Development of a Case-Based Reasoning expert system for the disturbance management in automated guided vehicle systems

Entwicklung eines fallbasierten Expertensystems für das Störungsmanagement in Fahrerlosen Transportsystemen

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Automated guided vehicle systems (AGVS) are an essential part of modern intralogistics. So far, the major part of the design cycle (implementation and operation) of an AGVS demands human expertise. Especially, the manually executed management of occurring disturbances leads to high maintenance costs since it often requires the consultation of experts. Therefore, the following paper discusses the development of a Case-Based Reasoning (CBR) expert system for assisting the disturbance management in AGVS. The development is sectioned into three major parts: (1) generation of the case-base, (2) development of the algorithms for case retrieval, case adaptation and retaining new cases and (3) the validation of the expert system. The generation of the case-base and the training data for the expert system is done by simulating the real production layout of a German white good manufacturer using the simulation environment Visual Components. The solutions for the simulated disturbances as well as the adaptation algorithms are based on knowledge extracted from system experts.

Keywords: expert systems, Case-Based Reasoning, automated guided vehicle systems, disturbance management

1 INTRODUCTION

In order to satisfy the increasing need of efficiency and automation of the material flow for production environments AGVS became an essential instrument used throughout several industrial sectors [SSH17]. The resulting growth of the AGVS market leads to a constant development of the technology and a rising complexity of the systems due to more demanding technical requirements (e.g. safety, navigation) [Fah04]. The rising complexity forces manufacturers and operators to invest resources in the design cycle and disturbance management. According to the guideline VDI 2710 the design cycle of an AGVS can be separated into six phases. Figure 1 categorizes the disturbance management into the design phases to illustrate the importance. An efficient disturbance management is not only essential while planning (Detailed system design) but also while operating the system (Resources scheduling). For a detailed overview of the design phases the reader is referred to [Vdi10].
For the successful design and implementation of an AGVS planners with expert knowledge are required. Depending on the system complexity the design cycle can take several months or years. For an optimal operation an efficient disturbance management is essential to avoid long downtimes of the system. The consultation of experts can cause high costs. Also, experts can be restricted due to time constraints to find and assess all possible solutions for an occurring disturbance while most of small and medium-sized enterprises mostly do not have the needed resources [GS98]. There are however approaches supporting the design phases (figure 1) partly through expert systems which are discussed in chapter 2. An approach for the support of the disturbance management however is missing, therefore this paper proposes an CBR expert system for the assistance of the disturbance management in AGVS.

Figure 2 shows the distribution of operating times of an AGVS. The data is extracted from monitoring log files from an AGVS manufacturer which is not mentioned due to company confidentiality policies. Figure 2 represents a setup of four vehicles over the period of 5 days. Failure (1%) and Blocked (3%) (both are considered disturbances in this context) represents periods where the system is not operating correctly. Since overall downtimes caused through disturbances are often higher the importance of an efficient disturbance management is on hand.

The rest of this paper is sectioned as follows: chapter 2 discusses related work in the field of expert systems for the design phases in AGVS as well as relevant research in the field of CBR approaches. Chapter 3 discusses the structure of the proposed solution. A conclusion and an outlook on further research are given in chapter 4.

2 RELATED WORK

2.1 EXPERT SYSTEMS FOR THE DESIGN PHASES OF AN AGVS

Considering the design cycle of an AGVS the following discussion on relevant research is sectioned according to the design cycles shown in figure 1.

System decision making

CHAN discusses an approach to support the system decision making of AGVS with an expert system [Cha02]. The input for the expert system is described through a set of requirement parameters in order to find the most applicable material handling system for a given use case. An analytical hierarchy process is implemented based on a decision tree structure consisting of four major categories including performance measures, technical, economic and strategic attributes expert knowledge is formalized using conditional statements and the edges between nodes of the decision tree are weighted using a pairwise comparison of the criteria. KULAK discusses a rule-based expert system to determine a material handling system for dedicated requirements [Kul05]. KULAK develops a fuzzy-based inference system for which the rule-base is generated through extracted system expert knowledge. A validation based on technical and economic criteria is executed.

Detailed system design

An essential step for the detail system design is creating a cost-optimized roadmap for the operating vehicles. There are several research approaches to support and automate that process. REVELIOTIL develops a control architecture containing a feedback loop to determine detailed paths for each vehicle dynamically to avoid collisions and deadlocks [Rev00]. Through implementation of a structural control method, the architecture determines the most efficient options through consideration of logically admissible and physically feasible movements of the vehicle. TER et al. discuss an approach to prevent deadlocks and collisions by using a “context-aware route planning algorithm” [TWZ10]. The aim is the implementation of a mathematical route planning algorithm similar to the A* algorithm based on a single-agent approach. However, these approaches may be mathematical optimal but are often not directly applicable in a real material handling environment. In [UO15, UO16] the combinational approach of classical mathematical optimized algorithms for path planning with a fuzzy-based expert system is developed. The model uses an adapted version of the A* (Mod A*) and the Bellman-Ford (Mod Bellman-Ford) algorithm. The rule-base for the
inference machine is formulized through structured inter-
views with system experts.

**Resources Scheduling**

EIERT develops a solution to automate the job assign-
ment through a decentralized agent-based model [ESO14].
For each significant entity (e.g. stations, vehicles) a specific
agent is defined. An efficient rescheduling of jobs is per-
formed through a cost evaluation of idle vehicles. UMAR et.
al discuss an expert system implementing genetic algo-
rithms in combination with a fuzzy logic controller
[UA115]. The developed genetic algorithms generate an in-
tegrated schedule while enabling a conflict-free routing for
the AGVS. The fuzzy logic controller generates adaptive
genetic operators and performs population fitness improve-
ments.

The discussion on related work for expert systems for
the design cycle of an AGVS concludes that the support
and partial automation is achievable through the formuliza-
tion of expert knowledge in a machine processable manner.
Using fuzzy logic or decision tree structures with condi-
tional statements based on expert knowledge can support
and accelerate certain design phases on AGVS. Since the
proposed expert system in this paper is based on CBR the
following discusses relevant research in the field of CBR.

### 2.2 CASE-BASED REASONING SYSTEMS

Experts solve a given problem mostly by applying
knowledge and rules based on experience and scientific
methods. For solving an occurring disturbance for instance
technicians recall similar situations naturally in order to re-
call a similar situation to apply the learnings to the given
problem. The background of developing a CBR system is
the implication that similar disturbances have mostly simi-
lar solutions. Figure 3 shows the basic principle of the CBR
cycle according to AAMODT & PLAZA [AP94].

![CBR cycle according to [AP94]](image)

The knowledge representation is realized in the form
of cases in a database. Each case represents a problem de-
scription and its respective solution or solutions. Retrieval
algorithms based on similarity or distance measures are ap-
pied to find the most similar cases. If necessary, reuse al-
gorithms adapt retrieved solutions of the most similar cases
to solve a new problem. In order to assess the success of
adapted solutions revise algorithms are implemented.
Lastly adapted and assessed cases are retained [AP94]. Using
CBR as a method for supporting a decision-making
process is the subject of many research approaches.
RECIO et al. discuss a CBR expert system to support determining
parameters (pressure points) for back pain treatment based
on patients’ pain records [RDJ17]. Attributes such as sex,
age, height and former treatment parameters are content of
cases in the case-base. Through applying a nearest neigh-
bor algorithm most similar cases are retrieved. Based on the
retrieved cases treatment parameters are computed to fit the
present patient’s medical needs. The assessment of the ap-
llicability of the proposed parameter is done by a physi-
cian. NASIRI et al. develop a CBR system to detect various
faults in an injection moulding production process. The
system is based on a fuzzy case-based reasoning (fuzzy
CBR) approach [NK19]. For the expert system attributes
are fuzzified and similarity measures are developed accord-
ingly. The usage of fuzzy logic in the retrieval phase en-
hances the transfer of knowledge across domains. The
knowledge of domain experts is formulized through fuzzy
weights which represent relationships between quality con-
trol, parts, mould and process parameters. Expert
knowledge is also represented in triangular fuzzy numbers
that are utilized to represent relationships between values
of each feature and related parameters. Results prove capa-
bility and accuracy of the proposed solution for an efficient
fault classification. MASSIE et al. introduces a system to de-
crease health risks of residents in a smart home environ-
ment by detecting falls [MFC18]. A sensor network in-
stalled in the Smart Home identifies low level events such
as cooking, eating, cleaning etc. to generate a resident’s
daily activity profile. These profiles are used as query cases
for a CBR system. The case-base contains historic param-
eters of typical and risky profiles to detect possible falls and
prevent them accordingly. OLSSON et al. develop an expert
system to determine faults in industrial robots with acoustic
signals as input parameters [OFB04].

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The database contains cases described by acoustic signal profiles formulated as feature vectors consisting of signal amplitudes and the corresponding frequencies. In order to prevent unwanted features a weight vector with the same dimensions is defined for each case. The distance between query cases and cases from the case-base is measured by applying the Euclidian distance. CBR based expert systems have proven to be a useful method for recommender systems and fault detection in different application fields such as medical or industrial environments. Approaches for automating certain design phases of an AGVS as well as relevant research of CBR systems are discussed. The approaches discussed in chapter 2.1 can partly be used in order to manage occurring disturbances in AGVS. However, those approaches are restricted to a small amount of possible disturbances and solution space. With routing algorithms, for instance only those disturbances can be cleared that cause a possible blocked route. Rescheduling has similar boundaries in terms of general applicability to an automated and efficient disturbance management. An evaluation of multiple solutions for occurring disturbances is missing and the interactions of disturbances and their respective solutions are not considered either.

3 STRUCTURE OF PROPOSED SOLUTION

Based on inputs from AGVS manufacturers and operators the disturbance management for AGVS is a highly manual process. Maintenance documents and standard work flows are used in order to find a solution for occurring disturbances.
Figure 4 shows a typical work flow a technician goes through to clear an occurring disturbance. The example is developed based on inputs from AGVS technicians and illustrates the scenario of a blocked sensor in the front left of the vehicle. Depending on the complexity of the system, knowledge and experience of the technician and type of disturbance, this process can cause high cost not only due to the expert consultation but also indirectly through long downtimes of the system. Due to the given time constraints and naturally limited experience of humans it is almost impossible to manually assess all possible solutions for a given disturbance. Figure 4 demonstrates the multidimensional structure of possible disturbance sources.

Figure 4. Disturbance sources of Automated Guided Vehicle Systems (AGVS)

Each disturbance class has multiple sub-classes which have multiple solutions. With rising complexity, the quantity of sub-classes increases naturally. Through literature review, system planner inputs and maintenance manuals the classification of disturbance sources was realized. According to the general structure of the CBR method a case-base needs to be generated with a defined case structure. Each manufacturer has their own structure of failure protocols logging different information, therefore a standardized case structure (table 1) is developed with inputs from AGVS system planners.

Table 1. Case structure of the case-base

<table>
<thead>
<tr>
<th>Attribute</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>vehicle_id</td>
<td></td>
</tr>
<tr>
<td>Timestamp</td>
<td></td>
</tr>
<tr>
<td>in.angle</td>
<td></td>
</tr>
<tr>
<td>x_coordinate</td>
<td></td>
</tr>
<tr>
<td>y_coordinate</td>
<td></td>
</tr>
<tr>
<td>battery level</td>
<td></td>
</tr>
<tr>
<td>size.x</td>
<td></td>
</tr>
<tr>
<td>size.y</td>
<td></td>
</tr>
</tbody>
</table>

In order to generate a case-base the real production environment of a German white good manufacturer is simulated using Visual Components (figure 6).

Figure 5. Overview of disturbance sources of AGVS

Case-base

Sources | Sinks / Buffers | #AGV | #Pallets per day
---|-----------------|------|-------------------
3 | 8 | 7 | 677

Figure 6. Reference scenario
The guidance control system is simulated using the task control function in order to execute transport orders based on a provided transport matrix and using the pathfinder function to assign the nearest vehicle for a certain job. Log files are created using the logger function. Simulated disturbances are examined and evaluated by system experts.

**Retrieval**

Figure 7 shows the flow diagram for the retrieval algorithm. To find the most similar cases to an occurring disturbance (query case) the distance for each case in the case-base is calculated through the weighted Euclidian distance:

\[
D_E(u, v) = \sqrt{\sum_{a=1}^{m} w_a \cdot |u_a - v_a|^2}
\]

where \(u\) and \(v\) are two cases and \(u_a\) and \(v_a\) respective attributes of the same case weighted by \(w_a\). The minimum threshold for the calculated distance can be adjusted to narrow down the results. Since the case structure consists of attributes with different value intervals a normalization of each attribute based on the minimum and maximum value is executed:

\[
D_E(u, v) = \sqrt{\sum_{a=1}^{m} w_a \cdot \frac{|u_a - v_a|}{a_{max} - a_{min}}^2}
\]

where \(a_{max}\) and \(a_{min}\) state local maxima and minima.

**Reuse and Revise**

The algorithm for the reuse stage of the CBR expert system in this paper proposes an adaptation through clustering based on the disturbance classes introduced in figure 5. The expert knowledge is formulized through initial classification of historic cases to the classes and subclasses shown in figure 5. This effort is required in order to calculate a weighting matrix for each class. Figure 8 shows the

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**Figure 7. Flow diagram of the retrieval algorithm**
Figure 8. Flow diagram for calculating the weighting matrix

Figure 9. Work flow for processing a new case

flow diagram of the algorithm for calculating the weighting matrix. Since the significance of each attribute varies depending on the disturbance class the approach shown in figure 8 is applied to determine the weighting matrix by minimizing the total deviation of each object (case) to the centroid of each class. Figure 9 shows the workflow for a new case (Query Case). By calculating the distance for the query case to all classes with the respective weighting matrix the query case is clustered. Through a verification the output is revised. Cases that have been revised are retained into the case-base. This step is considered the learning process and every new case is indexed. Since the case-base grows with each case the CBR systems accuracy increases as well.

4 CONCLUSION AND FURTHER RESEARCH

The design process of an AGVS demands many resources such as manpower, time or experience. It is a complex and multi-staged process. There are approaches to support certain design phases such as the system decision making, the generation of roadmaps or the resources scheduling by using expert systems. With an effective design of an expert system for instance by combining classical mathematical approaches with fuzzy logic it is shown that the generation of roadmaps can be accelerated significantly. Disturbance types and sources in AGVS are multidimensional due to the rising complexity of AGVS. In addition, each occurring disturbance can be solved by multiple solutions. In order to identify the best solution for a disturbance a human experts must rely on experiences. A detailed root cause investigation, an assessment of all possible solutions and the consideration of possible impacts to the overall system is not always possible due to resource limitations. The CBR systems goal proposed in this paper is the support of the disturbance management based on a database containing historic cases and formalized expert knowledge through weighting matrices. The reflection on related work in the field of expert systems in AGVS and CBR applications support the structure of the proposed CBR system to achieve this goal. With ongoing development of the CBR system the implementation is realized in MATLAB. Also, a parameter variation for different reference scenarios will be part of the further research. The validation of the CBR expert system is planned in test fields of manufacturers and operators of AGVS.

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**Literature**


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