17th International Conference on Space Operations, Dubai, United Arab Emirates, 6 - 10 March 2023.

SpaceOps-2023, ID # 307

ESTIM: the ESTrack Investigation and Monitoring tool for analysis of ground station passes

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Abstract

Downlink signal losses cause data losses, something that ground segment control teams aim to avoid. Such signal losses can be due to a wide range of causes, from atmospheric conditions to ground station hardware failures, from ground station software failures to spacecraft issues. Ground station engineers investigate the root causes of these signal losses and, if possible, solve them. At ESA's operations centre ESOC, this process is currently performed manually, often requiring time and effort from multiple teams. In the frame of the Artificial Intelligence for Automation (A^2I) Roadmap that ESOC recently developed with industry, an AI-based prototype to target this very pain point was ideated and developed. In this paper, we describe ESTIM, ESTrack Investigation & Monitoring tool. By consolidating and learning from historical station pass data from different data systems (ground stations, telemetry, anomaly reports, logs), ESTIM can support ground station teams in identifying passes with issues while also indicating the main contributors to root causes and highlighting similar anomalies that occurred in the past. This accelerates the incident resolution process. We show that the current version of ESTIM already produces benefits and identify further areas for improvement. This is another example that demonstrates the value of leveraging AI for automating mission operations.

Keywords: AI, automation, ground stations operations, root cause analysis

1. Introduction

At ESOC, when downlink signal losses occur, based on their type and severity, several teams may need to be involved in the investigation and resolution process. The first analysis comes from operators at the Network Operations Centre (NOC), followed by ground operations and ground stations engineers. In case of need, specialist systems engineers or even subsystems suppliers, manufacturers and external parties may be consulted. Among the most common causes, there are atmospheric conditions; ground station hardware failures, such as amplifiers, Tracking, Telemetry & Command Processor (TTCP), Front End Controllers (FEC); software failures; spacecraft issues. From the current investigation process multiple pain points emerged, stemming primarily from the following issues: many disparate data sources requiring manual cross-checks; lack of automation for manual and routine issues; overwhelming, verbose logs; rich data. These pain points revealed opportunities where comprehensive data consolidation and contemporary AI methods can improve the incident analysis and resolution process.

As highlighted in the Artificial Intelligence for Automation (A^2I) Roadmap [1], the potential of leveraging AI to bring more automation to mission operations is considerable. To further validate the roadmap, another prototype, in addition to OCAI [2], targeting the pain points just mentioned was developed. ESTIM, the ESTrack Investigation and Monitoring tool, is an AI-based prototype that offers three key functionalities: (1) centralisation of heterogenous data from multiple systems; (2) intelligent insights from data analytics; (3) an intuitive graphical user interface. Sec. 2 describes how ESTIM was developed and its architecture, Sec. 3 presents and discusses the main results and Sec. 4 draws the conclusions.

2. Methodology

The vision for ESTIM was to provide an AI-based pass investigation solution that utilises, consolidates, and learns from historical pass data from ESTRACK (ESA's Tracking Station network), spacecraft telemetry, the Anomaly Report Tracking System (ARTS), the Operational Service Provision Management System (OSPMS), and Station Computer (STC) logs. The prototype should support day-to-day operations in identifying passes with issues, indicate the main contributors to causes, and highlight similar anomalies across other related passes in a user-friendly manner. All in all, the tool should help users perform their investigation more effectively.

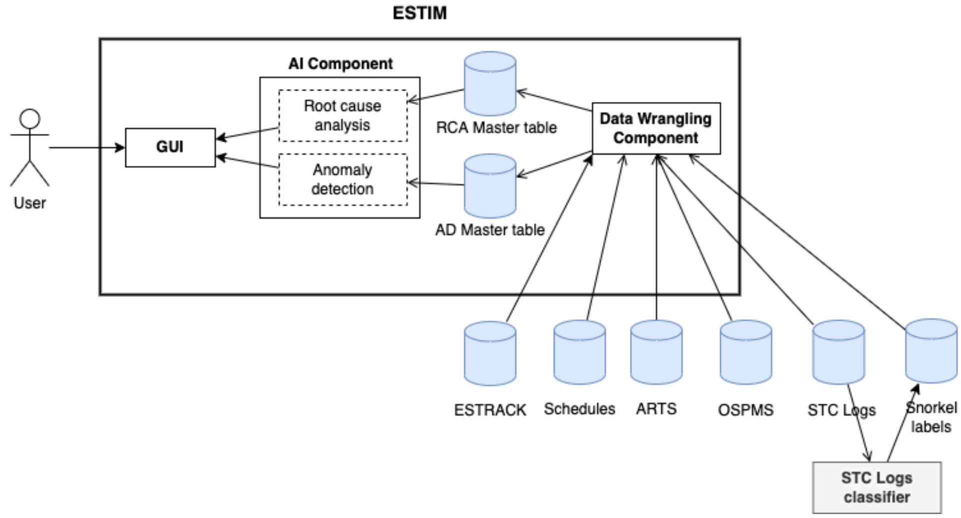

Figure 1. ESTIM's architecture.

To this aim, the first step entailed identifying and grouping the causes of issues occurring in ground stations into high-level categories and sub-categories, to achieve a more granular understanding. From the breakdown of OSPMS incidents, it turns out that issues are predominantly from three categories, "G/S - Other/Unknown", "G/S - Front-End" and "External". The first two can ultimately be attributed to equipment-related failures, while the last one can be related to local weather or atmospheric conditions. As such, the prototype will focus on identifying these failures, and use these categories as logical groupings.

2.1 Technical solution

ESTIM consists of three core components:

- Data wrangling: processes input data from different systems, i.e. schedules, ESTRACK, OSPMS, STC logs, and Snorkel classification labels and generates master tables that are then injected into the AI component;
- AI component: takes the master tables and builds machine learning models for cause analysis and anomaly detection;
- Graphical User Interface (GUI): provides the user with a dashboard to navigate through different passes and explanations of different causes of automatically identified issues and anomalies.

Another component is the STC Logs Classifier which is an external component used to classify STC logs and generate additional features used by ESTIM through an external system called Snorkel [3]. The prediction scores of the classes along with annotations are used as an input to the cause analysis model.

The AI component consists of an XGBoost [4] model with 20 trees, chosen from a grid search, conjugated with SHAP (SHapley Additive exPlanations) [5], a game-theoretic approach to explain the output of the model, for the cause analysis. For the anomaly detection, K-means clustering using the Euclidian distance was selected after investigation.

2.2 Implementation

Despite the challenges of working remotely due to the COVID-19 pandemic, a cross-functional ESA-industry team, composed of the authors of the present paper and professionals from McKinsey & Co. and QuantumBlack, developed ESTIM in only 12 weeks following an agile way of working. Main milestones of the prototype development included:

- deep analysis of underlying data, its structure and consistency;
- early identification of key datasets;
- data pipeline development;
- early convergence on the requested top-priority functionalities;
- early development of cause analysis models release;
- early creation of the graphical user interface.

2.3 Impact metrics

Quantitative and qualitative benefits of ESTIM were assessed through surveys sent to the end-users. The impact metrics included usability, effectiveness, and frequency of usage of the tool.

3. Results and Discussion

ESTIM has the following design constraints:

- Focuses on a single ESTRACK deep-space ground station, Malargue, and uses data of only one year covering passes for all supported missions;
- Estimates the probability of an operational pass having an issue (incident or failure);
- Has been trained on two main classes of issues (covering ~80% of incidents), each with several sub-categories:
    - External / weather related: rain, humidity, wind, attenuation, and hail
    - Equipment related: Antenna Control Unit (ACU), amplifier, TTCP, and other equipment problems
- Is not trained on other classes of issues (e.g., WAN outages, operator errors) – this means that some passes where incidents of these type occurred in reality might be indicated with a low probability of failure by ESTIM (since they are "unseen" by the current model).

ESTIM's key functionalities has two types of impact: digital user centric impact and AI-based feature impact. Digital user centric impact arises from pre-processing and centralising multiple data sources (including OSPMS, ESTRACK, scheduling, STC logs and telemetry) such that all data can be viewed at a pass segmented level in one system. Combined with an intuitive user experience, engineers can investigate pass issues with all relevant data available for plotting or viewing. On the other hand, AI-based features serve to augment the pass investigation process by intelligently recommending areas to focus on from analysing available data. Useful training labels were extracted from STC master journals using weak-supervision data labelling, which feeds into the variables-rich AI model used to estimate the probability of issues in historical passes. Additionally, an unsupervised machine learning model was used to identify anomalies in the Es/No curves to offer an alternative method to identify issues. Currently, model performance stands at 0.72 ROC AUC (Receiver operating characteristic Area Under the Curve), which is considered acceptable.

3.2 Graphical User Interface

ESTIM is a tool for efficient analysis of passes through the amalgamation of pass-related data from multiple heterogenous data sources and an intuitive visualisation of model outputs. There are two key features of ESTIM that enables this: (1) an overview page displaying key indicators of all passes and (2) a pass-specific view that displays relevant data, including model estimate of issue, atmospheric data and relevant logs. This results in a tool that allows users to triangulate problematic passes and view necessary data to identify the source of issue and diagnose them.

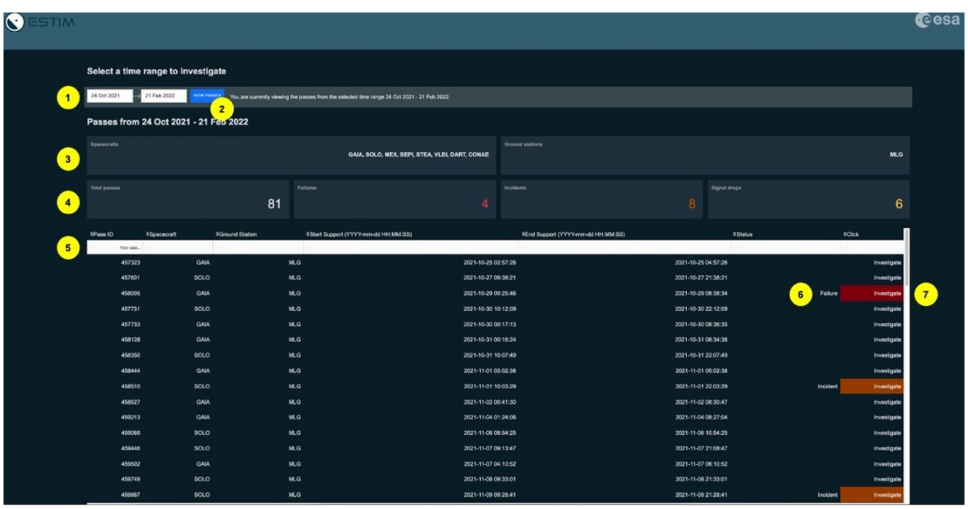

Figure 2. Screenshot of the homepage - the All Passes view.

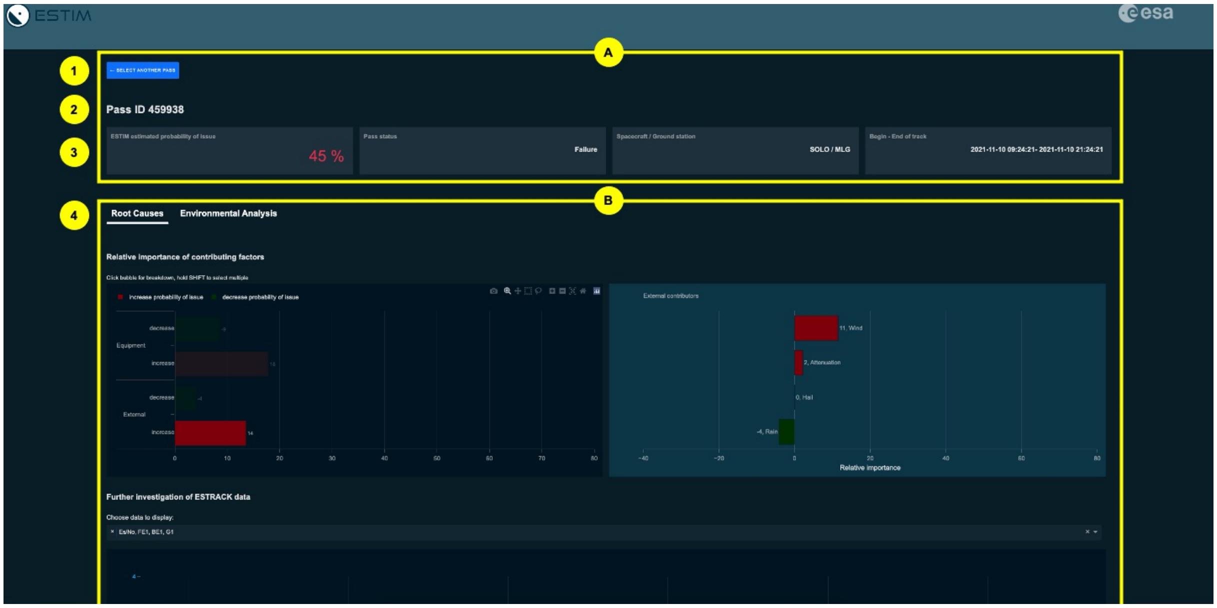

Figure 3. Screenshot of the Individual Pass view.

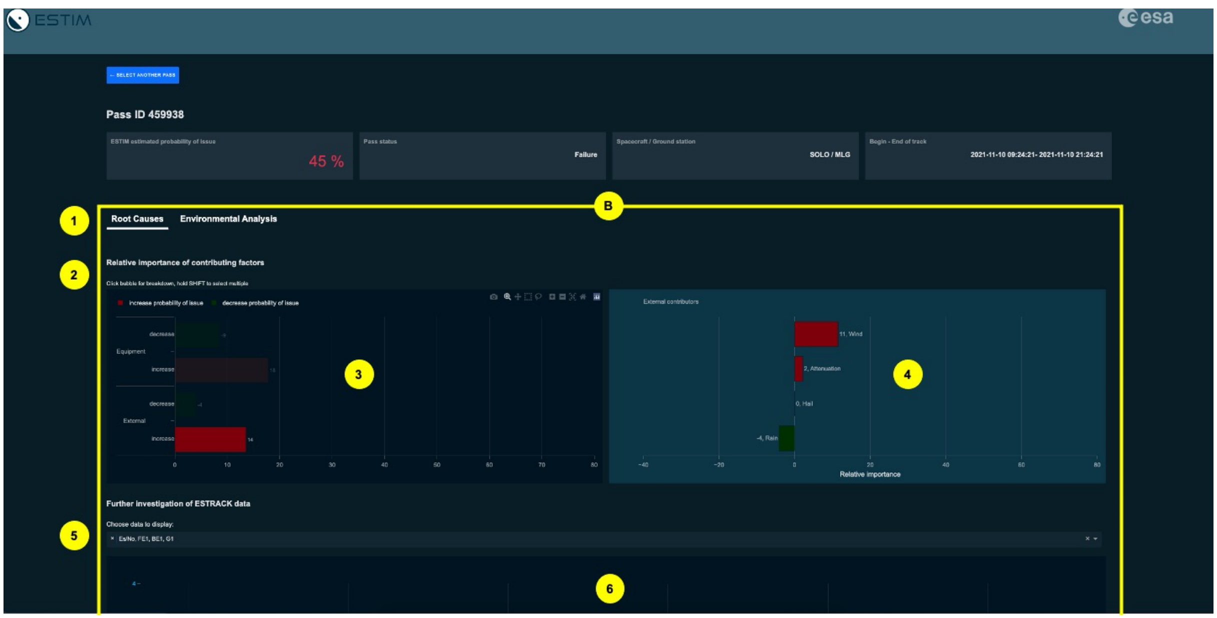

Figure 4. Screenshot of the Root Causes tab for a selected pass.

3.3 Impact and benefits of ESTIM

The results of the surveys showed that end-users were satisfied with the tool and its functionalities. In particular, the explainability feature together with the correlation of the incident under investigation with past similar instances through anomaly detection were appreciated. The benefits in streamlining and easing their day-to-day activities were also highlighted, as the time reduction in performing the same tasks without ESTIM.

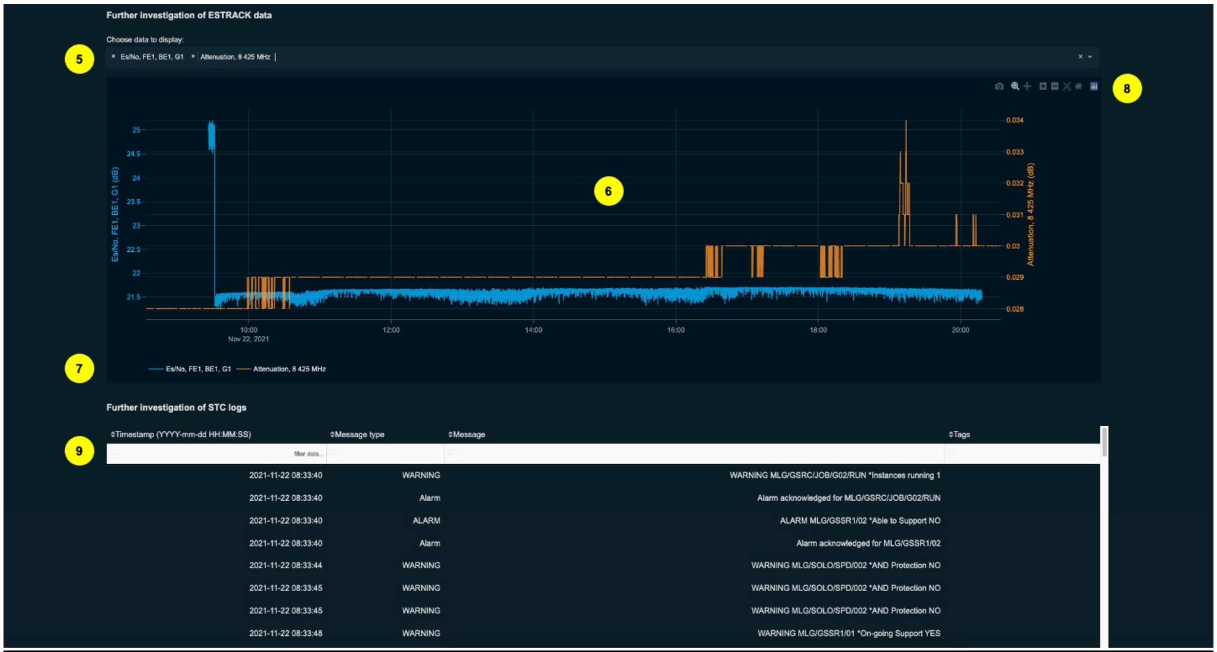

Figure 5. Screenshot showing the ESTRACK data plots and STC logs in the Root Causes tab.

Figure 6. Screenshot of the Observed Humidity/Rain Effects chart in the Environmental Analysis tab.

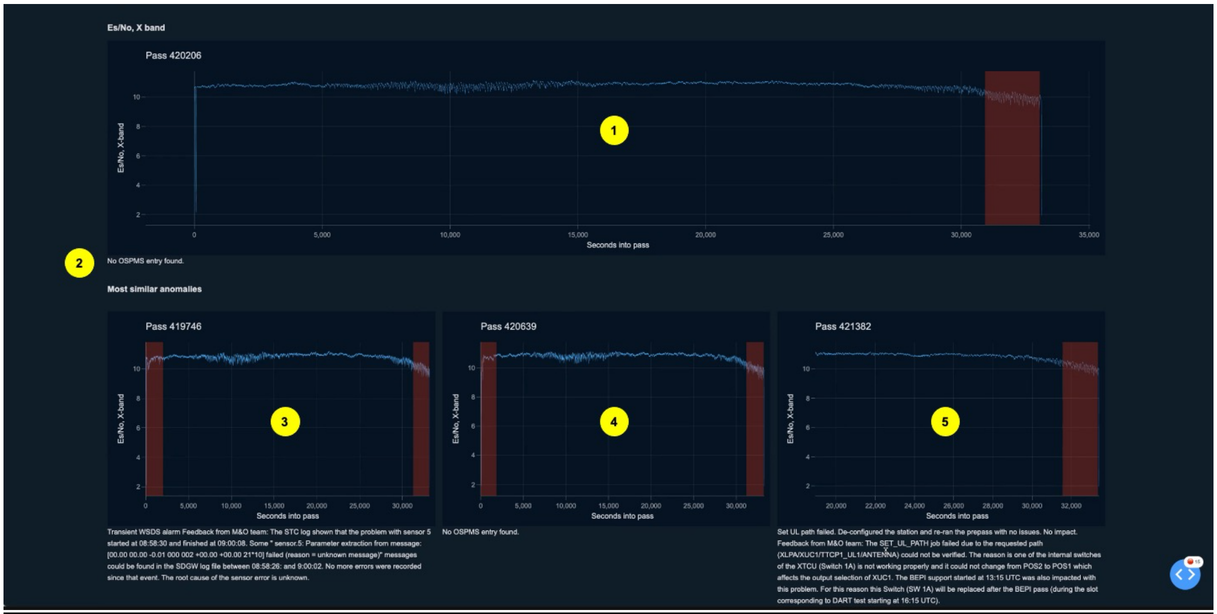

Figure 8. Screenshot of the Anomaly Analysis tab for a selected pass.

4. Conclusions

Automated diagnostics is one of the archetypes identified in the A^{2}I Roadmap [1] and covers use cases related to the ground systems. Specifically, being able to analyse historical data and understand causality in an automatic manner is also particular relevant to support the ground station teams who investigate incidents related to, for instance, downlink data losses. ESTIM is a prototype that belongs to this archetype.

Despite the challenges in developing ESTIM in terms of unlabelled and unbalanced data sets, the results achieved are promising. To improve the performance of the tool expected areas to further explore are increasing the amount of data (e.g. by including data from other ground stations); investigating other models and performing more advanced feature engineering; including the human in-the-loop to retrain the model by providing expert feedback on the causes. Besides, the prototype demonstrated once again that AI can bring tangible benefits to mission operations.

Acknowledgements

The authors would like to thank the team from McKinsey and Co. and QuantumBlack for their work and the ground stations and Network Operations Centre (NOC) engineers who provided valuable feedback and comments during agile development.

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