The Titan Control Center is a software platform supporting research on industrial big data analytics. Building upon a scalable and extensible architecture, the Titan Control Center analyzes and visualizes data streams from Internet of Things sensors in industrial production. It performs different types of aggregations, correlation, forecasting, and anomaly detection to provide deeper insights into industrial production data for enabling Industrial DevOps. Furthermore, the Titan Control Center is used in research for implementing and evaluating novel approaches on multi-dimensional sensor data stream aggregation, as a reference platform for benchmarking scalability in modular analytics software, and for research on analyzing industrial energy consumption.

1. Industrial DevOps analytics

Industrial DevOps is an approach for enabling continuous adaption and improvement in industrial manufacturing by making industrial data available for various stakeholders [1]. Since trends toward smart manufacturing, cyber–physical production systems, and Industry 4.0 result in huge amounts of Industrial Internet of Things (IIoT) sensors, which create data of immense volume, velocity, and variety (industrial big data), traditional analytics techniques are insufficient [2]. Implementing Industrial DevOps, therefore, calls for scalable, extensible, and resource-efficient data analytics in near real time.

In our research project Titan,¹ we work with several industrial partners on methods and tools for enabling Industrial DevOps.
one outcome of the project, the Titan Control Center for Industrial DevOps analytics emerged. Building upon a scalable and extensible architecture, the Titan Control Center allows to analyze and visualize data streams of IIoT sensors online in near real time [4]. Hence, it supports research on industrial big data analytics in general and Industrial DevOps in particular. In the following, we give an overview of the Titan Control Center’s functionalities for research (Section 2) and review its research impact (Section 3).

2. The Titan Control Center

The Titan Control Center is designed as a software platform deployed in cloud environments. It processes continuous streams of sensor data and performs various online analytics tasks. Key features of the Titan Control Center for research are:

Visualization. The Titan Control Center visualizes recorded sensor data and analytics results in information dashboards (cf. Fig. 1). These dashboards contain several visual components showing, among others, seasonal (e.g., daily or weekly) pattern, histograms, and the composition of aggregated data. Special focus is put on displaying previous measurements as time series plot. This plot is continuously updated with real-time data and allows exploring historical data by panning and zooming. Displayed data are dynamically retrieved in different resolutions considering the selected time domain and zoom level. For best accessibility, the Titan Control Center’s visualizations are implemented as a web-based application.

Aggregation. The Titan Control Center supports different types of aggregations on continuous sensor data streams. This includes aggregating data points in fixed-size, consecutive time intervals, aggregating data points having the same temporal attribute (e.g., day of week), and hierarchical aggregations of sensors into groups and groups of groups. Aggregated data are visualized as well as provided via data streams as basis for further analysis.

Correlation. Building upon previous research on analyzing ocean observation data [5], the Titan Control Center provides an interactive graphical tool for correlating time series data of multiple data sources. Time series can be arranged in multiple plots with synchronized time domains and allow analyzing certain points in time in detail.

Forecasting. The Titan Control Center supports forecasting by feeding measurements of sensor streams into a previously trained neural network. Thus, researchers can focus on building complex forecasting models, while applying these models to continuous sensor data streams (model serving) is delegated to the Titan Control Center.

Anomaly detection. The Titan Control Center comes with a general anomaly detection based on Z-scores. It compares sensor measurements with historical data recorded at the same hour of day and day of week. A more complex anomaly detection using our neural network forecasts is currently under development.

Sensor data integration. The Titan Control Center integrates seamless with the Titan Flow Engine, a low-code platform allowing domain experts to model industrial data flows in a graphical modeling language. We provide ready-to-use components for the Titan Flow Engine that connect these data flows with the Titan Control Center. Thus, integrating sensors requires only little to no programming skills. Likewise, we provide components for processing analytics results such as detected anomalies.

Extensible architecture. The Titan Control Center is designed as an event-driven microservice architecture (cf. Fig. 2). Analytics tasks are implemented as self-contained software components that communicate with each other asynchronously in a publish–subscribe fashion via a messaging system. This architecture allows for easy extension as analytics tasks have no compile-time dependencies to other tasks, but are still able to build upon their results. To add a microservice, researchers only have to encapsulate it in a Docker container and let it subscribe to required data streams.

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2 We provide a public show case of the Titan Control Center at http://samoa.se.informatik.uni-kiel.de:8185.
Large-scale data processing. The microservice-based architecture of the Titan Control Center allows its individual analytics tasks to be scaled independently [6]. Moreover, we apply big data stream processing techniques and tools within the microservices. Thus, analytics tasks can utilize cloud computing by distributing data processing over several computing nodes to cope with the rapidly growing amounts of IIoT data.

3. Research impact

The Titan Control Center supports research on event-driven, microservice-based IIoT analytics by providing a ready-to-use software platform. As such it was used for evaluating research on multi-dimensional aggregation of sensor data streams in a realistic scenario [7,8]. The presented aggregation approaches were later integrated as dedicated microservices into the Titan Control Center. Representing typical use cases for data stream analyses, the microservices of the Titan Control Center are employed to benchmark scalability of different stream processing engines and their deployment options [9,10].

Its diverse features for analyzing and visualizing sensor data enabled research on analyzing industrial energy consumption. The Titan Control Center was employed to implement reporting, optimization, fault detection, and predictive maintenance based on energy data [3]. Implemented measures for analyzing energy consumption were also evaluated in two industrial settings [3,4].

Besides employing the Titan Control Center as tool for research on industrial big data analytics, the Titan Control Center has also been used as a research object itself. This includes research on design, implementation, and evaluation of its scalable architecture [4], transfer of research on software performance monitoring [11], and research on clean code practices to build long living software [12].

The Titan Control Center is open source research software [13] licensed under the Apache License 2.0, such that it may be utilized commercially without any restrictions. In related research projects [14,15], we experienced that such a license is a good legal framework for technology transfer. In particular, we expect to stimulate research on and in an industry that rarely employs open source software.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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