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José Zapata Neto

Development of a Business Interface based on RAMI 4.0 for Flexible Manufacturing in Industry 4.0

Sorocaba
2022

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Dissertação de defesa apresentada como parte dos requisitos para obtenção do título de Mestre em Engenharia Elétrica, junto ao Programa de Pós-Graduação em Engenharia Elétrica, interunidades, entre o Instituto de Ciência e Tecnologia de Sorocaba e o Campus de São João da Boa Vista da Universidade Estadual Paulista "Júlio de Mesquita Filho".

Área de concentração: Automação
Orientador: Prof. Dr. Eduardo Paciência Godoy

Sorocaba
2022

Z35d

Zapata Neto, José
Development of a Business Interface based on RAMI 4.0 for Flexible Manufacturing in Industry 4.0 / José Zapata Neto. -- São João da Boa Vista, 2022
108 p. : il., tabs., fotos

Dissertação (mestrado) - Universidade Estadual Paulista (Unesp), Faculdade de Engenharia, São João da Boa Vista
Orientador: Eduardo Paciencia Godoy

1. Automação industrial. 2. Internet das coisas. 3. Interface de programação de aplicativos (software de computador). 4. Automação. I. Título.

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CERTIFICADO DE APROVAÇÃO

TÍTULO DA DISSERTAÇÃO: Development of a Business Interface based on RAMI 4.0 for Flexible Manufacturing in Industry 4.0

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ORIENTADOR: EDUARDO PACIÊNCIA GODOY

Aprovado como parte das exigências para obtenção do Título de Mestre em Engenharia Elétrica, área: Automação pela Comissão Examinadora:

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Sorocaba, 27 de outubro de 2022

THANK YOU TO

To God for strength and support at any time.

To Professor Eduardo Paciência Godoy for his guidance and dedication during all stages. To my colleague Joel Ravelli for the exchange of experiences throughout the conducting this research.

To my friend Yara Marinho for all the dedication to help me get through this challenge. To my family and my husband.

And to Unesp, for providing this amazing experience to build and share knowledge with our fellow.

ABSTRACT

The Industry 4.0, together with the Industrial Internet of Things (IIoT), enable to transfer information, analysis, and data over the internet, improving business productivity through rapid changes in production scope in an increasingly volatile market. In this scenario, the Reference Architecture Model for Industry 4.0 (RAMI 4.0) was defined the elements of I4.0 in a three-dimensional layer model. One of the major challenges for adopting RAMI 4.0 is the development of solutions that support the functionality of each layer and the necessary interactions among. Despite of many studies developing RAMI 4.0 compatible solutions, there are very few studies focusing on the top layers, such as Functional and Business. This research developed a business interface for flexible manufacturing in I4.0 focusing on the Functional and Business layers of RAMI 4.0. The interface uses concepts of Service-Oriented Architecture and Application Programming Interfaces (APIs) and provides a fully API-based interface to easily and scalable exchange information from the factory to clients. The Order Orchestrator is the main module for interaction to both sides, handling production in the factory, such as orders and items production updates from the stations, also, from the clients-side, using the API Gateway, the system is able to insert new orders, delete orders already in production and even modify an order that is currently in production to become a different final good, all of that receiving a response in matter of seconds. The API Gateway based in RESTful APIs is scalable and easy to integrate. The client can manage orders in its backend integration as required, using its own Enterprise Resource Planning (ERP) functions or via standard software connected to computer, gives a major advantage to the factory’s clients as they can quickly respond to market changes, orchestrating changes in their production orders. The business interface was tested and validated in an I4.0 factory-based simulated scenario of clothing production, managing different production orders and changes. This research shows how a combination of the Order Orchestrator in the Functional layer and API Gateway in the Business layer brings a Product as a Service perspective for flexible production and manufacturing, opening space to improve the way of factories and production systems interact with clients.

Keywords: Industrial Automation, Internet of Things, Application Programming Interface (Software Computing), Automation.

RESUMO

A Indústria 4.0 (I4.0), juntamente com a Internet das Coisas Industrial (IIoT), possibilitou a transferência de informações, análises e dados pela internet, melhorando a produtividade dos negócios por meio de rápidas mudanças no escopo de produção em um mercado cada vez mais volátil. Neste cenário, no Modelo de Arquitetura de Referência para Indústria 4.0 (RAMI 4.0) foram definidos os elementos do I4.0 em um modelo de camada tridimensional. Apesar de muitos estudos desenvolvendo soluções compatíveis com RAMI 4.0, são poucos com foco nas camadas superiores, como Funcional e Negócios. Esta pesquisa desenvolveu uma interface de negócios para manufatura flexível em I4.0 com foco nas camadas superiores do RAMI 4.0. A interface usa conceitos de Arquitetura Orientada a Serviços (SOA) e Interfaces de Programação de Aplicativos (APIs) e fornece uma interface totalmente baseada em API para troca de informações fácil e escalável da fábrica para os clientes. O Orquestrador de Pedidos é o principal módulo de interação para ambos os lados, tratando da produção na fábrica, como atualizações de produção de pedidos e itens das estações, também, do lado do cliente, usando o API Gateway, o sistema é capaz de inserir novos pedidos, excluir pedidos já em produção e até modificar um pedido que está atualmente em produção para se tornar um bem final diferente, tudo isso recebendo uma resposta em questão de segundos. O API Gateway baseado em APIs RESTful é escalável e fácil de integrar. O cliente pode gerenciar pedidos em sua integração de back-end conforme necessário, usando suas próprias funções de Enterprise Resource Planning (ERP) ou via software padrão conectado ao computador, dando uma grande vantagem aos clientes da fábrica, pois podem responder rapidamente às mudanças do mercado, orquestrando mudanças no suas ordens de produção. A interface de negócios foi testada e validada em um cenário simulado baseado em fábrica I4.0 de produção de roupas, gerenciando diferentes ordens de produção e alterações. Esta pesquisa mostra como a combinação do Order Orchestrator na camada Funcional e API Gateway na camada Business traz uma perspectiva de Produto como Serviço para produção e manufatura flexíveis, abrindo espaço para evolução de fábricas e sistemas de produção com os clientes.

Palavras-chave: Automação industrial, Internet das coisas, Interface de programação de aplicativos (software de computador), Automação.

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATION AND ACRONYMS

API	Application Programming Interface
AAS	Asset Administration Shell
AMQP	Advanced Message Queuing Protocol
BMM	Business Motivation Model
BPMN	Business Process Modeling and Notation
B&Q	Batch and Queue
CPS	Cyber-Physical Systems
CPPS	Cyber-physical Production Systems
COM	Component Object Model
CT	Cycle Time
CRM	Customer Relationship Manager
DB	Data Base
DPS	Dispersed Productive Systems
ERP	Enterprise Resource Planning
EPC	Electronic Product Code
FDI	Field Device Integration
GW	Gateway
ICT	Information and Communication Technology
IETF	Internet Engineering Task Force
I4.0	Industry 4.0
IOT	Internet of Things
IIOT	Industrial Internet of Things
IOS	Internet of Services
IT	Information Technology

ISA	**I**nternational Society of Automation
JSON	JavaScript Object Notation
HW	Hardware
HTTP	Hypertext Transfer Protocol
HTTPS	Hypertext Transfer Protocol Secure
KPI	Key Success Indicator
MaaS	Manufacturing as a Service
MBSE	Model-based System Engineering
MES	Manufacturing Execution Systems
MQTT	Message Queue Telemetry Transport
MTBF	Mean Time Between Failure
OPC UA	Open Protocol Communications Unified Architecture
OPC AE	Open Protocol Communications Alarms & Events
OPC HDA	Open Protocol Communications Historical Data Access
OPC DA	Open Protocol Communications Data Acquisition
OMG	Object Management Group
PAAS	Production as a Service
PN	Part Number
RAMI 4.0	Reference Architecture Model for Industry 4.0
REST	Representational State Transfer
RP	Relying Parties
SCADA	Supervisory Control and Data Acquisition
SW	Software
SDK	Software Development Kit
SEM	Structural Equation Modeling
SOA	Service-Oriented Architecture

SOC	Service-Oriented Computing
TCP	Transmission Control Protocol
UDP	User Datagram Protocol
URI	Universal Resource Identifier
WS	Web Service

CONTENTS

1. INTRODUCTION

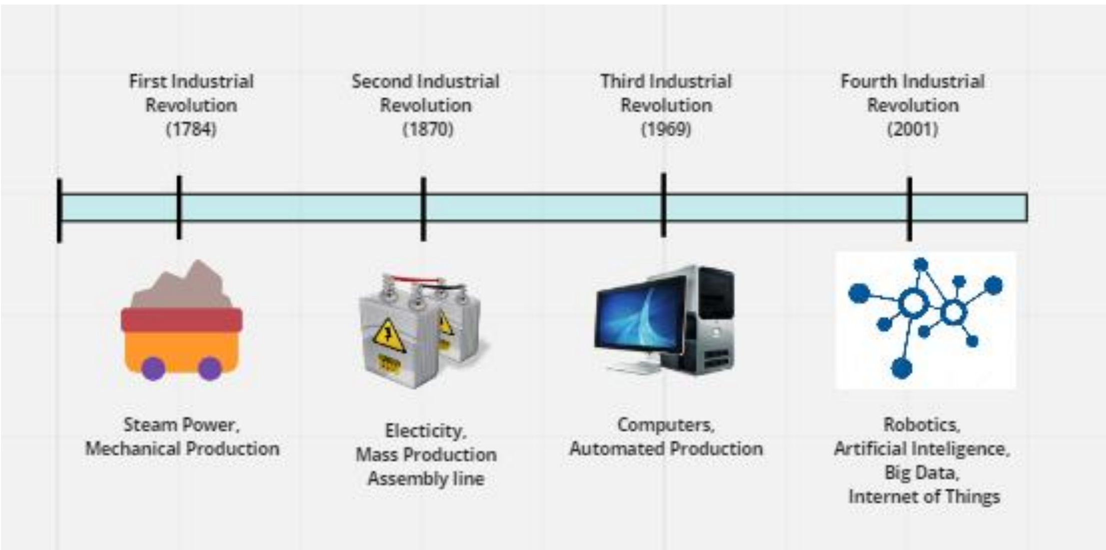
This section was created to give an introduction in the topic of Industry 4.0 and manufacturing as a service, to give the reader an opportunity to get more comfortable in the topic relevance and start to share this project main goals.

1.1. Relevance

Also known as "Smart Factory", the term Industry 4.0 has been coined at the 2011 Hannover Fair. The number 4.0 refers to be the fourth Industrial Revolution to come. According to Rüttimann and Stock (2016), the first Industrial Revolution is largely considered to be the steam machine which made the steam power exploitable and opened the industry age. The second Industrial Revolution remotes to the discovery and application of electricity allowing, for example, automobile mass production. The third Industrial Revolution is related to the possibility of data processing for computer integrated manufacturing (CIM), leading to the present era of information technology (RÜTTIMANN e STÖCKLI, 2016).

In Figure 1 it is possible to see all four Industrial Revolutions, and the main advances brought by them. The development of new digital technologies allowed the creation of new production methods in global industries based on automation, robotics, artificial intelligence, IoT, and data intelligence, among other innovations (BIGHETI e GODOY, 2020).

Figure 1. General vision of Industrial Revolutions, and it's important milestones.



Source: Own Authorship, adapted from (MELO, 2019).

The coordinated use of these technologies in the industrial context, making the business competitive, optimizing the efficiency of the production chain, adding value to the product, rationalizing the use of resources and customizing technological solutions is called Industry 4.0.

According to Suri et al. (2017), Industry 4.0 is one of the most prominent initiatives towards the vision of smart manufacturing to foster efficiency and synergy among suppliers, producers, and customers. The availability of a wide range of data and information in the context of Cyber-physical Production Systems (CPPS) provides a huge possibility to create novel business opportunities. However, there is an evident need to have efficient communication and clear visualization of the new strategies and the underlying operational process among all the stakeholders involved in the manufacturing value chain (SURI, CADAVID, *et al.*, 2017).

The majority of technologies necessary for the implementation of I4.0 already exists today, although in different stages of maturation. Zuehlke (2010) quotes the disruptive character that I4.0 brings as the result of the articulation and convergence of these technologies. First of all, the expansion of wireless networks to make communication and data acquisition flexible, combined with IPV6 protocol to expand the IP connection points; RFID for tracking products; cyber-physical systems (CPS); systems and services virtualization; the use of Industrial Internet of Things and Cloud Computing aiming at the integration and interoperable connection of all equipment on networks and the exchange of information in the cloud; and finally, Big Data and Artificial Intelligence for decision making (ZUEHLKE, 2010).

Several works have focused on studying the structure of RAMI 4.0. The big challenge for adopting RAMI 4.0 is found in the development of solutions, such as, equipment, systems, and standards, that support the functionalities of each layer and the interactions required between the elements of those layers (CONTRENAS, GARCIA e PASTRANA, 2017). As I4.0 currently represents a concept – not specifying, for example, communication technologies, integration tools and programming standards to be used – most works should look for different technologies that can be integrated and provide the functionality required by new applications. Kaggermann (2013) pointed out that solutions should be developed and made available to the market as soon as possible, considering their strategic implementation and the adaptation of existing technologies and basic experiences to manufacturing requirements (KAGGERMANN, WAHLSTER e HELBIG, 2013).

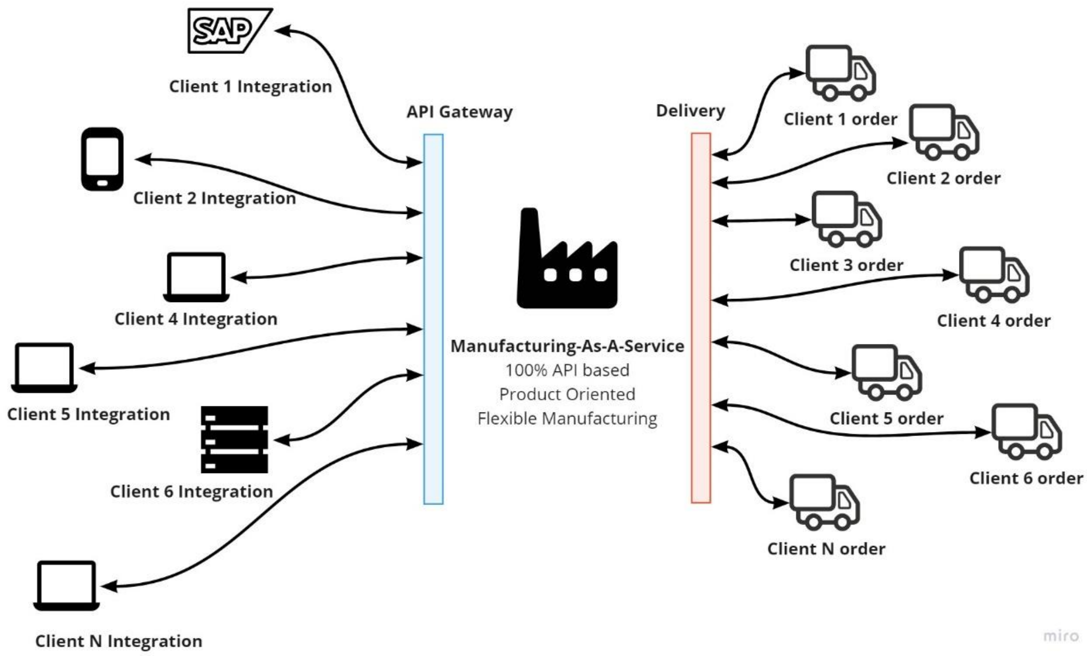
On top the that, with the increasing demand for product customization, manufacturing systems are becoming more flexible, customizable, and intelligent. Therefore, product factories with small-batch custom manufacturing needs often struggle with the task of underused production lines and sufficient system flexibility to integrate new products into the production line. Developing a method for automatically matching product fabrication with clients will enable faster production and more efficient use of the available resources in the manufacturing industry.

Delsing (2017) presents the concept of an on-premises automation cloud, in which automation components and devices are provided as services, allowing full interoperability for industrial applications. In this project, the entire integration and communication infrastructure was carried out through a Service Oriented Architecture (SOA), developed and called the Arrowhead Framework (DELSING, 2017). Leitão (2016) presents a review of some European Union-funded initiatives on industrial SOA applications. The developed SOA architectures are discussed and case studies in which these architectures have been validated are presented later in this research (LEITÃO, COLOMBO e KARNOUSKOS, 2016).

The concept of services allows any system to become clients or servers, depending on the need for the process or application, and for interaction, based on the exchange of messages, between any elements of the hierarchical levels of the industrial process. A service-oriented architecture consists of a collection of small autonomous services, where each service is independent and implements a single functionality.

Balta (2018), presented a Production as a Service (PaaS) framework and introduced the key structures and functionalities for PaaS realization. The PaaS framework enabled effective utilization of manufacturing resources for rapid realization of custom manufacturing needs of product developers (BALKA, LIN, *et al.*, 2018). The paper shows how precedence and batch splitting constraints efficiently evaluate optimal manufacturing solutions. The macro concept of Manufacturing as a Service (MaaS) can be seen in Figure 2. According to Annunziata (2019), extracted from *Forbes* Magazine, MaaS platforms bring three major benefits. First, they enable a higher degree of utilization of installed production capacity. Machines that would otherwise sit idle can be used to meet the new demand for parts from other companies, raising the return on investment; and the companies that buy the parts can, in turn, increase their production thanks to an improved and faster access to essential components. Second, the platforms improve transparency and price discovery by providing instant quotes generated by AI engines drawing on a large set of data on which companies can produce a specific product and a specific cost (ANNUNZIATA, 2019). Price transparency is a big deal; a more transparent marketplace will foster greater competition, speed, and efficiency. Third and last, these platforms enable greater and more efficient localization. Manufacturing as a Service platforms give access to a wider range of suppliers, and for equal price and quality, the choice will gravitate towards local firms.

Figure 2. The general concept of Manufacturing as a Service.



Source: Own Authorship.

Among the publications concerning RAMI 4.0, most of them are focused on the bottom layers, and only a few addresses the Functional and Business layers. This research is part of a major research group, that consists of a full architecture proposition to engage all six layers of RAMI 4.0 showing all cycles of production system combined for a centralized production end-to-end perspective. A platform 100% API based can bring a product-oriented perspective to a place that is client-oriented, and also, touchless connectivity to new clients and business opportunities. When the exterior is modern API based, the interior is ruled by OPC Unified Architecture and Molecular Framework, binging factory control and organization together.

This research is developed with other Master's Degree students project and the architecture developed and presented works as a unity and will be tested together end to end. This research is focused on the Functional and Business layers of RAMI 4.0, whilst the attention of (MELO, 2020), are the first three layers, Asset, Integration and Communication, and (RAVELLI, 2022) works with the Information layer.

1.2. Objectives and Contributions

This research develops a business interface for Industry 4.0 applications based on RAMI 4.0, Moleculer framework for microservices, and API Gateway, to exteriorize the control of production systems and also to enable flexible manufacturing *as a Service* in a Product-Client-oriented mass production.

1.3. Dissertation Organization

The structure of this dissertation was divided into 6 chapters considering this introduction and disregarding the Attachments, Appendix and Bibliographic References.

A brief introduction to Industry 4.0, its applications and potentiality are presented in Chapter 2. The highlights of the Service Oriented Architecture, clarifying the basic elements of the communication protocol for Industry 4.0 and RAMI 4.0, are also presented in Chapter 2.

In Chapter 3 is presented the first part of a conceptual review, addressing the main features of RAMI 4.0.

The Methods and Technologies used are shown in Chapter 4, and is described an architecture for the development of the project. It gives an overview of the technology used for the code development such as Node JS, Moleculer Framework, details of the API Gateway, and security protocol OAuth 2.0. Finally, it is given more details of the Functional and Business layers.

The development of this research and results are presented in Chapter 5. It is separated in the Functional layer, bring more perspective for the Order Orchestration, and the Business layer focusing more on the Gateway and in the API Swagger. A proof-of-concept scenario is also presented in Chapter 5 in order to test and validate the business interface developed in this project for flexible manufacturing in Industry 4.0.

And finally, in Chapter 6 is presented the remarks and conclusions drawn from the elaboration of the research.

6. CONCLUSIONS

This research presented a full microservice architecture to engage all six IT layers of RAMI 4.0 showing all cycles of production system combined for a service-based production end-to-end perspective but focusing on Functional and Business layers. A platform 100% API-based was able to bring a product-oriented perspective to a place that is client-oriented; also, touchless connectivity to new clients and business opportunities. When the exterior is modern API based, the interior is ruled by OPC Unified Architecture and Moleculer microservice Framework, bringing factory control and organization together to help the factory react to market changes.

The research has delivery an API Gateway and Order Orchestrator in the Functional layer of RAMI 4.0, an explained swagger in the Business layer, and an interpretation of a Client Business Interface. The Order Orchestrator was able to maintain control from both factory and client side, intermediating all communications talking to DB, to return reliable and quick data. API GW delivered a safe, organize, scalable way to connect the factory to the world, using state-of-art technology, and the Swagger gave the Business layer structured comprehensive documentation to improve client speed for integration and help them get the most of the factory services.

In this example for Proof of Concept, Order and Items were created, had their production Status searched, were deleted, and, most important, Items were converted from one PN to another, showing quick client-factory interaction and adaptation, allowing the client to respond quickly from market changes without the factory losing production governance, an important advantage to the client and a plus to the factory. In a market that is changing so fast, production has to be able to adapt, producing the items that the client needs very fast. Factory must not force the client to have orders requested in a different market time, that’s why this service is one of the biggest contributions of this research in relation to flexible manufactory where production line could be changes without affecting factory production. Side by side, the Order Orchestrator, Swagger, and API GW from top layers of RAMI 4.0 allows business-to-business simple, adaptable and scalable connectivity to clients.

This research is sited in a place of literature that does not have too many contributions. There are very few projects applied in the top layers of RAMI 4.0, so this project was able to delivery one of few implementations of RAMI 4.0. It also shows a full case and adaptability to work on flexible manufacturing and full set of OPC UA orchestration to have the factory as a production platform that can be orchestrated on client desires to produce for one or uncountable clients, and one or uncountable items, using the microservices and APIs.

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