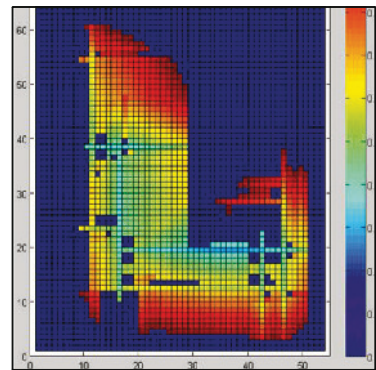
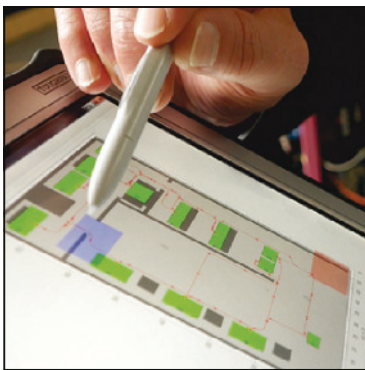


Sarah Uttendorf

Automated Generation of Roadmaps for Automated Guided Vehicle Systems





Institut für
Integrierte Produktion Hannover gGmbH

Berichte aus dem IPH

Wissenschaftliche Schriftenreihe des
Instituts für Integrierte Produktion Hannover gGmbH

Herausgeber:

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Zugleich: Dissertation,
Gottfried Wilhelm Leibniz Universität Hannover, 2018

Bibliografische Information der Deutschen Nationalbibliothek

Die Deutsche Nationalbibliothek verzeichnet diese Publikation in der Deutschen Nationalbibliografie; detaillierte bibliografische Daten sind im Internet über <http://dnb.d-nb.de> abrufbar.

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An der Universität 2 ♦ 30823 Garbsen
Tel: 0511-762-19434 ♦ Fax: 0511-762-18037
www.tewiss-verlag.de ♦ mail: info@tewiss-verlag.de

ISBN 978-3-95900-218-9
ISSN 1865-5513

Verlag: TEWISS Verlag,
Wissenschaftlicher Verlag der TEWISS – Technik und Wissen GmbH

Herstellung: Herstellung: DruckTeam Druckgesellschaft mbH, Hannover

Printed in Germany

AUTOMATED GENERATION OF ROADMAPS FOR AUTOMATED GUIDED VEHICLE SYSTEMS

Von der Fakultät für Maschinenbau
der Gottfried Wilhelm Leibniz Universität Hannover
zur Erlangung des akademischen Grades
Doktor-Ingenieurin
genehmigte Dissertation

von

M. Sc. Sarah Uttendorf

2018

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Tag der Promotion: 29.08.2018

Vorwort

Die vorliegende Arbeit entstand während meiner Tätigkeit als wissenschaftliche Mitarbeiterin am IPH- Institut für Integrierte Produktion Hannover gGmbH. Die Untersuchungen wurden im Zuge des IGF-Vorhabens (18007 N/1) „FTS- Wegenetz“ der Bundesvereinigung Logistik (BVL) e.V. über die Arbeitsgemeinschaft industrieller Forschungsvereinigungen (AiF) im Rahmen des Programms zur Förderung der Industriellen Gemeinschaftsforschung (IGF) vom Bundesministerium für Wirtschaft und Energie aufgrund eines Beschlusses des Deutschen Bundestages gefördert.

Herrn Prof. Dr.-Ing. Overmeyer, dem geschäftsführenden Gesellschafter des IPH und Leiter des Instituts für Transport- und Automatisierungstechnik der Leibniz Universität Hannover, gilt mein besonderer Dank für die vertrauensvolle und wohlwollende Unterstützung, die ich während meiner Tätigkeit am Institut erfahren habe.

Weiterhin danke ich Herrn Prof. Dr.- Ing. Nyhuis für die Durchsicht der Arbeit und die Übernahme des Ko-Referats und Herrn Prof. Dr.- Ing. Scharf für die Übernahme des Vorsitzes der Prüfungskommission.

Den Kollegen des IPH danke ich für die gute und interessante Zusammenarbeit, die mir sehr viel Freude bereitet hat und zu vielen wertvollen und anregenden Diskussionen während der Projektbearbeitung geführt hat. Besonders bedanke ich mich bei meinen Kollegen Dr.-Ing. Björn Eilert und Dr.-Ing. Sebastian Schirmacher für die kritische Durchsicht meiner Arbeit und die konstruktiven Anmerkungen.

Darüber hinaus möchte ich mich bei Herrn Dr.-Ing. Sebastian Behling von der Firma Goetting KG, Herrn Lutz Meier von der Firma MLR GmbH, Herrn Marc Wilhelm von der Continental AG und Herrn Karsten Bohlmann von E&K Automation GmbH bedanken, die mir viel Input für meine Arbeit im Projekt „FTS-Wegenetz“ geliefert haben.

Meinen Eltern bin ich sehr dankbar, dass sie mir diesen Weg ermöglicht haben und mich jederzeit unterstützt haben.

Hannover, im Februar 2018

Sarah Uttendorf

Kurzfassung

Automatisierte Auslegung der Wegenetze für Fahrerlose Transportfahrzeuge

In der vorliegenden Arbeit wird untersucht, wie menschliches Systemplanerwissen in Wegenetzalgorithmen integriert werden kann und damit menschliche Logik mit mathematischer Optimierung zu kombinieren, um als Resultat effiziente und anwendbare Wegenetze für Fahrerlose Transportsysteme (FTS) zu erzeugen. Die vorliegende Arbeit hat das Ziel, ein Expertensystem zu entwickeln, das automatisiert Wegenetze für FTS erstellt und damit die Anzahl von manuellen Planungsschritten reduziert.

Als Grundlage dient der A* Algorithmus, der in einem ersten Schritt das Hallenlayout in ein Gitter mit gleich großen Zellen unterteilt. Anschließend werden den einzelnen Zellen basierend auf einer Heuristik Zellen Kostenwerte zugewiesen. Die Kostenwerte sind abhängig von der Eignung der jeweiligen Zelle für den späteren Weg. Die Neuerung in der vorliegenden Arbeit liegt darin, dass das Expertenwissen von erfahrenen FTS-Systemplanern in Form von Regeln in einer Fuzzy Logik gespeichert wird, deren Output die vom A* Algorithmus ermittelten Kosten direkt beeinflusst. Zur Erstellung der Regelbasis wurden Treffen mit Systemplanern durchgeführt. Anschließend wurden darauf basierend Zugehörigkeitsfunktionen und Regeln für ein Fuzzy Inferenz System definiert.

Das konzipierte Expertensystem wurde mittels der Software MatLab in Form eines Softwaredemonstrators umgesetzt. Das Expertensystem wird anhand von zwei realen Referenzszenarien evaluiert. Die Modellierung der Referenzszenarien beinhaltet die detailgetreue Darstellung der Hallegegebenheiten und der Transportszenarien mit der Software PlantSimulation. In der ersten Experimentklasse werden sowohl das automatisierte, als auch das manuell erstellte Wegenetz getreu der Referenzumgebung modelliert und unter den real vorherrschenden Prozessen getestet. Es kann gezeigt werden, dass die automatisiert erstellten Wegenetze eine bessere bis gleich gute Leistungsfähigkeit aufweisen, was z. B. durch eine geringe durchschnittliche Durchlaufzeit und einen höheren Output ausgedrückt wird. In der zweiten Experimentklasse werden gesteigerte Anforderungen an die Wegenetze simuliert. Dazu werden die Einschleußraten von Gütern erhöht oder der Ausfall von einzelnen fahrerlosen Transportfahrzeugen (FTF) simuliert. Auch hier zeigt das automatisiert erstellte Wegenetz eine überwiegend bessere Leistung als das manuell erstellte.

Schlagworte: Wegenetzplanung, Expertensystem, Fuzzy Logik, Fahrerloses Transportsystem, Fahrerloses Transportfahrzeug, FTF, FTS

Abstract

Automated generation of roadmaps for automated guided vehicle system

This doctoral thesis examines how system planners' knowledge can be integrated into a pathfinding algorithm in order to combine human logic with mathematical optimization to generate roadmaps for Automated Guided Vehicle Systems (AGVS) that are both efficient and applicable. The goal of this work is to develop an expert system that automatically generates roadmaps for AGVS and minimizes the necessary manual planning steps.

An A* algorithm formed the foundation of this project and was chosen because it divides the given layout of the AGV environment into a grid with equally spaced cells. Costs are then assigned to the cells based on a heuristic. The costs depend on the feasibility of the cells examined for a future path. The benefit of the proposed solution is that expert knowledge of experienced system planners was included in a fuzzy logic in the form of fuzzy rules. The output of these rules directly influences the A* algorithm. For the setup of the rule base meetings with AGV experts were held. Based on these meetings, membership functions and rules were conducted to set up a fuzzy inference system.

The expert system developed was implemented as a software demonstrator using the software MatLab. The expert system was tested using three different real reference scenarios. The modelling of the reference scenarios included the detailed modelling of the AGV environment and the transport relations using the software PlantSimulation. In the first set of experiments, both the automatically and manually generated roadmaps were tested under real reference conditions. The shorter throughput time and higher overall output of the automatically generated roadmap demonstrates that it can perform as well as the manually generated roadmap and exceeds its capabilities. In the second set of experiments, increased demands were made on both types of roadmaps. The production rate of the stations has thus been increased accordingly while the removal of individual AGVs has been simulated. The automatically generated roadmaps are still able to perform better in most of these cases while requiring less generation time.

Keywords: pathfinding, expert system, fuzzy logic, automated guided vehicle system, automated guided vehicle, AGV

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Symbols and acronyms

Symbols

Symbol	Unit	Description
μ	-	fuzzy set
X	-	basic set
f(X)	-	set of all fuzzy sets
$\mu(x)$	-	mapping function for a set X: $\mu \in X \rightarrow [0,1]$,
a	-	lower bound of a trapezoidal function
b	-	upper bound of a trapezoidal function
c	-	core of a trapezoidal function
T_{ij}	-	cell in the transport matrix containing the amount of transports
G_{ij}	-	cell in the weight matrix containing a weight
T_{min}	-	smallest value in the transport matrix
T_{max}	-	highest value in the transport matrix
c_x	-	numerical cost factor calculated by the A* algorithm
T	-/h	number of transports per hour
v	m/s	vehicle speed
l_p	m	length of the path
l_v	m	length of the vehicle
U	[%]	utilization of the path
P_i	-	Path set containing all the cells defining a certain path
l_i	m	Length of a certain path i
n	-	number of paths
d_Σ	-	overall number of changes of directions of all paths in one roadmap
d_i	-	number of change of directions of a single path

Additional symbols for source code variables:

Symbol	Description
s_1	start station of the A* algorithm
s_2	goal station of the A* algorithm
$f(x)$	cost function of the A* algorithm
$g(x)$	cost function of the A* algorithm for the hitherto existing costs from start station to current point x
$h(x)$	heuristic cost function of the A* algorithm using the Euclidean distance
$c(x)$	cost of a specific cell in the A* algorithm
α	Numerical influence factor based on distance between parallel paths and additional length of alternative path
β	Numerical influence factor based on vehicle speed and utilization
γ	Numerical influence factor based on utilization and free space near a path
δ	Numerical influence factor based on regional free space and risk factor
ζ	Numerical influence factor based on vehicle speed at turns and the number of change of directions
θ	Numerical influence factor based on pick-up/drop-off time and count of transports

Acronyms

A*	A star algorithm
AGV	Automated guided vehicle
ANN	Artificial neural Network
BF	Bellman-Ford algorithm
CoA	Center of Area defuzzification method
FIS	Fuzzy inference system
FLC	Fuzzy logic controller
FRBS	Fuzzy rule base system
FTF	Fahrerloses Transportfahrzeug
FTS	Fahrerloses Transportsystem
Mod A*	Modified version of the A star algorithm
PFA	Pathfinding algorithm
PRM	Probabilistic roadmap method

RRM	Reachability roadmap method
SME	Small and medium-sized enterprise