AN ADAPTABLE ARCHITECTURE FOR INTELLIGENT CONVEYORS

Dennis Ommen, Jens Kamenik, Carsten Beth
OFFIS Institute for Information Technology, Escherweg 2, Oldenburg, Germany

Jan C. Busch, Alexander Kulas, Eckhard Cramer, Axel Hahn
Department of Computing Science, Carl von Ossietzky University, Ammerländer Heerstrasse 114-118, Oldenburg, Germany

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Abstract: To optimize the transportation processes inside transfer stations the degree of automation has to be increased without the loose of flexibility. Therefore this paper proposes a detailed architecture for an intelligent material flow system based on the technologies of Multi-Agent-Systems (MAS) and wireless sensor networks. Furthermore, a novel framework is proposed that eases the integration process between the MAS and the physical level of heterogeneous conveyors.

1 INTRODUCTION

Flexibility will be one of the most important drivers for technological improvements in material flow systems in the future. A new flexible material flow system has to be reconfigurable by design and in the end there are no additional costs allowed (Windth, 2007). To circumvent this problem new systems should be designed as autonomous decentralized cooperating objects, e.g. goods and the transportation system autonomously make decisions (Scholz-Reiter et al., 2007b). The autonomous decisions can be made in two ways (1) the good driven way(Scholz-Reiter et al., 2007a) (Scholz-Reiter et al., 2006): An embedded device attached to the package escorts the goods to its destination. During the transportation process the embedded device cooperates with the environment to achieve its goal. (2) The transportation system driven way: The environment around the goods makes the decisions. With the arrival and identification of a good at the entry transfer point the intelligent environment autonomously creates a specific transport order. From now on this virtual order escorts each intelligent transportation device that handles these goods.

We assume that for material flows system that are specialized on movement of goods, it will not be feasible to attach an intelligent device to each good, due to cost reasons. Therefore we follow the approach of the intelligent environment with its intelligent transportation devices. Thereby the intelligent conveyor is able to plan and drive the appropriate route through the environment to reach the sink transfer point. These intelligent transportation devices can have very different abilities and automation degrees and are therefore suited for different transportation task and situations. For example, automated guided vehicles (AGV) are used for basic load while traditional fork lift trucks (FLT) are used in peak load situation. The challenge that will be addressed here is the coordination of heterogeneous conveyors inside a transfer station which is based on Multi Agent Systems (MAS) and Wireless Sensor Networks (WSN).

Paper Organization. The remainder of the paper is organized as follows: Section 2 describes the transfer station scenario with the heterogeneous transportation devices within. Section 3 introduces the architecture of the proposed MAS. Section 4 describes a framework that eases the integration process between MAS and the field level of the different conveyors. Section 5 describes the intelligent environment that is based on WSN technology. Section 6 ends the paper with concluding remarks.

2 SCENARIO

Traditionally, heterogeneous conveyor types are used inside a transfer station. The transportation devices

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are operated and/or coordinated by human beings, to transport goods from the entry transfer point to the sink transfer point. Each kind of transportation device has different abilities to cope with the current load situation of the transfer station, depending on its degree of automation and flexibility. Each of these properties make an optimal coordination of the heterogeneous devices (regarding transportation cost, throughput or optimal balance load of the conveyors) very difficult. In the scenario depicted in figure 1, AGV and manually operated FLT work together to cope with the current load situation.

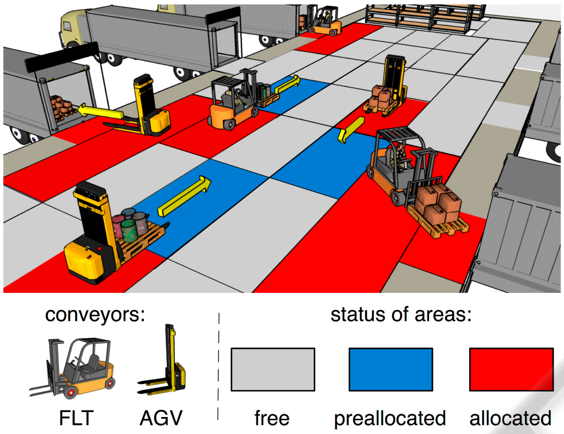

Figure 1: Material flow with an intelligent environment.

To ease the coordination process for an optimal throughput, all conveyors are intelligent transportation systems. This means each conveyor is able to decide itself if he is willing to take a transport order or not. But this freedom comes with duty. Each intelligent transportation system has to offer its position to an intelligent environment. The intelligent environment is virtually separated into areas that can either be free or set to be (pre)allocated by the intelligent conveyors. The different states of areas are needed to avoid collisions between the heterogeneous intelligent conveyors. Before an intelligent conveyor is entering a new area, it will allocate this area (depicted red) or will search for another route to reach his sink transfer point. During the planning process of routes, the conveyor will eventually be able to (pre)allocate the areas it will need during its transport process (depicted blue). The intelligent environment is physically represented by a WSN. This WSN is able to locate the intelligent conveyors and also could act as a database for the mentioned area status information.

3 CONTROL ARCHITECTURE

The scenario described in the previous section would traditionally require a central control, incorporating the state of every conveyor and the position of every good into work directives given to every conveyor. The design and implementation of a central control system is a non-trivial and lengthy task, and “a key cost driver” (Schmidt and Schulze, 2009) in the calculation of transport costs.

De-centralized systems promise to alleviate this costs by using self-organization of (semi-) autonomous agents, allowing for rapid adaption of the transport routes to new requirements. This paper proposes a decentral organization for material flows, using a system of multiple autonomous agents working together (MAS). This distributed approach is also the subject of other research projects, for example (Ten Hompel et al., 2008) and (Leit 2009).

3.1 Agents

Our architecture consists of two types of agents – transfer points and conveyors – interacting with each other and an intelligent environment. While conveyor agents expose a uniform set of properties and abilities to the MAS, the underlying physical objects they represent can differ widely. In this regard, an agent is an abstraction, providing a common way of interacting with physical objects that perform the same function (e.g. conveying goods), yet function in different ways.

Transfer Point. A transfer point represents a place where goods are transferred from one part of the system into another. The physical objects these agents represent could be terminals stationed at transfer stations, used to enter transport jobs into the MAS. The transfer point agents then communicate the job to all conveyor agents.

A transport job consists of the start and end transfer points, as well as a time constraint for finishing the transport and relevant information about the good to be conveyed, like weight and dimensions.

The conveyor agents, upon receiving a job, can bid on the job in the manner of an auction, giving a cost estimate for the transport. The transfer point agent selects the conveyor with the least cost estimate, and assigns the job to it.

Conveyor. A conveyor agent exposes the conveyors functionality to the MAS, allowing the transport of goods to be planned and executed. They receive job announcements from the transfer point agents, and bid on them with a cost estimate for the transport. The estimate is calculated by finding a route through the work area, querying the environment (see figure 2) for the states of the areas along the planned route (see section 2 and figure 1), and calculating the costs of a transport along that route. The winner of the auction then generates a job from the auction, and proceeds to pick up and deliver the goods.

To do this, a series of operations needs to be generated which the physical agent has to execute. This is done by breaking a transport job down into abstract actions, which are then turned into a series of operations using a device dependent transformation. An action is an abstract description of one step of the transport process, such as ‘pick up good X’ or ‘transport good to point A’, while an operation is an atomic function that a physical conveyor can perform, such as ‘drive forward’, ‘revolve belt’ or ‘locate good X within environment’. Operations are sent via a middleware, which allows for device independent communication. An overview of this process can be seen in 2.

However, in case of a human operating the conveyor, actions are not broken down further but sent directly, since it can be assumed that a human will understand the intention and act correctly, making fine grained instructions pointless.

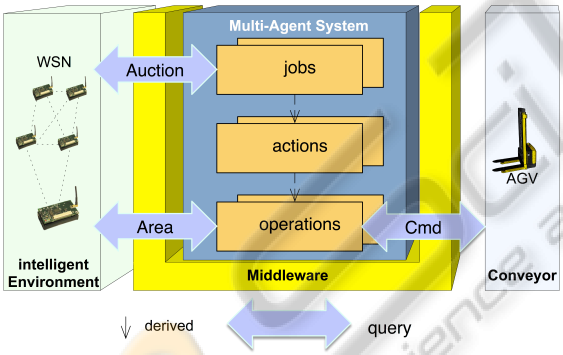

Figure 2: Control architecture of the conveyor.

3.2 Agent Requirements

To let an agent fulfill its tasks, it needs an intelligent environment and a physical conveyor. An additional middleware enables the agent to interact with the physical objects, which can differ widely, and the intelligent environment (see figure 2). For a detailed description of the middleware, see section 4. The intelligent environment consists of a WSN (see section 5), where sensor nodes are placed throughout the working area. It will be queried for information by the conveyor agents, for example for their own position in the environment, whether or not a certain area is currently occupied by other conveyors, or how the occupation of an area has been in the past.

In a pro-active scenario, the conveyors may additionally exchange information about their predicted usage of the environment, further improving the quality of the planned routes (preallocation, see section 2). However, since interactions with human beings can not be fully predicted, information generated this way is only of limited accuracy, possibly resulting in a probabilistic planning strategy. It is currently not determined how or where data about future usage of areas can be saved and kept available to all agents. Further research into this problem field is required.

4 MIDDLEWARE

The aforementioned MAS is one of the key component to operate the described material flow scenario with its heterogenous conveyors. But the MAS needs always direct contact to the conveyor or its operator to put the planned route into practice. Nevertheless the communication between the MAS and the conveyer is from the MAS point of view very abstract. Therefore is a link between the MAS and the Conveyer needed. This chapter presents a novel Integration Process for Conveyor with a corresponding configurable Middleware (MW). Thereby, the MW acts as mediator between the MAS and the Conveyers Sensor and Actors. Therefore we briefly discuss the requirements of the such a MW and than propose the MW architecture itself.

4.1 Middleware Requirements

Such a middleware should ease the integration process between the MAS and the conveyer. Therefore the MW should address the following aspects:

- adaptable to the unique conveyer specific query set, that the MAS is presupposing
- adaptable to the heterogenous sensors and actors the conveyer possesses. This means:
  - eased integration of different communication protocols, like CAN or ProfiBus, into the MW
  - on-the-fly transformation of the exchanged binary messages between the MAS and conveyors. This is necessary due to the different message content that the MAS and the Conveyors imply.

4.2 Architecture

To comply with the above stated requirements our approach is based on SOA Technology. Although we don't assume that XML based Automation-Protocols, e.g. OPC UA, will achieve the major acceptance in the domain due to real time constraint and overhead, we propose to adapt the SOA idea of an Enterprise Service Bus (ESB) to our needs. Historically ESB comes from the Enterprise Architecture Integration where systems and protocols are traditionally very heterogenous. Hence an ESB allows to integrate different protocols extensions (called adapters) to the middleware. To mediate now between the different semantic meaning of the messages a message transformation is needed, which is traditionally XSLT based. To overcome the realtime hurdles due to the XSLT interpretation of the ESB our Middleware acts as extendable Framework (see figure 3).

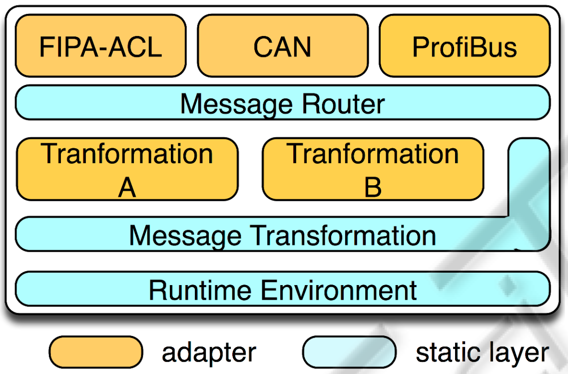

Figure 3: Middleware Architecture.

Each middleware layer (depicted in blue) will provide basic function that run the specific adapters (depicted in red). Such an Architecture will ease the portation step to other programming languages and other operating system so that this MW could even be ported to an Embedded System.

5 WIRELESS SENSOR NETWORK

In the cognitive environment of the proposed transfer station scenario (Ommen et al., 2009) (Beth et al., 2009) the routes are distributed and intelligent entities. They need to be networked to communicate with the conveyors to enable the distributed localization method. The routes have to provide the ability to localize the conveyor, to answer the occupation state of the route and to give an average usage feedback of the route (re-active approach). Furthermore the sensor network should acts as a communication relay for the conveyors and other sensor nodes.

5.1 Limited Resources

Resources are a critical point in designing a sensor network. For the deployment of the sensor network in the logistic in-door scenario the following points have to be considered.

1. One point to consider is the critical bandwidth and range of the sensor network.
2. For the deployment of a large number of nodes in industrial environments – with high flexibility and mobility requirements – the installation of a static electric power supply for all nodes is too expensive and not feasible. Therefore there are always nodes that can not be supplied with static electric power and the limited energy of the sensor nodes has to be considered.
3. A third point is the limited storage space of a sensor node, e.g. a typical sensor node like the MicaZ [1] has only 4KB RAM and 512 KB of flash memory on board.
4. A last point is the inaccurate RSSI-based localization of standard sensor nodes.

5.2 Approaches

In the proposed scenario the sensor network uses multi-hop communication to circumvent the limited propagation of radio waves in logistic in-door facilities and to extend the range of the sensor nodes and the conveyors.

Localization Procedure. The conveyors need to know their own position. The distributed fixed sensors nodes have an area to observe. This area is surrounded by at least three - in our model - four sensor nodes. A special node of the group is the home node, it is a sensor node responsible for fault tolerantly storing the data of one or more routes in the area. For the localization a trilateration method based on IEEE 802.15.4b compatible (Nanotron Technologies, 2007) ranging data will be used. In (Röhrig, 2009) this localization method, combined with appropriate Kalman filtering, provided an accuracy of 0,5m. The conveyor node has to initiate the localization procedure with the nodes of the localization group. A localization group is formed by issuing a broadcast call

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[1] www.xbow.com

for all neighborhood nodes able to localize the conveyor node. The localization procedure comprises the gathering of the distances from the mobile conveyor node to all nodes in the localization group and the necessary algorithms [2] to calculate the position. Afterwards, the conveyor node sends the position back to the home node. The home node of the route has to store the arrival time of the query, the ID of the conveyor and the estimated occupation time of the route. The estimated occupation time is a worst case time consisting of the average passing time for the route and an additional time for loading or unloading goods on the route.

Distributed Queries. Occupation and Average Queries from the conveyor nodes can be executed from every point in the scenario area and are answered by the home nodes of the localization groups. On *Occupation Queries* the conveyor asks for the occupation state of a route with a certain ID and at the time of the query. To answer this query, a message with the route ID and the occupation query type has to be sent to the home node of the route. If the route is occupied, the home node answers the query by sending back the occupation time to the inquirer ID. On *Average Queries* The conveyor asks for the average occupation state of a route in the past. This allows the conveyor to derive a usage estimation and to choose an alternative route in case of a possible jam situation. To answer this query, a message with the route ID and the estimation query type has to be sent to the home node of the route. The home node has to gather the past occupation times of the route belonging to the queried ID and averages them. Afterwards, it sends the averaged time back to the inquirer.

The data scheme for the localization of the nodes needs the attribute of the identity of the conveyors, the entry time of the conveyors and the (estimated) occupation time of the route:

RouteOccupation : { [ID: char, entrytime: float, occtime: float] }
The data scheme for the averaged values of the nodes needs the attribute of the identity of the route and the average occupation time $t_{occtime}$in time period $t_{average}$:

RouteAvg: { [RouteID: char,occtime: float] }

Storage Strategy and Energy Consumption. (Diao et al., 2007) stated that the storage of sensor data is energetically (Pottie and Kaiser, 2000) more efficient instead to transmit the data via the rf-channel. As a side-effect the bandwidth usage of the sensor network is reduced too. Furthermore, a consideration of the storage place of the sensor data necessary. The variables that have to be considered are the query rate, the event rate and the storage place. There are three approaches to choose the storage place in a distributed sensor network. The central data storage to an external server. This is optimal for applications where the query rate to the server is larger than the event rate (Tilak et al., 2006). For applications with a higher event rate than query rate the local storage is more energy efficient. For large scale sensor networks, e.g greater than 10000 sensor nodes, with a slightly higher event rate than query rate - the data centric storage (DCS) (Ratnasamy et al., 2002) is suitable. Here the place for data storage is chosen based on the attributes of the sensor data. For the scenario in this paper the *local storage* is suitable. The data is stored at the same place where the query takes place and therefore no additionally communication is necessary. The limited storage space on the sensor nodes has to be considered too. Assumed that the typical workload for an 100m x 100m sized cross-docking area is 750000 goods a year, the workload per hour would be 129 [3] goods. If the localization group is squared and has a side length x_{loc} of 25m , e.g. the typical working range for a nanotron localization system, the memory used per hour M_{hour} would be 9288 Bytes (8 localizations x 9 bytes per localization x 129 goods). A simple approach is to store every localization event occurred in one single home node responsible for the whole scenario. The (MicaZ) RAM would last for 1/2 hour and using the (MicaZ) flash storage would last for 56 hours. The intelligent approach is to store the localization events only for the occupation time of the conveyors and afterwards the time is used to build the average occupation time. If only the average value per hour is stored - the RAM is sufficient for 4 days (4kb / 5 bytes/ 8 localizations) and the flash storage would last for 546 days.

5.3 Wireless Sensor Network - Conclusion

The main problems for a wireless sensor network in a decentral logistic scenario are reliable localization and the limited resources of the nodes. It was discussed that the localization with IEEE 802.15.4b based ranging is suitable for the scenario. Furthermore, with an appropriate storage strategy the limited storage space and energy resources are sufficient for the scenario.

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[2] Solving a linear equation

[3] 365 days a year and 16 hours a day

6 CONCLUSIONS AND FUTURE WORK

In this paper several approaches for optimization of the transportation processes inside a transfer stations have been showed. The proposed architecture for intelligent material flow systems includes Multi-Agent-Systems and wireless sensor networks that are cooperating in a pro-active or re-active manner. Further research has to be done to decide the best cooperating manner. The main problems for a wireless sensor network in a intelligent material flow system have been figured out and it was discussed that with an appropriate storage strategy the limited storage space and energy resources are sufficient for an intelligent material flow systems. Furthermore, a novel framework was proposed that eases the integration process between the control level and the physical level of heterogeneous conveyors. In the future the architecture and the framework have to be tested for real logistic setups and the *lessons learned* will be demonstrated in successive publications.

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