Title	Efficient Evolutionary Algorithm of Multi-objective Optimization for High-Confidence Cyber-Physical Systems
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Citation	科学研究費助成事業研究成果報告書: 1-6
Issue Date	2018-06-01
Type	Research Paper
Text version	publisher
URL	http://hdl.handle.net/10119/15395
Rights	
Description	基盤研究(C)（一般），研究期間：2015～2017，課題番号：15K00120，研究者番号：90435793，研究分野：情報学

2版

様　式　Ｃ－１９、Ｆ－１９－１、Ｚ－１９　（共通）

科研費 KAKENHI

科学研究費助成事業　　研究成果報告書

平成 ３０ 年　 ６ 月　 １ 日現在

機関番号：１３３０２
研究種目：基盤研究(C)（一般）
研究期間：2015～2017
課題番号：１５Ｋ００１２０

研究課題名（和文）Efficient Evolutionary Algorithm of Multi-objective Optimization for High-Confidence Cyber-Physical Systems

研究課題名（英文）Efficient Evolutionary Algorithm of Multi-objective Optimization for High-Confidence Cyber-Physical Systems

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交付決定額（研究期間全体）：（直接経費）　　3,600,000円

研究成果の概要（和文）：本研究の目的は、制御則設計と実時間計算制約との間のギャップを大規模で分散し効率的かつリアルタイムに縮むための、高信頼なサイバー物理システム（HiCoCPS）の新しいモデルを提案することです。その成果は、スマートホームおよび他のCPSベースのアプリケーションにおけるHiCoCPSの3つのモデルを設計および提案することを含む。以下の結果も含む：（1）Satisfiability Module Theoriesに基づく新規リアルタイムスケジューリング方法論フレームワークとタスクモデル、（2）2つのsafe-to-processスキームを用いた時間遅れモデル、（3）モデル予測制御を用いた最適化モデル。

研究成果の概要（英文）：The goal of this project to propose a novel model of high-confidence cyber-physical systems (HiCoCPS) for bridging the gap between control law design and real-time computation constraints in a large-scale, distributed, efficient and real-time manner. The outcomes include designing and proposing three models, i.e., task model, time delay model, and optimization model for the HiCoCPS system in the smart home application and other CPS-based domain applications. In summary, the results are: (1) novel real-time scheduling methodology framework and its task models based on Satisfiability Module Theories; (2) time delay model with two safe-to-process schemes; and (3) optimization model with model predictive control.

研究分野：情報学

キーワード：Cyber-Physical Systems　Real-time System　Internet of Things　SMT　Predictive Control　Smart Homes

１．研究開始当初の背景

The motivation of this project comes from the observation of global transformative forces, i.e., Cyber-Physical Systems (CPS) that is initialized by the National Science Foundation (NSF), United State in late 2006 steers the technological trend to realize the fully automation system of systems in the ultramodern applications. In oversea trends, a high-confidence CPS (HiCoCPS) particularly is a novel research domain, which seeks to integrate computing, communication and storage capabilities with monitoring among connected systems through networks in a dependable, secure, safe, efficient, and real-time fashion.

In the HiCoCPS system viewpoint of smart homes, the mountains of raw data from the surrounding sensors and their measurements will be passed into a central computer for processing and spun back out to remotely control the physical actions, e.g., air-conditioner and window. The measurements may not be accurate because of unpredicted change of environments. Some measurements could be incomplete because of occlusion problems due to the wireless nature for example. Furthermore, because of the cheap sensors, inaccurate or faulty measurements are possible. Therefore, the HiCoCPS system is a complex closed-loop control system that makes use of inaccurate or incomplete data from the wireless sensor and actuator networks to make intelligent control decisions to operate the actuators for effective control of physical processes. The design and implementation of the HiCoCPS system in large-scale and distributed manner pose several challenges with respect to the issues such as time-driven and event-driven computation, time-varying delays, and transmission failures. As a result, a new model is required to able to capture the interaction between cyber and physical properties in a composable manner. This project is to ensure the new model of the HiCoCPS system that can meet the key interaction among the properties and eventually provide the requirement level of performance.

２．研究の目的

The purpose of this project is to propose a novel model of HiCoCPS system for bridging the gap between control law design and real-time computation constraints in a large-scale, distributed, efficient and real-time manner. To achieve it, this project has two main objectives.

(1) to propose and develop three models, i.e., task model, time delay model, and optimization model, which should be captured the interaction between cyber and physical properties in a composable manner; and
(2) to implement a HiCoCPS testbed environment for smart home application and other CPS-based domain applications.

３．研究の方法

This project consists of proposing three models, i.e., task model, time delay model, and optimization model in order to bridge the gap between control law design and real-time computation constraints in the HiCoCPS system. This project also implements the HiCoCPS testbed environment using the smart home environment, iHouse.

４．研究成果

In first fiscal year, a task model is proposed to attain an efficiency scheduling algorithm for the HiCoCPS system. To achieve this, a real-time scheduling methodology based on Satisfiability Module Theories (RSMT) framework is designed as illustrated in **Figure 1**. In RSMT, the task model is breaking down into a task dependency graph, which is used to illustrate the task execution orders before an optimization scheduling algorithm, i.e., the proposed SMT-based scheduling. The scheduling issue is formalized as a form of the constraint satisfaction problem that is using the first-order logic with equality. As a results, the proposed SMT based scheduling can maximize the total number of tasks to meet their deadlines regardless of the system and target constraints. **Figure 2** depicts the comparison analysis of success ratio versus task arrival rate. RSMT framework outperforms the baseline algorithms regardless of the input task arrival rate. To show the usage of RSMT framework in the practical applications, a case study on a running car, which is equipped with multiple processors is also studied.

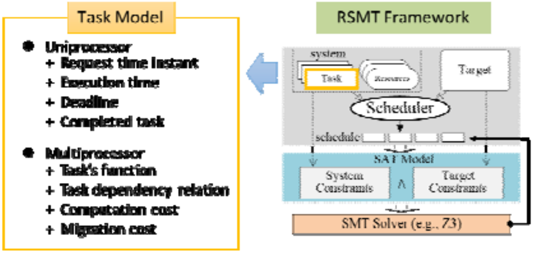

Figure 1: RSMT framework with its task model.

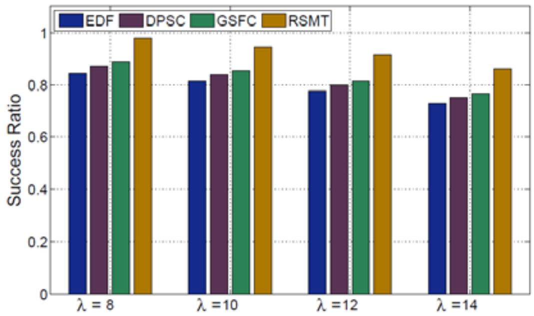

Figure 2: Comparison analysis of success ratio versus task arrival rate

In second fiscal year, a mathematical representation of the time delay model with consideration of network time delay, latencies of sensors and actuators, and clock error for the HiCoCPS system is studied and derived. Figure 3 shows a generic HiCoCPS system with three platforms. The concurrent issue happens at the merge in the platform 3. This concurrent arrival issue of two tasks is formalized as a critical problem of FIFO approach when those two tasks have a dependency of each other. Therefore, the proposed time delay model with a task dependency method is considered. To solve this problem in the HiCoCPS system, two safe-to-process schemes, i.e., the root mean square (RMS) based scheme and the double average (DA) based scheme are proposed.

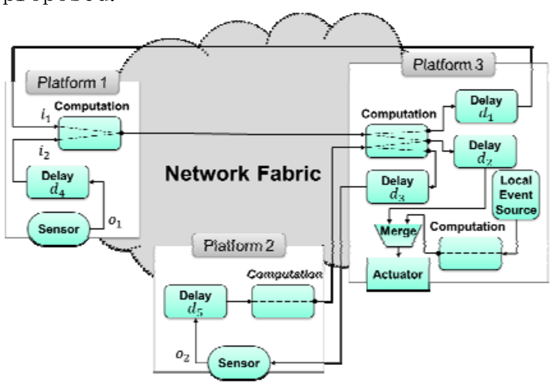

Figure 3: Generic HiCoCPS system with three platforms.

In third fiscal year, the proposed time delay model with the safe-to-process schemes for the HiCoCPS system, which consist of a main controller and two sub-controllers is evaluated. Figure 4 shows the percentage of safe-to-process performance of both RMS-based and DA-based schemes. As shown in Figure 4, the proposed DA-based scheme can guarantee 100% of safe-to-process regardless of any average inter-arrival time of two arrival tasks.

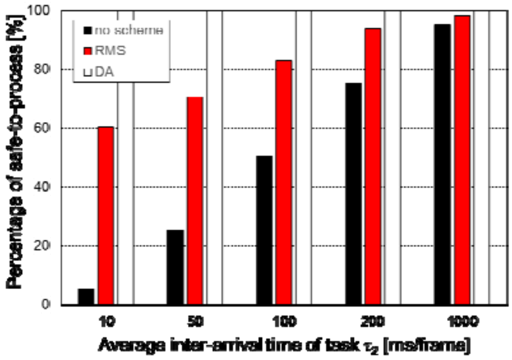

Figure 4: Percentage of safe-to-process performance.

On the other hand, a hybrid predictive control is proposed to optimize real-time control operations of the HiCoCPS system considering the different aspects of the multidimensionality of the HiCoCPS problem. To accomplish this, a model predictive control (MPC) is taken into consideration. The MPC controller is integrated into the existing energy efficient thermal comfort control (EETCC) system, which was developed for the experimental smart home environment as shown in Figure 5. The advantages of MPC is explored in a real time manner for two objectives, i.e., reference tracking and energy minimization scenarios. In this project, the implementation of the MPC is successfully derived, simulated and benchmarked with four different seasons by using an evolutionary algorithm pursues the optimization of a dynamic multiple objective function, i.e., settling time and energy consumption for the EETCC in cyber-physical home system. Figure 6 depicts energy consumption comparison for all seasons. MPC 1 uses single objective (reference tracking), whereas MPC 2 performs two objectives (reference tracking and energy minimization). As a result, MPC 2 is managed to reduce the energy consumption for all seasons. In addition, MPC 2 is extended with the self-adaptive model.

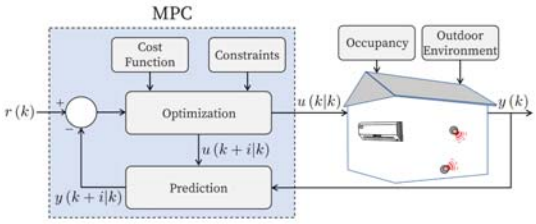

Figure 5: System model with MPC

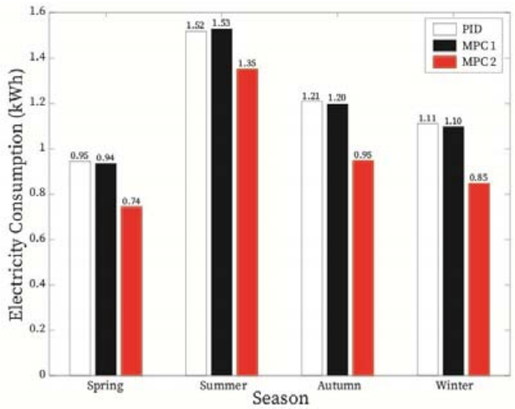

Figure 6: Energy consumption comparison for all seasons.

In summary, this project reveals many breakthroughs in contributing the research domain of the emergence concept of CPS in the era of Internet of Things. Some improvement and evaluation parts of this project are still needed to be accomplished. Nevertheless, this project leads to long-term research collaborations internationally and domestically although this project has been finished.

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〔その他〕

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