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Optimization of an embedded and distributed information and CAN-based communication system for a container terminal

The Institute of Control and Automation of the Technical University of Braunschweig develops a high efficiency container terminal for the entraining and entrucking of containers from train to truck and vice versa. In this container terminal a distributed information system consisting of some processors, sensors, actuators, communication systems (represented by CAN) and memories is embedded. By influencing the distribution of the tasks to the information ressources the specified hard real-time constraints have to be fullfilled. The new computation approach of balance equations for the integrated information system leads to the selection of a optimal task distribution strategy.

Using simulation models of the container terminal, the field bus system CAN and the information system computer experiments are performed, analyzing the real-time behavior of CAN.

1 Introduction

Modern automation systems influence material and energy flows with the help of embedded and distributed information systems. Only the integrated consideration of the three flows with all their interactions guarantees the computation of precise results regarding the behavior of the whole automation system.

The distributed information system itself consists of the three types of components *processors*, *communication systems* and *memories* which influence the temporal behavior. Therefore the strategy for the distribution of the tasks to the information ressources has to consider all three types of ressources at any time.

The embedded information system of the examinated container terminal consists of the field bus CAN representing the communication ressources, of static RAM representing the memories and of RISC processors. Using new balance equations for the whole information system a task distribution strategy can be choosen considering the time constraints of the automation system.

Simulation experiments of the container terminal including the simulation models of the information ressources are used to analyse the real-time behavior of the automation system and of the information system. Especially the real-time behavior of CAN with its stochstic access protocol CSMA/CA can be investigated [Wag96].

2 Description of the container terminal

The high-efficiency container terminal developed at the Institute of Control and Automation of the Technical University of Braunschweig at a scale of 1:42 for demonstration and scientific purposes consists of several cranes, two roller-conveying installations and two storage places as shown in figure 1 [Wen96].

The container terminal allows the entraining and entrucking between a train at slow speed and a standing truck including the moving roller-conveying installations and the storage places. Using an appropriate entraining and entrucking strategy the temporal behavior of the container terminal can be influenced taking the hard real-time constraints into consideration.

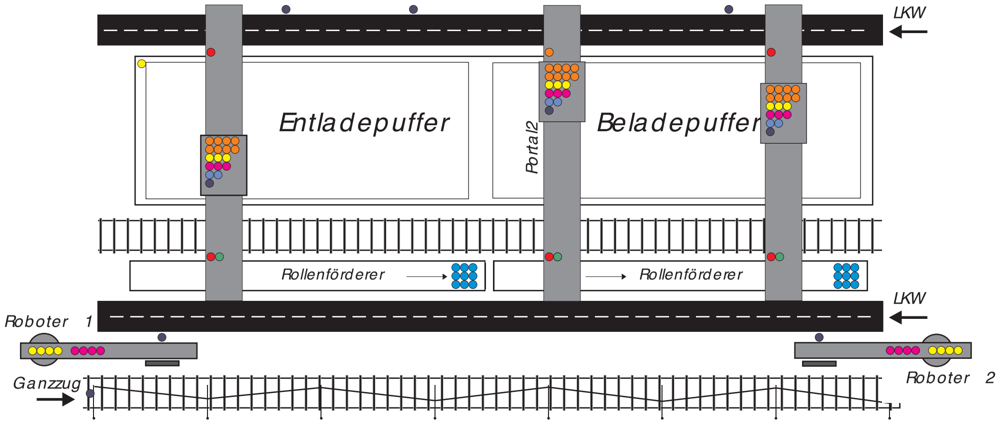

Figure 1: Model of the container terminal

Figure 2 [Kie95] shows the causal dependencies of the components of the container terminal using the Petri net notification.

The four modules *controlling device*, *cran carriage*, *gantry crane* and *spreader* have to be distinguished. This four modules demand an information system for the computation, storage and transmission of datas between the modules. Like for the automation system hard real-time constraints have to be fullfilled regarding the information system.

The container terminal includes an error-finding system for the checking of the position adherence. Depending on the occurence of an error different logical paths are followed by the automation system including different demands to the information system.

3 Description of the embedded and distributed information system

All components of the container terminal require information ressources for the computation, storage and transmission of datas between the different parts of the system. The sensors and actuators of the terminal must communicate with the control, diagnose and visualisation system, the datas transmitted by the sensors have to be stored in the control system for further computation and controlling algorithms have to be evaluated in real-time. Figure 3 [Wen96] describes the requirements to the information ressources of the container terminal.

The sensors of the spreader, cran carriage and gantry crane work on a deterministic basis sendig datas to the control system periodically. The frequencies and length of the data telegramms are described in figure 3. These telegramms have to be transmitted by the field bus system CAN to the memory of the control unit where they are stored. Using a parallel bus system the stored datas are transmitted to the processors of the control system where computation algorithms are evaluated, which depend on the information encoded in the telegramms. The computation times in ms are given in figure 3. These times are relative to a RISC processor with 16 $MIPS$. The task distribution to the information ressources has to take the real-time constraints into consideration which are given in table 1 [Nau94], [Rei93].

Nr.	Trigger	Time constraint
1	Control of cran carriage	19 ms
2	Control of gantry cran	19 ms
3	Cran carriage position	48 ms
4	Gantry cran position	48 ms
5	Cran carriage supervision	50 ms
6	Gantry cran supervision	50 ms

Table 1: Time constraints

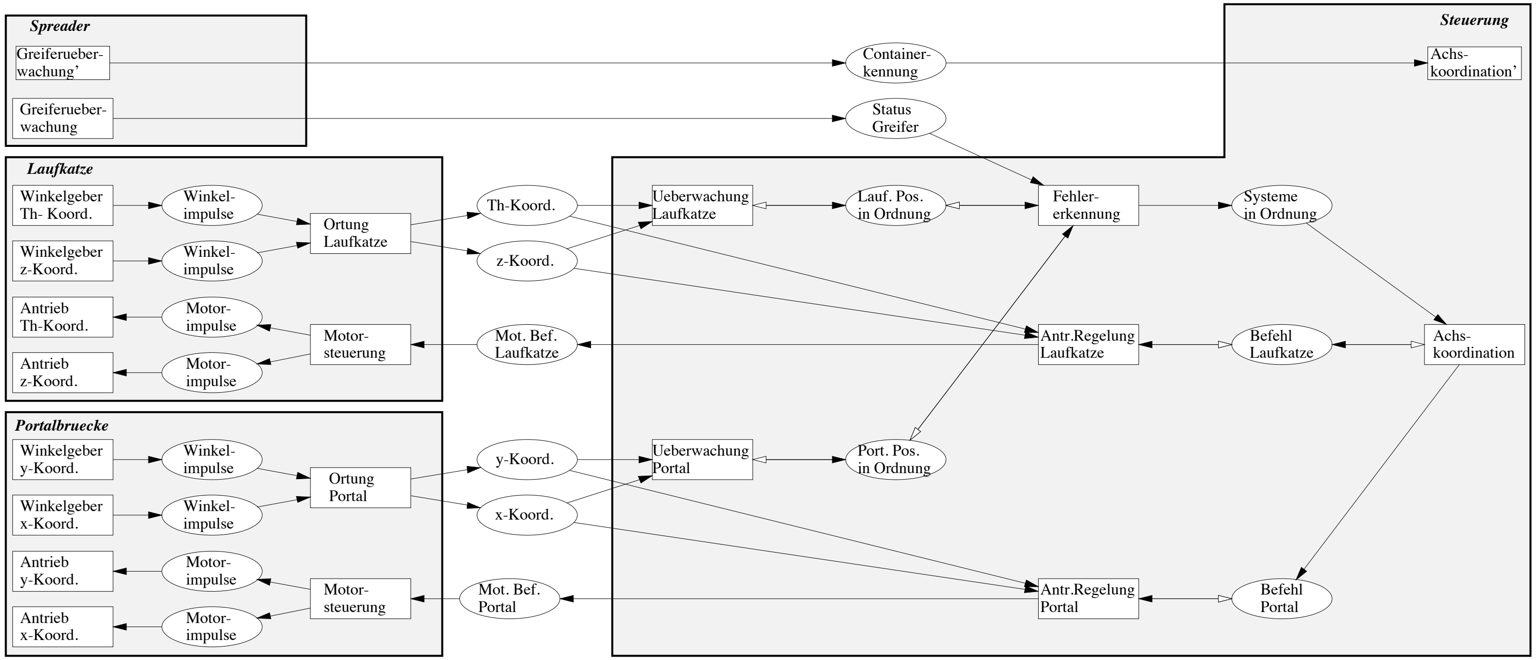

Figure 2: Petri net representation of the container terminal

Figure 3: Requirements to the information ressources

After the logical partitioning shown in figure 2 the 8 open transmission paths require communication ressources in form of a field bus system. The transmission of datas between the 8 participants is realized by the field bus system CAN.

4 Balance equations

Every (distributed) information system can be divided into the three components *processor*, *communication system* and *memory*. The processor is responsible for changes (induced by the algorithm) of the causal states of information; the processor is the *causal* part of the information system. The communication system does not change the causal states of information but only displaces information from one spatial point to another; communication systems build therefore the *spatial* part of the system. Finally the memory also does not change causal states but displaces information in time; memory builds the *temporal* part of the information system.

In the physical world the behavior of matter and energy is described in space and time by the conservation law:

$$\frac{dQ}{dt} + I = \text{const.}. \tag{1}$$

$\frac{dQ}{dt}$ describes the temporal change of the substance at a point in space, I describes the substance current at a point in time. For automation and information systems a generalized conservation law can be formulated in a generalized spacetime:

$$\frac{dQ}{dt} + I + \sum_{i=1}^{n} \frac{\langle \varphi_i | M | \psi_i \rangle}{dt} = \text{const.} \tag{2}$$

The first two components of the equation are identical with the physical equation. The third component represents the number of causal operations executed by the processor per time unit dt. For this causal component a fifth axis was added to four dimensional spacetime, the causal axis. For the derivation of generalized spacetime and the generalized conservation law see [Mir97a] [Mir97b].

In a distributed information system this equation can be interpreted as follows: $\frac{dQ}{dt}$ represents the number dQ of bits which leave or enter the memory per time unit dt. The second term, I, represents the number of bits circulating through the communication system per time unit. The third component finally describes the number $\sum_{i=1}^{n} \langle \varphi_i | M | \psi_i \rangle$ of causal operations executed by the processor per time unit dt. $\sum_{i=1}^{n} \langle \varphi_i | M | \psi_i \rangle$ is obtained analysing the computation algorithm executed by the processor [Mir97a].

Applying the conservation law for each partition of the information system a system of balance equations is obtained representing the actual occupation degree of the ressources. Analyzing the actual load the task scheduler distributes the tasks with respect to the hard real-time constraints.

5 Simulation experiments

For minimizing the number of information ressources a central control unit was developed for the container terminal. The information telegramms from the sensors are analyzed by the control unit and data telegramms are transmitted to the actuators. For the communication between the control unit, sensors and actuators the field bus system CAN is used.

The evaluation of the generalized conservation law for the information system of the container terminal represented in figure 3 is showed in table 2. All numerical values are specificated in *operations per second*.

The numerical values of table 2 are calculated as follows: begining with the generalized conservation law

$$\frac{dQ}{dt} + I + \sum_{i=1}^{n} \frac{\langle \varphi_i | M | \psi_i \rangle}{dt} = \text{const.} \tag{3}$$

every of the three components (temporal, spatial, causal) is computed for every of the six data paths of the container terminal. The six data paths are: the path of *container recognition*, of *status of crane*, of ϑ*-coordinate*, of z*-coordinate*, of y*-coordinate* and of x*-coordinate*, see figure 3.

The application of the generalized conservation law to the path of *container recognition* leads to: a frequency of 200 Hz is equal to a period length of 5 ms. Therefore every 5 ms 1024 bit have to be transmitted from the sensors via CAN to the control unit where they are stored and computed. A processing time of 1 ms means that 16000 operations have to be evaluated (with processors defined in [Rei93]). With a repetition rate of 5 ms the communication system transmits 1024 bit, the memory stores 1024 bit and the processor evaluates 16000 operations.

The temporal part (storage) of the generalized conservation law is:

$$\frac{dQ}{dt} = \frac{1024}{5} \frac{bit}{ms} = 2 \cdot 10^5 \frac{Operations}{s}. \tag{4}$$

The spatial part (communication) is then:

$$I = \frac{1024}{5} \frac{bit}{ms} = 2 \cdot 10^5 \frac{Operations}{s}. \tag{5}$$

Component	Ressource	without Error	with Error
Container recognition	Processing:	$3,2 \cdot 10^6$	-
	Communication:	$2 \cdot 10^5$	-
	Memory:	$2 \cdot 10^5$	-
	Σ:	$3,6 \cdot 10^6$	-
Status of crane	Processing:	$1,6 \cdot 10^7$	$5,9 \cdot 10^7$
	Communication:	$1,3 \cdot 10^4$	$1,3 \cdot 10^4$
	Memory:	$1,3 \cdot 10^4$	$1,3 \cdot 10^4$
	Σ:	$1,6 \cdot 10^7$	$3,8 \cdot 10^7$
ϑ-Coordinate	Processing:	$3,2 \cdot 10^6$	$7,1 \cdot 10^6$
	Communication:	2133	2133
	Memory:	2133	2133
	Σ:	$3,2 \cdot 10^6$	$7,1 \cdot 10^6$
z-Coordinate	Processing:	$3,2 \cdot 10^6$	$7,1 \cdot 10^6$
	Communication:	2133	2133
	Memory:	2133	2133
	Σ:	$3,2 \cdot 10^6$	$7,1 \cdot 10^6$
y-Coordinate	Processing:	$3,2 \cdot 10^6$	$6,9 \cdot 10^6$
	Communication:	2133	2133
	Memory:	2133	2133
	Σ:	$3,2 \cdot 10^6$	$6,9 \cdot 10^6$
x-Coordinate	Processing:	$3,2 \cdot 10^6$	$6,9 \cdot 10^6$
	Communication:	2133	2133
	Memory:	2133	2133
	Σ:	$3,2 \cdot 10^6$	$6,9 \cdot 10^6$

Table 2: Application of the balance equations

The temporal and spatial parts of the conservation law are for this special application identical because all information which is transmitted from the sensors to the control unit has to be stored automatically. Therefore $\frac{dQ}{dt} = I$.

The causal part (processing) of the conservation law is:

$$\sum_{i=1}^{n} \frac{\langle \varphi_i | M | \psi_i \rangle}{dt} = \frac{16000}{5} \frac{Operations}{ms} = 3,2 \cdot 10^6 \frac{Operations}{s}. \tag{6}$$

The numerical values of the other data paths can be obtained analogous. Table 3 shows the performance of the information ressources of the container terminal [Wen96]. All numerical values are specificated in *operations per second*.

Ressource	Performance
Processing	$5 \cdot 10^7$
Communication	$3 \cdot 10^5$
Memory	$9,4 \cdot 10^7$

Table 3: Performance of the information ressources

A comparison of the demands of table 2 with the numerical values of table 3 shows that the component *status of crane* claims (without the occurence of errors, see figure 3) half of the performance of one processing ressource. If an error would even occur permanently then the computation of the tasks could not be realized with one processor. The performance of the processors described in table 3 is so small that a new task would occur before the evaluation of the first task would be finished. The waiting time for new tasks would then grow rapidly.

Respecting the demands of table 2 and the performance of table 3 one processor is allocated only for the component *status of crane*. A second processor is allocated then for the other five components of the container terminal.

The analysis of the component *container recognition* (figure 3) leads to the result that the communication demands of this component claim $\frac{2}{3}$ of the performance of one communication ressource. The sum of all communication demands of the components of the terminal is greater than the communication performance of one CAN field bus system. A solution can be obtained by allocation of one bus system to the component *container recognition* and one bus system to the other five components.

The investigation of the memory performance with respect to the demands of table 2 yields to the result that one memory can satisfy all time constraints of the container terminal. The use of only one memory ressource would have the disadvantage of additionary waiting time caused by blockings and of additionary communication ressources (parallel bus system) for the communication between processors and memories. The division of the memory into two smaller ressources with equivalent performance avoids this disadvantages letting the costs unchanged.

The result of the analysis of the balance equations is that the application of two 16 MIPS RISC processors, of two CAN field bus systems and of two SRAM memories with properties specified in table 3 respects the temporal demands of the container terminal.

The simulation experiment of this distributed information system confirms the reflections of the previous sections, see figure 4 [Hüc97].

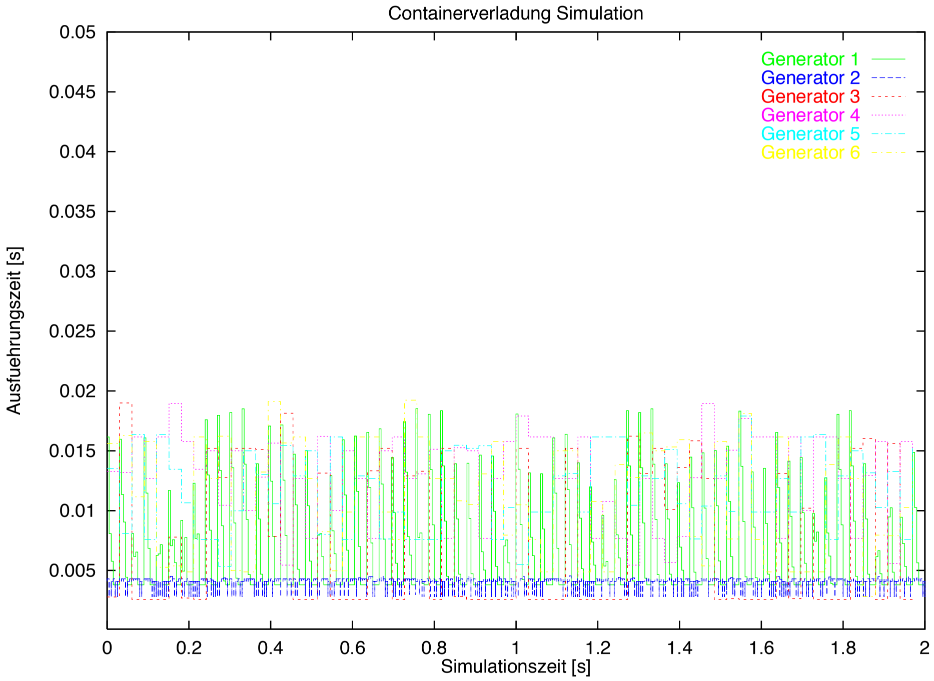

Figure 4: Simulation experiment of the container terminal

Here the transit time measured in seconds is plotted over the simulation time measured in seconds for the six data paths of the container terminal. The figure shows that all time constraints demanded in table 1 are respected. Even with an error probability of 10 % in the container terminal the performance of the ressources is high enough to respect the time demands.

6 Conclusions

Matter, energy and information are the substances of the world of automation engineering. For a correct and precise description of automation systems all substances and their interactions have to be considered at any time. Defining the five dimensional generalized spacetime the behavior of all substances can be modelled by a generalized conservation law including temporal, spatial and causal behavior.

The application of the generalized conservation law to technical ressources leads to numerical values describing the actual load of the regarded ressource. In this paper a container terminal with an embedded information system is analyzed using the generalized conservation law for the estimation of the information ressources and for partitioning the tasks to the ressources. Especially the field bus system CAN with its stochastic access protocol is applicated to a system with hard real-time constraints. The calculations are validated by simulation experiments showing that hard real-time constraints can be respected using CAN.

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