central tool.

B. Visualising Data

Analytical dashboards are data visualisation tools that are built with widgets. Widgets are single visualisations, e.g. graphs, diagrams or heatmaps. Arranged in a dashboard, widgets can provide a concise synopsis of a specific system. Dashboards are suited to quickly comprehend information, discover trends in data and to identify relations between various parameters.

One disadvantage of most current dashboard solutions is that they are not tailored for space mission operations, because these tools are implemented as generic as possible. However, because they are open-source, it is possible to create tailored custom widgets. Figure 1 shows an analytical dashboard, the BOSS[5] dashboard, based on Kibana with custom widgets. The widgets showing the status of telecommands, the battery widget, voltage widgets and angle measurement were added on top of the vanilla Kibana. Widgets customized to space missions provide the possibilities to directly assess several systems. They also facilitate the detection of trends, e.g. rising temperatures in a thermometer widget.

[5] http://solenix.ch/products

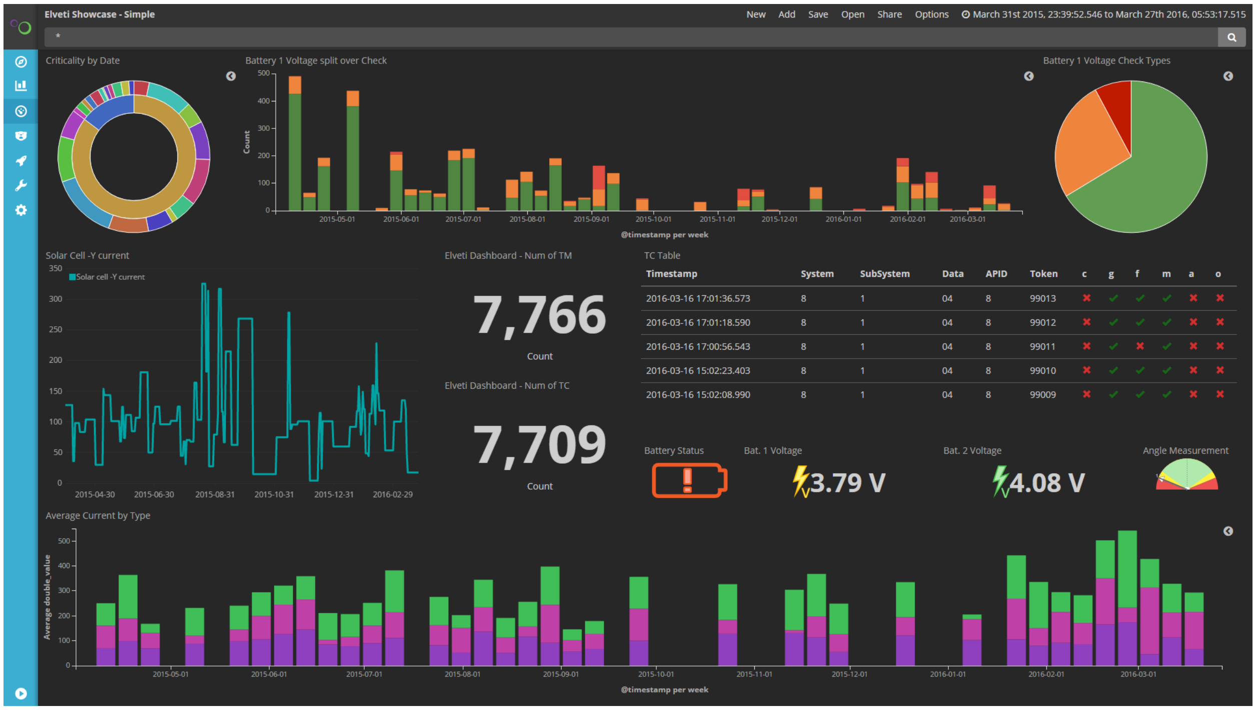

Figure 1. Analytical Dashboard based on Kibana with Custom Widgets

Another issue is that most solutions only work with a limited set of data sources. This constitutes a problem when space missions use data sources that are not supported, e.g. mission control systems, electronic logbooks, etc. A common solution is to copy all relevant data to a supported database and connect it to the dashboard solution. However, data duplication is ineffective and cumbersome to maintain. It is a better approach to implement adapters that connect the dashboard directly to the data sources, as shown in Figure 2. Again, this is possible because these open-source tools can be tailored to mission specific requirements. Connecting directly to data sources like mission control systems is faster and mitigates the load of copying data.

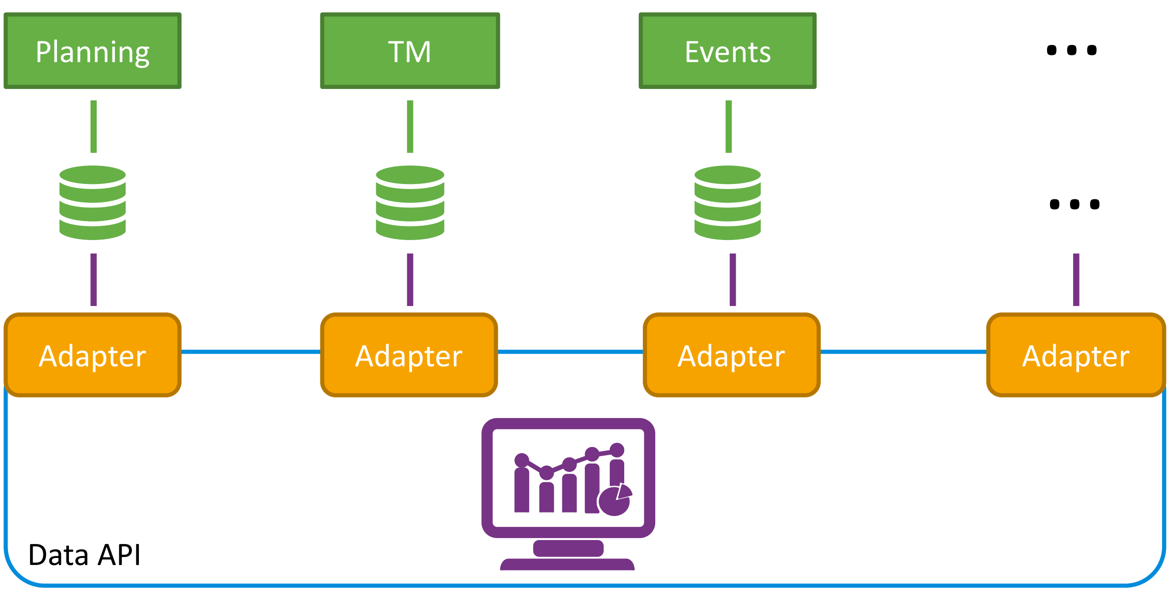

Figure 2. Connecting the Dashboard

Dashboards are powerful tools for efficient monitoring of space and ground segments. In the space sector, the main use cases for analytical dashboard solutions relate to observing the health of spacecrafts, providing cleaner views on incoming telemetry or visualising trends in the data to detect anomalous behaviour. However, data visualisation techniques can also be a proper tool to investigate interesting facts, e.g. how space weather affects spacecraft on various positions of its orbit via a combination and correlation of different data sets.

Many dashboard technologies allow to create logical groups of widgets by creating several dashboards. This can facilitate the monitoring tasks by creating dedicated dashboards for certain sub-systems, e.g. a dedicated dashboard providing an overview of all power aspects of the platform. With these features spacecraft operators can create dashboards that show very general information about their satellite or constellation and they can also create dedicated dashboards for each satellite in their constellation or dashboards showing certain parameters of all satellites in the constallation, e.g. showing all temperature readings of all satellites in one view.

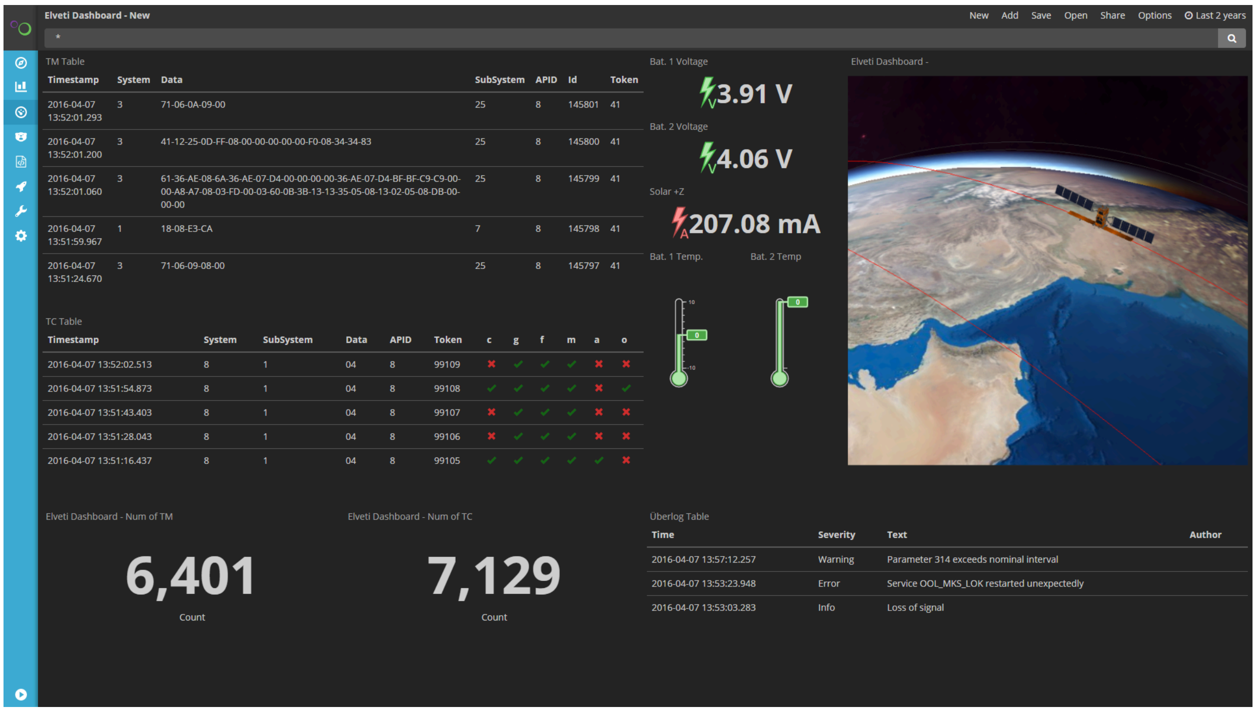

Figure 3. A Customized Dashboard for Monitoring

The potential of dashboards for satellite and constellation monitoring is unfolded when used with data from several different sources, as shown in Figure 3. The infrastructure of many space mission operations consists of various systems, e.g. for planning, commanding, and receiving and analysing telemetry and event reporting. With widgets visualising data from different systems at a glance, dashboards are suited to visualise data from different sources in the same view. The assessment of data with other available datasets of the same context is the foundation of gathering contextual information.

One outstanding example are widgets that are developed to allow annotating graphs with time series from other sources[6] as shown in Figure 4. This can be used to annotate telemetry values with messages from an electronic logbook, for example. Such annotations increase the situational awareness and facilitate the assessment of possible causes when telemetry parameters behave abnormally. Ultimately, such unified views on the data facilitate the detection of issues and the analysis of their root causes.

[6] https://www.elastic.co/guide/en/kibana/current/_featured_visualizations.html

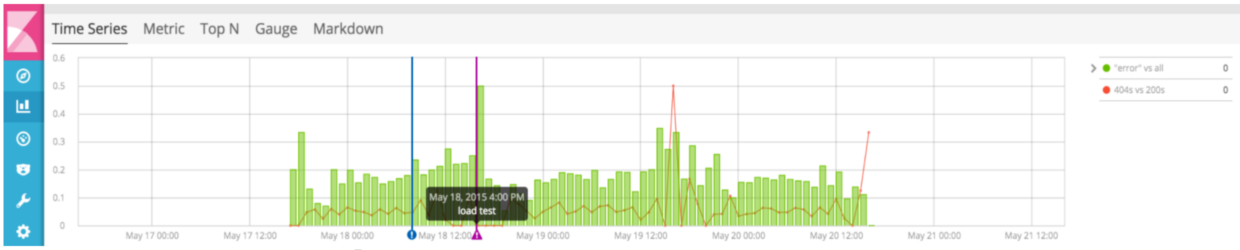

Figure 4. Annotated Time Series[7]

III. Benefits of Open-Source

Open-source dashboard technologies are often backed by a strong developer community. This leads to the development of plug-ins that can be integrated into the tool. These custom modules can add real value for satellite monitoring. Equipped with the right modules, dashboards are powerful enough to use machine learning for anomaly detection[8]. Tools exist that automatically analyse numerical time series and use unsupervised machine learning techniques to find anomalous values. Several metrics can be grouped to be analysed together, which allows the tools to show a chain of events that led to an anomaly.

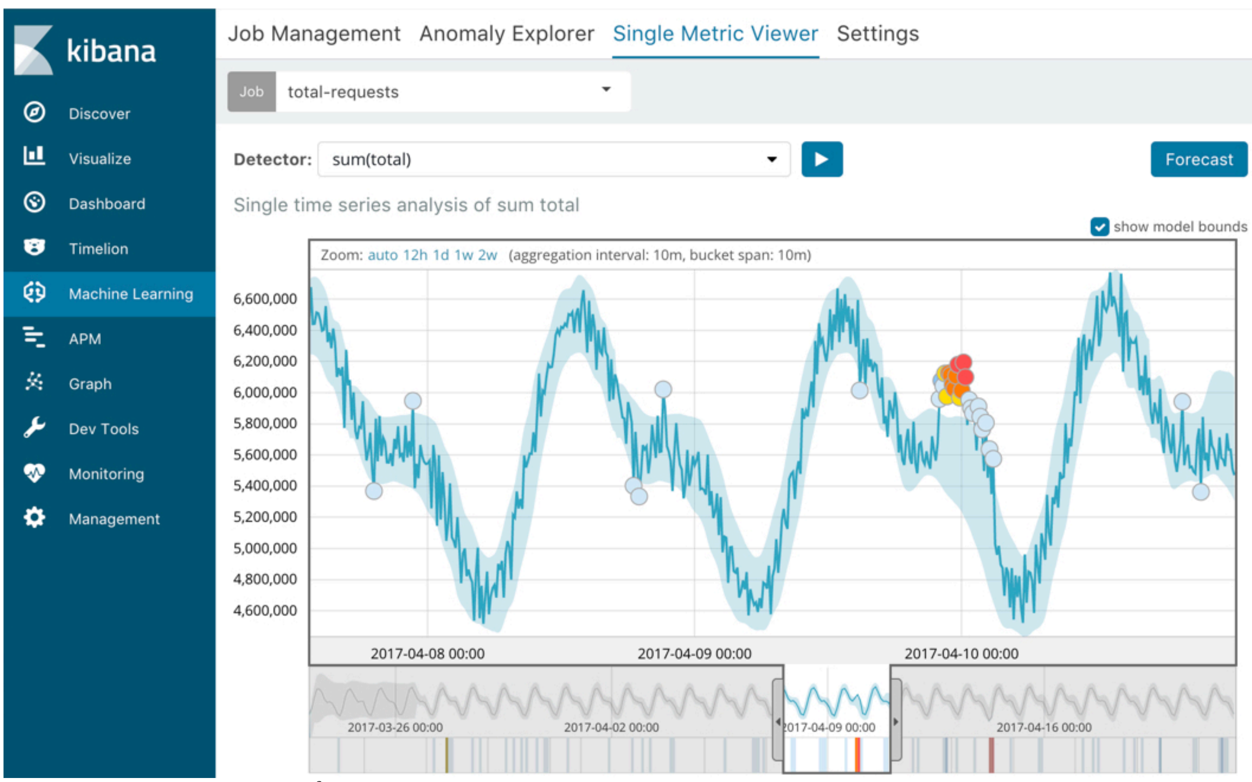

Figure 5. Anomaly Detection[9]

IV. Conclusion

The paper encourages the use of open-source tools for satellite monitoring in general and constellation monitoring in particular. Compared to the popular habit of creating specific custom solutions, open-source solutions often bring a wealth of functionality for free. In many cases, active and large developer communities of the open-source solution ensure a solid foundation, quality, and a continuously evolving and improving code base. Moreover, by having access

[7] https://www.elastic.co/blog/kibana-5-4-0-released
[8] https://www.elastic.co/products/x-pack/machine-learning
[9] https://www.elastic.co/guide/en/kibana/current/xpack-ml.html

to the source code, the tool can be modified and tailored, e.g. for integration with other tools or for extending the functionality. Using open-source solutions can save costs compared to custom solutions.

Dashboard solutions represent a prominent use-case of open-source solutions that have emerged in other industries, but can bring immense benefits to the space industry. Dashboards are perfectly suited to provide intuitive status overviews of complex systems. The underlying data is compressed and visualized in simple, graphical widgets that can be grouped logically on the dashboard. The level of abstraction from the base data is not limited and can range from instrument / component to subsystem, system (spacecraft level), and finally constellation. Vice-versa, it is very easy for engineers to drill down in this sequence of levels, e.g. in order to find the root-cause of an alarm.

Dashboards featuring smart widgets bring an additional powerful functionality. Smart widgets change their behavior and appearance depending on the status of the underlying data. Non-nominal situations can thus quickly be brought to the attention of engineers, who are alerted and can then analyse the situation using more detailed widgets and drilling down to the base data.