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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]

Fahrerlose Transportsysteme (FTS) sind ein wesentlicher Bestandteil der modernen Intralogistik. Der Designzyklus für die Einführung von FTS sowie das Störungsmanagement sind überwiegend manuelle – von Experten durchgeführte – Prozesse. Diese manuellen Prozesse sind durch die Notwendigkeit von Expertenkonsultationen kostenaufwendig. Speziell im Bereich des Störungsmanagements können lange Ausfallzeiten hohe Kosten verursachen. In diesem Beitrag wird daher die Entwicklung eines Case-Based Reasoning (CBR) Expertensystems zur Unterstützung der Lösungsfindung für auftretende Störungen in FTS diskutiert. Die Entwicklung ist in drei wesentliche Bereiche gegliedert: (1) Generierung der Fallbasis, (2) Entwicklung der Algorithmen zur Suche ähnlicher Fälle, Adaption und Speicherung neuer Fälle und (3) Validierung des Expertensystems. Die Generierung der Fallbasis des Expertensystems, erfolgt durch die Simulation des realen Produktionslayouts eines deutschen Weißwarenherstellers, mit Hilfe der Simulationsumgebung Visual Components. Die Lösungen der simulierten Störungen sowie die Adaptionsalgorithmen basieren auf Erkenntnissen aus Experteninterviews.

[Schlüsselwörter: fallbasierte Expertensysteme, Fahrerlose Transportsysteme, automatisiertes Störungsmanagement]

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].

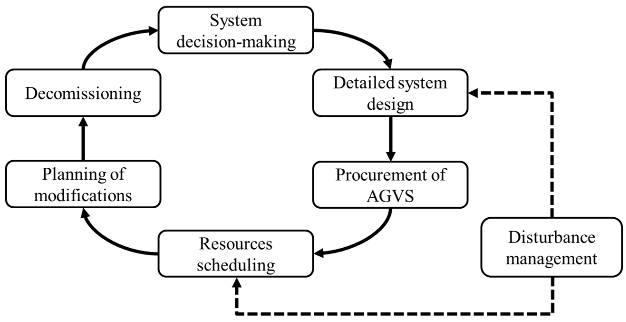

Figure 1. Overview of the design phases of an AGVS according to [Vdi10]

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.

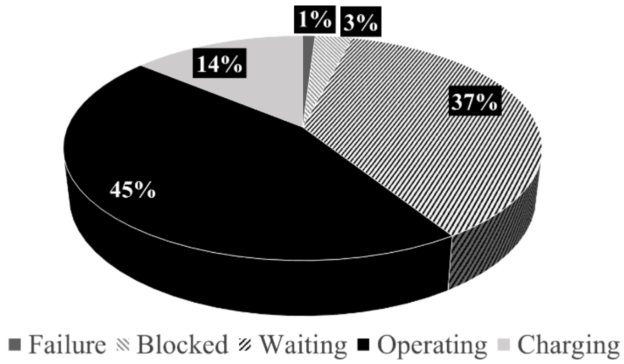

Figure 2. Distribution of operating times of an AGVS

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

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inference machine is formulized through structured interviews with system experts.

Resources Scheduling

EILERT develops a solution to automate the job assignment 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 performed through a cost evaluation of idle vehicles. UMAR et. al discuss an expert system implementing genetic algorithms in combination with a fuzzy logic controller [UAI15]. The developed genetic algorithms generate an integrated schedule while enabling a conflict-free routing for the AGVS. The fuzzy logic controller generates adaptive genetic operators and performs population fitness improvements.

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 formulization of expert knowledge in a machine processable manner. Using fuzzy logic or decision tree structures with conditional 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 recall 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 similar solutions. Figure 3 shows the basic principle of the CBR cycle according to AAMODT & PLAZA [AP94].

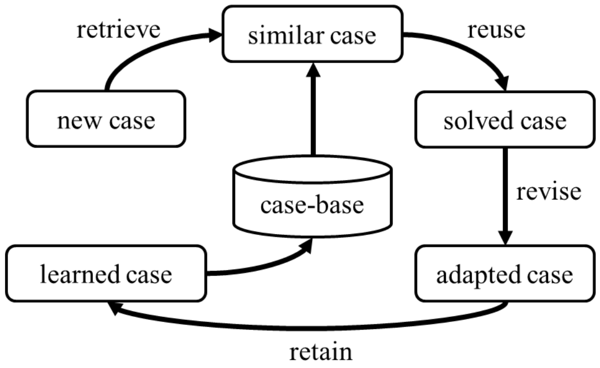

Figure 3. CBR cycle according to [AP94]

The knowledge representation is realized in the form of cases in a database. Each case represents a problem description and its respective solution or solutions. Retrieval algorithms based on similarity or distance measures are applied to find the most similar cases. If necessary, reuse algorithms 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 neighbor 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 applicability of the proposed parameter is done by a physician. 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 accordingly. The usage of fuzzy logic in the retrieval phase enhances the transfer of knowledge across domains. The knowledge of domain experts is formulized through fuzzy weights which represent relationships between quality control, 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 capability and accuracy of the proposed solution for an efficient fault classification. MASSIE et al. introduces a system to decrease health risks of residents in a smart home environment by detecting falls [MFC18]. A sensor network installed 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 parameters 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 formulized 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.

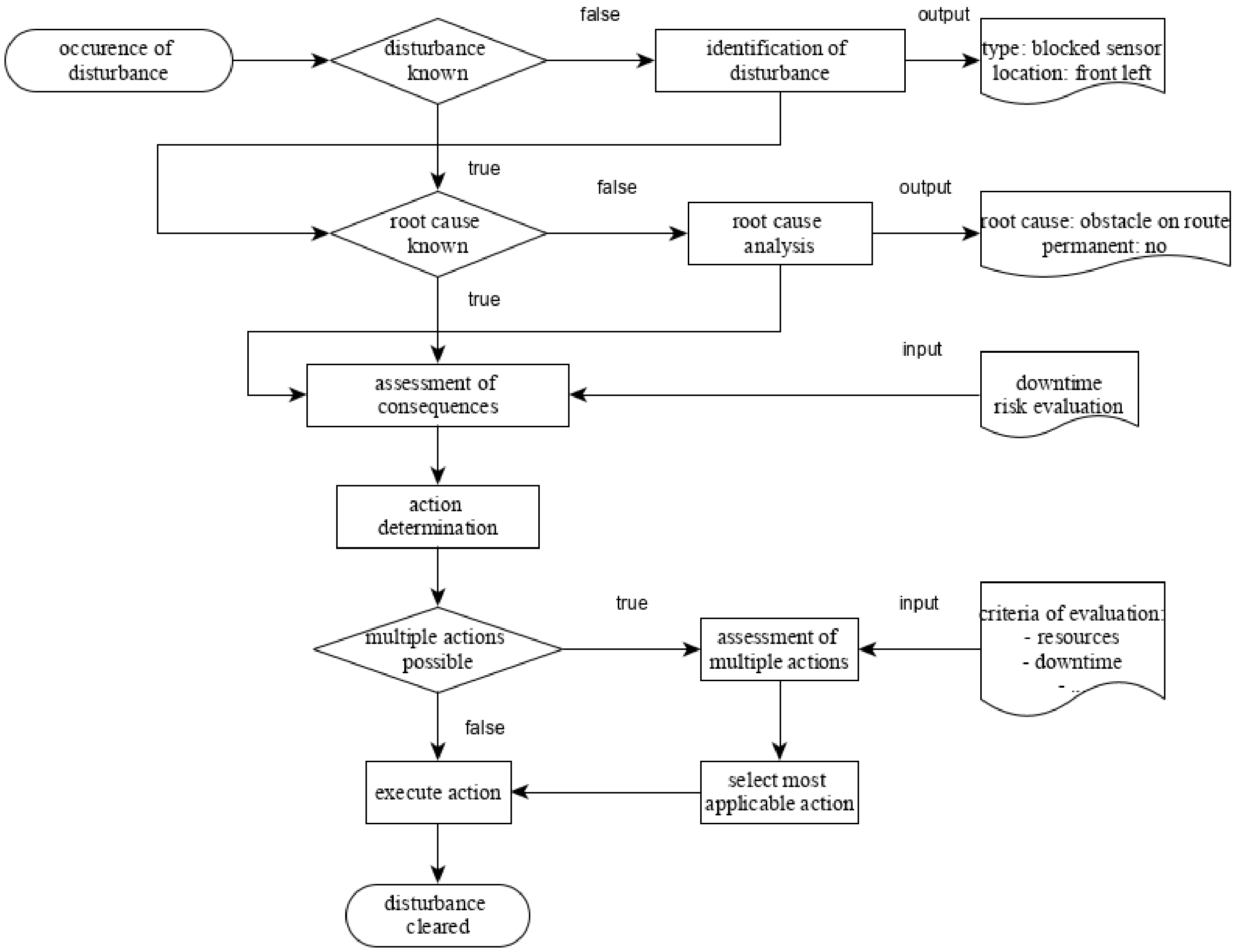

Figure 4. Typical workflow of a manual disturbance management

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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.

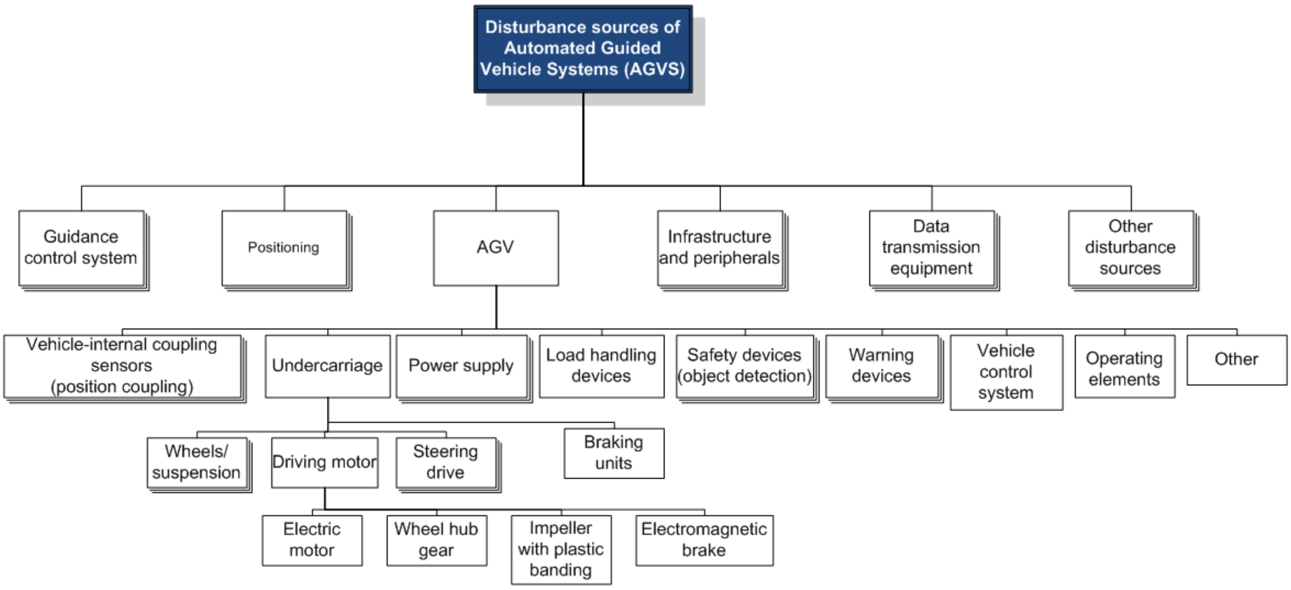

Figure 5. Overview of disturbance sources of AGVS

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

Attribute
vehicle_id
Timestamp
in.angle
x_coordinate
y_coordinate
battery level
size.x
size.y

Case-base

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

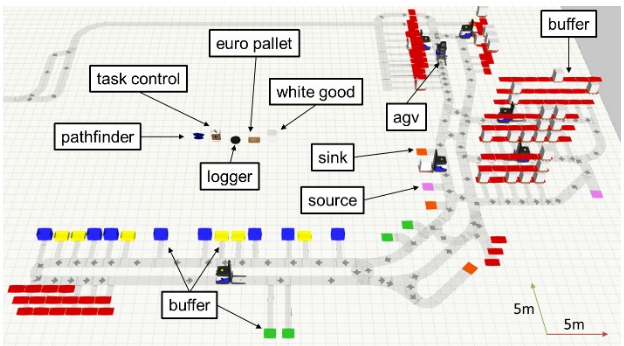

Figure 6. Reference scenario

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

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:

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

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:

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

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

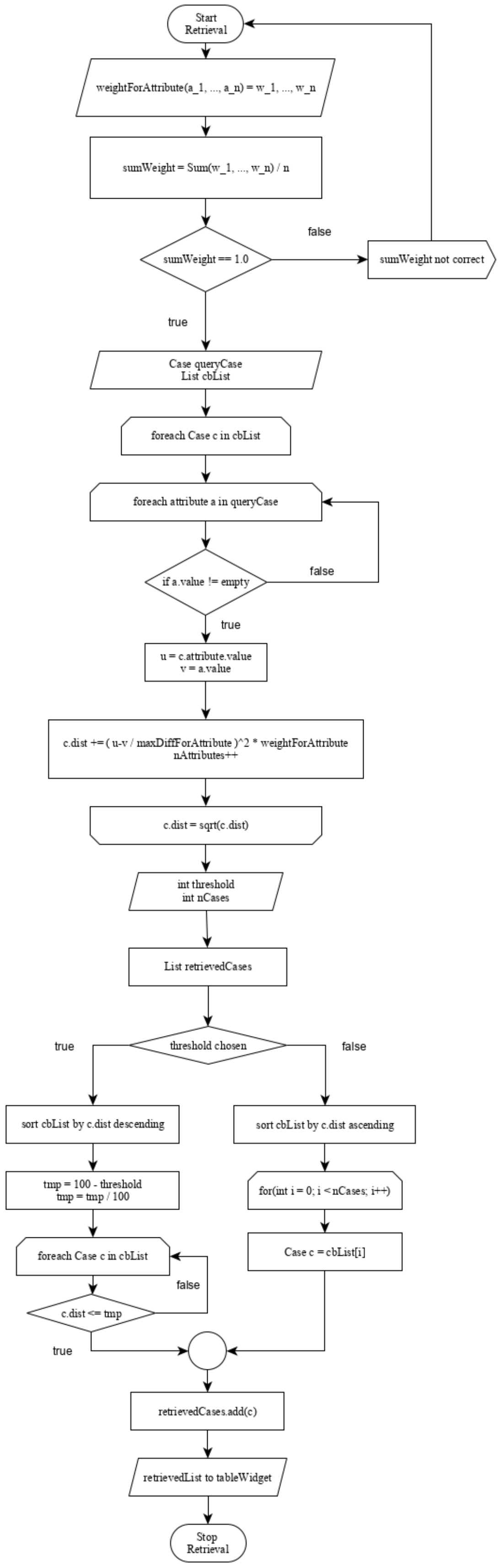

Figure 7. Flow diagram of the retrieval algorithm

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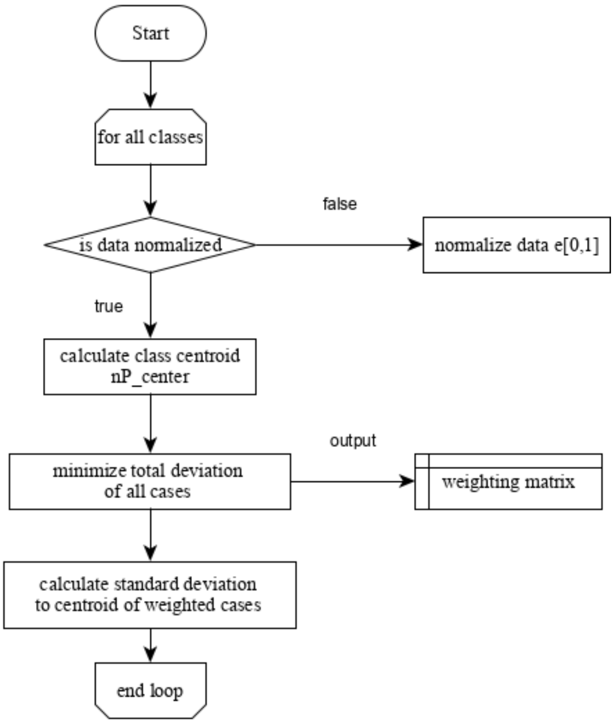

Figure 8. Flow diagram for calculating the weighting matrix

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 work flow 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

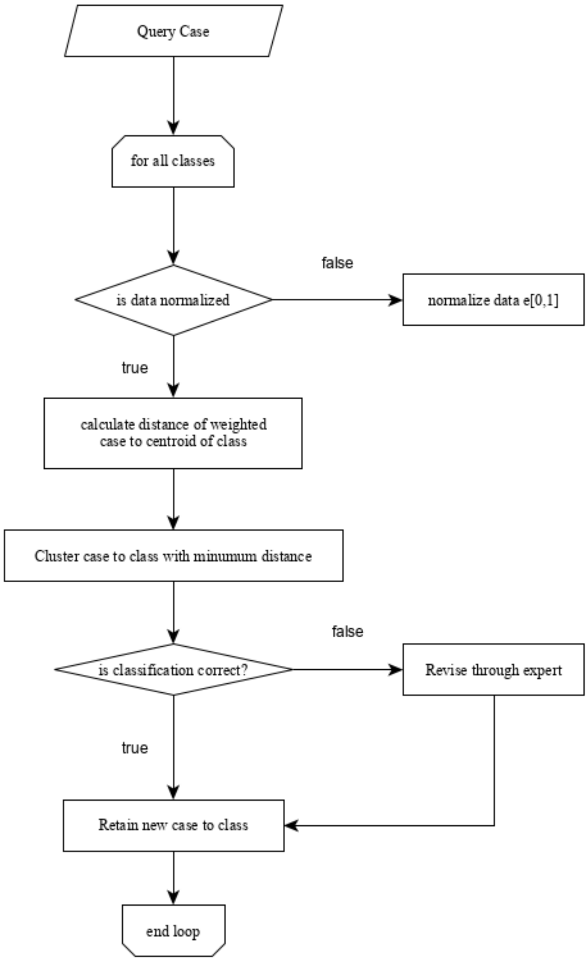

Figure 9. Work flow for processing a new case

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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