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学位論文内容の要旨

Big data means horizontally networked yet independent data systems containing a vast number of structured and unstructured datasets. Statistical and logical computational arrangements (referred to as big data analytics) must be installed to make sense of big data. Like human-cyber-physical systems, digital twins, artificial intelligence, Internet of Things, and sustainability, big data and big data analytics are essential elements of the fourth industrial revolution or smart manufacturing. This thesis considers the problem of developing big data and big data analytics for smart manufacturing, focusing on the following three issues.

Issue 1: Digital twins of manufacturing phenomena are supposed to machine-learn the required knowledge using relevant datasets available in big data. Therefore, a research question is how to preprocess manufacturing phenomena-relevant datasets for using them directly in digital twins.

Issue 2: Big data is often visualized using several two-dimensional plots. These plots are then used to make a decision informally. Consequently, a research question is how to make formal decisions by computing two-dimensional plots, not numerical data.

Issue 3: Big data and analytics require expensive resources and sophisticated computation arrangements. Thus, big data hardly benefits small and medium-sized manufacturing organizations, resulting in “big data inequality.” Consequently, a research question is how to eliminate big data inequality.

Thus, this thesis is organized as follows. Chapter 1 presents the background, objective, scope, and limitations of this thesis. It also presents a comprehensive literature review on big data relevant to smart manufacturing. Chapter 2 presents the mathematical settings needed to understand the computational aspects of the proposed big data analytics.

Chapter 3 deals with Issue 1. A digital twin consists of five modules (input, modeling, simulation, validation, and output modules), and big data must supply datasets for building these modules. This chapter presents a manufacturing phenomenon-related datasets preprocessing method considering the four modules of digital twins (input, modeling, simulation, and validation modules). As an example, the preprocessing of surface roughness-relevant datasets is considered.

Chapter 4 deals with Issue 2. A big data analytics is developed to compute two-dimensional plots generated from big data. The efficacy of the tool is demonstrated by applying it to assess sustainability in terms of Sustainable Development Goal (SDG) 12 (responsible consumption and production). Regarding SDG 12, functional, economic, and environmental issues of engineering materials play a vital role. Accordingly, three two-dimensional plots generated from big data of engineering materials

are computed using the proposed analytics. The plots refer to six criteria (strength, modulus of elasticity, cost, density, CO2 footprint, and water usage). The proposed analytics correctly rank the given materials (mild steel, aluminum alloys, and magnesium alloys).

Chapter 5 deals with Issue 3. A big data analytics is developed for manufacturing process-relevant decision-making. The proposed analytics consists of five integrated systems: 1) big data preparation system, 2) big data exploration system, 3) data visualization system, 4) data analysis system, and 5) knowledge extraction system. The big data preparation system prepares contents that exhibit the characteristics of digital manufacturing commons. Thus, the system can support user-defined ontology and automatically produces Extensible Markup Language (XML)-based datasets. The big data exploration system can extract relevant datasets prepared by the first system. The system uses keywords derived from the names of manufacturing processes, materials, and analyses- or experiments-relevant phrases (e.g., design of experiment). The third system can help visualize relevant datasets extracted by the second system using suitable methods (e.g., scatter plots and possibility distribution). The fourth system establishes relationships among the relevant control variables (variables that can be adjusted as needed) and evaluation variables (variables that measure the performance) combinations for a given situation. In addition, it quantifies the uncertainty in the relationships. The last system can extract knowledge from the outcomes of the fourth system using user-defined criteria (e.g., minimize surface roughness and maximize material removal rate). The efficacy of the proposed big data analytics is demonstrated using a case study where the goal is to determine the right states of control variables of dry electrical discharge machining for maximizing material removal rate. It is found that the proposed big data analytics is transparent and free from big data inequality.

Chapter 6 describes future research directions and discusses the implication of this study from the viewpoint of smart manufacturing. Finally, Chapter 7 provides the concluding remarks of this thesis.

審査結果の要旨

要旨

申請者はスマートマニュファクチャリング用ビッグデータアナリティクスの開発に関する研究を行い、その内容を博士論文として提出した。

多くの場合、ビッグデータは、グラフを用いて視覚化する。ユーザーは、これらのグラフを参考にし、正式に計算せずに意思決定を行う。本論文はビッグデータから得られたグラフを数値化するシステムについて述べた。特に持続可能な開発目標（SDGs）に関するビッグデータを用いて行う意思決定工程のより正式化に成功した。

スマートマニュファクチャリングでは、生産加工に関わる現象をデジタルツイン化することで、製造問題を解決する。こういうデジタルツインは、産業用ビッグデータから機械学習によって必要な知識を獲得する。そのため、生産加工に関するデータを前処理し、産業用ビッグデータに導入する必要がある。本論文は表面粗さのデータをビッグデータ化に必要な前処理について述べた。さらに本論文は生産加工に関する実験データをビッグデータ化し、そのデータから加工条件の最適化を行うため必要な解析システムを考案し、そのシステムの有効性を放電加工のデータを用いて示した。こういう解析システムはビッグデータの不確定要素の定量化を行うため有効であることを明らかにした。

従って、本論文は学術上、実際上寄与するところが少なくない。よって、本論文は博士（工学）の学位論文として価値あるものと確認し、合格と認めた。