Further Developments on Applying Generic Task Approaches to the Industrial Process Control Problem

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Abstract

The Intelligent Process Control Architecture (IPCA) is a control architecture for dynamic processes which is rooted in the Generic Task approach to knowledge-based systems. The first generation of IPCA has been completed, and experimentally proved in the testbed domain of microwave processing of polymer composite materials. The next generation of IPCA is now being designed, and will incorporate more advanced computing techniques as well as employ more sophisticated processing equipment for the testbed domain.

Intelligent Process Control Architecture: First Generation

The Intelligent Process Control Architecture (IPCA) is a control architecture for dynamic processes which has been developed in our laboratory in previous work of Decker[1] and Adegbite[2]. This control architecture is rooted in the

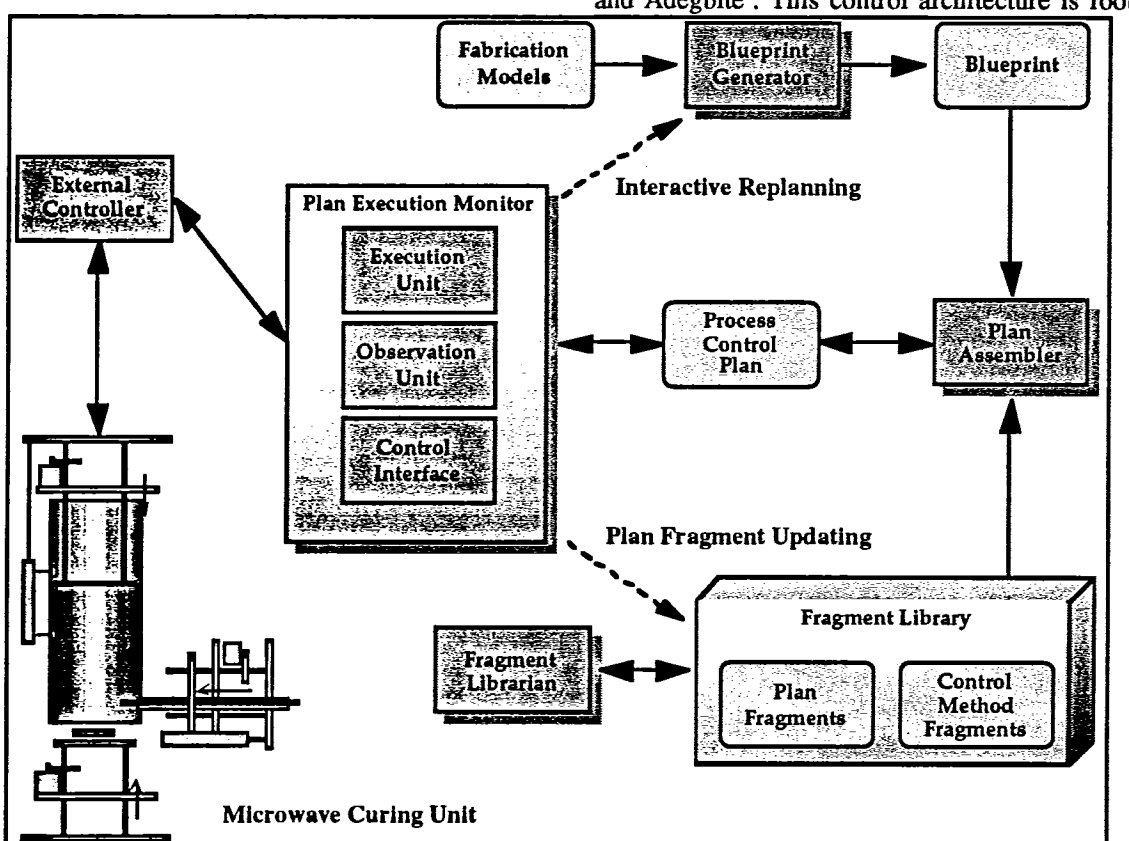

Figure 1: IPCA System Architecture

Generic Task (GT) approach to knowledge-based systems, which is an approach that emphasizes similarity in reasoning, knowledge acquisition and knowledge organization among certain types of problem solving tasks. IPCA has expanded on the GT base with extensions that provide a complete architecture supporting knowledge-based control system synthesis and real-time execution. IPCA incorporates three primary components: a Blueprint Generator, a Plan Assembler, and a real time reactive Plan Execution Monitor(Figure 1). The Blueprint Generator produces a specification for a complex process control plan which is designed for a specific execution environment. The Blueprint Generator's problem solving mechanism is based on a GT known as Routine Design, which emphasizes the commonality in design problems which do not require "innovation". The Plan Assembler implements each blueprint by combining pre-compiled plan and control method fragments and assembling them to form an executable process control plan. The Plan Execution Monitor incrementally determines the execution of appropriate fragments from the process control plan based on sensory input (temperatures, reflected power, mode setting) gathered from real-time process monitoring, reactively selecting an appropriate path through the process control plan structure. The Plan Execution Monitor selects the appropriateness of a code fragment using a GT Sponsor/Selector decision mechanism. Experiments were performed on a carbon-fiber reinforced DGEBPA prepreg (see domain overview). Thermal gradients across the part were reduced to below 10 degrees C. This represented a 66% reduction over previous automated processing methods.[3] These results demonstrated that IPCA effectively controlled the microwave curing apparatus, resulting in high-quality, high-speed composites processing for the relatively simple planar material samples used to date.

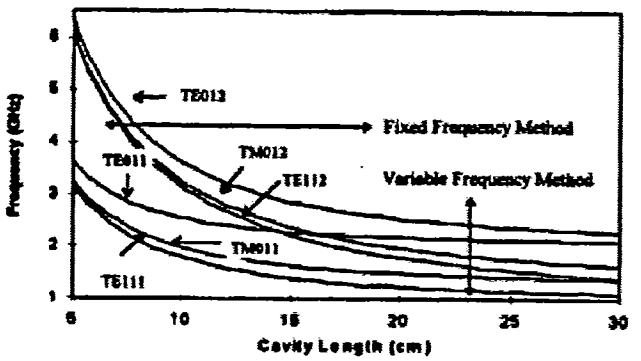

Figure 2: Mode Chart of Empty Cylindrical Cavity

Domain Overview

As described above, the utility of the approach has been demonstrated experimentally for microwave curing of polymer composites. Microwave heating can be either single-mode or multi-mode in nature, depending on cavity dimensions and electromagnetic frequency. Typical household microwaves heat in a multimode fashion. In this type of heating, the microwave energy is shared by multiple modes which have different heating patterns, and therefore heating is neither efficient nor uniform. Single-mode heating sets up a single standing wave in the cavity so that the energy is highly focused and heating is efficient, however the heating pattern is generally uneven.[4] To cure composite materials efficiently in a short time, the single-mode method offers an attractive alternative because of the potentially higher heating rate. However, large thermal gradients across the structure are a normal by-product of single mode curing. High gradients can negatively impact final material properties, and are thus undesirable. To minimize thermal gradients, different modes can be selected throughout the cure cycle so that heating is uniform across the structure. Using this technique, microwave energy can be applied when and where it is needed for optimal heating and the control of material properties, provided the proper mode is applied at appropriate times during cure. Mode selection can be achieved either through mechanically altering the dimensions of the microwave cavity, thus altering the standing wave mode, or through manipulation of the frequency of the microwave power source. The previous version of IPCA tuned the microwave using mechanical mode tuning. This method inhibits fast processing because mode switches may take a minute or longer. The current emphasis of the microwave research group is on moving the microwave curing system from a mechanical tuning method to a frequency tuned method[5].

Frequency Based Tuning

Theoretically, there are two factors that determine the resonant modes in a microwave cavity: the microwave frequency, and the dimensions of the cavity. Therefore, as stated above, and as seen in figure 2, two methods can be used to select a mode in a cylindrical cavity, mechanically modifying the length of the microwave cavity, or electronically altering the frequency of the microwave power source[6]. As seen in figure 2, the number of resonant modes available when tuning by varying frequency is greater than those available when changing cavity length at a fixed frequency. Because of the nearly instantaneous mode switching that frequency based tuning will provide, the process of power application and mode selection in real-time curing must be even more carefully monitored and adjusted to further minimize thermal gradients.[6] Frequency-based tuning provides access to more modes, almost instantaneous mode tuning, and enhanced reliability, and will clearly enhance the commercial applicability of the microwave processing domain if it can be efficiently controlled.

Current Work

Current work on IPCA is expanding the architecture along several dimensions. The first step for the next generation of IPCA will be to integrate the current architecture with a frequency modulated, tuned microwave composite material processing system. Beyond the mechanical tuning limitation, the current system is limited in domain coverage, having used one composite system as a proof of concept for the testbed. Further expansion of the planner's knowledge base and the library of plan and control fragments will be incorporated to cover a larger array of composite material systems. More advanced control and planning fragments are also being investigated to try to deal with more complex fiber and part geometries, which tend to cause perturbations in the microwave EM field, making heating patterns far more unpredictable. In addition, we are investigating interactive replanning ability between the execution monitor and the plan generator to enable the system to replan in response to radical changes in operating conditions. Finally, we are investigating the addition of learning mechanisms to automatically update the planning knowledge-base through experience of past curing solutions.

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