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論　文　名	「Agent-based Dynamic Integrated Process Planning and Scheduling in Flexible Manufacturing System」 (エージェントを用いたフレキシブル生産システムのための動的工程設計とスケジューリングの統合化)	
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論文要旨

Process planning and scheduling are most important tasks in manufacturing systems. The tasks strongly influence the profitability in manufacturing processes, resource utilization and product delivery time. Process plans specify the raw materials needed to produce final products, and the manufacturing processes and the resources required to transform the raw materials into the final products. The outcome of the process planning is the information required for the manufacturing processes, including the identification of the machines tools, cutting tools, and fixtures. The scheduling systems receive the process plans as their input, and their task is to generate suitable schedules of the resources, taking into consideration of the precedence relations given in the process plans. Both the process planning and the scheduling involve assignment of the products to the resources, and are highly interrelated. It is the link of the two production steps, which are the preparing processes and putting them into action. Although there is a strong relationship between the process planning and the scheduling, the integration of them is still a challenge in both the research and applications.

The integrated process planning and scheduling are very complicated and time consuming tasks, if it is applied to the dynamically changing FMSs (Flexible Manufacturing Systems). The objective of the research is to propose both job agents and machine tool agents representing the products and the machine tools, and to develop a multi-agent architecture for the dynamic process planning and scheduling of multi jobs that rapidly adopt the process plans and schedules to cope with the job changes and the unexpected disturbances in the FMSs. As the efficiency becomes important in today manufacturing systems, mathematical optimization models was applied for optimizing the assigning job agents to the machine tool agents, which are suitable for real time applications.

The organization of the dissertation chapters are as follows;

In chapter 2, related literatures are reviewed to clarify the background and importance of the

integrated approaches for process planning and scheduling in the Flexible Manufacturing Systems. The conventional techniques and new approaches are reviewed for developing integrated process planning and scheduling architecture. Based on the literature survey, new areas for research and contributions are identified and proposed.

In chapter 3, a search algorithm is developed for generating the alternative process plans in the FMSs. The process plan domain is expanded by adding the fixture layer to the process plan hierarchy. The generated process plans become more realistic by adding the fixture layer to the process plan domain. A search algorithm is proposed to generate a set of alternative process plans and to select the suitable process plans. The proposed search algorithm provides the users with an effective algorithm for generating the alternative process plans from the wide areas of the process plan networks by setting the search parameters. The benefit of this algorithm is that the whole process plan networks do not have to be generated, and the networks are generated and expanded only along the search paths. Some case studies are carried out to evaluate and to compare the algorithm with the previous one. In most cases, the proposed algorithm generates the optimum solutions.

In chapter 4, a multi-agent architecture is proposed to a real time and dynamic process planning system in the FMSs, which generate suitable process plans based on the status of the FMSs. The objective is to develop a multi-agent architecture for the process planning of one kind of product that rapidly adopt the process plans to cope with the product changes and the unexpected disturbances in the FMSs. A multi-agent system consisting of five basic agents and a negotiation protocol is customized and improved to carry out the various tasks in the process planning. The individual agents have the capability for the distributed decision-making and the communications with the other agents. A process plan network and a heuristic search algorithm are proposed to generate suitable process plans real-timely. Some case studies are carried out to verify the effectiveness and the robustness of the proposed method to the dynamic process planning problems in the FMSs. It is shown that the proposed distributed methods are effective to incremental generation of the process plans, and that the near optimal solutions can be generated. It is also shown that the proposed architecture generates alternative process plans dynamically to cope with the malfunctions of the machine tools.

The multi agent architecture is expanded, in chapter 5, for real time integrated process planning and scheduling system in the FMSs for multi jobs. The negotiation protocol and simulation software are expanded to carry out the various tasks in the process planning and the scheduling. A systematic procedure is proposed to generate suitable process plans of the jobs and suitable schedules of the machine tools. The proposed method is able to solve the process planning and scheduling problems concurrently and dynamically, with use of the search algorithms of the process plan networks. Some case studies are carried out to verify the applicability of the proposed method to the integrated process planning and scheduling problems in the FMSs including 7 machine tools and 10 jobs. It is shown, through case studies, that the proposed multi-agent architecture is capable to generate appropriate process plans and schedules. It is also shown that the proposed architecture generates alternative process plans dynamically, to cope with the malfunctions of the machine tools and unforeseen job specification changes.

In chapter 6, a coordination agent and a mathematical model are introduced for improving the generated process plans and schedules by the autonomous agents. The efficiency of the multi-agent architecture for integrated process planning and scheduling are improved by applying optimization techniques, which are suitable for real time applications. It is shown through case studies that the multi-agent systems with the coordination agents generate more suitable process plans and schedules from the viewpoint of the average flow time of the all the job agents. It is because that the mathematical programming methods applied here are suitable to reduce the average flow time of the job agents of the job shop process planning and scheduling problems. The calculation time for coordination is enough short and the proposed method are suitable for the real time application, when the FMSs include enormous

number of job agents and machine tool agents.

The concluding remarks are summarized in the followings. Firstly, a search algorithm is proposed to generate a set of alternative process plans and to select the suitable process plans for one kind job for the static environment. The remarks of the developed algorithm are concluded as follows.

- A class diagram was proposed for process planning and generating the process plan networks of one kind job.
- A search algorithm was developed for generating and searching the process plan networks. The benefit of this algorithm is that the whole process plan networks do not have to be generated, and the networks are generated and expanded only along the search paths.
- Some case studies have been carried out to evaluate and to compare the algorithm with the previous one. In most cases, the proposed algorithm generates the optimum solutions. The algorithm is efficient for the large and vast process plan networks. The user can expand the different portions of process plan networks by adjusting the search parameters.

Secondly, a multi-agent and distributed for dynamic integrated process planning and scheduling system is proposed, which generate suitable process plans and schedules for multi jobs based on the real time status of the FMSs. The remarks of the developed architecture are concluded as follows.

- A multi-agent system consisting of six agents and a negotiation protocol among the agents were proposed to carry out the various tasks in the dynamic process planning and the scheduling. The individual agents have the capability for the distributed decision-making and the communications with the other agents.
- A systematic procedure was proposed to generate suitable process plans of the jobs and suitable schedules of the machine tools. The proposed method is able to solve the process planning and scheduling problems concurrently and dynamically. The efficiency of the architecture was improved by using the mathematical optimization methods and search algorithms of the process plan networks.
- A Petri net based synchronization mechanism was proposed to control the negotiation protocols among the agents for solving the multi job problems. The Petri nets modules, developed in this research, control both the sequence and the timing of the interactions and the messages between the agents.
- Some case studies have been carried out to verify the applicability and effectiveness of the proposed methods to the integrated process planning and scheduling problems in the FMSs. It was shown, through the case studies, that the proposed multi-agent architecture is capable to generate appropriate process plans and schedules. It was also shown that the proposed architecture generates alternative process plans dynamically, to cope with the malfunctions of the machine tools and unforeseen job specification changes.
- It was shown that the proposed architecture is robust and can dynamically cope with the unforeseen breakdowns of the manufacturing resources and the change in the job specifications

審査結果の要旨

本論文は、フレキシブル生産システム(FMS)の動的な変化に柔軟に対応することを目的として、機械生産における加工工程設計とスケジューリングの統合化を試みたものである。そのために、エージェントをベースとする分散処理により、工作物および工作機械が協調しながら工程設計および生産スケジュールの策定を行う手法を提案し、次のような成果を得ている。

(1) 可能なすべての機械加工工程を表現する工程計画ネットワークを用いて、適切な加工工程を探索する手法を提案している。ここでは、コンピュータによる計算時間と加工工程の最適性のトレードオフを検討し、適切な計算時間で可能な工程計画を策定する手法を提案している。

(2) 分散エージェントの考え方に基づいて、単一部品について工程設計を行い、工作機械の生産スケジュールを策定する分散処理システムを開発している。ここでは、工作機械エージェント、ジョブエージェントなど、システム構築に必要なエージェントを提案し、システムを開発している。

(3) (2)で開発したシステムを拡張し、複数の部品について工程設計を行い、工作機械の生産スケジュールを策定する分散処理システムを開発している。ここでは、工作機械エージェントとジョブエージェントが協調しながら、スケジュールと工程計画を策定する手法を提案している。

(4) 工作機械エージェントとジョブエージェントとの協調プロセスの改善を目的として、協調エージェントを新たに導入し、このエージェントを用いた新たなプロセスを提案している。これにより、部品の加工終了時刻が短縮されることを検証している。

以上の諸成果は、機械生産システムの工程設計およびスケジューリング技術に関する新しい知見であるとともに、新たな生産システムの研究開発に寄与するものであり、本分野の学術的・産業的な発展に貢献するところ大である。また、申請者が自立して研究活動を行うのに必要な能力と学識を有することを証したものである。

学位論文審査委員会は、本論文の審査ならびに最終試験の結果から、博士（工学）の学位を授与することを適当と認める.