capri

Cognitive Automation Platform
for European PRocess Industry
digital transformation

Deliverable

D3.2 CAPRI Industrial IoT Platform and Data Space

Deliverable Lead: Engineering Ingegneria Informatica

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Title	CAPRI Industrial IoT Platform and Data Space
Lead Beneficiary	Engineering Ingegneria Informatica
Description	This deliverable of type OTHER presents the implementation results of the data-driven Reference Architecture for Cognitive Plants in the process industry, with smart IoT cognitive components, as developed in T3.1. Part of the final outcomes will be provided in the zip file to be submitted together with the present report. It should be noticed, that since there is the intent of patenting CAS1, all the confidential information regarding the prototype's details on '4.1.1 Cognitive sensor of bitumen content in recycled asphalt [CAS1] 'was removed.
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EXECUTIVE SUMMARY / ABSTRACT SCOPE

D3.2 – "CAPRI Industrial IoT Platform and Data Space", is a deliverable of type OTHERS that, together with D3.3, D3.4 and D3.5, describes the concrete achievements in the development of the Smart sensors cognitive solutions, leveraging state of the art open standards such as OPC UA and MQTT for data ingestion and NGSI-LD for data representation.

After an introduction on document scope, audience and structure, for each domain a summary view of cognitive solutions at sensor level is presented in Section 3, followed by a more detailed description of the solutions in Section 4. For each cognitive solution the work done until M24 is explained, along with an introduction to a video showing the cognitive solution in a laboratory environment. Where possible, data and metadata description, sample data used for testing, and a user manual of the applications are included as well. Some of these contents cannot be included in this document, so they will be uploaded in a separate file.

Section 2 describes the distribution of the various developed CSs in the D3.2, D3.3, D3.4 and D3.5 deliverables, with the used content structure aimed at making it easy to find the relevant information.

Conclusions can be found in the final Section 5.

1 Introduction

1.1 Scope of Deliverable

D3.2 – "CAPRI Industrial IoT Platform and Data Space", is a deliverable of type OTHERS aimed at describing the implementation of the cognitive sensor laboratory prototypes in the process industry, as designed in CAPRI task T3.1. It is part of a series of reports describing the solutions at different layers, from sensors (this report) via control (D3.3), operation (D3.4) to planning (D3.5).

The cognitive sensor solution lab prototypes have been implemented using open-source components, where possible, and with regard to the software reference architecture described in deliverable D3.1, the so-called cognitive automation platform (CAP). The final integration into the CAP was not the aim of this task, however, a migration to this target architecture is ongoing at the time of writing and will be reported in the upcoming deliverable D4.1.

Part of the final outcomes are provided in a zip file along with the present report. For each Cognitive Solution (CS) the following details will be provided:

- **Textual description** (this document): explaining the work done, introduction to video, user manual of the apps, including the available links, data and metadata description, description of everything else in the ZIP.
- **Executable of the program/app**, if any
- Any kind of **data** that can be publicly shown (full data, sample data, metadata, surveys results, …)
- **Video** introduction to the sensor solution.

1.2 Audience

D3.2 – "CAPRI Industrial IoT Platform and Data Space", is a deliverable of type OTHERS that presents the implementation results, targeting the Alpha release of the CAPRI implementation, that represents the standalone implementation of cognitive sensor solution. In this deliverable the practical details of the smart IoT cognitive components will be provided, with textual information explaining the work done, introduction to videos or screenshots, user manual information on apps used to showcase results, data and metadata description, to better explain the zip file contents.

For this reason, while D3.2 is conceived to be a public report, it is addressed mainly at a reader with a technical background related to Sensors Technologies and Data Architecture.

1.3 Relationship with other deliverables

D3.2, together with D3.3, D3.4 and D3.5, trace a continuation line after D3.1. While the latter D3.1 describes the Reference Implementation of the Cognitive Application Platform (CAP) to support the integrated implementation of the four cognitive layers, D3.2 describes in detail the standalone development of the sensor-based solutions, to be integrated in the final plants in the different domains.

At the same time D3.6 will describe the overall picture of activities performed within WP3, presenting the openness approach on cognitive solutions and investigating the generation of Open Data, whose specific results at Sensors, Control, Operation and Planning level are documented in D3.2, D3.3, D3.4 and D3.5. Furthermore, recommendations and lessons learned from the standalone implementations will be reported in D3.6.

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On the other hand, final results in WP3 will feed the integration step to be covered in WP4, paving the way to the final demonstration in WP5 tasks at plant level. In particular, deliverable D4.1 will report on the integration of the cognitive sensor solutions presented in this report into the CAP architecture.

1.4 Document Structure

This document is organized with three main sections (Section 2 – Section 4), in addition to the introductive chapter (the current one, which describes the scope of the deliverable, audience, relationship with other deliverables and the structure are described) and the conclusive one, which summarizes main achievements and shaping next steps.

Section 2 – Attachment Structure Description explains the distribution of all developed CSs in D3.2, D3.3, D3.4 and D3.5 deliverables, with the used content structure to make it easier to find the relevant information. Since there will be a unique zip file collecting all contributions of the four deliverables, this section will be the same in all four deliverables.

Section 3 – Smart IoT Connection Cognitive Solution Overview provides a summary view of cognitive solutions at sensor level, split by domain.

Section 4 – Smart IoT Connection Cognitive Solutions Results aims at reporting the detailed description of what is going to be included in the zip file. Sample data and data format will be provided through .csv files, demonstrative screenshots will be .jpg file, videos will be .mp4 files, and Applications used to showcase particular features will be .exe files.

2 Attachment Structure Description

The objective of the current chapter is twofold: first of all, it aims to provide an overview of the structure of the four deliverables D3.2 – D3.5 of type Other, including the current one; secondly to provide the list of the documents attached to the present report, including the Zip folder, the Zenodo folder and any other external link.

Actually, at month M24 (March 2022), WP3 is delivering four deliverables of type Other to summarise and provide evidence of what has been implemented so far; each deliverable consists of a textual part (the present document) and a set of attachments, which is the core of the deliverable.

This section aims at providing a summary picture of the structure of the four documents and of the attachments to make it easier to find relevant information, since the subjects presented in each report may overlap with the others and it may not be straightforward for the reader to understand where to find what. Hence, the objective of this chapter is to provide support in orientating inside them.

Since it deals with the four deliverables, it will be replicated almost the same in all of them:

- Deliverable D3.2 – "CAPRI Industrial IoT Platform and Data Space" as output of Task 3.1, the current one;
- Deliverable D3.3 – "CAPRI Industrial Analytics Platform and Data Space" as output of Task 3.2;
- Deliverable D3.4 – "CAPRI Smart Knowledge and Semantic Data Models" as output of Task 3.3;
- Deliverable D3.5 – "CAPRI Smart Decision Support" as output of Task 3.4.

As mentioned above, each deliverable is related to a specific Task, but the activities performed in WP3 can't be siloed per Task since they involve more than one at the same time. Actually, the CAPRI Cognitive Solutions are 19 assets implemented at laboratory level, split by the three domains (Asphalt, Steel and Pharma) and encompassing the four layers of WP3 (Sensor, Control, Operation and Planning, corresponding to the four Tasks). It means that each CS is developed within one specific use case, but it presents features that cross more than a layer, so practically, it is part of more than one Task.

To overcome this situation and the fact that each CS should be described in more than a deliverable, it has been agreed to include in the report an initial section (Chapter 3) to describe the activities associated to the Task. So, Chapter 3 is at Task level and takes care only of the CS's component related to the task, even if it means to depict it only partially.

Conversely, Chapter 4, that is the core of the deliverable together with the set of attachment, provides the overview at CS level, in order to avoid jumping from a document to another to find information. Each Chapter 4 (of the four deliverables) contains only a subset of CSs but they are fully described: for each cognitive solution, the main achievements are presented.

The following table shows in which way the 19 Cognitive Solutions encompass the four WP3 layers and so, also the four WP3 Tasks (in bold, the percentage that drove the choice of the deliverable where the CS has been assigned).

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Table 1: CAPRI CSs encompassing the four layers/tasks

DOMAIN	CS'S NAME	CS'S CODE	T3.1 Sensor	T3.2 Control	T3.3 Operation	T3.4 Planning
ASPHALT	Sensor for bitumen content	CAS1	**50%**	50%		
	Sensor for amount of filler	CAS2	**80%**	10%		10%
	Control of the asphalt drum	CAC1		**85%**	15%	
	Predictive Maintenance of baghouse	CAO1	10%		**30%**	60%
	Planning and control of asphalt production	CAP1		10%	10%	**80%**
STEEL	Sensor for product tracking	CSS1	**70%**	30%		
	Sensor for Solidification	CSS2	20%	**80%**		
	Sensor for Product temperature	CSS3	20%	**80%**		
	Scale sensor for scale build-up	CSS4	20%	**80%**		
	Sensor for risk and anomalies	CSS5			30%	**70%**
	Digital twin architecture	CSO1		10%	**60%**	30%
PHARMA	Sensor for blend uniformity	CPS1	**80%**	20%		
	Sensor for granule quality	CPS2	**80%**	20%		
	Sensor for product moisture	CPS3	10%	30%	**60%**	
	Sensor for prediction of dissolution	CPS4		40%	**60%**	
	Sensor for fault detection	CPS5		10%	**60%**	30%
	Cognitive Control Concept	CPC1		**70%**	30%	
	Cognitive Operation Concept	CPO1		10%	**70%**	20%
	Cognitive Planning Concept	CPP1		10%	10%	**80%**

We agreed to assign each CS to a specific deliverable, even if it encompasses more than a layer (and so, more than a Task) to ease and speed-up the reading of the document and to show all the information related to a Cognitive Solution in a single report.

Hence, the 19 CSs have been split in the four deliverables as follow, according to the most relevant layer:

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Figure 1 The 19 CSs into the deliverables D3.2, D3.3, D3.4, D3.5

In this way, the four deliverables are well balanced: 5 CSs are described in D3.2 and D3.3, whose main component is the Sensor and the Control, respectively; 6 CSs are described in D3.4, focused on Operation and finally, 3 CSs are described in D3.5, about Planning. In each deliverable, Asphalt, Steel and Pharma domains are always represented.

Namely, the current deliverable contains the following 5 Cognitive Solutions:

- CAS1 - Sensor for bitumen content [Asphalt]
- CAS2 - Sensor for amount of filler [Asphalt]
- CSS1 - Sensor for product tracking [Steel]
- CPS1 - Sensor for blend uniformity [Pharma]
- CPS2 - Sensor for granule quality [Pharma]

Since we are talking of deliverables of type Other, each Cognitive Solution listed above is equipped with:

- A number of attachments of different nature (video, data, metadata, …), containing additional information that helps to better understand the final output of the CS and to provide a concrete evidence of what has been implemented in WP3;

  A textual part, available in Chapter 4, which complements the "physical" content in the attachment, explaining what it is and how to use it.

All attachments are available under the Capri's Zenodo folder and, in case of videos, under the Capri's channel in YouTube. Due to limitations of space (52Mb) in EC portal not all the assets could be included into 1 single file. That is the reason we have decided to include all files into CAPRI's Zenodo account and CAPRI YouTube channel video for the videos showing specific demonstrations. The table below lists all the links (zenodo and youtube) of the different files described in the present report.

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Table 2: D3.2 – List of attachments

Cognitive Solution	Content	Type	Location
CAS1 - Sensor for bitumen content	CAS1_video_1.mp4	Video	Under CAPRI's YouTube channel https://www.youtube.com/watch?v=u0MQIRFY_bE Under Zenodo account https://doi.org/10.5281/zenodo.6367896
CAS2 - Sensor for amount of filler	CAS2_Data_1.hdf5 CAS2_Data_2.hdf5 CAS2_Data_3.xls CAS2_Data_4.xls CAS2_DMP_dataset1_2.xlsx CAS2_DMP_dataset3.xlsx CAS2_DMP_dataset4.xlsx	Data	Under Zenodo account https://doi.org/10.5281/zenodo.6367574
	CAS2_Video_1.mp4 CAS2_Video_2.mp4 CAS2_Video_3.mp4	Video	Under Zenodo account https://doi.org/10.5281/zenodo.6367574 Under CAPRI's YouTube channel https://youtu.be/GKSPXHdpXtE https://youtu.be/yytCgzjcuL8 https://youtu.be/hx01YzK31Dk
CSS1 - Sensor for product tracking	CSS1_Video_1.mp4	Video	Under Zenodo account https://doi.org/10.5281/zenodo.6367630
CPS1 - Sensor for blend uniformity	OPCClient_Prediction_V05.py KaiserRamanVirtual_V03.py calibspectra\01_0117_Spectrum_20211021-13_56_21_364446.csv calibspectra\05_0189_Spectrum_20211021-14_20_21_186483.csv calibspectra\11_0297_Spectrum_20211021-14_56_21_174045.csv model\General_List_M13.xlsx Model\Workset_Statistics_M13.xlsx	Data	Under Zenodo account https://doi.org/10.5281/zenodo.6367593
CPS2 - Sensor for	A3_exe_CPS2_realtime_V01.py		Under Zenodo account

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granule quality	A3_exe_CPS2_tests_V01.py test_q3.csv test_sieve_vec.csv		https://doi.org/10.5281/zenodo.6365084

It is worth to mention that each data file shared is accompanied by the corresponding data management plan file (DMP file) to comply with the F.A.I.R.[1] principles as CAPRI project is part of the open research data pilot of H2020[2].

Finally, an overview of each Cognitive Solution is available in the CAPRI website, at the "Use Cases" section[3].

If you are interested in the details other CSs different from the five associated to the current deliverable, please refer to related deliverable according to the structure shown in Figure 1.

[1] Under these principles, each data file must be Findable, Accessible, Interoperable and Reusable. http://ec.europa.eu/research/participants/data/ref/h2020/grants_manual/hi/oa_pilot/h2020-hi-oa-data-mgt_en.pdf

[2] https://www.openaire.eu/what-is-the-open-research-data-pilot

[3] https://www.capri-project.com/technology

3 Smart IoT Connection Cognitive Solutions Overview

3.1 Asphalt smart sensors solutions

Current asphalt production plants contain different types of sensors in order to be able to monitor and control the different asphalt recipes needed for their applications. Usual sensors at the asphalt manufacturing plant are part of one of the following types among others:

- Temperature sensors to monitor the heating of the cold aggregates and their storage at the hot bins and the final asphalt mix
- Humidity sensors to better dry the aggregates
- Pressure sensors to control gases extraction and rotary dryer drum performance
- Load cells to adjust the needed quantities of aggregates to add to the final mix
- Flowmeters to dose the corresponding additives
- Gas concentration sensors to monitor the combustion process and the exhaust gases to improve the heating process and avoid sending pollutants to the atmosphere
- Rotary speed sensors (at variable frequency drive (VFD) level) to control the aggregates dosing and heating processes
- Etc.

However, not all these sensors per se give a smart understanding and approach to the process. During process assessment, two types of smart cognitive sensors have been identified to find an optimal behaviour and reaction to the manufacturing of asphalt mixes to give a high-level cognition reaction to optimize and detect variations and have a cognitive sensing and support of the process that commercial sensors cannot give. These are:

- Cognitive Sensor of Bitumen content in recycled asphalt

This cognitive sensor's purpose is to provide the real bitumen content present in Reclaimed Asphalt Pavement (RAP). The bitumen content in RAP is currently estimated using a small sample of RAP in a laboratorial lengthy process (around 5,5h) that uses chemical solvents. The RAP added to the asphalt mixer is not measured since there are no commercial sensors available for this purpose. The development of this sensor, based on optical components and intelligent algorithms, will help to reduce the human resources needed, eliminate the use of health hazard solvents, reduce the amount of virgin bitumen used in the asphalt mix, and enlarge the usage of RAP in the final asphalt mix, making it a more efficient and environmentally friendly process.

- Cognitive sensor for filler estimation measurement

This cognitive sensor is developed to estimate and measure the fine filler quantity that goes out of the aggregates drying process and exits both to the baghouse filter and also the one that is poured on to the hot bins. The high-level outcome of this cognitive sensor is to obtain the real amount of filler present in the mix of aggregates, which allows then wasting less energy in the rotary drying drum and in the filtering (baghouse) process.

This CS has two kinds of physical sensors, one is a commercial solution, to measure the concentration of particles through a pipe, that has never been used before for this type of application, which includes extreme conditions (high temperature and pressure) and a high concentration of abrasive particles. The second sensor is a custom sensor based on another commercial sensor, not intended to measure concentrations of particles, but to measure perturbances of the flow, which can

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then be used to estimate the amount of filler flow through the pipe of baghouse. This second sensor is a research and innovation action of this project.

In addition, thanks to the knowledge that this sensor yields, the needed filler addition at the final mix is minimized and added only if it is detected that there is less amount of filler than the final hot mix needs.

The cognition that this smart sensor gives is based on two different parts:

- Estimation and measurement of the filler that goes out of the drying process to the baghouse filter using a mix of commercial sensor measurements based on particles impact technologies and tailor-made calculations based on accelerometer sensors placed at that pre-filter location.
- Adjustment of the aspiration in the baghouse as a function of the filler needed in the final mix.

Therefore, the outcomes of this smart sensor are to know the estimation of filler that is mixed with the sands and to avoid excessive recirculation and/or unnecessary addition of filler, making the process more energy efficient.

These two smart cognitive sensors are the core of the Sensor Layer of the Reference Architecture at Asphalt Use case of the CAP system of the project. Hence, they will be integrated in the overall CAP platform of the project, and they provide reference implementations that can serve as templates for other cognitive solutions. The rest of the layers of the Reference Implementation (cognitive control, operation and planning solutions) that will also be integrated in the plant will require access to the data provided by these sensors.

3.2 Steel smart sensors solutions

The steel use case cognitive sensor covered in this deliverable is the CSS1, the cognitive sensor for tracking billets and bars. The interest and concept of this sensor is strictly related to the production process steps: the final product of steel long producers are bars of different composition, size and length. As the process is discontinuous and the product varies in form, size and number during the whole production operation, the detailed tracking of the final bar and links to the detailed data collected at different moments is a challenging issue. In fact, the amount of data is also very variable, from the liquid steel as one unit, to the intermediate product (a billet) in units of tens up to the final bars in units of hundreds.

Historically the tracking capability was limited to coarse units such as heats and fabrication orders. In this smart sensor the combination of hardware and software aims to go to a much more detailed level, to be able to trace data that occurred in the liquid steel process and the solidification up to the bar level measured in the final steps of the process occurring many days later. This connection needs to be done in different steps and needs to connect data from different sources and systems up to the physical level.

The developments done for that are explained in this document and the attached video.

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3.3 Pharma smart sensors solutions

The two pharma-related cognitive sensor solutions covered in this deliverable, CPS1 and CPS2, both deal with the implementation of a process analytical technology (PAT) tool into continuous manufacturing process equipment (ConsiGma CTL 25, GEA). Alongside the mechanical interface, algorithms have been developed for processing the obtained raw data. The output of these sensor solutions will be part of the cognitive control concept CPC1, and their implementation covers the following topics:

1) Mechanical integration of the probe into the process equipment (KaiserRaman PhAT probe in the case of CPS1, Parsum particle probe IPP80-P in the case of CPS2).
2) Implementation of the data interfaces between the sensor solutions and existing manufacturing line, as well as between sensor solutions and the cognitive automation platform.
3) Development and implementation of algorithms required for computing the relevant information from the captured raw data (spectral data in the case of CPS1, particle size raw data in the case of CPS2).

The purpose of the two sensor solutions is to monitor the quality of granules produced by means of twin screw wet granulation. The wet granulation unit is part of a ConsiGma CTL 25 (GEA) manufacturing line. Details about the functions of CPS1 and CPS2 are provided below.

<u>CPS1 - Cognitive sensor for blend uniformity:</u> The concentration of active pharmaceutical ingredient (API) in the intermediates of a continuous manufacturing line is an important critical quality attribute (CQA). In case of API concentration exceeding threshold limits, appropriate material discharge to waste needs to be undertaken. This information is available in real-time and therefore can be used by the quality control strategy (being developed in CPC1), in order to discard non-conforming material. Through monitoring the API concentration after the twin screw wet granulation, feedback control concepts can be implemented in order to keep the API concentration close to its reference value, but also discharge decisions can be made based on reliable knowledge of API concentration.

<u>CPS2 – Cognitive sensor for granule quality:</u> This solution aims at quantifying the particle size distribution of granules directly after twin screw granulation. The size of the granules impacts important properties of the final tablet, such as the dissolution profile. By measuring the size of the granules in-line, that information can be used to actively adjust granulation parameters, in order to ensure the granule size tracks a given reference signal. CPS2 captures size distribution raw data in real-time and the algorithms then provide the information required by the control concept.

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4 Smart IoT Connection Cognitive Solutions Results

4.1 Asphalt domain

4.1.1 Cognitive sensor of bitumen content in recycled asphalt [CAS1]

CAS1, the cognitive sensor for bitumen content in Recycled Asphalt Pavement (RAP), is a sensor that has been developed from scratch for the asphalt use case. CAS1's aim is to provide a not commercially available solution for the asphalt industry: a sensor that can measure the bitumen content in RAP, in-line in the plant and in real-time, allowing the asphalt plant's planning system to adapt the amount of virgin bitumen to be added, accordingly, leading to savings in raw materials and a more environmentally friendly process.

Currently, this measurement is done at EIFFAGE's laboratories following the European Standard EN 12697-1:2020, which describes a unified approach to the examination of bituminous mixtures. Following this European Standard, the process takes around 5,5 h to be completed, comprising the following basic operations: a) binder extraction by dissolving in a hot or cold solvent, b) separation of mineral matter from the binder solution, c) determination of binder quantity by difference or binder recovery, and d) calculation of soluble binder content. This process, besides needing a number of equipment (balances, oven, solvents, binder extraction apparatus, desiccator, etc) to be completed, also demands a lot of human resources and precautions for preventing health hazard (because of the use of dangerous chemical solvents). Hence, using a sensor such as CAS1 would considerably lower the personnel time required for this process, besides diminishing the personnel's health risks by eliminating the usage of dangerous chemical products.

As described on *Table 13* of '*2.1.5 Plan for Dissemination and Exploitation of Results'* in the project proposal, the '*Commercialization of the new Bitumen monitoring tool is expected to occur 2 years after project completion, during which period AIMEN envisages protecting the new tool by patenting*'. As a result of this intention in patenting CAS1, all confidential information regarding the prototype's details cannot be disclosed to the general public, and as so it was removed from this deliverable. In the same way, the video **CAS1_Video** describing the labor developed on this work package will lack information on such details.

Within the scope of WP3, the development from scratch of CAS1 entailed several steps: 1) basic research, which included the characterization of RAP and asphalt samples, as well as its data analysis (this was a time consuming essential step); 2) optical design, which entailed the definition of illumination and detection systems, purchase of required hardware components, and 3D design of the laboratory prototype; and, 3) prototype assembly, which entailed the assembly of the laboratorial prototype, its testing in laboratory environment, its improvement and tailoring. Only once this laboratorial prototype was assembled and tested, it was possible to envision the start of the construction of the plant's prototype.

Regarding the basic research development, it started with the optical characterization of RAP and asphalt samples with different contents of bitumen, using a commercial hyperspectral camera (see Figure 2 a). [CONFIDENTIAL INFORMATION REMOVED]

The second step on CAS1's related basic research was the data processing, which required the analysis of the images and their comparison with the correspondent chemical laboratory data (obtained at EIFFAGE's laboratories according to European Standard EN 12697-1:2020). In Figure 2 b) an example of several spectral graphs can be found. [CONFIDENTIAL INFORMATION REMOVED]

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a) b)

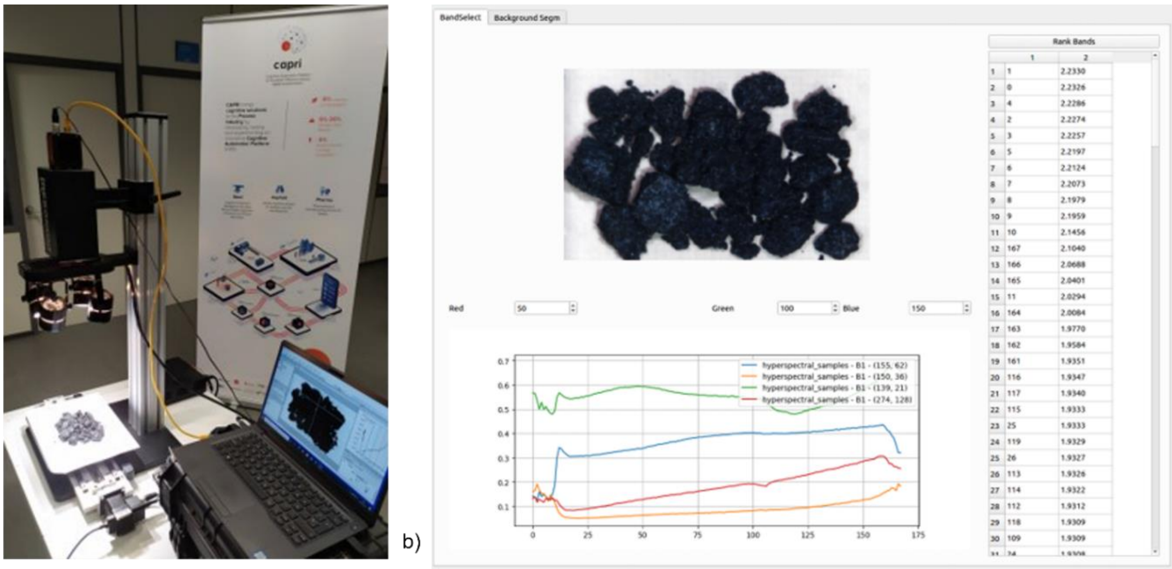

Figure 2 a) Photograph of laboratorial set up using commercial hyperspectral camera for the optical characterization of samples, and b) Image of in-house developed software for preliminary visualization [CONFIDENTIAL INFORMATION REMOVED].

[CONFIDENTIAL INFORMATION REMOVED]

The next step on the development of CAS1 was the optical design of the laboratory prototype. Based on the results of the data analysis, the preliminary definition of possible illumination systems and detection systems was made. [CONFIDENTIAL INFORMATION REMOVED]

[CONFIDENTIAL INFORMATION REMOVED]

Figure 3 [CONFIDENTIAL INFORMATION REMOVED]

Due to the continuous experimental optical characterization and data analysis of the data collected by the different versions of the laboratory prototype, there was a need for different optical component's testing, and spectral analysis of illumination systems and samples for the corroboration of the results. Performing an optical characterization using a spectrometer, several of the data analysis conclusions were corroborated. [CONFIDENTIAL INFORMATION REMOVED] This continuous labor led to improvements on the illumination system and overall components, culminating with the purchase of different COTS and continuous optimization of the opto-mechanical 3D design of the prototype.

[CONFIDENTIAL INFORMATION REMOVED]

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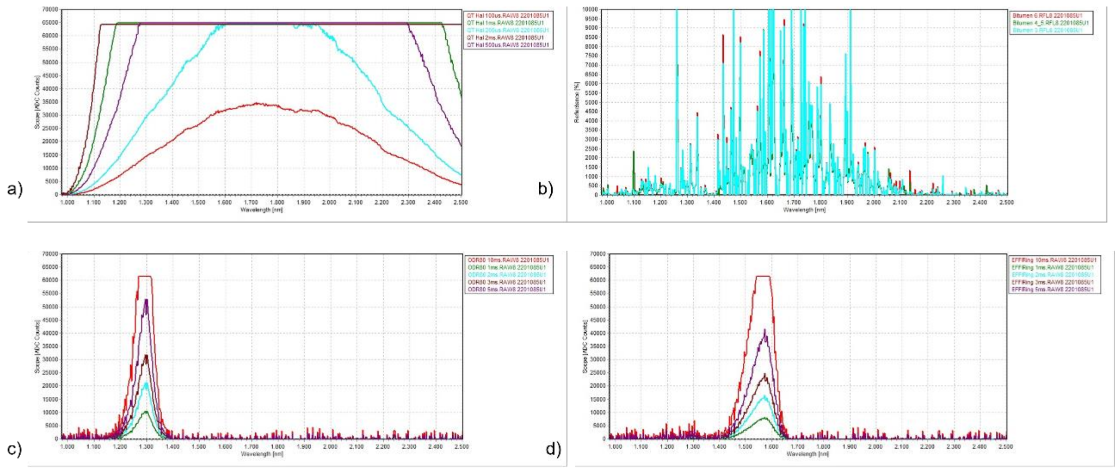

Figure 4 Spectrometer data for different integration times [CONFIDENTIAL INFORMATION REMOVED]

[CONFIDENTIAL INFORMATION REMOVED]

Figure 5 a [CONFIDENTIAL INFORMATION REMOVED]

The main components of the final prototype are defined. Nevertheless, some more experimental tests are currently undergoing to improve [CONFIDENTIAL INFORMATION REMOVED] continuously to tune the last details on the final laboratory prototype on Figure 6.

a) [redacted] b)

Figure 6 Photograph of CAS1 laboratory prototype [CONFIDENTIAL INFORMATION REMOVED].

The final CAS1 prototype will be the plant's cognitive sensing solution, which will entail an up-to-scale prototype based on the laboratorial prototype, which will include the automation of all its parts, as well as an almost real-time output of the bitumen content of the sample passing in the conveyor belt to the RAP weighting silo.

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4.1.2 Cognitive sensor for amount of filler [CAS2]

This Cognitive Solution is developed, to help to the asphalt sector, to measure the amount of filler present in the cold aggregates. This filler is the smallest part of the raw materials, 63 µm, that is necessary to the asphalt mix, but have to be measured. To obtain this measure, Cartif have been developing sensors and applications, and at the same time, analyzing a commercial sensor not defined for these conditions of works.

CAS2_Video_1.mov: laboratory test no load, without filler.

This video shows the vibration spectrogram registered during the aspiration used in laboratory conditions from 0Hz to 50Hz and from 50Hz to 0z. The test is done without any filler aspirated.

The App shown in the video is developed by Cartif in LabVIEW, this app is an internal development used for this solution. It has to be calibrated to measure the real flow of particles through a pipe and could be adapted for use in other types of plants.

CAS2_Data_1.hdf5: laboratory test no load, without filler.

This raw data file in hdf5 format contains the vibration (in g) and current consumption (in A) during the laboratory test without any filler involved. It represents the data recorded as shown in CAS2_Video_1.mov file.

The DMP associated to this Data generated is included in the file CAS2_DMP_dataset1_2.xlsx

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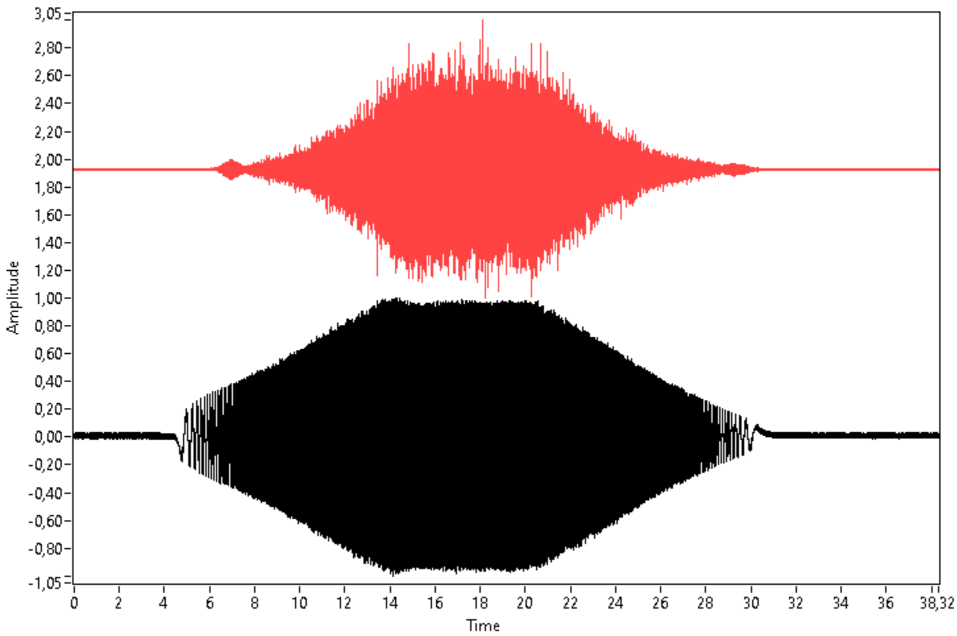

Figure 7 data representing the vibration (red) and current consumption (black) aspiration without filler. Values of the graph shown per unit values.

CAS2_Video_2.mov: laboratory test aspiration of filler

This video shows the aspiration of filler of three piles (each of 5g) while the aspiration is working at 30Hz. The spectrogram of the vibration on the left screen shows the bursts of the different piles of filler while they are aspirated.

CAS2_Data_2.hdf5: laboratory test aspiration of filler

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This raw data file in hdf5 format contains the vibration (in g) and current consumption (in A) during the laboratory test while aspirating three piles of filler (each of 5g). It represents the data recorded as shown in CAS2_Video_2.mov file. Each time a pile of filler is aspirated, the vibration increases. The figure below only shows the vibration as the current consumption is practically constant.

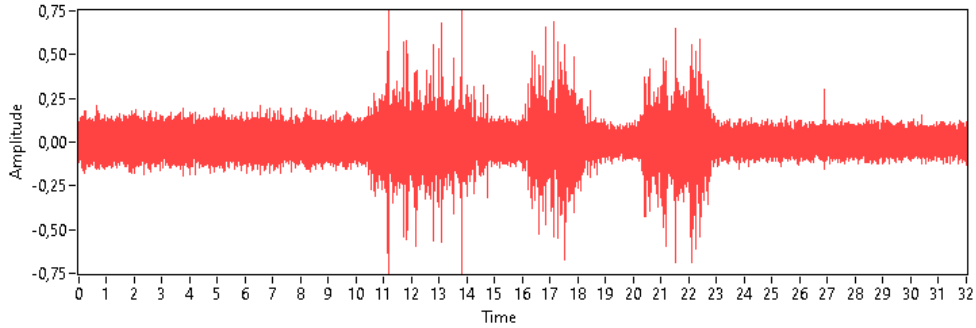

Figure 8 data representing the vibration (red) during the aspiration of three piles of filler. Values of the graph shown in g.

The DMP associated to this Data generated is included in the file CAS2_DMP_dataset1_2.xlsx

CAS2_Video_3.mov: estimation of filler aspirated in laboratory experiment

The video shows an estimation of the quantity of filler aspirated in the previous example of data (CAS2_Data_2.hdf5) where the raw vibration is processed and calibrated so the final amount of filler corresponds to the three piles of filler aspirated (each of 5g). The result of the calibration shows a translation from the vibration measured in g to the flow of filler in grams per second.

CAS2_Data_3.csv: estimation of filler flow and accumulated quantity of filler

The data represents the estimated filler flow from vibrations in grams per second and the accumulated grams aspirated at the end of the experiment corresponds to the 15 grams separated in the three piles.

The DMP associated to this Data generated is included in the file CAS2_DMP_dataset3.xlsx

CAS2_Data_4.csv: Asphalt Plant, comparison of process variables with CAS2 sensors

The data file represents the amount of vibration measured in the EIFFAGE asphalt plant during the drying process of aggregates. The vibration is compared with the results offered by the commercial sensor tested in parallel (in ppm). The data also contains relevant process variables from the control of the plant like the set point of aggregates flow into the drying drum (in T/s) the aspirated pressure (in mm H20) and the temperature input at the baghouse. The sequence of operation of the baghouse and drying drum is the following:

Table 3: Important points of comparation the process variables from Gerena Plant and the CAS2

INSTANT	EXPLANATION
1	Starts the aspiration of the baghouse
1 2	Baghouse at depressure of maintain, sensors starts to measure the flow without filler
2	Star the flow of aggregates
2 3	Production, measure of filler
3	stop the flow of aggregates
3 4	Measure of filler, production off, baghouse on
4	decrease the depressure of the baghouse, stop flow of filler
4 5	No aggregates, baghouse with maintain depressure, low vibration of sensor
5	Stop the plant

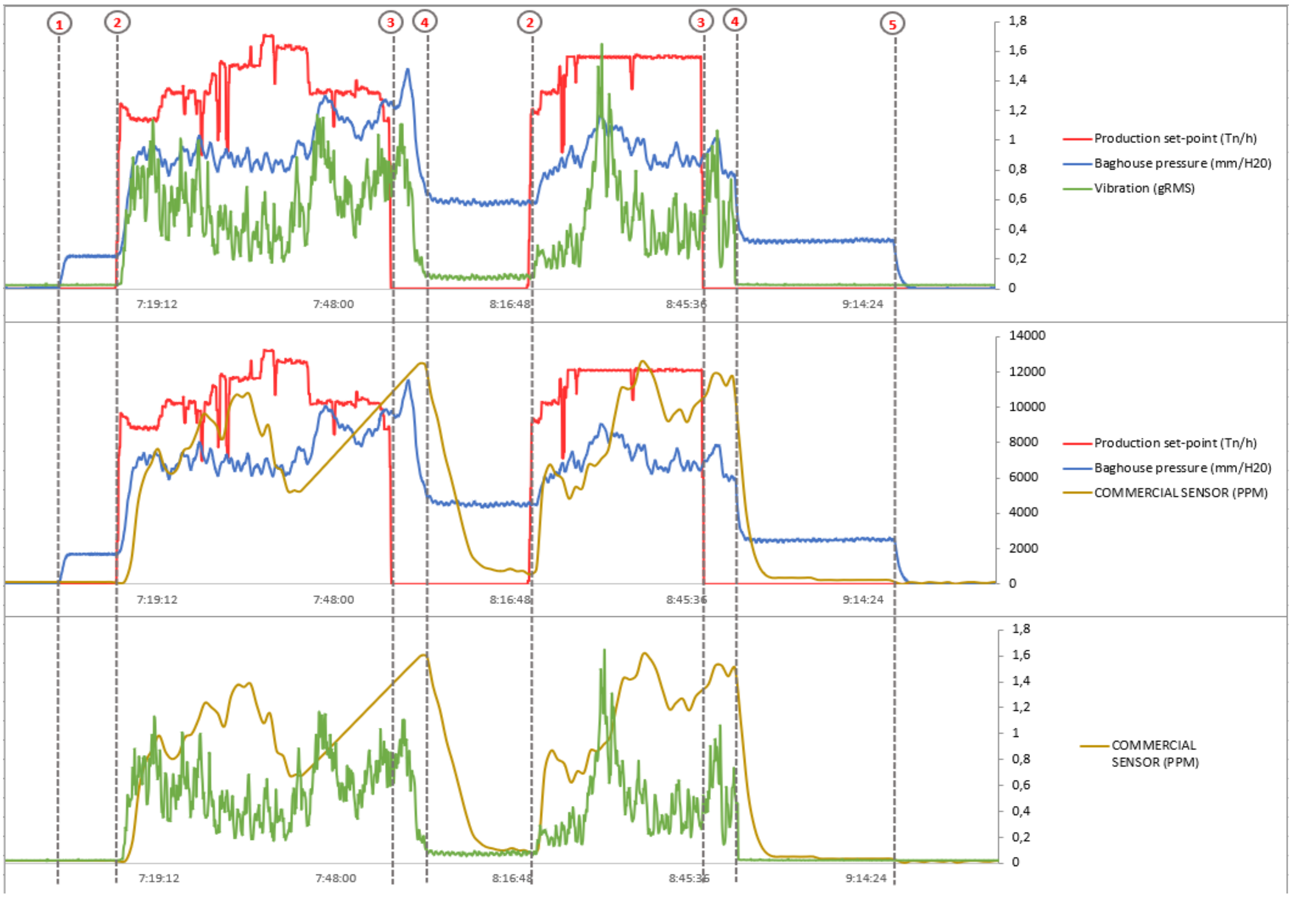

Figure 9 Comparison of vibration and commercial sensor in the actual asphalt use case plant located in Gerena village (Sevilla). The process variables of aggregates flow, pressure at the baghouse and temperature at the baghouse is also shown.

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The DMP associated to this Data generated is included in the file CAS2_DMP_dataset4.xlsx

NEXT STEPS

The platform for user interaction has not been finalized at the time of writing, since the WP3 scope was only for laboratory development. This part of the CS is still under development, with the final version of the Cognitive solution it will be launched.

The objective is that once all the CAPRI solutions will be running the results will be shown on a screen available to the plant operator. Providing continuous decision support, the plant operator doesn't need to actively engage with the cognitive solution. The advices that to be displayed on the screen will be to increase or decrease the depressure of the baghouse, to work with the best magnitude of depressure, whose final objective is to extract only the filler extracted not necessary to lose the least energy. In this moment. The plant operator extracts all the filler (except the 2%, is not possible to extract this percent) after the process of drying in the drum, and adds the necessary filler for the recipe of asphalt in the mixer. This filler added is cold, and leading to an unavoidable loss of energy.

The final cognitive solution of amount of filler will need the following input of data: the algorithm collects the data of the physical sensor by UDP connection, the data frames of production and the depressure of the baghouse of the plant and historical data. The historical data required is the correlation between the depressure of the baghouse and the filler not extracted. With these three frames of data, the processing can start. When the plant is working, the automatic process of identification is started and this process reads the depressure of work and compares it with the historical data to know the amount of filler that will pass to the hot aggregates. This percentage of filler then has to be compared to the amount of filler in the recipe for the final mix. If the % of filler obtained with the depressure of work of the plant is less than the % of the final mix, the algorithm will recalculate the optimal depressure of the baghouse to extract only the excess of filler. The other situation that can occur, is that the filler present in the cold aggregates is less than the filler necessary to the final mix, in this case, the algorithm will send an alert to add new filler to the mix.

4.2 Steel domain

4.2.1 Cognitive Product Tracking Sensor [CSS1]

The final product of steel long producers are bars of different composition, size and length. As the process is discontinuous and the product varies in form, size and number during the whole production operation, the detailed tracking of the final bar and links to the detailed data collected at different moments is a challenging issue. In fact, the amount of data is also very variable, from the liquid steel as one unit (the heat), to the intermediate product (a billet) in units of tens up to the final bars in units of hundreds. The fabrication orders are linked to sets of billets from the same heat. Historically, both heat and fabrication order tracking has been strictly checked and recorded: it is always known the heat of origin from any fabrication order, and, in consequence, of all the bars belonging to it.

In CSS1 the objective is to go up to more detail and be able to know the particular history bar by bar. CSS1 is done in two parts:

- The first part connects the billet from the casting machine to the rolling mill by marking each billet with a laser and later reading with visual cameras. This part allows to know with more detail the data that corresponds to one billet. This aspect is interesting as the billets are

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casted in different strands, that, in principle and design, are alike but, in practice, can have some small differences. Even more, the billets are produced in different moments of the casting process, if there have been differences in some production parameters they will not be exactly the same for all the billets.

- The second part connects the output from those billets, the bars, from the rolling mill to the finishing units, using laser marking and visual cameras too. So, connecting both systems, each bar has the information about the casting data and some rolling data too.

In both cases, a close connection with the MES systems and Level 2 systems is necessary as the marking system has to know what to write in each billet/bar and has to add the machine tracking information. The system to track the product from process to process is an engraved QR code containing the relevant information that is stored physically on the product surface. The cognitive aspects of the CSS1 come in those parts, the connection with the original data and the tracking to be able to write the correct QR code. After that, the reading part consists of an image analysis, which is frequently challenging in industrial conditions.

The first part of the sensor is fully operative, whereas the second one has been operatively tested but faces some implementation difficulties due to a revamping in the rolling mill. This has some impact on the other cognitive steel solutions under development in CAPRI, since the tracking sensor is an important enabler for them. For this reason, a mitigation strategy has been developed based on one concrete type of orders, which consist of only one billet.

CSS1 is interesting by itself, but at the same time is a helper system to other cognitive solutions in the steel use case.

CSS1_Video_1.mp4

The video shows real life images and videos of the different parts that form CSS1, the product transformation (liquid steel, billet, bar) can be observed and the marking process is highlighted as well as the result over billets and bars. The part that is not seen in the video is the connections with the level 2 and MES databases and the identification process of the products; these aspects are not as visual and easily explainable in video format.

4.3 Pharma domain

4.3.1 Cognitive sensor for blend uniformity [CPS1]

Raman spectroscopy (utilising the Kaiser Optical Systems RamanRxn2™ Hybrid in situ analyser + PhAT probe) is the technique used for quantifying the API concentration after the twin screw wet granulation. A mechanical interface at the outlet of the granulator has been designed and constructed to integrate the probe into the line, specially fitted to the requirements of the Raman technique. A fixed amount of material is periodically sampled and presented to the sensor, excluding interference like light. A stainless-steel cylinder of sufficient diameter was constructed with an opening on the side to insert the probe, easy to clean and with Tri-clamp flanges attached. This metal part is also used for implementing CPS2 and is shown in Figure 10. Three-dimensional-printed parts have been developed which are suitable for collecting the material sample, presenting it to the probe and holding the PhAT probe. These are shown in Figure 11. By means of an electric drive, the sample holder is rotated precisely 180°, which leads to an emptying of the cup and an immediate start of filling for the other cup. During rotation, a sealing lip cleans the probe window of residual granules. Additionally, a pneumatic cleaning mechanism has been implemented in order to remove granules from the 3D-printed sample chamber. The rotation of the sample holder and the pneumatic cleaner need to be synchronised to the measurement rate of the Kaiser RamanRxn2 system.

Figure 10 Metal cylinder to hold the Raman or Parsum probe

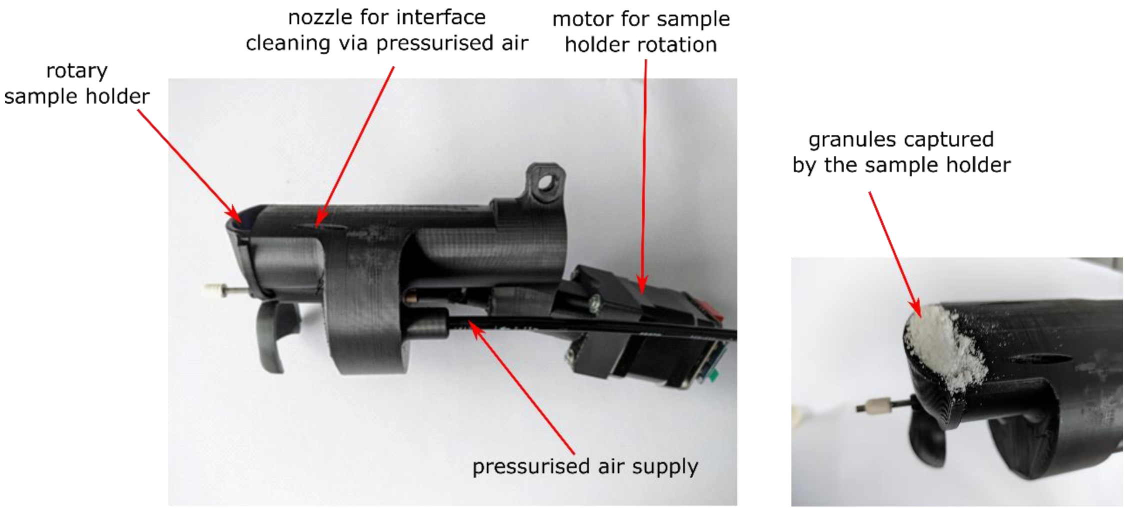

Figure 11 3D-printed prototype of the sampling device and probe holder

The RamanRxn2™ is configured by means of dedicated measurement software. A CSV formatted file, saved on the local hard disk of the measurement computer, is used to store the measurements of each acquired spectrum. A Python program was written that reads these files and publishes the acquired spectral data via an OPC UA server. Whenever a new file is stored by the measurement software, the spectrum is read and the OPC UA server data tag is updated accordingly. The data of one such CSV file contains two columns, the first one containing the Raman shift in cm^{-1}, the second one the intensity of the backscattered photons counted by the Raman spectrometer. Each column has 1741 elements. The acquisition rate of the spectra is approximately every 20 seconds. This raw data is then processed by the algorithm in order to predict the concentration of API. The algorithm is implemented in Python and executed on a small single-board computer, a Raspberry PI. The computed concentration value is then written to the OPC server that is running on the Kaiser Raman

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measurement computer. Next to the concentration prediction, the motor control and pneumatic control is also executed on the Raspberry PI, which communicates via UART and SPI interface with the actuators (motor to turn the sample holder and air pressure regulator to pneumatically clean the probe). Status information and motor commands are shared via the OPC UA protocol with the OPC UA server, which is located on the Kaiser Raman measurement computer. A schematic overview is shown in Figure 12. Details about the concentration prediction algorithm are provided in the next subsection.

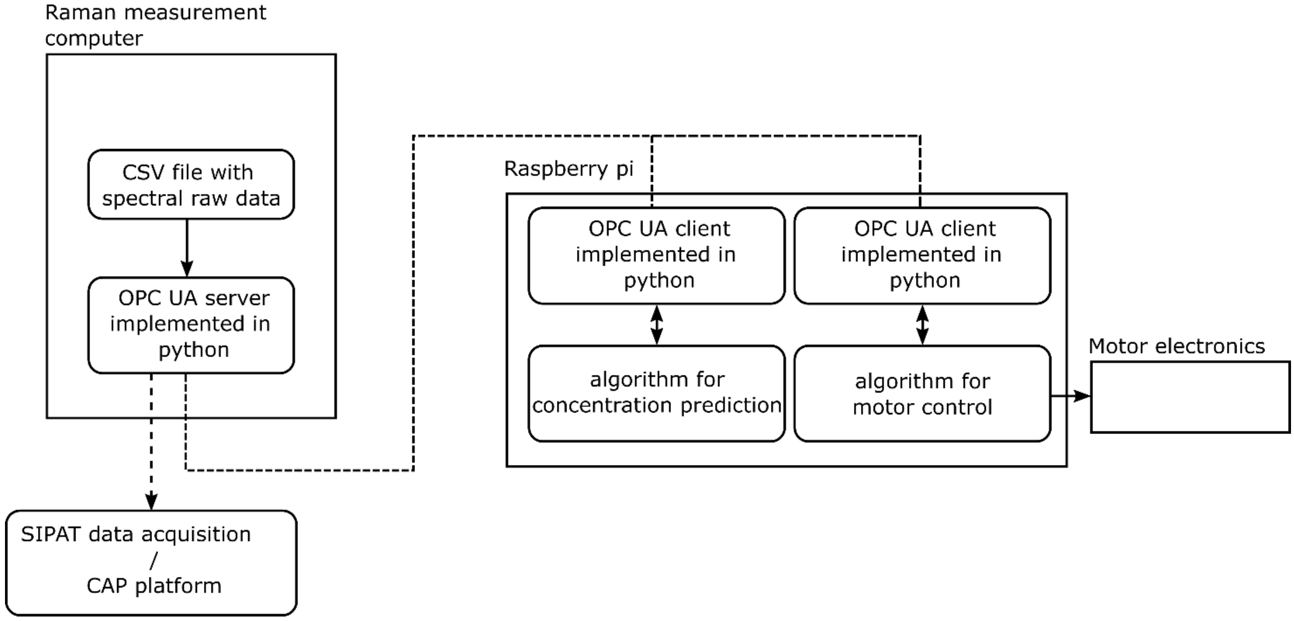

Figure 12 Overview of the data flow

1) The following tasks are accomplished by the concentration prediction algorithm. Their execution is triggered by the availability of a new Raman spectrum on the OPC UA server, which is automatically pushed to the client. Initially, the baseline of the captured Raman spectrum is corrected. This is accomplished by means of the Python library “pybaselines”.
2) Standard Normal Variate (SNV) processing of the selected part of the baseline corrected spectrum (subtraction of spectrum mean value, normalisation by standard deviation)
3) Normalisation to PLS-model by subtraction of average spectrum, selection of PLS- covered wave and execution of PLS prediction in order to compute the API concentration.

After the concentration has been computed, its value is written back to the OPC UA server.

The algorithm used for motor control is also triggered by the availability of a new Raman spectrum on the OPC UA server. Whenever a new spectrum is available, the motor is rotated by 180° and the adjustable air purge is triggered for cleaning the sampling device of granule residuals. The reaction to user input is also covered by this algorithm (e.g., manual rotation of the sampling device is possible by pushing a button).

The zip file related to CPS1 contains the following files:

Table 4: Contents of the zip archive related to CPS1, CPS1_App_and_Data_1.zip

OPCClient_Prediction_V05.py	Python implementation of the prediction engine used to compute the API concentration from the spectral data

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KaiserRamanVirtual_V03.py	A test version of the OPC UA server running on the KaiserRaman system. It reads sample spectra and provides them via OPC UA. In addition, the tag for the computed concentration value and the motor control tags are provided by that server.
calibspectra\01_0117_Spectrum_20211021-13_56_21_364446.csv calibspectra\05_0189_Spectrum_20211021-14_20_21_186483.csv calibspectra\11_0297_Spectrum_20211021-14_56_21_174045.csv	Sample spectra of the KaiserRaman system. These are being read by the KaiserRamanVirtual_V03.py script and provided via OPCUA.
model\General_List_M13.xlsx	Excel sheet containing the chemometric model data that is needed by OPCClient_Prediction_V05.py for the prediction.
Model\Workset_Statistics_M13.xlsx	Excel sheet containing average spectrum that is needed by OPCClient_Prediction_V05.py for the prediction.

The DMP associated to this Data generated is included in the file CPS1_DMP_App_and_Data_1.xlsx

4.3.2 Cognitive sensor for granule quality [CPS2]

A Parsum IPP80-P particle size probe based on the special filter velocimetry technique was used. The particle size measurement range is between 50µm to 6000µm. A mechanical interface to mount the probe at the twin screw wet granulator outlet has been designed and constructed. The same metal cylinder, as for the CPS1 solution, has been used. A 3D-printed part holds the Parsum probe and fits to the metal cylinder. See Figure 13.

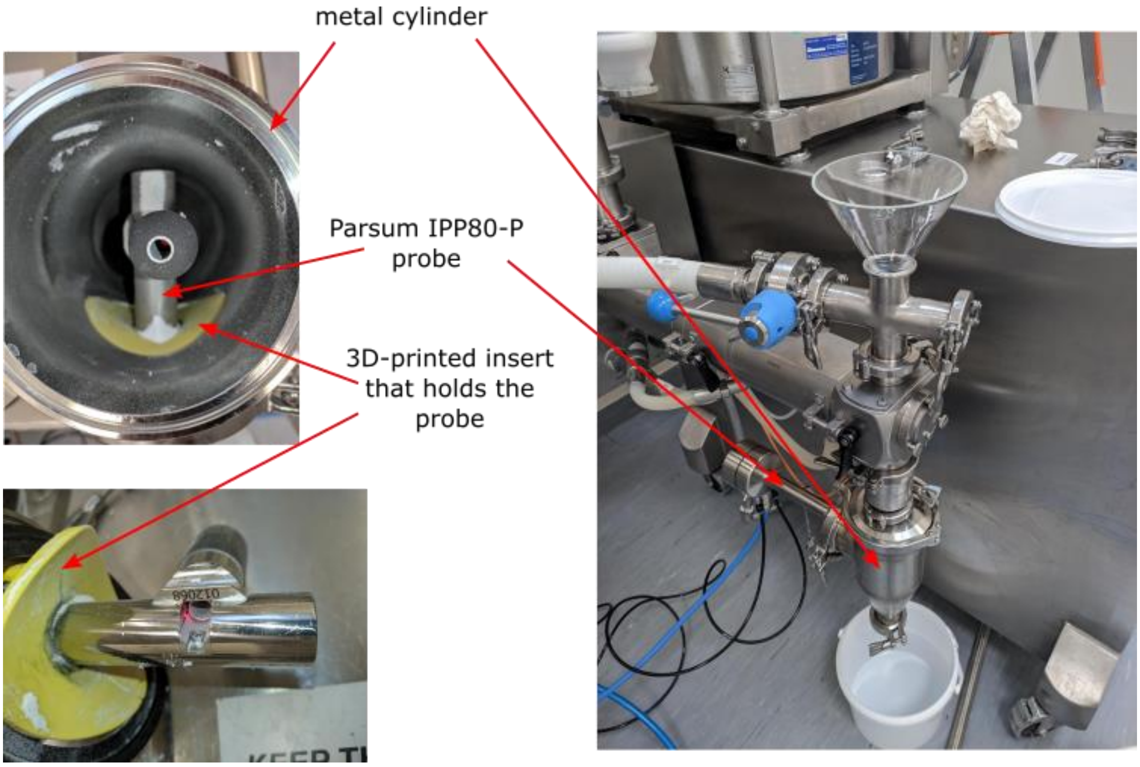

Figure 13 Mechanical interface built for connecting the probe to the process

The measurement software of the Parsum system provides the measurement results via an OPC server. The raw particle size distribution is available in the form of a multivalue-array. The number of array elements is equal to the number of size classes defined in the measurement software. Further, an array containing the corresponding particle size classes is also available. These are the two main sources of information used by CPS2. Example size distributions are shown in Figure 14. In addition to those arrays, data tags indicating the quality of the provided raw measurement data are available (e.g., particle loading in %, number of particles used to compute the size distribution).

Besides the data originating from the Parsum system, process data provided by the ConsiGma CTL 25 system was used in CPS2. The goal is to substitute the physical sensor by means of a data driven model, acting as a soft sensor for granule size characteristics. Specifically, the solid and liquid flow rates at the granulator inlet were captured to compute the liquid to solid ratio, which in turn was used as input to the soft sensor.

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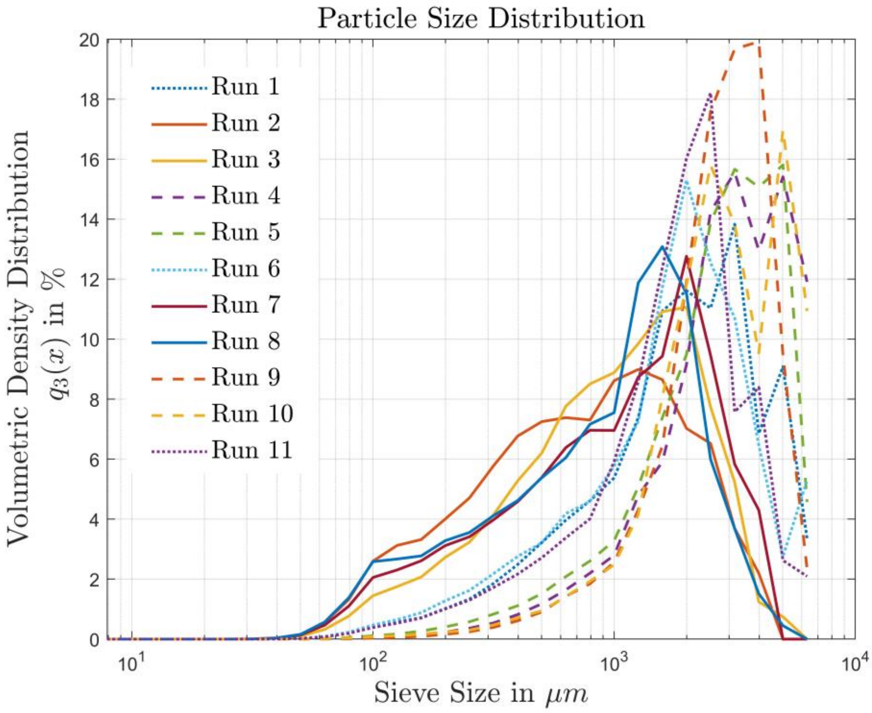

Figure 14 Size distributions captured during 11 trial runs

From the raw spectra provided by the measurement system, characteristic size values have been computed. These characteristics are then used in CPC1 (see deliverable 3.3). The first four moments M_k of the volume-based size distributions, given in the equation below, were computed.

$$M_{k,3} = \int_{x_{min}}^{x_{max}} x^k q_3(x) dx$$

The integral was approximated by the trapezoid rule available in the “numpy” package of Python.

A soft sensor has also been developed. The purpose of the soft sensor is to predict the moments from available process data. The use of this soft sensor allows the removal of the Parsum probe from the process, but still obtaining an estimate of the moments of the granule size distribution. Since in the current setup, only one of the PAT tools (either Raman or Parsum) can be installed at a time, this soft sensor for the granule size can be a valuable tool, in case the Raman probe is mounted at the granulator outlet. The model used for estimating the moments from process data is based on the so-called local linear model tree (LOLIMOT) algorithm. Model input is a granulation liquid-to-solid ratio and model outputs are the first four moments of the size distribution. The LOLIMOT-model was trained with experimentally obtained process data. A dedicated set of validation experiments was also performed.

Table 5: Contents of the zip archive related to CPS2, CPS2_App_and_Data_1.zip

A3_exe_CPS2_realtime_V01.py	Python implementation of the function that performs the computation of moments.
A3_exe_CPS2_tests_V01.py	Test file to call A3_exe_CPS2_realtime_V01.py; this file reads sample data from test_q3.csv and test_sieve_vec.csv. In the real implementation,

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	the two variables q3 and sieve_vec will be collected from an OPC UA server, each of them being a 36-element float array.
test_q3.csv	Sample size distribution to test the functionality.
test_sieve_vec.csv	Size bins corresponding to the q3 distribution.

The DMP associated to this Data generated is included in the file CPS2_DMP_App_and_Data_1.xlsx

5 Conclusions and Next Steps

D3.2 – "CAPRI Industrial IoT Platform and Data Space", is a deliverable of type OTHERS that, together with D3.3, D3.4 and D3.5, contributes to target the 'MS4' milestone related to technology validation of different cognitive solutions at M24. The document describes the concrete achievements in the development of the standalone smart sensors cognitive solutions. Main practical results have been detailed for each domain and cognitive solution, providing algorithms, sources, data format, data samples, and videos showcasing the implementation done in laboratory activities in WP3.

The output of WP3, starting from the sensors based cognitive solutions described in this deliverable, will be integrated with the CAP platform in order to satisfy the needs of the three CAPRI domains (i.e., Asphalt, Steel, and Pharma) supporting all use cases and covering the entire data life cycle from the data ingestion to the data presentation. The algorithms, already analysed in terms of rationale, technology, and intellectual property, will be integrated into the CAP platform for implementing the processing layer in WP4. After the integration of the cognitive modules, the platform will be tested and tuned, thus feeding the validation scenarios in the three plants, to be addressed in WP5 through two iterations. On the other hand, a toolbox of cognitive solutions for sensing, control, operation and planning will be developed to help the adoption of the CAP for batch, continuous and hybrid process industry plants. The final validation will take place in WP5, addressing manufacturing challenges in industrial operational environments of the three chosen process sectors, and providing useful feedbacks and lessons learned.

Next steps will be in T4.1 (on Cognitive sensor solutions for process industries), where cognitive sensors developed within WP3 will be integrated with the CAP following a modular and iterative approach, to provide a holistic solution, managing the cognitive functions embedded in cognitive sensors. At the same time, the integration will enable a higher level of intelligence exploiting the vertical integration of such sensors with other processing modules, at both edge and cloud level, delivering the cognitive applications towards the appropriate user role (e.g. planners, managers, workers), with first deliverables due by M28.

The "Sensor Layer" Reference Implementation of the CAP will be developed and will enable further customizations for the implementation of the three tailored instances of the CAP for the three pilots. This layer will provide features and capabilities to enrich physical sensors with soft sensors and digital twin representations required for further control and business services.

The progression in the maturity of the cognitive solutions will enable an in-depth analysis in WP7, for the shaping of the exploitation opportunities of the different CAP layers and the CAP platform as a whole, as well as opportunities for replicating cognitive solution in other sectors of process industry.

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