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A MULTI – AGENT SYSTEM FOR DISCRETE PROCESS-DESIGN

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Abstract

This paper presents a multi-agent approach for process flow design of discrete manufacturing systems. In this approach, it is assumed that equipment suppliers advertise their technologies throughout the network by using intelligent agents. The process design is carried out by cooperative distributed agents that communicate through message exchange. Message exchange is possible by means of a shared knowledge representation encoded in Web Ontology Language

Keywords: Process design, multi-agent systems, equipment selection.

1. INTRODUCTION

In the world market, expanding customer expectations, intensifying competition, and rapid changes in technology are increasing pressures. As a result, manufacturers are compelled to decrease the development time and cost of manufacturing systems. However, manufacturing is very much affected by design decisions, as process design contributes in great measure to the total life-cycle cost. It has been shown that decisions made in preliminary design affect 60% of all product life-cycle cost (Welch and Dixon, 1991).

Process flow design can be defined as a mapping of the specific processes that raw materials, parts, and subassemblies follow as they move through a plant (Chase, *et al.*, 2004). Much effort has been done in the area of Computer – aided Process Planning (CAPP). Most CAPP systems implement AI techniques such as genetic algorithms, artificial neural network, and fuzzy logic (Dereli and Filiz, 1999). But existing approaches used CAPP systems have limitations, especially in the area of collaborative product development in distributed environment. For this reason, agent technology is considered a practical solution for distributed AI (Zhang and Xie, 2006).

This paper presents a multi-agent approach for process flow design of discrete manufacturing systems in a distributed environment. In this framework, it is assumed that equipment suppliers advertise their technologies throughout the network by using intelligent agents. The process design is carried out by cooperative distributed agents that communicate through message exchange. Message exchange is possible by means of a shared knowledge representation encoded in Web Ontology Language (W3C, 2004). In the next sections the previous related work and methodology of the approach are described. Then the multi-agent environment is explained. Finally, a case study is presented to illustrate the proposed approach.

2. PREVIOUS WORK

The aim of process design is to generate an optimal process flow by selecting the best combination of technologies. A process flow is composed of an ordered set of operations that together convert raw materials into products. Unfortunately, traditional process design has been characterized as subjective, time consuming, labor intensive, limited in variety and inconsistent in quality as it depends only on the human experience and skills.

Much research has been done in the area of process design of chemical continuous processes (Li and Kraslawski, 2004). Existing methods in such domain can be classified as: knowledge–based (such as heuristic and case–based reasoning); mathematical formulation methods (usually in the form of MINLP problems); and hybrid methods (that combine features of the two last methods) (Gani, 2004). However, little has been published in the area of process design for discrete processes.

Related research carried out in the field of Computer-Aided Process Planning include cooperative distributed problem solving framework (CDPS) which was proposed by Bose to solve the CAPP problems based on a given hierarchical structure of tasks (Bose, 1999). In that work, automated process planning is done by a negotiation mechanism among three types of agents, namely, process planning manager (PPM), the work center manager (WCM) and center knowledge experts (CKE). Each agent has its own functions and they act cooperatively to get a solution for automated process planning problems.

Feng (2005) presents a preliminary design approach in which six types of web – based agents are developed. Agents can communicate with engineering application software systems such as CAD/CAM systems, mathematical solving tools, expert systems and database management systems by using CORBA. In addition, agents are connected to web services providing the users with control functions over the agents. Process planning is done by group of process planning agents connected with a CAM system.

Nau et al. (2000) propose a tool for Integrated Product and Process Design (IPPD) specifically developed for the design and manufacture of microwave modules. IPPD is based on (i) finding all alternative parts that meet a set of requirements, (ii) finding all alternative operation steps to be performed on each part, (iii) finding optimal combinations of parts and processes, and (iv) facilitating the optimal alternatives to user exploration. This approach is limited by the fact that the designer has to specify all the possible equipment interconnections (similar to the super-structure in continuous processes) in the form of process template. The larger the number of equipment items, the more complex and difficult to maintain is process template. Design and cost models have to be available locally in computer encoded in a format used by the specific method. Unfortunately, this is not always possible because many machine and equipment suppliers keep their design and cost calculations confidential.

Batres and Takashima (Batres *et al.*, 2007) present a multi agent approach to process design of discrete processes that consists of a technology selection agent (TSA) that submits design requests to technology agents. If a technology agent determines that the design is possible then proceeds to design the technology and submits the design to the TSA. Although the TSA is responsible to bundle the designed technologies into a solution, technology agents help to find the best solution by assisting the TSA in pruning away inefficient partial solutions. Unfortunately, the algorithm of this method is not always capable to generate the optimal process design.

3. METHODOLOGY

The objective of the proposed approach is to choose the mix of technologies that meet product requirements and provide the optimal process with least development time and manufacturing cost. The process design framework consists of three types of agents: Process Selection Agent (PSA), Equipment Selection Agent (ESA), and the Equipment Agents (EAs).

The framework

a) obtains from the user an initial information - the desired product with defined set of constraints

b) finds the equipment items that match the given requirements

c) estimates the evaluation function for each equipment item that satisfies constraint requirements

d) generates the optimal process design path according to the evaluation function.

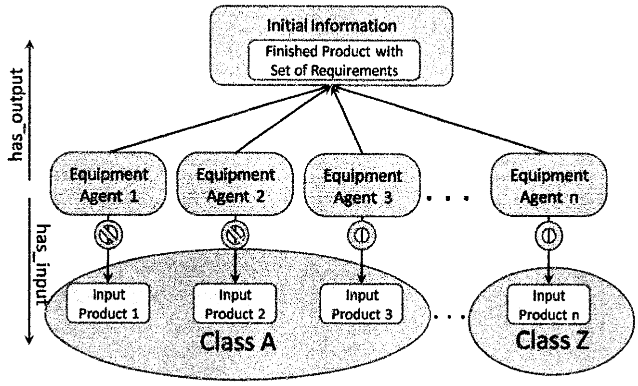


Fig. 1 Optimization done by Equipment Selection Agent (ESA)

The PSA agent is responsible for requesting the equipment items from ESA agent, building optimal process design on the base of evaluation function and proposing the solution to the user. ESA agent is responsible for doing optimization process among the proposed equipment items, finding the best equipment items that can produce an output which meets a set of requirements submitted by the PSA agent and sending the information about the selected equipment items as optimal options to the PSA agent. And EA agent receives the requests from ESA agent and checks the equipment if it is able to satisfy specified set of constraint requirements. It feeds the ESA agent with equipment information as a proposal if the equipment matches the requirements and sends the failure message if the equipment does not the requirements.

Firstly, the user specifies the desired product in terms of constraint requirements and the class of product. This is done on the PSA agent. Then PSA agent sends these specifications to the ESA agent. Then ESA finds available EA agents. Afterwards, the ESA agent queries the EA agents for equipment items that produce the desired product by sending the desired product specifications obtained from the PSA agent. For each query one or more proposals can be made, each proposal specifying an input product different from the other in respect of product family group. Then the proposal containing equipment information is sent by the EA agent to the ESA agent if the EA agent concludes that design is possible and that it is able to produce the desired product. After completing the collection of proposals from the EA agents, the ESA agent carries out the optimization process based on the evaluation function for each group of the equipment items whose input products belong to the same class of products and selects only one equipment item which is considered as the best option from each group. In figure 1 this optimization process is illustrated. In the figure the group consisting of EA1, EA2 and EA3 has input products “Input Product 1”, “Input Product 2” and “Input Product 3” which belongs to the same class “Class A”. From these equipment items on the base of evaluation function the equipment item of EA3 is selected as an optimal option. Such an optimization process aims at minimizing the number of types of input products thus further reducing useless node expansion and the communication load on the system. Subsequently, proposals selected as optimal options are sent to the PSA agent and input products of optimal options take the place of desired product. Afterwards, ESA requests from the EA agents for the further equipment by sending the desired product specifications. And this procedure is repeated until the stopping criterion is done. The stopping criterion is chosen according to the objective function (cost of product, operation time, obtaining certain type of raw material etc).

In the PSA agent, all options are stored in solution memory of PSA agent. If the output product is the feed of existing equipment in the solution memory of PSA agent, an equipment item has to be found and connected downstream. If there is no corresponding feed then the equipment is stored as the first equipment. The process flow is built this way and it goes on until the stopping criteria are done. PSA agent also carries out the optimization process among the sequences reached the stopping criteria. Finally the PSA agent reports to the user the last solution which is also the optimal process design flow.

4. SYSTEM IMPLEMENTATION

Agents communicate through the network by exchanging the messages using a shared knowledge representation encoded in the Web Ontology Language (OWL). Information about the classification of the equipment, classes of objects in the inputs and outputs, as well as physical quantities in the constraints and cost is represented using classes and relationships in these ontology as shown in the figure 2. Classes and properties of things such as materials and processes are defined by means of extending an upper ontology. The upper ontology defines domain-independent concepts such as physical objects, activities, mereological and topological relations, classes and relations for physical quantities (Batres, *et al*., 2007).

Each EA agent has its own knowledge base containing equipment classes, properties, constraints and design equations (simple algebraic equations). The knowledge base is encoded in OWL and is built using an upper ontology.

The equipment selection environment was programmed in Java using the JADE (Java Agent Development Framework) (Bellifemine, *et al*., 2007) library for distributed agent applications and JTP (Java Theorem Prover) (Fikes *et al*., 2003) inference system. The agent platform can be distributed across computers and other Java enabled machines. It also provides tools for monitoring and configuration of agents.

Messages are encoded in FIPA ACL (Agent Communication Language) (Bellifemine *et al*., 2007). An ACL message contains a number of parameters such as performative, sender, receiver, content, language and ontology. Specifically, the equipment selection environment implements the request, propose and inform performatives.

The queries for equipment agents are encoded in CLIF (Common Logic Interchange Format). Queries and technology requirements are evaluated using JTP which is a reasoning system capable of deriving inferences from knowledge encoded in the OWL language (Fikes, *et al*., 2003). For instance, the query like "can you produce PCB in rectangular shape whose width is equal to 100 mm and length is 250 mm" can be requested in KIF language like:

```
(and
(prefix:has_output ?equiment ?output)
(rdf:type ?output prefix:PCB)
(prefix:has_form ?output ?form)
(rdf:type ?form prefix:rectangle)
(prefix:has_width ?form 100)
(prefix:has_length ?form 250)
(prefix:has_unit ?form ?mm)
(rdf:type ?mm prefix:millimeter)
)
```

When the ESA agent sends a message to an EA agent to evaluate an input the EA agent momentarily asserts the resources as facts in the knowledge base of JTP. Subsequently, the EA agent checks the requirements against the equipment specifications by performing queries to the knowledge base.

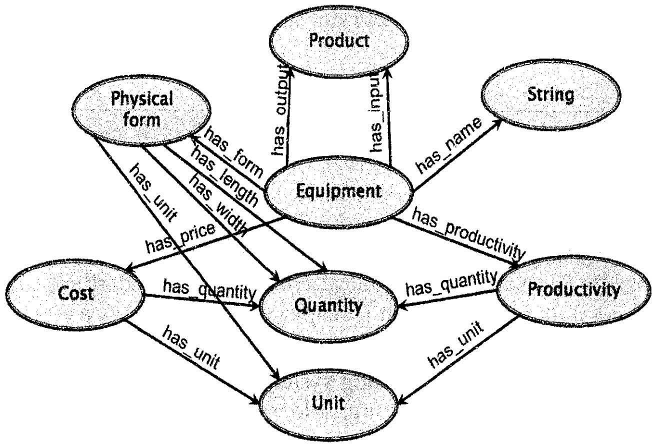


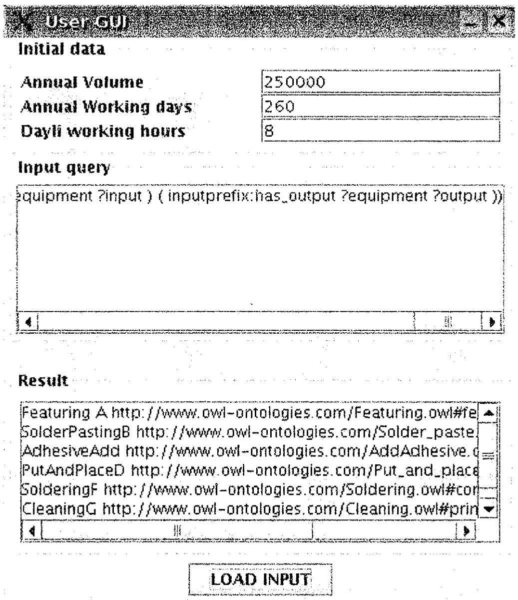
Fig. 2 Diagram of equipment ontology

5. CASE STUDY

As an application of the proposed methodology, we consider a design problem from the electronic industry. The objective is to assess the process design options that can produce printed circuit boards (PCB) and select out the optimal option. PCB assembly consists of attaching the electronic components to the printing wiring boards (PWB). Printing wiring board is a physical structure holding together various electronic components of a printed circuit board. For this particular example methodology has been augmented to take into account cost and cycle-time evaluation so that are used to rank the results.

For this example we assume that the targeted annual volume of product is 250000 units, there are 260 working days per year and each day has two eight-hour shifts.

The user initiates the process design by loading the product specifications and constraint requirements which are encoded in CLIF. Consequently, message exchange takes place until all feasible alternatives have been created and optimal one has been selected. In the current implementation the design stops when the ESA finds that one of the feeds is the original raw material specified by user (the board). The selected optimal alternative (here according to the cost) of process design is displayed to the user as a solution.



Annual Volume 250000
Annual Working days 260
Dayli working hours 8

```
equipment ?input ) ( inputprefix:has_output ?equipment ?output ))
```

```
Featuring A http://www.owl-ontologies.com/Featuring.owl#fe
SolderPastingB http://www.owl-ontologies.com/Solder_paste
AdhesiveAdd http://www.owl-ontologies.com/AddAdhesive.
PutAndPlaceD http://www.owl-ontologies.com/Put_and_place
SolderingF http://www.owl-ontologies.com/Soldering.owl#cor
CleaningG http://www.owl-ontologies.com/Cleaning.owl#prin
```

Fig. 3 Result of a process design session on the main user interface

The resulting manufacturing system is composed of six types of equipment: featuring, solder pasting, adding adhesive, pick and place, soldering and cleaning as shown in the figure 3.

6. CONCLUSIONS

In this paper we described a multi-agent approach to choose the mix of technologies that meet product requirements and provide optimal development time and manufacturing cost. Process flow is built from equipment items that are offered through the network by intelligent agents. This approach has been tested for PCB production problem. Nevertheless, there are several aspects that need further study. For instance, the current approach only produces linear processes, so improvements are needed in order to manage the recycles. Additionally, ongoing work considers applying multi-objective optimization methods for generating the best process flow design.

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