ISBN 978-93-84422-40-0
Proceedings of 2015 International Conference on Computing Techniques and Mechanical Engineering (ICCTME'2015)
Phuket, October 1-3 2015, pp.33-38

A Protocol Structure for Controlling Adaptive Conveyor System in Automatized High Complex Distribution Centers

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Abstract**:** *This paper shows a protocol and execution structure of modules for opportunistic routing with forecast on decentralized control with PLCs. Current routing algorithms focus on small to middle material flow systems. Deadlocks can be determined easily because of the lack of dynamic behavior of the goods. The forecast to determine the expected time of the good at one transportation system can be computed more reliable. For high complex distribution centers with several hundred transportation units the forecast is not reliable enough to ensure the system consistency by avoid deadlocks. Therefore, a routing protocol with a execution structure is needed to manage the partial path and recalculate when needed.*

Keywords: *Computer Science & Engineering, Automation and Mechatronics*

1. Introduction

Current research in Industry 4.0, Cyber-Physical Systems or Internet of Things focus on decentralized decision making for adaptive components. It decreases the installation time and increases the layout flexibility of distribution centers by decentralized decision making and self adaption and organization. In contradiction the strict hierarchical order of control, which dominates the control paradigm, each component interaction has to be implemented individual based on close components, due to the heterogeneous nature of the structure of working groups (WG). Specially in high complex distribution centers each WG (consists of continuous conveyors, turntable).

Distribution centers (DC) distingue themselves from warehouses or other building by their focus on redistribution of goods to another entity in the supply chain. Automatized DCs are specialized in automated and human free transportation by mainly continuous conveyors for bidirectional transportation and turntable for sorting and distribution inside the transportation system. The automatism is realized by programmable logic controller (PLC) they are capable in controlling and parameterizing the motor based on sensor data and commands form a higher entity, e.g. material flow control system.

The high complexity in automatized DCs result in the amount of components used for transportation and the dynamic in transportation. Goods in such DCs can be transported by several hundred continuous conveyors and turntable which have to be coordinated to ensure a feasible routing. Each component has to be implemented manually by using reusable function blocks [1] in one of the standard logics defined in [2, 3]. The interaction between components in one WG and between the WGs has to be implemented specific, which relies on the layout defined during the project phase. Therefore, current research focuses on adaptability of transportation units to reduce the implementation effort. Several approaches exist, like model based development by generating executable code out of reusable models, self recognizable units, which are capable of recognizing the type adapt their code to ensure a proper communication and coordination.

Dynamic transportation is an important factor in automatized DCs. It describes the behavior and interaction between transported goods. In high complex and automatized DCs like e.g. air cargo terminals the goods arrival time is bounded to the arrival time of the cargo aircraft. The aircraft arrival time is dependent on environmental conditions like weather. This results in short time shifts in arrival time of goods in the DC. Specially in high complex systems, where a good will be transported for a higher period of time the forecast in route determination becomes inaccurate and results in a lower overall throughput.

In routing several key factors become important. The local cost at one transportation unit, the decision making algorithm for route finding and the selection of found routes. Routing algorithm in material flow systems are in practice conservative, compared to network routing, using a rule based routing. But due to the complexity in size and unpredictable arrival times of goods an online algorithm is needed reacting on changes during runtime. Such changes like late arrival of goods, congestion and possible deadlocks.

2. Background

This provides an insight in current automatized systems. First it introduces current software and hardware architectures. Afterwards a detailed few in local control of hardware is given.

2.1. Architecture of automation system

Adaptive Systems key feature is their flexibility and scalability in designing and installation. The system is split in small subsystems capable in neighborhood recognition, reconfiguration and self organization to fulfill a global task to overcome the complexity and dynamicity of modern software systems [4]. An adaptive system consists of two layers the managed system dealing with the domain functionalities and the managing system to archive qualitative objectives [5].

The amount of software has doubled in one decade from 20% to 40%. [6] concludes that the main task of automation supplier and developers will be software engineering.

Fig. 1 shows current used factory floor automation systems split in three layers. The upper layer with the engineering station is for remote control of the system. Automatized systems use also a material flow system for controlling the goods and route finding in the system during runtime. The middle level is the programmable logic control (PLC) for controlling actuators (e.g. motors on conveyor belt) based on read sensor data and data given by the material flow system. It communicates directly with the lower level by sending analog or digitalData to parameterize the actuators

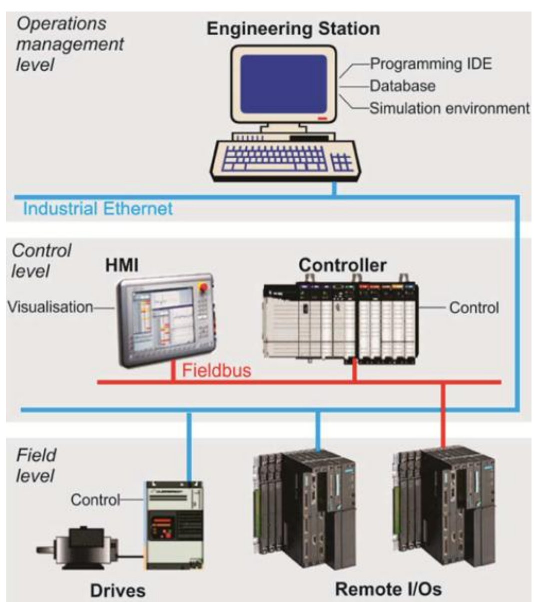

Fig. 1: Typical hardware architecture of factory floor automation systems [6].

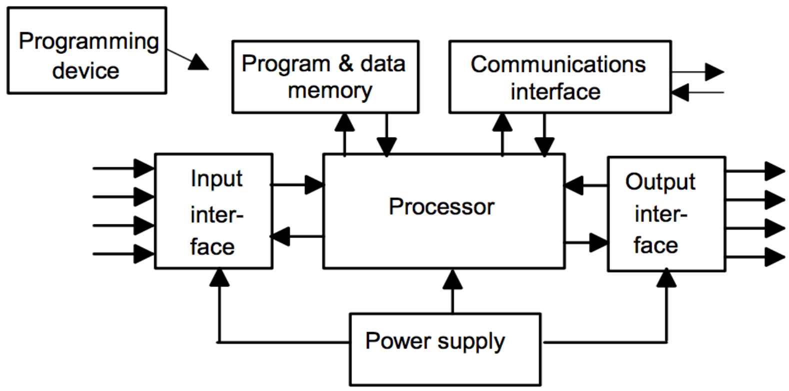

Fig. 2: A PLC system [7].

Fig. 2 shows a regular PLC system used in practice. It is sequential operating by taking a snapshot of all attached inputs (e.g. sensors) at the Input Interface. The processor will execute the program operating on the input interface and write the output data to the Output Interface. The last step in the sequence is the sending of the data at the Output Interface to all attached drives. This sequentially operation limits the programming power to ensure determinism and security. Current research is focus on moving the function oriented programming to an event based programming [8].

Besides the local control of motor to transform electric energy in kinematic energy the local PLC has to communication with his neighborhood in adaptive systems. The goal is to find in a decentralized manner a feasible routing and ensure the system consistency. A feasible route is a route from the source to the target independent of costs. The system consistency is crucial to ensure a continuous flow of goods. The consistency is violated by a deadlock between two goods. For example, on one bidirectional conveyor belt on each side two goods are waiting for transportation in the inverse direction. Therefore, the control structure has to provide a local representation of the current state of goods for a specific period of time. The communication in automatized industrial networks differs from commercial communication. The most essential difference is that industrial networks control and monitor real-world actions and conditions. Therefore, a high need quality of service is needed [9].

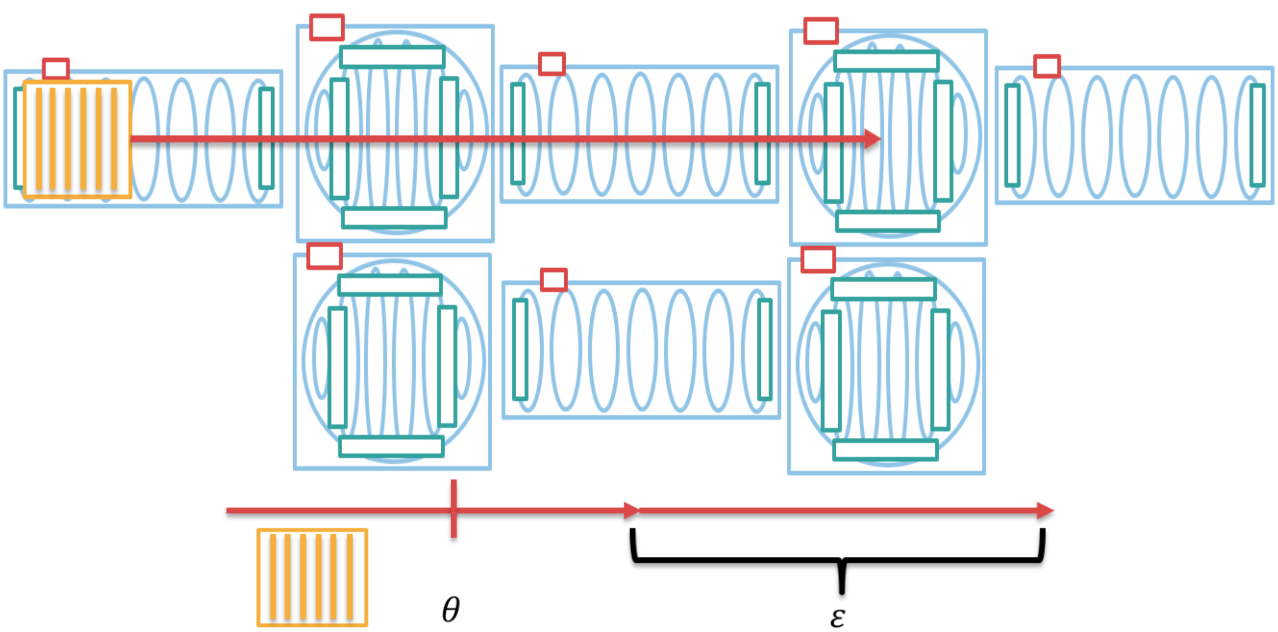

Fig. 3: Partial path for good with threshold for recalculation.

The third needed module, besides local control and communication, is the organization (called routing). The routing itself is done by an opportunistic routing with forecast to determine partial graphs during runtime. After a specific threshold is reached the current path will be extended by a defined maximum path length.

Fig. 3 shows an example of a conveyor system with four decentralized controlled continuous conveyors and four turntables to distribute the good in the system over several possible paths. The routing algorithm calculates at the arrival of one good a path with the particular length with at least ε. Turntables are considered only in path length because of their distributional nature. Each good will stop in front of one turntable which allows more freedom in distribution when inverse flows (flows of containers in opposite direction) occur. If threshold θ has been triggered (arrival of the good at a turntable) a new path with length of ε will be calculated from the last turntable at the path and added to the current path of the good. Already assigned path do not consider further system changes. Therefore, a high ε is more comparable to a static routing and a low ε result in short path and high calculation power.

3. Method

This section describes the general protocol structure used in the test environment for finding partial paths between the source and the target. It determines the current state of a subsystem, evaluates and select the most expecting path with lowest overall cost.

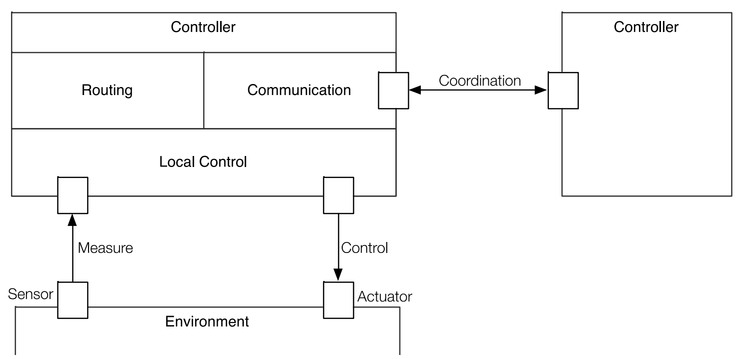

Fig. 4: Module structure of the protocol used in PLC

Fig. 4 shows the structure of the modules in the protocol implemented and executed by an PLC and the interfaces to the environment and to other PLCs.

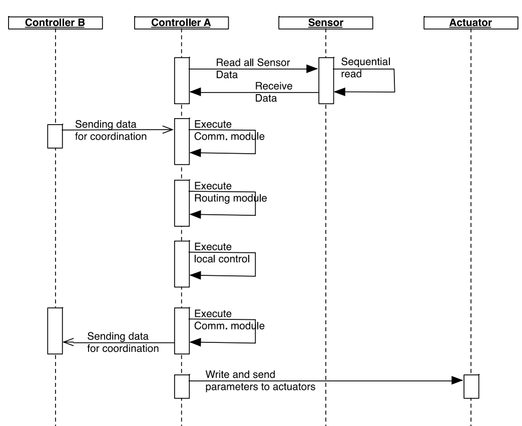

Fig. 5: Activity between the modules, the environment and other PLCs.

Fig. 5 shows the four intractable elements from one PLC. In the first step all sensor will be read and stored in the local memory of the PLC. Each sensor will be read sequential and mapped to the Input Interface of the PLC. Afterwards the communication module reads the input buffer of the TCP interface to other PLCs. Following messages are able to arrive:

- Cost_Determination – to compute the cost for one specific good for future transportation. If there exists no path to the target, the message will be dropped.
- Message_Forward – forwards the message to the target PLC stored in the internal transmission path.
- Find_Route – Adds the current executed PLC to the path and duplicates the message and send it to all neighbors except the source. If the current PLC is already in the looked up path the message will be dropped to ensure a loop free routing. If ε as path length is reached, the message will be passed back to the source.
- Next_Route – will be called when the threshold θ will be reached. The PLC at the end of the path receives the message: Calc_Route.
- Calc_Route – forces the PLC to determine the candidate set of feasible paths to the target, select one path out of the set based on a metric evaluating the current subsystem.
- Reservate_Route – After a partial path has been selected, all PLCs on the path will reserve a determined timeslot on the transportation unit.

The routing module executes one function in each execution step of the PLC. The executed function will be determined based on the inputs from the communication module.

Next step is the execution of the local control. This module operates independed on the communication and routing algorithm to ensure a robust operation (e.g. emergency stop). Local control receives the execution information for one good from the schedule with the reserved timeslots. The timeslot stores following information:

- GoodID – Unique ID to identify the good in the system.
- ArrivalTime – the expected arrival time of the good at one transportation unit.
- Duration – the expected duration to transport the good over the unit.
- TargetInterface – the direction where the good will be transport.

Afterwards the communication module will be called again for message sending to other PLC with the computed data. The last step is writing the output data to the actuators computed by the local control.

4. Conclusion and Further Work

The introduced protocol has been used in a transportation system with the opportunistic routing algorithm. It consists of 910 continuous conveyors and 550 turntables. It was able to show that a decentralized control structure was able to find feasible routing paths with dynamic behavior. It was able to reach a higher throughput than a conservative rule based routing algorithm based on decision making on turntables. A third routing algorithm has been tested, which looks for a routing path between the source and the target before transporting. It became apparent that this algorithm could not overcome the dynamic behavior of the goods during runtime. The result was that the goods missed their arrival time at the turntables and the system consistency could not be ensured .

Further work focus on the dynamic optimization of the determining of the partial paths by evaluating the transportation units also instead the goods only. Specially the optimization of bidirectional transportation of bulk transport of series has not been considered too.

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