Decision Tree-based Hybrid Multiprocessor Task Scheduling for the Cyber-Physical System

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Abstract

Scheduling is a critical process in cyber-physical systems to ensure the computation will be over within the physical system's deadline. Under the cyber-physical system, the processor is distributive and hydrogenous. Less latency task scheduling under this distributive cyber-physical system with a hydrogenous processor and resource is challenging. This article presents a decision tree based less complex mechanism of task scheduling in a heterogeneous processor environment this proposed mechanism model the tasks and the processor resource, current load level, their individual computational capability, memory availability, communication delay in the distributive system to move the task from one point to another point is taken into account for the scheduling purpose the numerical results prove that the proposed mechanism able to schedule the task quickly and with more task deadline meet the ratio.

Keywords

Cyber-physical Systems, Tree-Based Hybrid, Communication Networks.

Introduction

Cyber-physical systems (CPSs) are the latest technology that consists of the sensor system, communication networks, a computing system, and a control system. Real-time performance proving is one of the essential things in the cyber-physical system when concerning about physical system. The design of CPS, which will meet the demands of the physical system's response time in real-time, is a challenging one. One of the significant components of the design for meeting this type of real-time deadline is task scheduling. There are various scheduling frameworks provided in the literature. A review of few works of such real-time scheduling is presented below among different CPS systems automotive CPS system requires more attention of meeting the real-time deadline because those systems involve more safety kind of things. This direction task scheduling framework for automotive CPS concerning the mixed critical tasks scheduling algorithm is presented (Capota, Eugenia Ana, Cristina Sorina Stangaciu, Mihai Victor Micea, and Daniel-Ioan Curiac, 2019). The mechanism also comes out with a suitable scheduling algorithm that can be implemented in the automotive CPS system.

The distributive system-based implementation of the CPS system will be efficient where multiple processors are distributed and available as a computing resource shared among multiple physical systems. The important aspect in such distributed CPS system is the multiprocessor task scheduling. This kind of task scheduling is typical a combinatorial optimization problem. Ant colony optimization algorithm is one of the efficient algorithms with excellent robustness, and it is easily implementing the algorithm in a parallel manner. It can deal with the constraint very easily. An aunt Colony-based best distributed CPS tasks scheduling algorithm is provided (Yi, Na, Jianjun Xu, Limei Yan, and Lin Huang, 2020) with a task model and task management mechanism to improve the task scheduling optimization process.

Periodic real-time task models are widely used in the CPS system to represent the time-bound response time requirement of physical systems. A new scheduling mechanism with a new periodic fault tolerance task model is proposed in this direction (Lee, Jinkyu, and Kang G. Shin, 2017). This system generalizes the existing periodic rate time task model and incorporates the tolerance on the number of control updates missing. The algorithm work based on the nature of the task and the number of consecutive previous task deadline misses the result of the work shows that the proposed task model and its scheduling algorithm show more stability and efficiency than conventional task scheduling.

Communication of data in real-time is an essential part of a cyber-physical system. Still, those data need to be transmitted on a heterogeneous delay constraint transmission system. To provide real-time delay assured delivery of communication, a distributed scheduling algorithm is proposed (Shen, Bo, Xingshe Zhou, and Mucheol Kim, 2016) with the game theory approach. Under this algorithm, the scheduling problem is formulated as a noncooperative game on multiple access mechanisms of contention-based multiple access protocol. Under the system, it is assumed every communicating element has the knowledge of the delay and makes the decision by competing with other elements. The system's pay is designed so that a more urgent packet transmission-supported system will be given more pay.

Age of information is a new mechanism (Sinha, Devarpita, and Rajarshi Roy, 2020) used to measure the freshness of information. In the real-time system, this Parameter measurement is essential to generate real-time response and ensure the timely reception of the information with the latest updated data for real-time applications on time updation of sensor data with the newest value is essential in the cyber-physical system where the information age concept will help do identify the latest sensor data. The scheduling of transmission of the latest sensor data copy is essential in the cyber-physical production system. A problem of transmission scheduling of sensor data with the information age is presented for the production system. It is proved that the information age-based transmission scheduling will provide Efficient and maximum utilization of the information for time-critical applications performance. A greedy mechanism-based scheduling policy with deadline awareness and works with the highest latency first approach is presented.

Another scheduling algorithm for the cyber-physical system's product manufacturing system is proposed what the machine learning-based approach (Shiue, Yeou-Ren, 2009) under this model, a mixed product environment is considered where scheduling knowledge-base system should be more dynamic and a procedure to modify the scheduling knowledge automatically is also proposed. Typically, reinforcement learning-based scheduling algorithms are proposed for the cyber-physical system, which requires periodically available data to train and make decisions. This type of scheduling mechanism results in an overflow of data and increases scheduling database update time and the scheduling response time that is not suitable for the real-time control system. Decision tree can support quick decision-making (Wang, Xiaowei, and Feng Liu, 2020). A 2 level decision tree mechanism is proposed. In the first level, a suitable scheduling knowledge base class is selected, then under each knowledge base class, the best rule for the next scheduling is selected. The proposed system focus on training sample generation, the mechanism for future selection, mechanism for generating knowledge base class label, knowledge base class selection and decision tree-based dynamic dispatching rule selection model.

Another decision tree mechanism for discovering the database's knowledge and using it for the CPS system operation is presented (Panhalkar, Archana R., and Dharmpal D. Doye, 2021). In this work, the African Buffalo Optimized Decision Tree (ABODT) algorithm avoids optimal local value and generates a globally optimized decision tree using African Buffalos' intelligent and collective behavior. The African Buffalo Optimized Decision Tree can provide more accuracy with reduced size, which is also very stable compared to that of the convention decision tree.

Reducing thermal dissipation at the computing unit of the CPS system is essential to save energy and to avoid the failure of the computing unit a task scheduling mechanism that will reduce this kind of thermal stress while scheduling tasks among the computing unit without compromising the performance goal is presented (Xu, Shikang, Israel Koren, and C. Mani Krishna, 2021).

Heterogenous computing is prepared in the CPS system to meet the high-performance computational demand with a limited budget. Those heterogeneous CPS systems can be modeled as direct-acyclic task graphs (DTGs) because of complex interactions and distributed nature. Integer Linear Programming based scheduling mechanism for such heterogenous Directed-acyclic Task Graphs is presented (Roy, Sanjit Kumar, Rajesh Devaraj, and Arnab Sarkar, 2021). It works on a distributed heterogeneous processors with shared buses. A Contention Cognizant Task and Message Scheduler (CC-TMS) is also reported for low complex task scheduling.

Since machine learning algorithms are widely used in many applications to solve different kinds of problems (Ponnusamy, Vijayakumar, and S. Malarvihi, 2017; Ponnusamy, Vijayakumar, Kottilingam Kottursamy, T. Karthick, M.B. Mukeshkrishnan, D. Malathi, and Tariq Ahamed Ahanger, 2020; Vijayakumar, P., R. Abhishek, and Kundala Sandeep, 2016), this paper focuses on scheduling the task using a decision tree to provide low complex task scheduling in the heterogeneous processor-based CPS system.

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The remaining part of the article is organized as follows: section 2 deals system model; section 3 gives the result and analysis; section 4 concludes the article.

System Model

The cyber-physical system with the heterogeneous multiprocessor-based computing system is considered a system model is shown in figure 1. The system consists of an n processor with different computational capabilities, representing in terms of million instruction per second (MIPS) execution capability. Under this system, it is assumed that the nth processor has xn MIPS rate. Similarly, in other computing resources like memory, the catch is represented as rn for the nth processor. Those multiprocessors are connected through the communication bus. The physical system and control system task is communicated to the scheduler through the communication subsystem

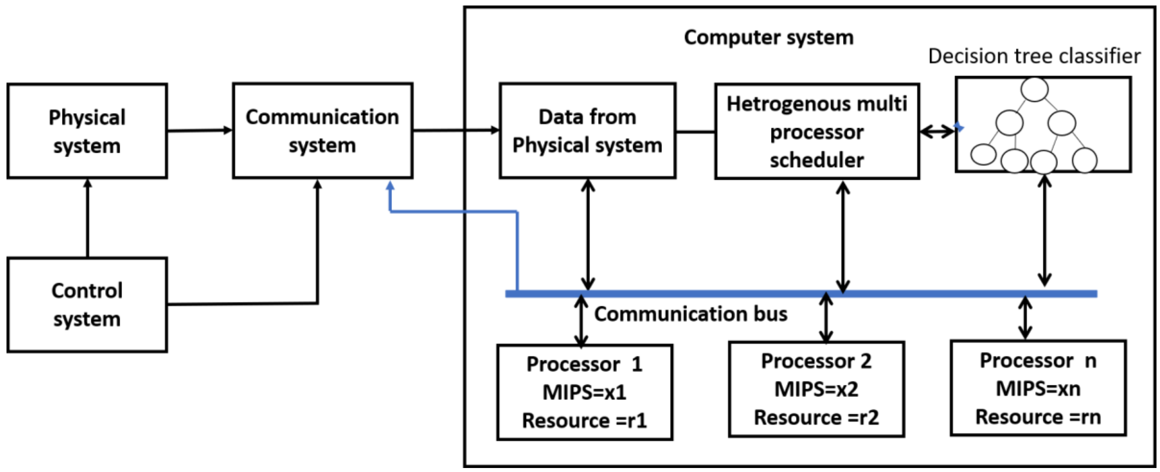

Figure 1 System model for heterogeneous multiprocessor scheduling in cyber-physical

The heterogeneous multiprocessor scheduler collects the data and task from the physical system and utilizes the decision tree classifier for deriving optimal schedule .the decision tree is trained with the data of task like the deadline, periodicity, physical movement delay, current loading state of all n processor and the availability of the resource of all n processor .the decision tree is grown with the training data with the depth of n and all the ‘n’ leaf node of the tree has the schedule of the all the n processor. We can easily extract all processors' schedules just by reading for the leaf node of the tree.

Result and Discussion

Random task set of 280 with random periodicity, random execution time, MIPS rate requirement of the tasks are simulated for training and testing the decision tree. Four processors' computational capability in terms of a million instructions per second and available resources are also generated randomly to make heterogeneous processors. This random data set is used to train and construct the decision tree. Here Gini index-based impurity measurement is used as the key element for the construction of the tree. For the target value generation, a load-aware task allocation scheduling algorithm is executed. The class label/target label is assigned to the training data set from the schedular algorithm's output. The data are split into training and testing by 65% and 35%, respectively. Standard Scaling of the data is carried out as a pre-processing task before applying to the data for the training process. The 65% training pre-processed data are used for training the decision tree construction process and the decision tree is constructed as shown in figure 2.

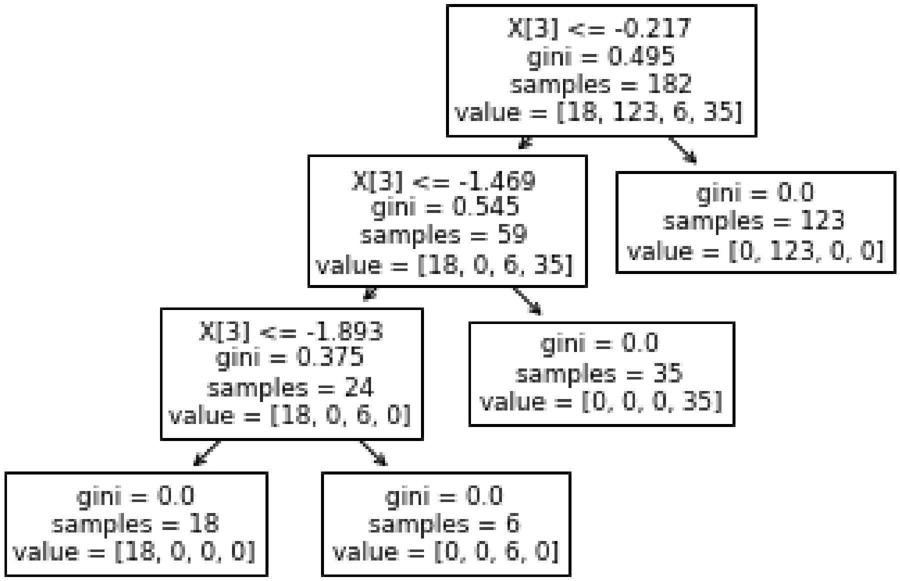

Figure 2 Heterogeneous four-processor task allocation decision tree

After training the decision tree, the 35% test data set is used to evaluate the constructed decision tree's performance and the confusion matrix is derived as an outcome of it. Figure 3 shows the confusion matrix of the decision. From figure 2, it is evident that all the testing data is correctly classified to schedule the target processor and 100% accuracy of classification is achieved thus it is clear that the decision-based classifier is possible to apply for heterogeneous multiprocessor scheduling job.

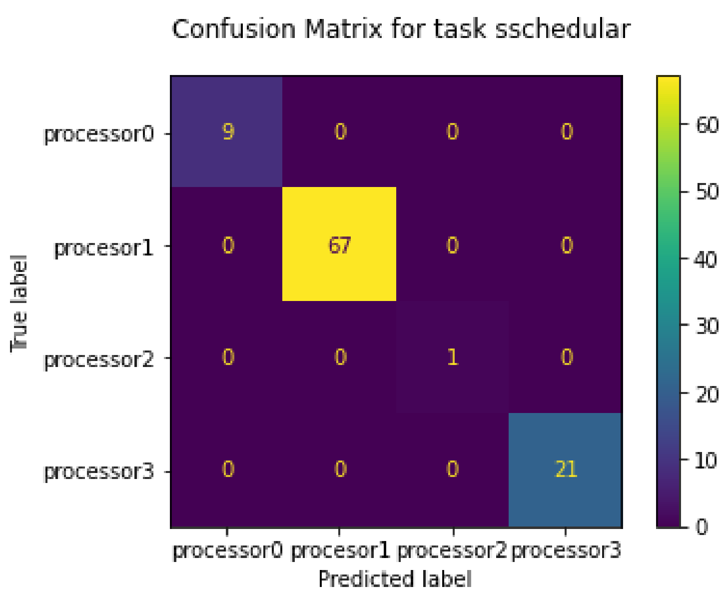

Figure 3 confusion matrix of decision tree heterogenous four-processor task allocation

Now it is possible to decide on task allocation by simply travels through the constructed decision tree. From the constructed tree from figure 1, we can conclude that the maximum tree step search is only required for reaching the leaf node where the task allocated processor's classification label can be reached for the given task. This four search time is a constant time for any implementation which is not the function of the task size and processor size. Table 1 provides the comparison of the time complexity of the proposed decision tree algorithm with traditional task scheduling mechanism from table 1; it is evident the proposed decision tree-based four-processor scheduler outperform with only three search time of constant value whereas the standard scheduling algorithm has m*n number of search for the scheduling. This low complex scheduler will be efficient for the real-time task scheduling for the cyber-physical system. From figure 1, it is evident among 280 tasks, 123 tasks are allocated to the processor 2, 18 tasks are assigned in processor 1, six tasks are assigned in processor 3, and 35 tasks are assigned in processor 4.

Table 1 Time complexity comparison

Mechanism	Time complexity
Traditional task scheduling	O(mn)=4*280
Proposed decision tree mechanism	Three search time

Conclusion

The heterogeneous multiprocessor scheduling in the cyber-physical system is modeled as a classification problem and solved using the decision tree approach. This decision tree-based multiprocessor scheduling cable provides the optimal schedule with less computational complexity, i.e., with the least response time. Thus, this least response time schedular can be utilized effectively for any time-critical application of a cyber-physical system. The future direction of work will be analyzing the performance of this schedular on a typical time-critical application.

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