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Visually Enhanced Situation Awareness for Complex Manufacturing Facility Monitoring in Smart Factories

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Abstract

With the widespread application of networked information-based technologies throughout industry manufacturing, modern manufacturing facilities give rise to unprecedented levels of process data generation. Data-rich manufacturing environments provide a broad stage on which advanced data analytics play leading roles in creating manufacturing intelligence to support operational efficiency and process innovation. In this paper, we introduce a process data analysis solution that integrates the technologies of situation awareness and visual analytics for the routine monitoring and troubleshooting of roller hearth kiln (RHK), a complex key manufacturing facility for lithium battery cathode materials. Guided by a set of detailed scenarios and requirement analyses, we first propose a qualitative and quantitative situation assessment model to generate the comprehensive description of RHK's operating situation. An informative visual analysis system then is designed and implemented to enhance the users' abilities of situation perception and understanding for insightful anomaly root cause reasoning and efficient decision making. We conduct case studies and a user interview together with the managers and operators from manufacturing sites as system evaluation. The result demonstrates its effectiveness and prospects its possible inspiration for other similar scenarios about complex manufacturing facility monitoring in smart factories.

Keywords: Visual Analytics, Situation Awareness, Manufacturing Industry, Smart Factory, Roller Hearth Kiln

1 INTRODUCTION

Industry 4.0 or smart factory is a world-wide attention topic that refers to the promotion of the fourth industrial revolution[1]. Compared with traditional industry, manufacturing facilities in smart factories are highly digitalized and connected through emerging technologies such as Internet of Things and Cyber Physical Systems[2]. These interconnection technologies create data-rich environments that support the acquisition, transmission and sharing of industrial process data across the factory[3]. Meanwhile, advanced analytics extract meaning from the data, and then inject "intelligence" into manufacturing facilities. The intelligence is able to benefit operators and managers in the improvements of operational efficiency and process innovation[4].

Visual analytics, as an important technology for gaining insights from large complex data, has played a crucial role in many domains. However, in manufacturing industry, besides use cases of scientific and information visualization to meet the analysis requirements of the simulation data generated by computational models[5-6-7-8], only a few works have introduced visual analytics into the investigation of the process data captured from modern manufacturing facilities[9-10-11]. With the advance of Industry 4.0, it is anticipated that the amount and complexity of process data will continue to grow. Visual analytics will be very valuable for both industrial and academic circles to explore the possibility of applying it in various manufacturing scenarios.

This work, taking the practice of a manufacturing company in upgrading its production lines for lithium battery cathode materials as background, focuses on addressing the process data analysis problems that the operators and managers of the company encounter on their routine monitoring and troubleshooting of roller hearth kiln (RHK). RHK is the most important facility for producing lithium battery cathode materials with a long continuous structure consisting of dozens of temperature zones. With the necessity of maintaining long-term uniform high temperatures inside the RHK, its electrical heating elements and temperature controllers age easily and often meet with various malfunctions. If not dealt with timely, the resulting temperature anomalies may seriously affect the stability of product quality. However, the alarm mechanism and process data analysis functions provided by current control desk cannot fulfil their daily work demands. Overwhelming false positives and uninformative data presentation lead to serious cognitive burden and time-consuming troubleshooting. They are desperate for new advanced solutions to improve their work efficiency and quality management level.

After working alongside with the target users to clarify their actual demands, we believe that the essential reason for the above problems is the lack of a comprehensive indicator of RHK's operating status and a well-designed tool for process data exploration. Regarding to RHK's multi-component and complex dynamic characteristics, the concept of situation awareness is a great fit for indicating the state, progress and trend of a running RHK. We thus propose a visually enhanced situation awareness solution that is mainly composed of a situation assessment model for comprehensive and measurable situation description and a visual analysis system for efficient situation perception and insightful situation understanding. Fig.1 gives the interface overview of the prototype system.

For the situation assessment model, we first design a hierarchical assessment index system to generate the quantitative situation of a temperature zone from bottom to up by taking full account of a variety of temperature anomaly factors and the relevant clues that can be extracted from process data. We then conclude the overall situation of a RHK from local to global based on the generated situations of all the zones. In order to adequately integrate users' expertise and experience, we work closely with the target users to develop the index system, and allow them to set the weights of indexes and zones as well as the thresholds for the conversion of