

Agent Oriented Smart Factory (AOSF): a MAS based framework for SMEs under Industry 4.0

A thesis submitted by
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Statement of Originality

I hereby certify that the work embodied in the thesis is my own work, conducted under normal supervision. The thesis contains no material which has been accepted, or is being examined, for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made. I give consent to the final version of my thesis being made available worldwide when deposited in the University's Digital Repository, subject to the provisions of the Copyright Act 1968 and any approved embargo.

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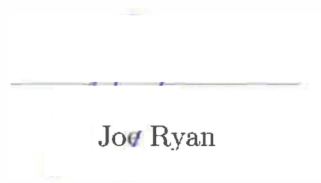
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I hereby certify that the work embodied in this thesis contains published papers/scholarly work of which I am a joint author. I have included as part of the thesis a written declaration endorsed in writing by my supervisors and co-author, attesting to my contribution to this thesis and joint publications/scholarly work.



Fareed Ud Din

By signing below I confirm that Fareed Ud Din was the principal contributor in conceptualisation, writing and revision of this complete thesis.



Joe Ryan

By signing below I confirm that Fareed Ud Din was the principal contributor in conceptualisation, preparation, design, analysis, writing and revision of the papers/publications entitled in the publications list below.



David Paul

List of Publications included as part of the thesis

- Ud Din F., Henskens F., Paul D., Wallis M. (2018) “Agent-Oriented Smart Factory (AOSF): An MAS Based Framework for SMEs Under Industry 4.0”. In: Jezic G., Chen-Burger YH., Howlett R., Jain L., Vlacic L., Šperka R. (eds) Agents and Multi-Agent Systems: Technologies and Applications 2018. KES-AMSTA-18 2018. *Smart Innovation, Systems and Technologies*, vol 96. Springer, Cham
- Ud Din F., Henskens F., Paul D., Wallis M., (2018) “Formalisation of Problem and Domain Definition for Agent-Oriented Smart Factory (AOSF)”, in *IEEE Region 10 Symposium (TenSymp)*, *IEEE*, 2019, pp. 265-270
- Ud Din F., Henskens F., Paul D., Wallis M. and Hashmi M., (2019) “AOSR-WMS planner associated with AOSF framework for SMEs, under Industry 4.0”, In review with *Cybernetics and Systems*

List of Achievements during candidature

- **Best Research Paper Award** at International Conference on Agents and Multi-Agent Systems: Technologies and Applications 2018, Gold Coast, Australia
- **Best Technical Research Poster Award**, at Poster Competition 2018, Faculty of Engineering and Built Environment, The University of Newcastle, Australia.
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Glossary

ABM	Agent Based Modelling
ACL	Agent Communication Language
ADN	Advance Delivery Notices
AOSF	Agent Oriented Smart Factory
AOSR	Agent Oriented Storage and Retrieval
AS/RS	Automated Storage and Retrieval System
ASNs	Advance Shipment Notices
AUML	Agent Unified Modelling Language
BDI	Belief Desire Intention
BPR	Business Process Re-engineering
BRM	Business Relationship Management
BNF	Backus-Naur-Form
CNP	Contract Net Protocol
COI	Cube Per Order Index
CPS	Cyber Physical System
CPPS	Cyber Physical Production System
CR	Critical Ratio
CRM	Customer Relationship Management
DCS	Distributed Control Systems
FCFS	First Come First Serve
FIFO	First In First Out
FIPA	Foundation of Intelligent and Physical Agents
EA	Expedition Area
ECU	Enterprise Central Unit
EDD	Earliest Due Date
EI	Enterprise Integration
EMBBO	Ensamble Multi-Objective Biography Based Optimisation
ERP	Enterprise Resource Planning Systems
IDE	Integrated Development Environments
IIC	Industrial Internet Consortium

IoT	Internet of Things
IS	Information Systems
IWN	Intra-Enterprise Wireless Network
JADE	Java Agent Development Environment
JIT	Just In Time
KQML	Knowledge Query and Manipulation Language
LIS	Logistical Information System
MA	Mediator Agent
MA-HTN	Multi-Agent Hierarchical Task Networking
MAP	Multi-Agent Planning
MAS	Multi-Agent Systems
MIS	Management Information System
OO	Object-Orientation
OLAP	Online Analytical Processing
PA	Planner Agent
PLC	Programmable Logic Controllers
RA	Receiving Area
RMI	Remote Method Invocation
S/R Machines	Storage or Retrieval Machines
SC	Supply Chain
SCM	Supply Chain Management
SDA	Smart Device Agents
SPT	Shortest Processing Time
SKU	Stock Keeping Unit
SME	Small to Medium Size Enterprises
SOA	Service Oriented Architecture
TA	Timestamped Actions
UA	User Agents
UML	Unified Modelling Language
WMS	Warehouse Management System
xAOSF	Extended Agent Oriented Smart Factory

Abstract

Recently, the inception of a fourth industrial revolution, termed Industry 4.0, gave a boost to the concept of the smart factory, which offers the advanced features of enterprise integration, automation, seamless information exchange, intelligent self-organisation of components and decentralised decision making. In order to accomplish these promises, a mature amalgamation of allied technologies e.g. Internet of Things (IoT), Cloud Computing, Big Data and Multi-Agent Systems (MAS) is incumbent. Recent research explains that the idea of Industry 4.0 focuses mainly on large enterprise but, for its compatibility with Small to Medium Size Enterprises (SMEs), there is still much research to be done.

This dissertation focuses on providing a comprehensive SC architecture for SMEs under the umbrella of Industry 4.0 to resolve the issue of compatibility, by presenting the MAS based Agent Oriented Smart Factory (AOSF) framework. This framework provides a general architecture for the whole value chain, incorporating concerns from both ends of a firm: Supply Chain Management (SCM) and Customer Relationship Management (CRM). In order to provide a complete solution, this thesis also includes the associated framework of Agent Oriented Storage and Retrieval (AOSR) system to alleviate the persisting problems of SMEs in warehouse management. The classification and categorisation of constituent agents of this two-fold system, with their negotiation and communication strategies, are also discussed. Problem and Domain definitions for AOSF are extracted using a multi-agent extension of Hierarchical Task Networking (MA-HTN). Heuristics and experimental results for the implementation and validation of this system are also presented in comparison with existing standard strategies. The results reflect improvements in overall efficiency within SME-oriented warehouses. Some of the possible future work recommendations, scalability of this system and industry interest for this proposed strategy are also discussed.