An approach to integrating manufacturing data from legacy Injection Moulding Machines using OPC UA

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Abstract

To achieve the ambitions related with the concept of a Smart Factory, manufacturers of new industrial devices have been developing and releasing products capable of integrating themselves into fully-connected environments, with the communication capabilities and advanced specifications required. In these environments, the automatic retrieval of data across the shop floor is a must, allowing the analysis of machine performance for increased production quality and outputs. On most of the recently released industrial devices this machine data is readily available. However, the same is not true when using legacy devices. It is also well established that most SMEs are unable or do not intend to radically replace their industrial devices with this purpose only, since that would imply a high investment, and mainly because many of these legacy machines remain highly productive. That said, there is a need to develop integration methodologies for these legacy industrial devices and provide them with smart factory communication capabilities that make them suitable for the new Smart Factory environments.

In this work, an approach is proposed, using as a case study an industrial shop floor, to integrate data from a range of injection moulding machines, from different generations and different models / manufacturers. This equipment diversity renders the automatic interconnection extremely challenging, but is also representative of many existing industrial scenarios. This research will contribute to the development of integration methodologies and, consequently, improve equipment compatibility. To apply these methodologies, information about specific machines within the shop floor was gathered, as well as their communication and I/O capabilities, together with other features deemed relevant. A trend in recently released machines can be identified, revealing a special focus on the use of OPC UA standard, making use of its address space based on the structured Euromap information models. On the other hand, the legacy devices mainly allow outputting a text file to an external storage unit connected to the machine, containing machine and injection cycles related information. Regarding the communication interfaces available, the Ethernet interface reveals to be the most common among the recently acquired machines, while USB is the main interface in older equipment.

An experimental solution was developed for the presented case study, which uses the machine's USB interface to access these files at each injection cycle, mapping the acquired data to structured information model variables, according with Euromap specifications, and making it available through an OPC UA server address space. The developed server provides a standardized, interoperable, scalable, and secure approach for data exchange between the injection moulding machines and various OPC UA clients, allowing device monitoring and control during operation, as well as transmitting this data to higher-level management systems, e.g., MES and ERP systems. This solution shows that older legacy devices, available across the shop floors, can be retrofitted and integrated in Smart Factory scenarios, side-by-side with recently released equipment, giving production managers access to information needed to monitor and improve the production process, thus moving towards the Factories of the Future.

Key Words: Smart Factory, Legacy Equipment Integration, Injection Moulding Machine, OPC UA.

1. INTRODUCTION

The broad interest area for this research work is the application of the Industry 4.0 paradigm to existing industrial processes, encompassing the problems of applying new technologies to different generation industrial devices, as they are integrated into the overall management information system of an industrial production facility or

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company. Actual companies, industrial facilities and existing workcells, are far from ideal settings for the application of this wide paradigm, taking into consideration the heterogeneity of technologies in areas such as automation, data collection, communication capabilities and protocols, or compliance to standards. This makes the choice of the appropriate approach a key success factor since it impacts directly on the complexity of the integration task at hand, and in its cost.

Manufacturers of new industrial devices have been developing and releasing products capable of integrating themselves into fully-connected environments, with the communication capabilities and advanced specifications that it requires, to achieve the ambitions associated with the concept of a Smart Factory (Mabkhot et al., 2018). In these environments, data retrieved automatically by machines across the shop floor is critical, allowing for machine performance analysis and improved production quality and outputs. This machine data is readily available on most recently released industrial devices; however, this is not the case when using legacy devices. It is also true that most Small and Medium-size Enterprises (SMEs) are unable to, or do not plan to drastically replace their industrial devices with this aim solely, because it would entail a significant investment, especially owing to the fact that many of these legacy equipment remain extremely productive (Rauch & Matt, 2021).

This work's main goal is to develop an approach to integrate manufacturing data from legacy Injection Moulding Machine (IMM), developing a retrofit system that makes process data available in a standardized, interoperable, scalable, and secure way, through an increasingly adopted technology – Open Platform Communications (OPC) Unified Architecture (UA). This work focuses on injection machines with at least one USB interface available and supporting the creation of process data files containing data about the injection process. The use of the developed system aims to convert older IMMs Euromap77-compatible machines, thus allowing the system to be supported by many Manufacturing Execution Systems (MES) (Ogorodnyk et al., 2020), as well as other production process software supporting OPC UA.

The remainder of this paper is organized as follow: The first section contextualizes the research field, motivation, and the specific subject to approach. Section 2 provides a literature review on the subject. Section 3 describes details about the developed integration solution. Section 4 presents the tests and results. Finally, in Section 5, the main conclusions of the work are presented and some paths for future work are briefly described.

2. LITERATURE REVIEW

There are several works available regarding monitorization and optimization of the injection moulding process (Ketonen & Blech, 2021) (Jung et al., 2021), mainly works that use production and process data from the injection process to feed machine learning algorithms with the aim to generate fault alerts and predict machine events.

A study proposed by Obregon et al. (Obregon et al., 2021) provides a rule-based explanations approach, that supports operators and managers to visually and easily understand the most important manufacturing process parameter that influence the production process. The data supplied to this machine learning algorithm, is collected during the injection process, through several sensors installed in the IMM. In our approach, in order to keep the costs and system complexity low, the priority is given to the collection and manipulation of data already made available by the IMM controller and, only if the needed information is not available, use external sensorization.

Research by Tripathi et al. (Tripathi et al., 2019) analysed production data from an injection moulding process, containing around 70 process variables from different machines. Here, the raw data was collected from 33 IMMs and recorded into production files, process data and ERP-generated files during a production process. The analysis mentioned on this paper was performed in the end of the injection process, while in our approach the goal is to have this data readily available in "real-time", at each injection cycle.

Silva et al. (Silva et al., 2021) developed a data acquisition and monitoring system for legacy IMM, based on the data from the files generated by the machines. This system covers the data collection, treatment, storage, and monitoring process from legacy IMMs, but without making the data available in a standard format. However, this author identifies OPC UA combined with Euromap77 as the communication approach being increasingly adopted by recently released machines. The work presented here intends to solve this gap, developing an integration system for legacy IMMs based on OPC UA technology.

Regarding the injection process variables, they are transversal for the different brands of IMMs presented in the tests and results section of this paper, the only limitation here is the Negri Bossi V330 machine, which allow a maximum of six variables per file. Considering this and despite not being relevant in this context, as this is just to prove the concept of legacy IMMs integration, process engineers were asked about which variables would be the most important to monitor during the injection process if they only had access to six of them. The answers to this question resulted in the chosen variables shown in the Figure 4.

In the literature it is possible to find studies performed in this field to identify the injection process variables that should be monitored in order to understand the process through variation and to be able to draw conclusions about the produced parts quality, behaviour, and process variations, among others. Concerning the identification of which variables should be monitored, Tripathi et al. (Tripathi et al., 2019) states that the melt temperature, the maximum force and the cushion are variables that must be taken in consideration. Ribeiro (Ribeiro, 2005) states that cycletime, plastification time, injection time, barrel temperature before nozzle, cushion, and injection time must be monitored. Saleh et al. (Meiabadi et al., 2013) identifies that the variables that have the most impact on the injection process are melt temperature, plastification time, maximum pressure, mould wall temperature and injection time. As we can see in these and other research works, there are variables to be monitored that are transversal to almost all works, and they are according to those chosen in this work by the process engineers.

3. DEVELOPED INTEGRATION SYSTEM

This section describes details about the developed experimental system, which uses the machine's USB interface to access IMMs process data files at each injection cycle, mapping this data to structured OPC UA *Variables*, according with Euromap specifications, making them available through an OPC UA server.

In *Figure 1*, the overall system architecture is shown. The information flow starts on the "Legacy Injection Moulding Machine" that represents legacy IMMs that can generate files with data about the injection process. Other submodules, such as the power meter and interface modules for external sensors data acquisition, through protocol such as Modbus TCP are not in the scope of this work, although is possible to integrate this data in the created OPC UA server address space, as shown in previous works (Martins, 2021). The "IMM OPC UA Server" represents the experimental system developed in the scope of this work, based on a Single-Board Computer (SBC), that emulates a mass storage device through its USB On-The-Go (OTG) port while, at the same time, running an OPC UA server that can be accessed by an Ethernet connection through its RJ45 port. The connection to this server by "OPC UA Clients", allows accessing the OPC UA *Variables* that contains the mapped IMM data from machine files.

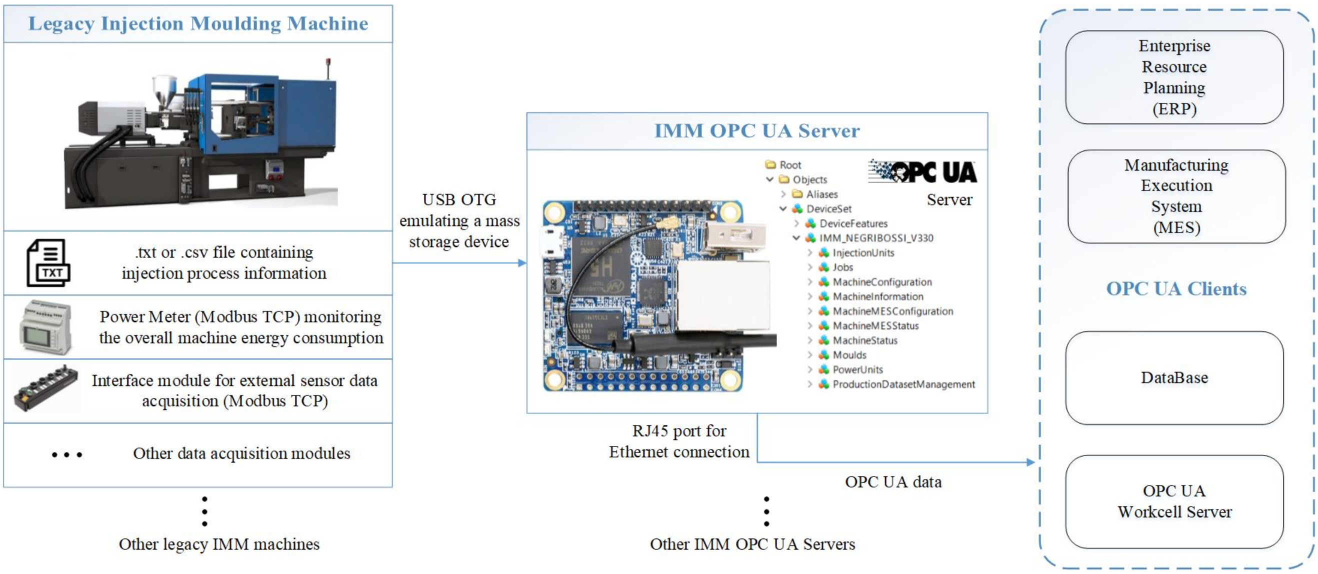


Figure 1. Overall system architecture.

3.1 Emulating a mass storage device

In the approach followed in this work, “legacy IMM” are considered to be devices with, at least, one USB interface available and supporting the creation of files containing data about the injection process. The USB interfaces available on these generation of IMMs, are intended to use a connected external mass storage device to store these files. These process data files are created in different formats, such as “.csv”, “.txt”, among other file type extensions. The developed integration system is a binding between the data available on these files and a high-level OPC UA server that will make this data available using a standard protocol and semantics. Considering this, the chosen hardware has a USB interface that support OTG specification and emulates a mass storage device. This is achieved by using the “g_mass_storage” Linux module, which needs to be compiled as part of the default kernel configuration in order to be activated, if not already available.

3.2. Parsing data from the IMM process data files

For different machines models, manufacturers use different ways to generate these IMM process data files, with variations in the file type extensions, the file header information, as well as the number of variables they store in each of these files during the injection process. In order to accommodate all this variety, the developed system implementation starts with the creation of a machine-specific parsing file that will manipulate that specific data file into a single variables array. This array of variables is then used by the main OPC UA server file to populate the address space variables. Usually, the process data files are created by the IMM at the beginning of one injection process, starting with a header, and then appending one line at each injection cycle with information about it, when cycle completes.

3.3. OPC UA server

OPC UA, the successor of OPC Classic[1], is defined by the international standard IEC 62541, which ensures the open connectivity, interoperability, built-in security, scalability, and compliance of industrial devices and systems. Regarding open connectivity, unlike OPC Classic that depends on MS-Windows, OPC UA supports multiple operating systems right from its inception, allowing to run our OPC UA applications in Linux-based ones. This characteristic allowed us to use an open-source SBC, named Orange Pi Zero[2], running a specially adapted Linux distribution called Armbian[3]. This specific SBC was selected mainly due to three characteristics:

(i) **USB OTG** – Devices supporting USB OTG allow us the emulation of various USB peripherals using the Linux USB gadget drivers. This functionality is used here to emulate a mass storage device, that will be used by the IMM to store the data file containing information about the injection process.

(ii) **RJ45** – Recently released equipment that have built-in OPC UA communication, usually have RJ45 ports for making it accessible via Ethernet interface.

(iii) **Low-Cost** – This SBC costs around 20€. Keeping the investment low can contribute to an increasing adoption of such integration technologies, allowing the conversion of legacy machines in Smart Factory-compatible devices, by companies (even SMEs).

Regarding the OPC UA server development, the open-source C99 implementations of OPC UA, open62541 library[4], was employed.

The address space was developed based on the OPC UA Companion Specifications (CS) DI, Euromap83 (VDMA, 2019b) and Euromap77 (VDMA, 2019a) data types definitions. The CS Euromap77 defines the IMM_MES_InterfaceType (Figure 2). This is an OPC UA ObjectType used for the root object that represents an IMM, with all its subcomponents. In this experimental system, one OPC UA Server will be coupled to each IMM controller, therefore only one instance of IMM_MES_InterfaceType will be created per IMM. This instance is created under the DeviceSet Object of the server (according with OPC UA Part 100) and following the BrowseName nomenclature “IMM_<Manufacturer>_<SerialNumber>”.

[1] https://opcfoundation.org/about/opc-technologies/opc-classic/
[2] http://www.orangepi.org/orangepizero/
[3] https://www.armbian.com/
[4] https://open62541.org/

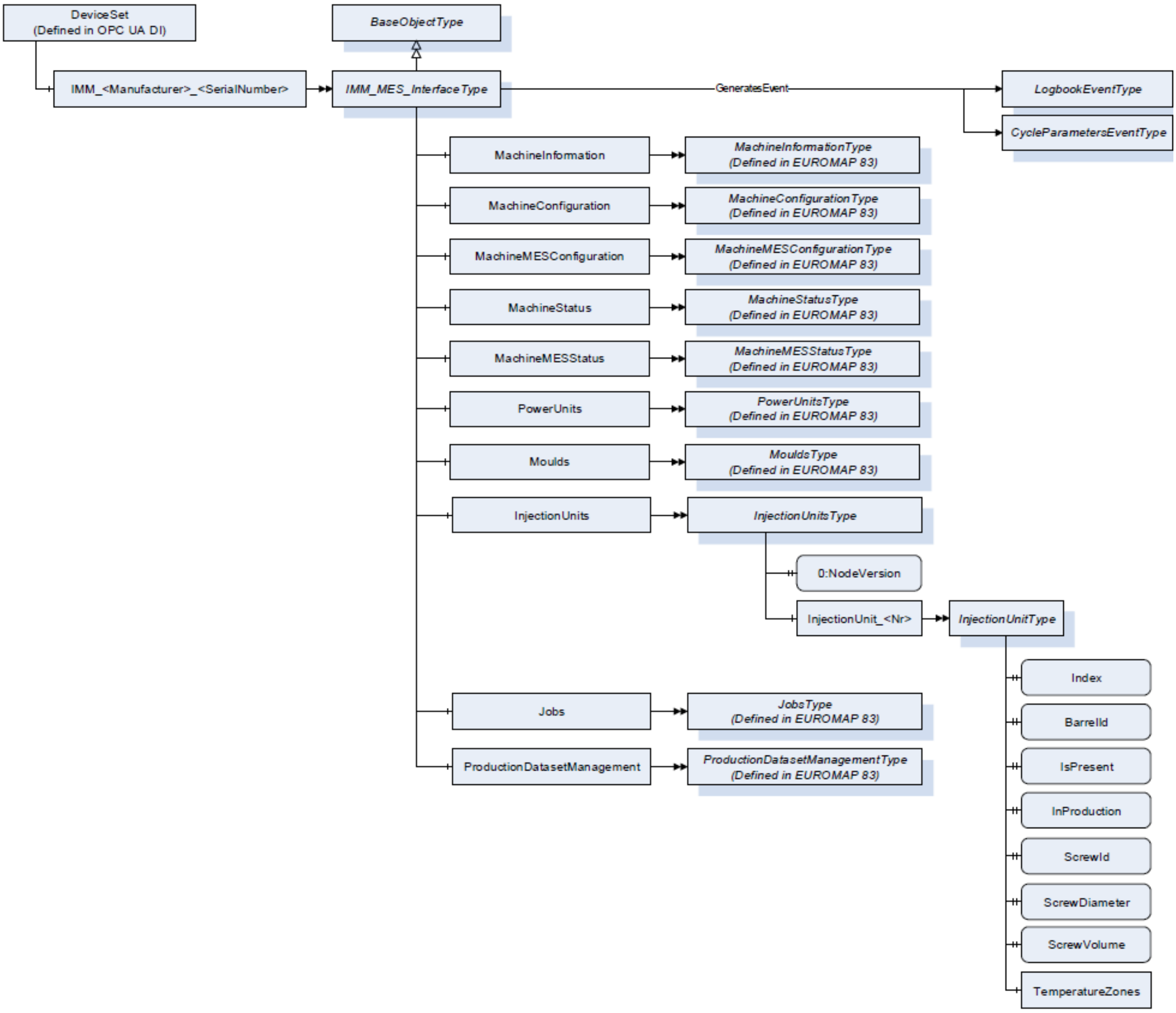


Figure 2. IMM_MES_InterfaceType Euromap77 information model (VDMA, 2019a).

Namespaces are used by OPC UA to create unique identifiers across different naming authorities. *Table 1* provides a list of the namespaces used in an OPC 40077 (Euromap77) OPC UA server.

Table 1. Namespaces used to build the IMM OPC UA Server.

Namespace	Index	Description
http://opcfoundation.org/UA/	0	Base OPC UA data types
Local Server URI	1	Instances used in the device represented by the server
http://opcfoundation.org/UA/DI/	2	Generic devices data types
http://www.euromap.org/euromap83/	3	Data types defined in the Euromap83
http://www.euromap.org/euromap77/	4	Data types defined in the Euromap77
Vendor specific types and instances	5	Vendor specific data types (optional)

4. TESTS AND RESULTS

The developed system was tested with three different file structures, generated by three different legacy IMM in industrial environment operation: Negri Bossi V330 BI – Bi Injection, Engel 600 and Tederic DH850. In this section, the file structures generated by each of these machines are described, as well as the results obtained when applying the developed system, described in detail on Section 3. The hierarchically structured address space built by the OPC UA server for the Negri Bossi V330 machine, viewed by the generic OPC UA client interface, UAExpert[5] from Unified Automation, is shown in Figure 3, as an example. The scope of this work is about making the IMM data available, developing an OPC UA server, and using a readily available generic OPC UA client with a graphical user interface to test the developed applications. Nevertheless, the data made available by the developed server can be accessed and consumed by any device with an OPC UA client, such as the ones mentioned in *Figure 1*.

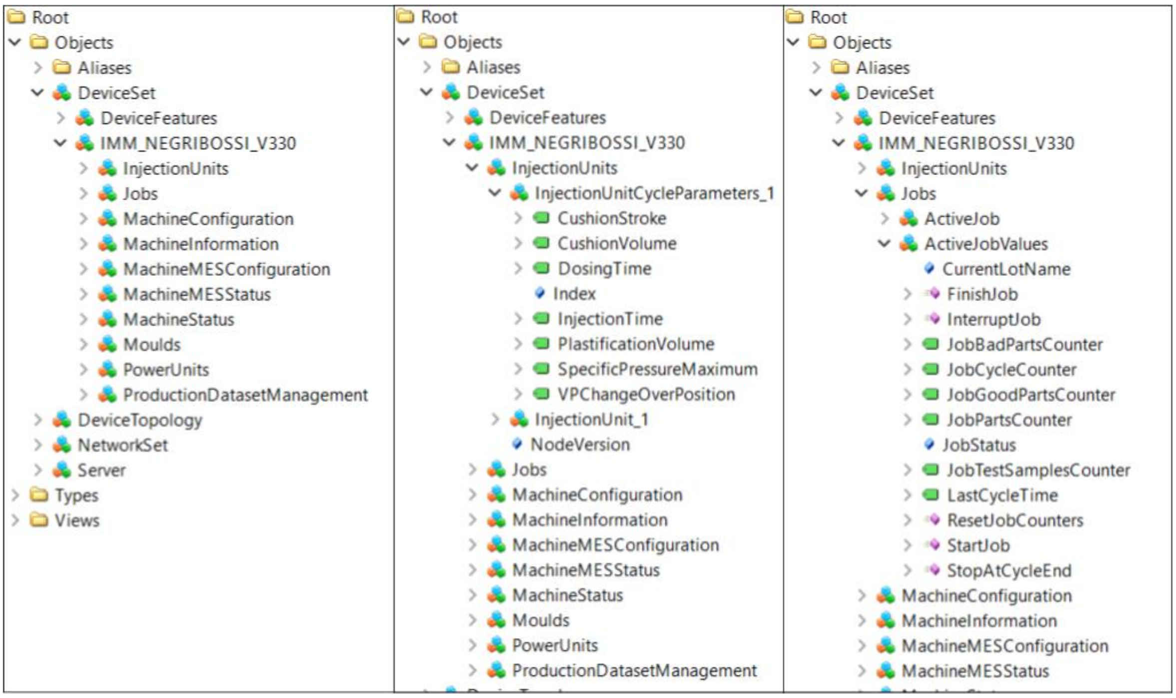
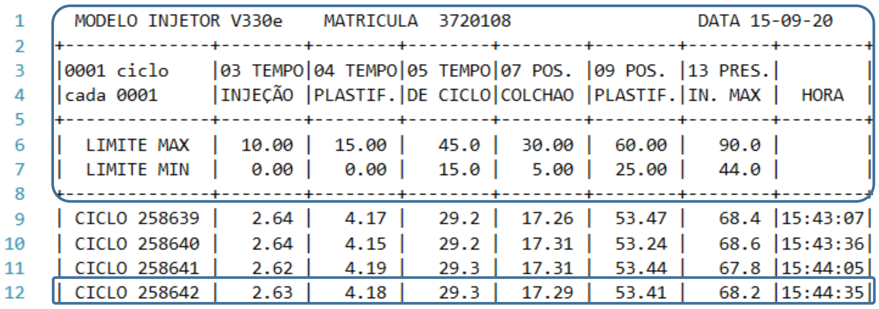


Figure 3. IMM OPC UA Server address space.

4.1. Negri Bossi V330

The Negri Bossi eCANBIO 330 Bi IMM, is an horizontal injection machine, and was manufactured in 2015. Regarding its technical specifications, it has a closing force of 3300 kN, and a maximum injection pressure of 1655 bar in the main group, and 1760 bar in the vertical group (bi-injection).

This machine generates a file with the ".tqc" extension, whose name can be configured in the IMM controller interface. It is limited to six variables registered in the file at a time, so they need to be selected in the machine controller from a list of available variables, before the injection process starts. The structure of such file can be observed in Figure 4, showing, in the first eight rows, the file header information and, in the last four rows, the data generated by four completed injection cycles. Each new completed injection cycle generates one line with information about that cycle, which is appended to the end of the file. The information generated on the first line of the header include the machine model, the serial number, and the machine date. Rows three and four contain the labels of each variable, per column, and rows six and seven their value range.



```
1   MODELO INJETOR V330e    MATRICULA  3720108                DATA 15-09-20
2  +--------------+--------+--------+--------+--------+--------+--------+--------+
3  |0001 ciclo    |03 TEMPO|04 TEMPO|05 TEMPO|07 POS.  |09 POS. |13 PRES.|        |
4  |cada 0001     |INJEÇÃO |PLASTIF.|DE CICLO|COLCHAO |PLASTIF.|IN. MAX |  HORA  |
5  +--------------+--------+--------+--------+--------+--------+--------+--------+
6  |  LIMITE MAX  |  10.00 |  15.00 |   45.0 |  30.00 |  60.00 |   90.0 |        |
7  |  LIMITE MIN  |   0.00 |   0.00 |   15.0 |   5.00 |  25.00 |   44.0 |        |
8  +--------------+--------+--------+--------+--------+--------+--------+--------+
9  | CICLO 258639 |   2.64 |   4.17 |   29.2 |  17.26 |  53.47 |   68.4 |15:43:07|
10 | CICLO 258640 |   2.64 |   4.15 |   29.2 |  17.31 |  53.24 |   68.6 |15:43:36|
11 | CICLO 258641 |   2.62 |   4.19 |   29.3 |  17.31 |  53.44 |   67.8 |15:44:05|
12 | CICLO 258642 |   2.63 |   4.18 |   29.3 |  17.29 |  53.41 |   68.2 |15:44:35|
```

Figure 4. Negri Bossi V330 data file.

[5] https://www.unified-automation.com/products/development-tools/uaexpert.html

For this specific machine, tests were performed on an industrial environment during an injection process, although, for confidentiality reasons, the data file from Figure 4 is not the one generated from those tests. In Figure 5, using the data access view from the UAExpert client, those variables can be observed, as well as their last values, matching the values from Figure 4's last row.

Data Access View

#	Server	Node Id	Display Name	Value	Datatype	Source Timestamp	Server Timestamp	Statuscode
1	open62541-...	NS1|Numeric|54598	JobCycleCounter	258642	UInt64	11:20:04.390	11:20:04.390	Good
2	open62541-...	NS1|Numeric|54662	InjectionTime	2.63	Double	11:20:04.390	11:20:04.390	Good
3	open62541-...	NS1|Numeric|54661	DosingTime	4.18	Double	11:20:04.390	11:20:04.390	Good
4	open62541-...	NS1|Numeric|54602	LastCycleTime	29.3	Double	11:20:04.390	11:20:04.390	Good
5	open62541-...	NS1|Numeric|54659	CushionStroke	17.29	Double	11:20:04.390	11:20:04.390	Good
6	open62541-...	NS1|Numeric|54663	VPChangeOverPosition	53.41	Double	11:20:04.390	11:20:04.390	Good
7	open62541-...	NS1|Numeric|54656	SpecificPressureMaximum	68.2	Double	11:20:04.390	11:20:04.390	Good

Figure 5. Negri Bossi V330 OPC UA server variables.

4.2 Engel 600

The Engel 600 IMM, is an horizontal injection machine and was manufactured in 2010. Regarding the technical specifications, it has a closing force of 6000 kN, and a maximum injection pressure of 1820 bar.

Concerning the process data files generated by the IMM, their structure can be observed in Figure 6. The first twenty-two rows contain the file header information and the last four rows show the data generated by four completed injection cycles. The files generated by this machine have the ".csv" file extension. Similarly, to the previous machine, each new completed injection cycle generates a line with information about that cycle that is appended to the end of the file. The first eight rows of the header describe the model and name of the machine, date and time, number of the attached mould and material in use. From row ten to nineteen, a list of variables labels, and their corresponding abbreviation version is observed. Line twenty-one contains the abbreviated version of the labels and their corresponding units. The tests with this machine were carried in a laboratory environment, although using files generated from real machines during injection processes in industrial scenarios.

```
1   ;12/Out/20 9:58:46;
2   Nr.peça injetada;1;
3   Número da máquina;DUO 600;
4   Número do molde;EFM 1093;
5   nr. material;ABS TERLURAN GP 22 ;
6   número do pedido;;
7   Tipo de máquina;DUO 2550/600;
8   Nome da máquina;174029;
9
10  Modo de medição: 12/Out/20 9:58:46
11  SZx;Contador de injeções;
12  Datum;data;
13  Zeit;Tem;
14  CPx;Comprimento da almofada valor real;
15  ZSx;Tempo de injeção valor real;
16  ZUs;Tempo do ciclo até final da desmoldagem;
17  ZDx;Valor efetivo do tempo de dosagem;
18  Ms;Torque valor de pico ciclo em andamento;
19  Mm;Torque valor médio ciclo em andamento;
20
21  ASZ [Inj];SZx [Inj];Datum [ ];Zeit [ ];CPx [mm];ZSx [s];ZUs [s];ZDx [s];Ms [Nm];Mm [Nm];
22   ;111;12/Out/20;9:59:09;17,26;2,06;29,69;9,23;2159,7;2039,7;
23   ;112;12/Out/20;9:59:39;17,42;2,05;29,70;9,19;2161,7;2042,8;
24   ;113;12/Out/20;10:00:08;17,31;2,06;29,65;9,17;2158,7;2046,5;
25   ;114;12/Out/20;10:00:38;17,24;2,06;29,69;9,25;2158,4;2041,5;
```

Figure 6. Engel 600 data file.

4.3 Tederic DH850

This machine, Tederic DH850, is an horizontal injection machine and was manufactured in 2017. Regarding its technical specifications, it has a closing force of 8500 kN, and a maximum injection pressure of 2311 bar.

Regarding the process data files generated by the IMM Tederic model DH850, they have the ".txt." file extension whose structure is shown in Figure 7. The first four rows, similarly to the previous machines, represent the file header, containing machine model, date and time information, variables labels and their corresponding units. The last four rows represent the completed injection cycles information.
The tests with this machine were carried in a laboratory environment, although using files generated from real machines during injection processes in industrial scenarios.

```
Exportação SPC
Produção;MCB22779;27/Jul/20 15:30:40
Sucata [ ];Shots [Ciclos];Tempo ciclo máquina [s];Tempo de injeção [s];Tempo de plastificação [s];Almofada [mm];Pressão máx. injeção
Sucata;Shotcounter;Tempo ciclo máquina;Tempo de injeção;Tempo de plastificação;Almofada;Pressão máx. injeção;Pressão na comutação;Tem
 ;8244;65,6;5,9;9,8;21,6;1308;1303;232;240;242;223;224;222;10,0;183,7;32,0;0,9;34;15,0;28,9;3,0;4,3;1,5;30;0,8;0,4;0,5;1,7;0,9;0,5;
 ;8245;53,5;6,1;9,9;23,5;1245;1239;230;240;241;223;224;221;10,0;183,8;32,0;0,9;34;15,0;30,0;3,1;4,3;1,5;30;0,8;0,4;0,5;1,6;0,9;0,6;
 ;8246;55,2;6,1;9,7;24,0;1174;1172;229;240;241;224;224;221;10,0;183,7;32,0;1,0;31;15,0;29,9;2,7;4,3;1,5;30;0,8;0,4;0,5;1,7;0,9;0,6;
 ;8247;55,5;6,1;9,7;23,7;1155;1151;228;240;241;224;223;220;10,0;183,6;32,0;0,9;31;15,0;30,1;3,1;4,3;1,5;30;0,8;0,4;0,5;1,7;0,9;0,6;
```

Figure 7. Tederic DH850 data file.

At the time this paper was written, this OPC UA server is at an early testing stage, parsing only the information from each new injection cycle line to the OPC UA *Variables* available on the address space that match the original information meaning. In further developments of this system, information from the file headers should also be used to set OPC UA *Properties* from *MachineInformation* and *MachineConfiguration* nodes, that also describe the machines.

5. CONCLUSION AND FUTURE WORK

Although legacy industrial equipment does not provide the intelligence needed for smart factory connectivity, its integration is important, given that these are still being highly productive for the main purpose they were built for. Within this context, this work developed an approach to integrate the manufacturing data from legacy IMM using OPC UA technology. The developed system parses text files generated by the machines and maps them to the structured address space from an OPC UA server, using Euromap77 and the corresponding OPC UA companion specification to provide a standardized approach.

There are a wide range of legacy IMM models available across the factories shop floors, with different characteristics and different ways of making the injection process data available. Considering this, following an approach that is multi-vendor compatible but makes the information available in a standard way, will allow data to be collected from a broader range of legacy IMMs. The presented case study, shows the feasibility of such data integration, gathering the information from three different legacy IMMs (Negri Bossi V330 BI, Engel 600 and Tederic DH850) within the same application.

Further development of this system includes the creation of a runtime configuration interface that allows to, from a list of supported IMM, select the one we want to collect data from, as well as other configurations, without the need to recompile the code. The machine-specific parsing files should allow the incorporation of file header information using it to set OPC UA *Properties* from *MachineInformation* and *MachineConfiguration* nodes. The natural evolution of this application includes supporting a broader range of IMM models, as well as other peripheral equipment commonly used in the injection process, such as thermoregulators, injection material dryers, flowmeters, among others. The market is already beginning to move in this direction, with manufacturers already offering new equipment with OPC UA-capable communication.

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