An agent-based framework for local model approaches

A.J.N. van Breemen* T.J.A. de Vries† J.B. Striper‡

Abstract

In this paper the conceptual framework of multi-agent systems is combined with Local Model Approaches that are known in the field of control engineering. By doing so, a general and structured design methodology is obtained for solving complex modeling and control problems. This methodology consists of making a hierarchical decomposition of the complex problem into a set of partial problems. The solutions of these partial problems are represented as agents. The overall solution is obtained by combining elementary agents by using coordination operators. These operators allow the use of different combination techniques within one model by using a uniform description. A modeling and simulation example of an industrial cardboard producing machine is given to illustrate the proposed method.

Key words: multi agent system, local model approach, simulation, corrugated cardboard production.

AMS subject classifications: 93A30, 93C65, 68Q85, 68U20.

1 Introduction

The work presented in this article is related to a rapidly growing modeling technique that is known by researchers from the field of control engineering under different names, such as Local Controller/Model Networks [2], Operating Regime Approach [4] and Multiple Models Approach [10]. These techniques originate from a need for approaches to solve complex modeling and control problems. The main difficulty in solving these problems is often not how to solve elementary parts of the problem, but rather how to decompose the problem into a set of supposedly independent partial modeling problems and how to combine the individual solutions (models) into a coherent overall solution. Although there do exist methods for combining partial solutions, most approaches rely on a fixed 'mindset' and are only applicable to a particular class of problems. For example, the Multiple Model approach considers switching between models only; Local Controller/Model Networks rely on fuzzy interpolation only; etc. A unifying language is required that describes alternative local modeling techniques by the same concepts in order to develop a general solution methodology for complex control and modeling problems. The conceptual framework of multi agent systems can help to meet this requirement.

The field of multi-agent systems is closely related to the field of distributed problem solving and is concerned with solving complex problems by using a group of autonomous entities called agents [3]. Each agent is designed more or less independent from the group to solve a particular part of the whole problem. Here we notice a resemblance with local model approaches. Because the field of multi-agent systems is more abstract and is concerned with solving complex problems in general, we suggest to combine the conceptual framework of multi-agent systems with different local modeling and control techniques. By doing so, a general and structured design method for solving complex modeling and control problems is obtained. In this paper we show how this combination can be made and what the benefits are for modeling by presenting a case study of the modeling and simulation of a corrugated cardboard producing machine.

*Faculty of Electrical Engineering, EL-RT, University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands, phone: +31 53 4892788, fax: +31 53 4892223, macs@rt.el.utwente.nl

†University of Twente

‡University of Twente

The remainder of this text is organized as follows. In section 2 the multi-agent system concept is described. The production process of corrugated cardboard is described in section 3, as well as a hierarchical decomposition of it into a set of partial models. The basic equations of the partial models are described in section 4. In section 5 the partial models are combined into a total model. Simulations results are given in section 6. Finally, conclusions are given in section 7.

2 Multi-agent systems

Over the past view years, the concept of an agent has entered the field of computer science. Although there is no generally accepted definition of an agent, it is well agreed upon by most researchers that *an agent is an autonomous object that has an objective* [7]. By modeling aspects of a problem as agents, a different stance is obtained toward this problem and its solution. For instance, by modeling some machine part as an agent, it will be responsible for its own behavior in a simulation model. That is, it will watch over the conditions under which must be active and it will properly initialize if necessary. Besides a conceptual advantage, agents also give a practical advantage, because everything related to a particular partial solution (algorithm, working conditions, initialize/terminate function) is implemented in one entity (an agent), which makes it easier to add and remove agents from the whole solution.

In [3] a design strategy for multi-agent systems is described. This strategy consists roughly of three steps:

- *Decompose* the whole problem into a set of independent partial problems.
- *Solve* the partial problems by designing an agent that knows how to complete a particular *task* that solves the partial problem.
- *Combine* the set of obtained agents into a coherence whole by properly *coordinating* the activities of the agents.

In [6], three axes of decomposition are mentioned to decompose a problem into a set of partial problems. Either the decomposition is based on objects, on space or on functions. In general, the decomposition is not unique and formal methods to carry out an ”optimal” decomposition do not exist.

Solving the partial problems is done by using solution techniques from the problem domain. If the partial problem is still too complex to solve, it should be further decomposed into a set of simpler problems. When a solution is found, it is represented as an agent. The objective of the agent is to solve the partial problem it is designed for. Whenever the partial problem becomes relevant in the whole solution, the agent will become active and start carrying out its task.

Because agents have their own objective, incoherent behavior may arise when combining the agents. Therefore, it is necessary to carry out an additional task that is not directly objective-oriented. This task takes care of forming a coherent whole and is called the *coordination task* [6]. A group of coordinated agents can be viewed by as an agent itself, and therefore we may write that [8]

$$\texttt{Agent1} := C_{coordination}(\texttt{Agent2}, \texttt{Agent3}, \ldots); \tag{1}$$

which means that the behavior of `Agent1` is the result of the coordinated behaviors of the set of agents $\{\texttt{Agent2}, \texttt{Agent3}, \ldots\}$. By using this approach, agents with a complex behavior can be recursively defined from agents with simple behaviors. Different coordination mechanisms exist, each resulting in different overall group behavior ([8], [9]). Which coordination mechanism to use in a particular situation depends on the structural and temporal relations between the agents.

Most combination techniques used by local model approaches can be described in terms of a supervisor and a gating block [4]. Compared to coordination operators, the main differences are that coordination operators 1) make the temporal and structural relations between local models explicit, 2) create an open architecture; whenever an agent is added or removed, the coordination operator is unaffected, and 3) offer a uniform way to apply *different* combination techniques in a solution.

3 Production process description

3.1 Corrugated cardboard

In this section, the production process of corrugated cardboard is described. A model is needed that can be used to evaluate possible control strategies for improving the production speed and quality of the production process. The corrugated cardboard that is produced is composed of three layers. The top layer is called the *duplex*. The middle layer gives the cardboard more solidity and is called the *medium*. The bottom layer finishes the cardboard and is called the *liner*.

The quality of the corrugated cardboard is directly related to the moisture content it contains [1]. Therefore, the model should a least predict the moisture content of the corrugated cardboard during production. The production process contains three sources

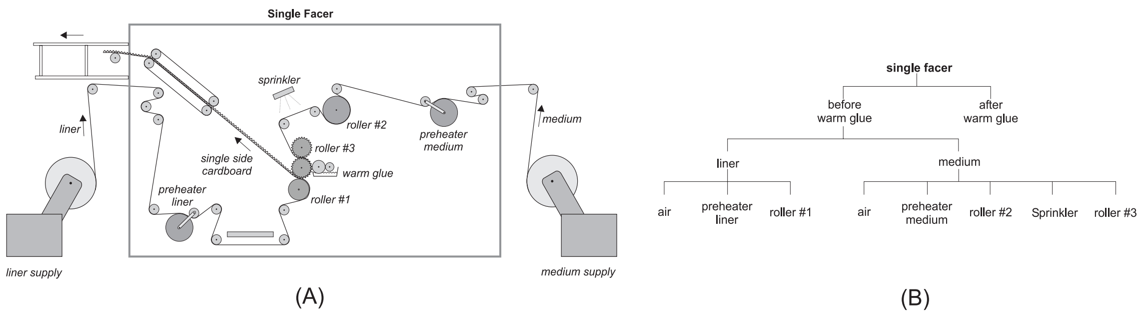

Figure 1: Single facer.

of moisture. These are: 1) the initial moisture content of the layers that enter the production process, 2) the glues that are used to attach the layers to each other, and 3) actively controllable sprinklers to add additional moisture. The moisture content is also influenced by the temperature of the layers. Heating a layer results in a decrease of the percentage of moisture.

3.2 Single Facer

The production process starts at a machine called the Single Facer, that attaches the liner to the medium to produce so called single side cardboard. Only this part of the production process is described in this article. The liner and medium enter the Single Facer and are heated by use of preheaters (see fig. 1a). The amount of heat delivered by the preheaters can be controlled during the production process. The two preheaters are the main control instruments to control the moisture content of the corrugated cardboard. After the liner has been heated by the preheater, it is heated once more by roller #1 and it will reach the glue stage. The medium is heated by roller #2 and #3 and can be moistened by a sprinkler before it reaches the glue stage. The amount of heat delivered by a roller is fixed during the production process.

During the glue stage, the liner and the medium are attached to each other by use of warm glue (40 °C). This results in an instantaneous fixation of the liner and the medium.

3.3 Decomposition of production process

A model is needed that calculates the moisture content and the temperature of the materials within the Single Facer during normal production. Because of the numerous places where temperature and moisture of the cardboard are influenced, it is a laborious task to create one overall model. Therefore, the Single Facer is decomposed into a set of partial models.

The Single Facer contains three types of material, namely liner, medium and single side cardboard. Before the glue stage, only liner and medium exist, while after the glue stage there is only single side cardboard. This means that different models are needed. The Single Facer is therefore divided into two partial models: ”before warm glue” and ”after warm glue”. The ”before warm glue” model is divided once more into ”liner” and ”medium”, that model the production stages of liner and medium respectively. During these production stages, the liner/medium is either in contact with air, or with some source of heat or with a sprinkler.

A picture of the overall decomposition of the Single Facer is given in figure 1b. The models at the bottom of this hierarchy are *elementary models*. Elementary models describe several production stages, and are not hard to formulate in terms of differential equations. The other models are compositions of these elementary models.

4 Partial models

4.1 Elementary equations

The partial models describe the behaviour of the temperature and the amount of moisture of the materials (liner, medium, single side cardboard) at any position in the production process. To obtain the equations that describe this behaviour, an elementary volume part of the material that travels through the production process is considered. The dynamics of the temperature and amount of moisture in the volume are approximated by a first order differential equations of the form [5]:

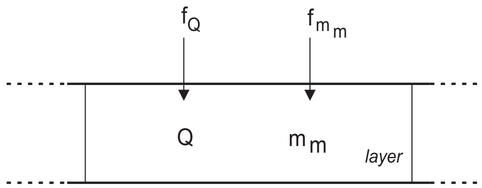

Figure 2: Basic layer.

(2)
$$\begin{aligned}\frac{\partial T(t)}{\partial t} &= \frac{1}{c_d m_d + c_m m_m(t)}\left\{ f_Q - c_m T(t)\frac{\partial m_m(t)}{\partial t}\right\}\\ \frac{\partial m_m(t)}{\partial t} &= f_{m_m}\end{aligned}$$

where T [°C] is the temperature of the volume part, m_m [kg/m^2] is the amount of moisture per square, c_d, c_m [J / kg K] are the specific heat constants of the dry material and moisture respectively, m_p [kg/m^2] the mass of the dry material per square, f_Q [J/m^{2}s] the amount of heat transfer per square and f_{m_m} [kg/m^{2}s] the amount of moisture transfer per square (see fig. 2). The moisture content is defined as $m_m/(m_d + m_m)$. Depending on the position of the elementary part within the production process, the amount of heat and moisture transfer per square differs. For each particular situation, a partial model is created. For instance, partial models for liner in contact with air, with preheater and with roller are defined. When the liner and medium are attached to each other, a model with 3 layers (liner, glue, medium) is defined. The set of partial models that are defined in this way are all the ones listed at the bottom of the hierarchy pictured in figure 1b.

4.2 Elementary agents

The elementary models are defined as agents. Beside the differential equations that describes the behaviour of the temperature and moisture content of the volume part of the material, conditions under which the model is valid and an initialize function for the state variables of the differential equation are added to the agent. For instance, the agent `liner_preheater` models the liner at the preheater and wants to get active for $x_s \leq x < x_e$, where x is the position of the elementary liner volume part in the production process, and x_s, x_e are the begin and end position of the liner preheater. The differential equation is initiated by $T(t) = T(t^-)$ and $m_m(t) = m_m(t^-)$; that is, the model is initialized by the values of the temperature and moisture content of the liner just before `liner_preheater` gets active. Hence, these are obtained from the "liner_air" agent.

5 Combining partial models

The partial models are combined into an overall model that describes the temperature and moisture content of the materials at every position in the Single Facer. The elementary agents are combined into new agents by use of the coordination operators, as described in section 2. Three particular coordination operators are used to combine the agents of the Single Facer. The first is the parallel coordination operator C_{par}, which defines a composition of agents that may execute their task in parallel. The second operator is the sequential coordination operator C_{seq}. This coordination operator combines agents whose tasks must be carried out in sequence. The third coordination operator is the fixed priority coordination operator C_{fp}. This operator assign to each agent a fixed priority and the agent with the highest priority that wants to carry out its task may do so. The priority is determined by the argument order in the declaration of the fixed priority coordination operator.

By using the coordination operators, the elementary agents are combined into a total model. E.g., The `single_facer` agent is defined by:

(3)
$$\begin{aligned}\texttt{liner} &:= C_{fp}(\texttt{preheater\_liner}, \texttt{roller\#1}, \texttt{liner\_air});\\ \texttt{medium} &:= C_{fp}(\texttt{preheater\_medium}, \texttt{roller\#2}, \texttt{sprinkler}, \texttt{roller\#3}, \texttt{medium\_air});\\ \texttt{before\_warm\_glue} &:= C_{par}(\texttt{liner}, \texttt{medium});\\ \texttt{single\_facer} &:= C_{seq}(\texttt{after\_warm\_glue}, \texttt{before\_warm\_glue});\end{aligned}$$

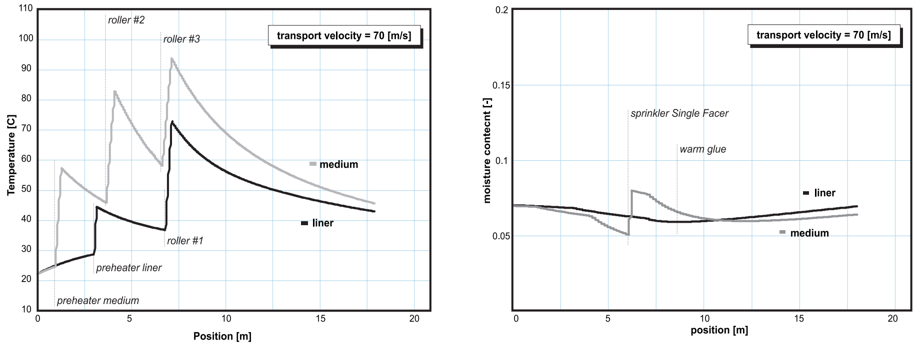

Figure 3: Simulation results.

6 Simulation results

The overall model was implemented in C++ and simulated using 20-Sim [11]. The parameters of the partial models were identified using measurements from a real production process. An Euler integration method was used with a step size that was small compared to the transport velocity of the materials. In fig. 3, the result of a simulation run is shown. The temperature and moisture content are plotted. It can be seen that at particular positions, the temperature and moisture content of the liner and medium increase drastically. At these positions, particular agents started carrying out their task. Influences of the transport speeds, preheater angles, supply moistures, etc., are readily assessed using the proposed model.

7 Conclusions

It was suggested in this article to combine the conceptual framework of multi-agent systems with local modeling and control techniques to develop a general and structured method for solving complex modeling and control problems. A design strategy was discussed and applied to a real world modeling problem. By modeling partial solutions as agents, and by combining them using coordination operators, the overall solution can be formulated easily.

An additional advantage of the approach discussed here is that a simulation model can be created incrementally. Each agent model can be designed and tested separately. Furthermore, parameters of an agent can be locally estimated without influencing the performance of the other agents in the model.

By using coordination operators different, combination techniques can be used and an open architecture in which it is easy to add and remove partial models was created. However, switching between agents introduces some problems. Attention should be given to a proper initialization of the partial models. Furthermore, the problem of finding the exact switching moment should be addressed.

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