INTELLIGENT DECENTRALIZED PLANNING AND COMPLEX STRATEGIES FOR NEGOTIATION IN FLEXIBLE MANUFACTURING ENVIRONMENTS

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ABSTRACT

The use of autonomous systems with local planning intelligence permits the optimization of task-processing in flexible production environments. Integration of local planning intelligence into the general task-planning process is necessary if the overall planning process is to be handled productively. For this purpose the coordinating instance distributes the tasks to the individual systems by means of its own, purpose-developed negotiation mechanism. Adequate approximate planning of the coordinating instance and negotiation capabilities provide the autonomous systems with maximum scope for performing their planning and decision-making tasks.

KEYWORDS: decentralized planning, coordination, negotiation agents, distributed knowledge base, negotiation protocols,

1 Introduction

The tasks of the work required in the Special Research Project (SFB) 331[1] include the development of autonomous systems, and above all boosting the efficiency of these systems. In addition to simply executing tasks, efforts are now being made to create local intelligence in autonomous systems with a view to enable local planning tasks to be carried out. As a result, it will become possible to use the autonomous systems' local data in particular, for the rectification of malfunctions.

2 Integration of autonomous systems into a general task-planning process

In order to optimize the overall process in a production plant, it is necessary to integrate the various autonomous systems into an overall, coordinated task-planning process. Its main task is to plan orders in approximate terms, to initiate the execution of tasks and to monitor the progress of work in the production process. It is crucially important that the autonomous systems' capabilities for independent task-planning and for dealing with

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malfunctions are used as effectively as possible. However, this renders dedicated advance planning of a task at a global level, in terms of its schedule and procedure, inadvisable. Instead, a general task-planning process must allow sufficient planning scope for the autonomous systems, so that their planning and decision-making capability are not impaired and that global objectives, such as meeting deadlines, can nevertheless be achieved.

3 Concept for a global coordinating instance

Following the evaluation of the various central and decentral approaches to control and instrumentation technology, it emerged that autonomous systems can best be integrated by hybrid means. This both renders it possible to pursue global objectives and provides scope for exploiting the autonomous systems' planning and operative capabilities.

3.1 Approximate concept

In order to allow the autonomous systems maximum planning scope, tasks should be distributed on the basis of a negotiation mechanism and not according to rigid directives. The negotiation protocol used for this purpose is based on the contract net protocol [1] which was extended by *Levi & Hahndel (1992)* [2] and *Reinhart & Pischeltsrieder (1995)* [3] specifically for the distributed planning of autonomous systems as part of SFB 331.

A coordinating instance for performing the tasks and satisfying the requirements as effectively as possible is being developed at the iwb. In its initial form, it consists of two parts: global planning and negotiation management. Only the global planning aspect is presented here.

3.2 Integration of decentral planning intelligence into the coordinating instance's global task-planning process

For local planning intelligence to be used to optimum effect, the global planning process has to accommodate flexible schedules and exhibit scope to rearrange of the sequence of work processes performed by the autonomous systems. In addition, it provides freedom to manoeuvre if the dedicated allocation of work processes to machines only takes place in the negotiation process, and not during planning at coordination level. However, in order to approximately estimate capacity during the planning stage, there is the restriction that the work processes are loosely assigned to capacity groups *(Fig. 3.2.1)*. A capacity group consists of the same type of autonomous systems.

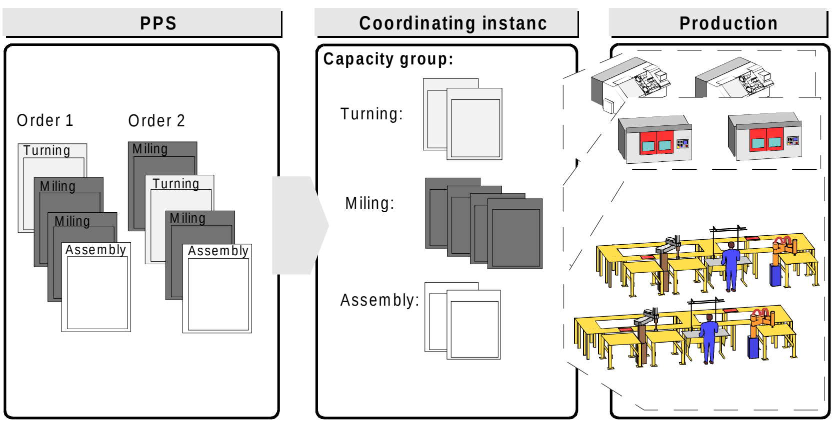

Fig. 3.2.1 Formation of capacity groups

In the first planning stage, the order data provided for example by a Production Planning System are scheduled as part of global planning, working backwards from the order's final deadline. An order-specific extrapolation factor by which the duration of the work processes is multiplied is now determined, taking account of various criteria such as the scheduled start of task and end of task dates, the average processing time of the work processes and the current production capacity situation.

The resulting time spans form a planning period within which a work process (WP) can be freely repositioned. The overall scheduling consistency is upheld if any overlaps between the planning periods for successive work processes are initially prevented *(Fig. 3.2.2)*.

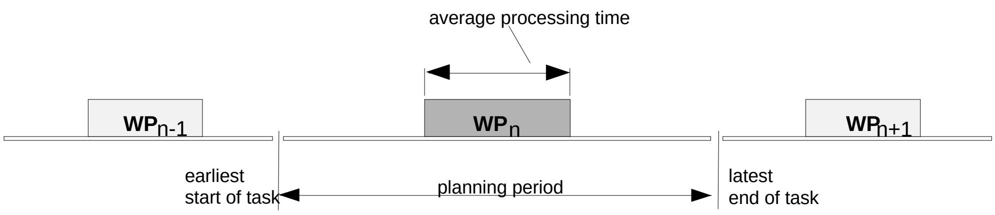

Fig. 3.2.2 Technical and scheduling consistency of work processes (WP)

Since the exact position of a work process is not known at this point in time, for purposes of establishing how much planning capacity is required it is assumed that the tasks will be evenly distributed throughout the entire planning period. If the average processing duration of a work process is deemed to be capacity 1, the capacity requirement F is obtained from the product of the average processing duration and the capacity with the value 1. For the duration of the planning period, the required capacity k is then obtained from the quotient of the capacity requirement F and the planning period (*Fig. 3.2.3)*.

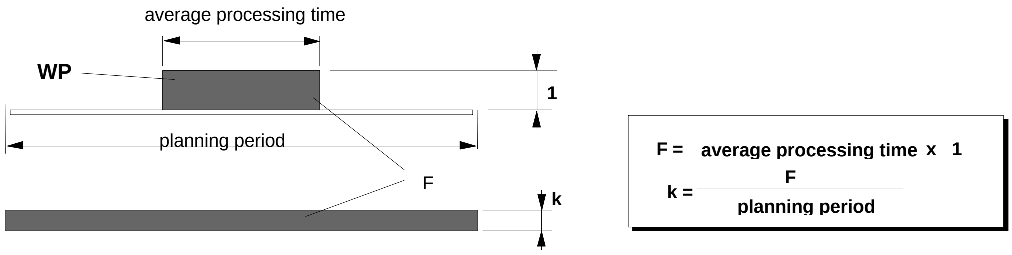

Fig. 3.2.3 Distribution of capacity throughout planning period

Since scheduling bottlenecks may nevertheless occur in spite of extrapolation of the work processes, they are explicitly localized and resolved by extrapolating the planning periods of the work processes affected. This makes it possible to calculate the capacity requirements for all capacity groups at any time t by totaling the capacity values (k) of the corresponding work processes.

4 The Communication Model of the SFB 331

Trying to increase the scope of planning for the autonomous systems leads to higher requirements in the field of the communication abilities of the autonomous systems. If the systems are allowed to optimize their local planning, it becomes necessary that the systems take care by themselves for the coordination of their own planning with the planning of the other autonomous systems or with the coordinating instance. To realize this, it is necessary to integrate negotiation mechanisms into the autonomous systems. Our current model of the communication connections between the different autonomous systems of the SFB 331 has the following structure:

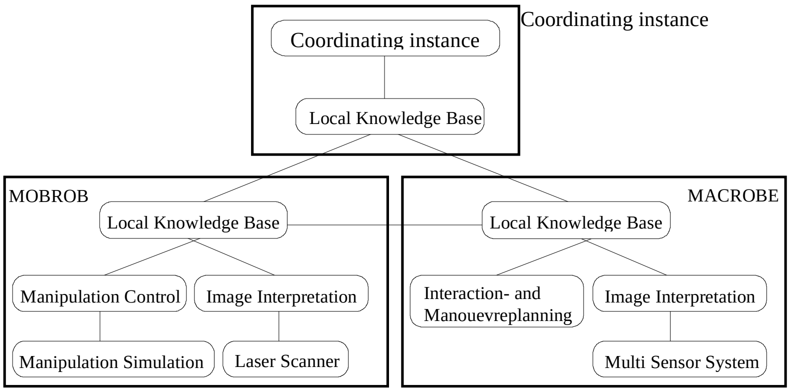

Fig. 4.1 Structure of the manufacturing environment of the SFB 331

In the center of our communication structure you find three instances of local knowledge bases, which together form our distributed knowledge base [4] [5] [6]. This knowledge base has been developed at the chair of robotics and real-time systems of the Institute of Computer Science at the TU München. The three main autonomous systems which have been developed in the SFB 331 are the coordinating instance, which has been described above, the autonomous vehicle MACROBE, and the mobile robot MOBROB. Each of these autonomous systems has its own local knowledge base, in which - among other information - their specific model of the environment is stored.

As the distributed knowledge base represents the central communication unit, it is the obvious medium to integrate intelligent protocols for negotiation into it.

5 Negotiation Concepts

The concepts for negotiation in our current work concern the following three fields:

- examination of a pool of tasks
- support of special cooperation tasks between mobile systems
- support of path planning for the mobile systems of our factory environment

In this article only the first aspect will be discussed.

5.1 The Pool of Tasks

Up to now the distribution of tasks was relatively fixed. That means that tasks were given for example by the coordinating instance to a specific autonomous system. This happened by placing the full task data into the knowledge base and specifying the receiving autonomous system. The system was informed by the active components of our knowledge base [7]. The concepts of the knowledge base guaranteed complete and correct transportation of the data and its transformation into the format of the autonomous system. The next step in our development will make this concept more flexible:

- tasks are no longer given to a specific autonomous system. The autonomous systems themselves decide whether they are interested in getting a certain task.
- negotiation protocols are used to decide which autonomous system takes the task.

- the autonomous systems work at more than one task at a time. This enables them to use local planning abilities to optimize their work.

To realize negotiations in our factory environment, in a first step we implemented a Contract Net Protocol. Systems which are interested in offering a certain task create an instance of the class *invitation to bid*. The data is sent to all local knowledge bases using the concepts of our distributed knowledge base [4]. Every system which is interested in working on this task generates an instance of the type *offer*. These offers are sent to the inviting system. The inviting system judges the offers and chooses one system to receive a particular task. Depending on the problems which may arise while rating the offers and choosing a system, the steps of invitation and offering may be repeated. In its first realization an instance of the class *invitation to bid* has the following structure:

instance of the class invitation to bid
identifier
invitating system
status of invitation
earliest time to start the task
latest time to end the task
average duration of task
type of task
Evaluation of the task: (*bonus/malus points*)
parameters according to type of task
duration of validity of invitation

Depending on the type of task the attributes contain a lot of information which is needed to solve the tasks. These parameters were developed during the practical utilization of the systems and are not relevant to the principles of negotiations discussed here. The inviting system puts its demands for the two time stamps into the attributes and fills in its evaluation. The *bonus points* are comparable to a priority system. The name was chosen to make clear that in the context of autonomous systems there is no obligation to respect such priorities. Thus this figure is only a proposal which shows the level of interest of the inviting system. Besides, these points show a kind of reward, depending for example on how fast the task is solved. *Malus points*, on the other hand, are comparable to a penalty. This field may also contain a sort of a function, depending on the type of fault of the autonomous system. It may depend on whether the task is only finished late or is not finished at all. Thus *malus points* show the risk which the offering systems takes, if it accepts the task. Beside these aims, the system of points fulfils the following tasks:

- the inviting system is able to keep lists of the offering systems and their reliability. This will be taken into consideration or may be used to learn about the other systems.

- the offering systems are able to learn about their own planning capabilities, using the *malus point* system as a kind of a corridor, which should be reached. The number should stay within a certain limit. Scoring too many points means that the system is planning to riskily, scoring never any points means the system is saving its ressources.

Similar point systems are integrated into the class *offers*. The point system in this class has the additional significance of enabling the autonomous systems to tell their estimated costs to the inviting system.

5.2 Agents for Negotiation

The main difficulty in introducing intelligent negotiation protocols in the SFB 331 arises from the fact that the autonomous systems taking part in these negotiations are very heterogeneous. For example the mobile system MACROBE has been designed to find its path in an environment which is only roughly known to it. However, to choose a task or a sequence of tasks MACROBE has to rely on a simple priority-oriented system. The mobile robot MOBROB on the other hand is very autonomous on the planning level. Its sensorial capabilities on the other hand are limited, as the vehicle itself is track-bounded and uses landmarks. In order to increase the scope of planning for the autonomous systems we will improve the strict assignment of the tasks to single autonomous systems. Therefore we developed a theoretical concept based on our knowledge base which adds so called *agents for negotiation* to each autonomous system. These *negotiation agents* build a homogenous layer and enable our autonomous systems to lead complex negotiations. In this article only the first realisation for the practical use within the SFB 331 is discussed. The first system for which we developed a simple negotiation agent was the autonomous vehicle MACROBE. For this purpose an application program has been developed that is able to handle the data structures for *invitations to bid* and which is also able to create offers for MACROBE. The negotiation agent on the other hand supplies MACROBE with task data using its normal interface to its local knowledge base. Using the negotiation agent MACROBE gets as powerful in negotiation as its negotiation agent.

6 Conclusion

We are currently working on integrating negotiation mechanisms into our factory environment and have integrated the first simple Contract Net based protocols into our autonomous sytems. We proved their applicability by building a first negotiation agent for our system. The next task is to include the negotiation management of the coordinating instance and to connect the autonomus systems with the coordinating instance. We will then test the efficiency of the whole system in the different conditions of the production enviroment.

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