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Strategies of Social Insects and Other Bio-Inspired Algorithms for Logistics: State of the Art and New Perspectives

Abstract

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1 Introduction

The rising demand on current logistic applications results in needs for increasing functionalities and complexity of todays software solutions. The ever-changing conditions of todays markets have considerable influences on planning and control of logistics processes. Because of the increase of relative scarcity of logistic infrastructure combined with the increasing quantity of processes in the value chain in more and more spatially and organizational distributed networks, complex and often contrary requirements for logistic planning and control systems arise. Logistics, i.e. production as well as transport logistics, has to deal with intrinsic structural complexity emerging from both the number of interacting entities including their interdependencies and the virtually infinite number of logistic items.

The majority of currently used production planning and control systems as well as transport management systems are based on centralized optimization procedures. Their successful application in the sketched dynamic environment is often not feasible because such conventional system can not cope properly with disturbances and uncertainties and even suffer from insufficient scalability. To overcome the problems of centralized architectures a number of far reaching new conceptual frameworks for distributed control in the area of manufacturing (including production logistics) have been proposed during the last decade, presenting similar concepts but with different origins. This includes the fractal

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factory concept, which focuses mainly on an assumed self-similarity of organizational units, the Bionic Manufacturing System (BMS), which emphasizes biological evolution principles for dealing with dynamic changes or the Holonic Manufacturing System (HMS). The latter approach identifies key elements of manufacturing, such as machines, factories, parts, products or operators etc. with so called holons, which should have autonomous and cooperative properties. With this identification it compares closely to the main ideas of distributed artificial intelligence (DAI), especially the multi agent systems (MAS) paradigm.

2 Multi-Agent Systems in Logistics

At a glance logistics has the objective to transport materials or goods from one place to another, where a demand for these specific goods must be satisfied. This main objective is subjected to several process related constraints as e.g. time windows for delivery, special sequencing demands etc. Furthermore, usually alternative means of transportation are available and at the same time the resources are constrained. Thus, a number of decisions regarding routing and scheduling tasks have to be made under time constraints and uncertain or incomplete knowledge. These characteristics applies both to logistics in production environments (shop floors and production networks of connected production facilities or plants) and transport logistics in general.
Many authors have mentioned that such problems in logistics are a well suited application area for multi-agent technologies. By nature, logistic systems are modular, these systems can be physically decomposed into separated entities like production facilities, machines, operators, orders, packets and pallets, conveyors, parts, sub-assemblies, products, etc. Logistic items are spatially distributed and logistic systems have a decentralized structure. Additionally, the main objective of logistic processes requires the coordination of various logistic items and the allocation of scarce resources. Thus cooperative appendages and communication are prerequisites in successful logistic operations. These prerequisites are congruent with the requirements for promising application of MAS.

3 Using Swarm Intelligence and Ant-Like Agents

A number of known applications of agent technologies in logistics uses intelligent agents with a relatively complicated architecture [1].
In contrast we will explore the usage of a large number of individually simple agents. Because of the layout of logistic systems it is preferable to choose a concept with a high number of agents with limited capabilities than a setup with a few highly intelligent agents.
One main question is how the communication between the elements is performed. In biological inspired artificial intelligence (AI) concepts like the swarm intelligence approach, where the behavior of social insects like ants or bees is copied, communication is carried out exclusively through the environment [2].

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Stigmergy depicts indirect communication and coordination within a dissipative field through asynchronous information exchange between agents. Such a coordination mechanism can be observed in social insect societies. For example, the interaction of ants is based on pheromones only as ants do not communicate directly. Ants put down pheromones in their environment leaving signals to other ants thus influencing their behavior. The main requirements for information sharing in logistics, i.e.:

- sharing information on possible paths and means of transportation locally
- sharing information on the costs and the degree of fulfillment of objectives for different alternatives
- sharing information on preferable clustering of goods in order to allocate a shared resource

can be fulfilled by a stigmertic information storage and updating. In addition, the concept of Stigmergy could provide a solution for logistic scenarios in which the bandwidth for communication between the elements is limited.
A similar approach for shop floor logistics was recently presented in [3]. This proposal of a swarm intelligence approach for manufacturing control is based on the assumption that logistic entities are represented in a centralized computer architecture by agents. For coordination purposes, these agents send out a kind of mobile agent (artificial ants) to lay down information in the environment. Three different types of such artifical ants are used: feasibility ants that track feasible routes, exploring ants for a forward exploration and intention ants that represent preferences of the entity agents. Whereas the concepts are realizable on the shop floor they fail in wide area transportation because they have to map both the biological stigmergic system and the application domain, i.e. the World as Valckenaers et.al. call it, onto a software system that must be able to communicate with the real world items every time. In contrast, we aim to partially distribute the information (pheromones) indeed locally, such that even under temporarily not available communication infrastructure routing decisions can be rendered from locally available stigmergic information. Such a concept of stigmergy was already successfully applied to adaptive telecommunication routing problems where it was implemented in fields of distributed optimization and problem solving [4]. In telecommunications systems artifical ants are sent out in regular time intervals to explore the available transmission lines and to update routing tables in several routing nodes. Here the artificial ants are data packets and in principle their properties and enviroment are the same as for the data packets that have to be routed. This is not necessarily the case in manufacturing or traffic systems, where on the one hand physical materials have to be transported and on the other hand artificial ants can be transmitted through communication lines. In the latter case, communication times are often negligible compared to the processing time, i.e. the transportation time of physical goods. These special properties of logistic systems have to be carefully assessed for design and development of adapted swarm intelligence algorithms for distributed optimization in logistics.

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4 Conclusion and Further Research

In this contribution we present an overview of recent developments in application of swarm-intelligence approaches to logistic systems. We argue that for wide area applications where a large number of logistic entities have to be coordinated with limited communication and computational resources the application of swarm intelligence principles may be beneficial. Inherent properties of swarm intelligence like the massive system scalability and the emergent intelligent behavior from local interactions by communication through distributed information in the environment are desirable properties of this bio-inspired approach. However, to realize these promises a careful design of the overall system, including a concept for distribution and updating of stigmertic information is necessary. Thus much work remains to be done. This includes careful estimation of the performance of the herein proposed approaches compared other possible distributed problem solving algorithms for the specific logistics problems.

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