COGNITIVE TECHNICAL SYSTEMS IN A PRODUCTION ENVIRONMENT

Outline of a Possible Approach

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Abstract: High-Wage countries face the dilemmas of value- vs. planning orientation and the dilemma of economies of scale vs. economies of scope summed up in the term polylemma. To reduce the dilemma of planning vs. value orientation cognitive technical systems seem to be a promising approach. In this paper the requirements of such a cognitive system in a production environment is presented. Furthermore a first concept of a software architecture is given. To implement a knowledge base for a cognitive technical system certain formalism were scrutinized for their suitability in this approach and a possible use case for such a cognitive technical system is presented.

1 INTRODUCTION

Today's production industry in high-wage countries is confronted with two dichotomies value orientation vs. planning orientation as well as economies of scale vs. economies of scope. In the last years, production in low-wage countries became popular with many companies by reason of low production costs. To slow down the development of shifting production to low-wage countries, new concepts for the production in high-wage countries have to be created.

The question of developing these concepts is connected to the polylemma of production, shown in Figure 1, which summarizes the two dilemmas mentioned above. Production systems of the future have to accomplish the apparent incompatibility of the two dichotomies. To improve the competitiveness compared to production in low-cost countries, it is not sufficient for production in high-wage countries to achieve a better position within one of the dichotomies, it will have to resolve the polylemma of production (Schuh, 2007). The research questions of the Cluster of Excellence "Integrative Production Technology for High-Wage Countries" aims at the resolution of this polylemma.

A reduction of the polylemma would widen the operational range of production systems over the batch size resulting in a smoothed unit cost curve as shown in Figure 2.

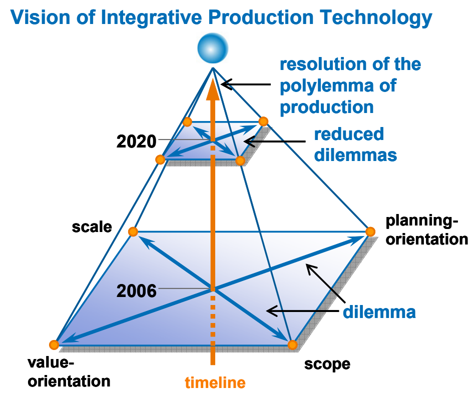

Figure 1: Polylemma of production.

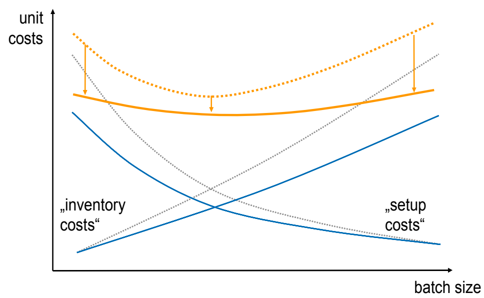

Figure 2: Unit costs above batch size.

Our approach to reduce the dilemma of value orientation vs. planning orientation leads towards an intelligent manufacturing environment realised by the use of artificial cognition. A cognitive architecture is one of the central parts for an intelligent production system to become reality.

Using cognitive mechanisms like learning, planning and problem solving in connection with interaction with a real environment is not a new consideration anymore. Over the years, cognitive science has become an important part of research in psychology as well as in robotics. It is our ambition to study the different theories of cognitive architectures and finally to conceptualize a control unit suitable for a production system. Before we will present a possible concept of a cognitive control unit, we will give a brief overview of the state of the art of cogntion in technical systems and then focus on the requirements and an architecture of a cognitive system for the production industry.

2 COGNITVE TECHNICAL SYSTEMS

Cognition is defined as the acquisition, storage, transformation and usage of knowledge (Matlin, 2005). A cognitive system could imply following mental processes:

- Perception and action
- Learning
- Problem solving
- Reasoning
- Decision making

To create technical systems using some of the mentioned abilities, cognition started to play a major role in more and more fields of technical environments in the last years. Many variations of (partial) autonomous systems have been developed (Putzer, 2004), e.g. service robots or robots for sports competitions which mostly strive to copy human behaviour. Also in numerous areas of our daily life intelligent technical systems become more and more common, applications like driving assistance systems (Heide, 2006) or assistance robots in the kitchen (Burghart, 2005) try to improve the daily routines of our society in the future.

In today's production industry cognition is beginning to enter the fields of sophisticated production systems, which so far are mostly automated systems. A disadvantage of these systems is the lack of flexibility. Changing the characteristic of a product leads to a great effort to reprogram whole process steps or even requires a partial change of the used modules. For a large process chain these changes can be the most cost intensive part and could cause a loss of efficiency. In conjunction to our research to conceptualize a cognitive unit for a production environment, an associated research group of the Cluster of Excellence is focussing on technology enablers for embedded cognition. These enablers should also be capable of self-optimisation.

2.1 Requirements of a Cognitive Technical System

A technical system including cognitive abilities could possibly circumvent the aforementioned problematic situation in current automation. To be suitable for a production environment such a system has to meet at least the following requirements. First multimodal Interaction with the environment and with human controllers should be possible. Also Information processing (mental processes) in addition with the availability of planning and coordination modules is required. To ensure a flawless interaction with human controllers transparent machine behaviour is essential.

A cognitive technical system must be able to perceive and to influence its environment, which is realised through a perceptional and an actoric component. Figure 3 shows the different communication levels acting upon a cognitive control unit. Aside from the communication with a human operator it has to interact with other production systems from shop-floor level to whole production networks. To ensure a flawless information and knowledge flow a well-balanced multimodal interaction between operator and machine is indispensable. This is also especially relevant for providing embedded training (Nolden, 1999) of human operators on these systems which leads to technological and methodological competence of a joint cognitive system of human and machine.

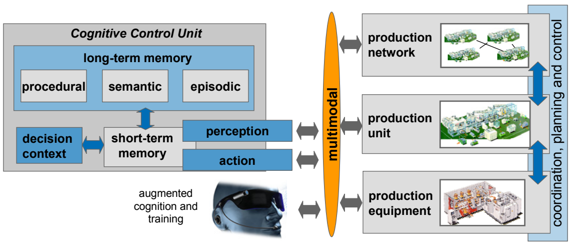

Figure 3: Multimodal interaction of a cognitive technical system.

In addition to that the gained information has to be processed – comprehending knowledge storage, learning and problem solving. This requires an explicit knowledge representation within the system and the possibility to reason about the given problems. The knowledge has to be stored in an inferable way that deterministic algorithms can be used to find possible ways through the problem space to the desired goal.

For more complex processes the system has to arrange the different tasks in a useful combination to accomplish the job. This requires a sophisticated planning module, which is one of our research focuses. A coordination module is responsible for the implementation of the scheduled tasks with the action module.

Transparency of machine behaviour to a human user will be one of the crucial aspects of the cognitive technical system. The system itself and human operators should be able to comprehend the decisions the technical system takes and the subsequent actions it executes. That is necessary to prevent handling errors by the human operator and increases the chance to discover and correct malfunctions. Also the mental models of the operator and the technical cognitive systems have to be compatible. This leads to an increasing acceptance of the system by the human operator (Hartmann, 1995).

2.2 Cognitive Architectures

A possible approach to fulfil the discussed requirements is the use of a cognitive architecture. In 1987 Newell defined the Unified Theory of Cognition (UTC) (Newell, 1990). An approach conforming to the UTC has to be composed of a set of mechanisms which accounts for all forms (processes) of cognition. In robotics and cognitive science research aimed for developing architectures sufficient to the UTC. Two popular representatives are ACT-R (Adaptive Control of Thought—Rational; Anderson, 2004) and Soar (originally SOAR - State, Operator And Result; Laird, 2006). Soar and ACT-R are both rule-based and goal-oriented architectures, which can be used for creating artificial intelligence.

The structure of Soar is characterized by different models of the memory (Figure 4). Production Rules entered by a user are included in the long-term memory. With the help of the perception module, the actual state of the environment is modelled in the working memory. Depending on this state and the preference memory Soar elaborates and fires within a decision cycle dertermined production rules and modifies entries in the short-term memory.

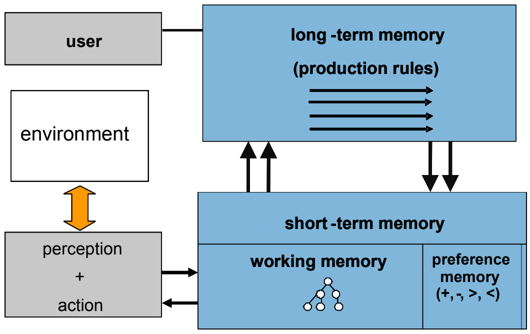

Figure 4: Structure of the memory in Soar.

The basic architecture of ACT-R consists of a set of modules for processing different forms of information (Anderson, 2004). In comparison to Soar, ACT-R differs between declarative and procedural knowledge. The basic idea of modelling cognitive abilities like learning and problem solving by using production rules is similar to the Soar architecture. However, the functional aspects of the different modules are deduced from psychological theories. Since ACT-R is a theory focussing on modelling human cognition, it also simulates inefficient human behaviour which is not consistent with industrial applications. Thus, there is only a minor presence of the theory in the field of robotics or automation so far.

Unlike more specialized approaches in cognitive science and robotics, Soar and ACT-R provide a generic concept for developing artificial intelligence. We studied the two architectures in the face of their pros and cons for their use in production environments by examining criterias like persistence, expandability and autonomy.

Soar is a suitable approach for modelling cognitive systems for production environments. It provides a wide field of the required capabilities like learning, planning and problem solving within a complex production rule system. However, our research so far has shown that not all components of Soar are adequate for a production environment. Due to complexity of the application area, the real time capability of Soar-architectures decreases with the higher amount of knowledge stored in the procedural memory, provoked by an increase in possible matches for the reasoning algorithm (Doorenbos, 1995). This is a common problem of deliberative rule-based architectures. Architectures which are used for mobile robots claiming improved real time capability often don't include an explicit representation of a knowledge base. The main problem of these systems is that it cannot be ascertained that the implicit knowledge is sufficient for a given problem.

A hybrid approach to this problem seems to be the most feasible. A possible software architecture for such an approach is presented in the next section. The above mentioned requirements for a cognitive system like problem solving and planning is satisfied by Soar. In addition to that the interaction between a cognitive unit with other systems or human workers has to be researched.

2.3 The Cognitive Control Unit (CCU)

The challenge of developing a system sufficient to the aforementioned requirements lies in combining dynamical system adaption to mutable goals with a real-time capability regarding operations in the production environment. Concerning our chosen handling operation, which will be presented in the following, we developed a first concept of a cognitive control unit (CCU) usable in the field of production technology.

The CCU (see Figure 5) underlies a concept from a planning level down to the operating level represented through components for perception and action. This concept is derived from the multi-level approach for cognitive technical systems proposed by Paetzold (Paetzold, 2006) The modules for planning and coordination take over the aspired cognitive abilities. Due to the symbolic representation from objects in Soar the perception module has to connect the perceived information to a symbol in the knowledge base to allow proper reasoning in the planning module. The coordination module is responsible for the correct execution of the planned tasks on the hardware level. The actual execution of the tasks is then done via the action module. This allows a separation of the deliberative and reactive parts of the system and ensures a real time capability. Sensor information which needs an immediate response won't reach the deliberative level of the system and will be executed without reasoning. This is important for the safety of human operators, who work in a human machine cooperation.

To control external modules, the CCU has a generic interface which enables a direct communication on machine level. Additionally knowledge engineering processed by multimodal human machine interaction should be possible.

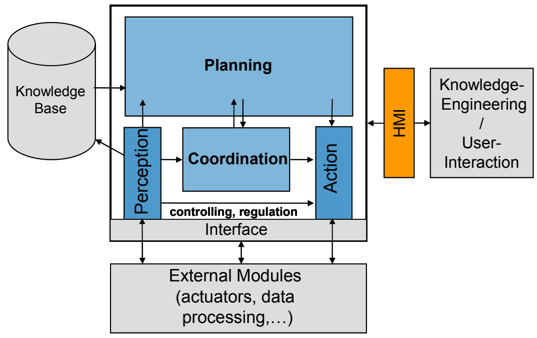

Figure 5: Possible concept of a CCU.

The cognitive mechanisms on the planning and organisational level combined with additional modules like a Human-Machine Interface and an external knowledge base will complete our approach to a multi-level architecture used in today's robotics. Due to the important role of internal and external knowledge bases of the aspired system different formalisms of knowledge representation have to be evaluated.

3 KNOWLEDGE BASE

Besides an internal representation of knowledge within the cognitive architecture, e.g. production rules in Soar, it is a subgoal to develop an external knowledge base, which should contain an explicit declaration of knowledge. Generally a representation of knowledge has to accomplish at least the ability to recover the stored knowledge. Furthermore the formalism of knowledge should enable the system to process the stored data (Haun, 2000). Several formalisms of knowledge representations for different purposes are available. Within our project we try to determine which formalism(s) are suitable for the knowledge base of the CCU and could improve the associated cognitive abilities. It has to be researched which additional data has to be stored in the external knowledge base. A knowledge base for our purpose could contain next to a representation of the real environment data for internal computations as well as episodic knowledge which memorizes all past events.

Formalisms of knowledge representations ranging from declarative to procedural forms are:

- Semantic Nets
- First Order Logic
- Frames
- Production Rules
- Object-Oriented-Representations

An explicit representation model of the environment of the production unit could be summarized by the term ontology – which we will refer to as an explicit specification of a conceptualization (Gruber, 1993). In the last years, the use of ontologies became popular and got more important in computer science and artificial intelligence. The possibility of reasoning makes an ontology to an adequate modeling structure of representing knowledge. Not all of the aforementioned formalisms are suitable for an ontological representation of the relevant environment. Also it has to be evaluated which amount and level of detail of knowledge is essential for a proper description. To generate new knowledge and possibly new production rules, the formalisms have to provide the ability of inference.

To realise reasoning it is essential that the knowledge has a semantic structure. Consistency and completeness are also requirements for the process of reasoning. An Ontology defined in OWL (Web Ontology Language) (Smith, 2004) could fulfil our demands of a knowledge base. Because of OWL-DL features computational completeness and decidability, such an ontology would be suitable for a model of the real environment as well as other inferable semantic connected data.

The translation of the knowledge representation form (Figure 6) between the knowledge base and the cognitive unit has also to be realised. The CCU should be capable to generate production rules out of the external knowledge and to extend the external knowledge base with collected and elaborated data within the working memory. For this operation a compiler for both directions is required. This compiler should be able to translate complex and big sized ontologies but also be generic enough to be adaptable to other representation formalisms.

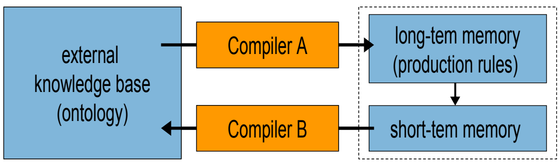

Figure 6: Knowledge Translator.

4 HANDLING OPERATION (USE CASE)

As mentioned before we want to realise a handling operation with a cognitive technical system. The focus of this use case is the realisation of an intelligent grasp behaviour by cognitive means. What actually needs to be described is driven by the process itself which means that here one has to care about center of gravity, material and surface attributes but not for the inner structural composition. Figure 7 shows the layout of the test-setup. The aim is the assembly of a pile out of different coloured bricks. This involves the identification and position of a needed part, the picking operation and the transfer from the belt conveyor to the assembly area. In the assembly area the cognitive control unit has to choose the right grasp strategy depending on the current state of the to be assembled parts. To do this the cognitive unit needs multi sensorical input. For the identification of colour and position an image recognition is required. The transfer operation will be realised by integrating already known collision-free transfer moves whereas the fine movements for the gripper have to be planned cognitively by the system itself.

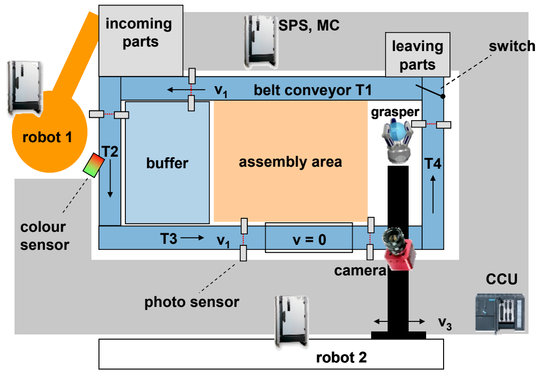

Figure 7: Layout of use case.

5 CONCLUSIONS

In the scope of this research project we hope to achieve a complete assembly operation by cognitive means and therefore reducing the dilemma of planning and value orientation by means of self organisational systems. In the Cluster of Excellence this is one of the researched approaches. In this paper requirements for a cognitive technical system applicable in production environments and a first concept of a software architecture have been presented. Furthermore possible knowledge representation forms which could be suitable for a deployment in production environments were shown. The future work will focus on the implementation of the needed domain knowledge for a handling operation and the interaction of human controllers with the system. Furthermore we will develop a knowledge translator which satisfies the requirements given in Chapter 3.

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