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Utilisation of a Hybrid Approach for Immersive Industrial Process Control Visualisation

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Abstract—**The objective of this paper is to present a proposal of hybrid system architecture for industrial process control visualisation. Leveraging of interoperability standard protocols for industrial automation, it is possible to create process agnostic visualisations. An application of this approach will lead to a hybrid system, which provides HMI (Human Machine Interface) layer for simulation, as well as real-world based industrial processes. An immersive 3-D visualisation is examined for the purpose of complex real-time process variables exploration. Reasonable 3-D visualisation types for industrial process HMI are identified. The idea is to create an immersive virtual environment for displaying industrial process related information, in order to help human operators to understand observed system behaviour and support them in the decision making process.**

Index Terms—**SCADA/HMI, n-D visualisation, OPC, simulation.**

I. Introduction

IN the field of industrial automation, we can identify software systems labeled as IaCS (Information and Control Systems). According to [1], all of them have similar characteristic properties such as: distribution, integration, openness and scalability. The hierarchy diagram for IaCS is shown in Figure 1.

This paper is focused on development of an immersive HMI system. The main purpose of a HMI is to present raw or calculated (abstract) data from industrial processes to the human operator. The main objective of a HMI is to gain glue on the overall state of an industrial process and, if necessary, enable direct human operator interventions (e.g. alarm situations). Visualised data could originate from different levels of the system hierarchy (starting with the low SCADA (Supervisory control and Data Acquisition) layer up to the high ERP (Enterprise Resource Planning) layer). Visualisation is one of the most common used techniques for data representation. It helps operators to find relations and behaviours which usually cannot be observed directly from the raw form.

The trend which is nowadays visible all across the automation industry is to decrease the number of operators necessary for the task of process control. However the amount of information which have to be processed by human operators is continuing to increase. The complexity of different industrial processes is causing a high cognitive load for each operator and accordingly could result into wrong decisions during the process control task. The purpose of this paper is to design architecture for the new generation of immersive HMI systems capable to generate n-D visualisations from complex industrial processes regardless of the real or simulated character of process variables.

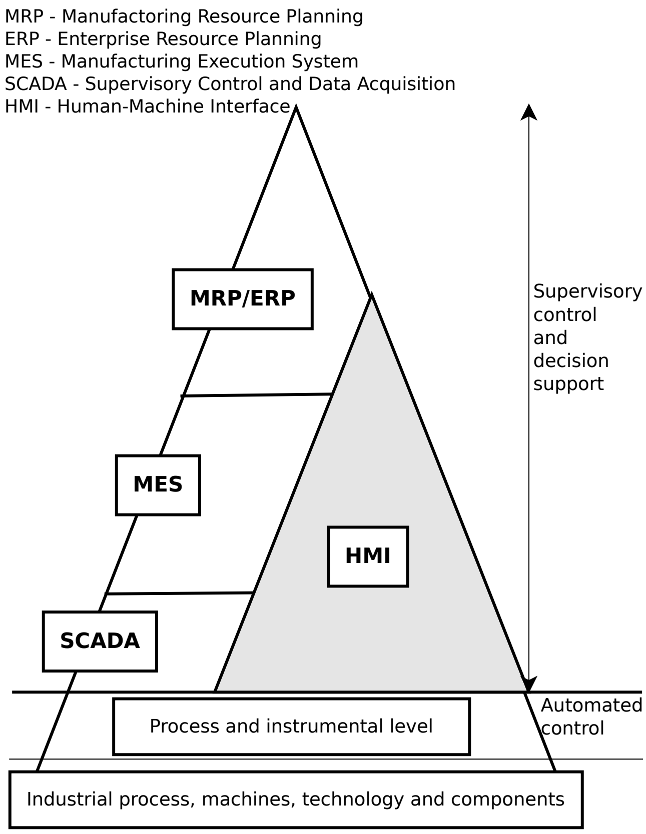

Fig. 1. Hierarchy of Information and Control Systems [2]

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II. Industrial process control visualisation - state of the art

Visualisation is a technique very often used in the research, academic and industrial area. By utilisation of an abstraction, it presents the data in a better understanding form. Regarding to [1] visualisation in the field of industrial automation is defined as a process of making information and relations between information (both real and abstract) visible. Two types of visualisations used in the automation industry are distinguished:

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1) Industrial visualisation: focuses on making objects and relations between them visible specifically in the automated control level of IaCS.
2) Process visualisation: focuses on making objects and relations between them visible in the technological/manufacturing or automated control level for the purpose of supporting the decision making and enabling an operator control in IaCS.

The concept of visualisation matrix, shown in Figure 2., was introduced in [3]. According to this, it is possible to picture the flow of information from the low level (machine) to the operational level as it is figured in Figure 3.

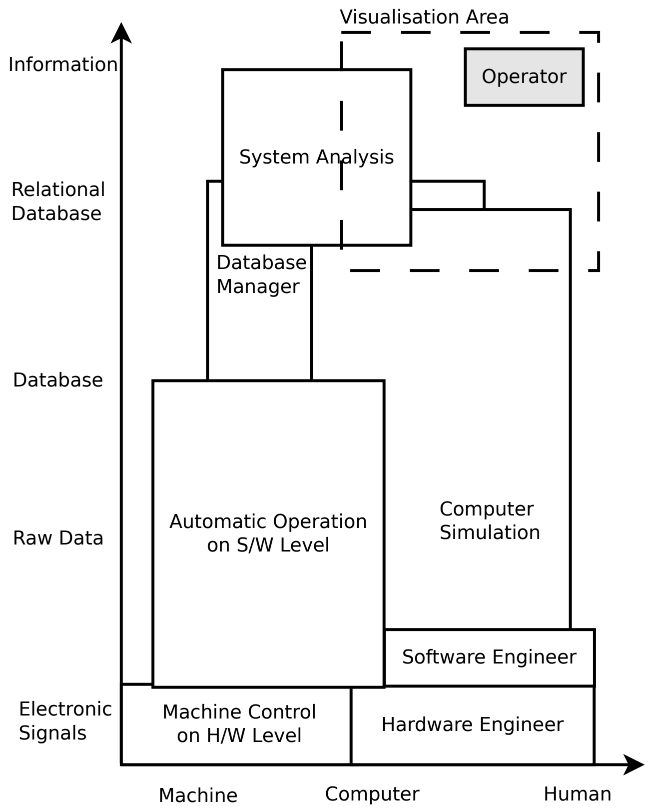

Fig. 2. Visualisation matrix concept [3]

During the evolution of visualisation systems in the automation industry, a shift from special purpose analog devices (e.g. light signalisation), through graphical GUI interface [4] up to more advanced approaches (remote visualisation distributed over the Internet), was made. Current commercial SCADA systems are leveraging from modern software engineering paradigms as usage of rich user interfaces (AJAX, Silverlight, ...) [5] , [6] and SOA (Service Oriented Architecture). Additionally cloud technologies, usage of mobile devices and integration of GIS (Geographical Information System) are starting to influence industrial automation software solutions [7].

Current research trends in the field of the industrial process control visualisation are leading into the utilisation of more dimensions for the data representation. A conventional HMI with a schematic industrial process representation and trending 2-D graphs are subject of new design approaches.

The main SCADA system producers are already providing 3-D extensions to their standard HMI, however the acceptance rate for this approach from industry professionals is not very high [8] (referring to the situation in Slovakia). This is one of the reasons, why there is an ongoing discussion, focused on discovering new solutions for an industrial process control visualisation. Commercial solutions focusing purely on the realistic 3-D visualisation were introduced in [9] and [10]. Another interesting work, dealing with the development of an industrial process visualisation framework was published [11] and [12]. An utilisation of the classical schema representation for SCADA/HMI as a foundation for 3-D UI (User Interface) construction was proposed in [13]. Furthermore Lange et al. [14] provided an example of flight control management utilising virtual reality with 3-D interaction techniques. Most of those researches were primarily oriented on the construction of realistic 3-D HMI, focused on making a virtual environment as close as possible to the real world processes. On the other hand only a little work have been done in actual experimenting with n-D environments, which are not exact replica of the real world but rather create more abstract visual representations of industrial process variables. Meissner and Hensler [15] provide one example concentrating on the new generic visualisation technique for industrial processes. Evaluation of n-D process data visualisation was recently presented in [16].

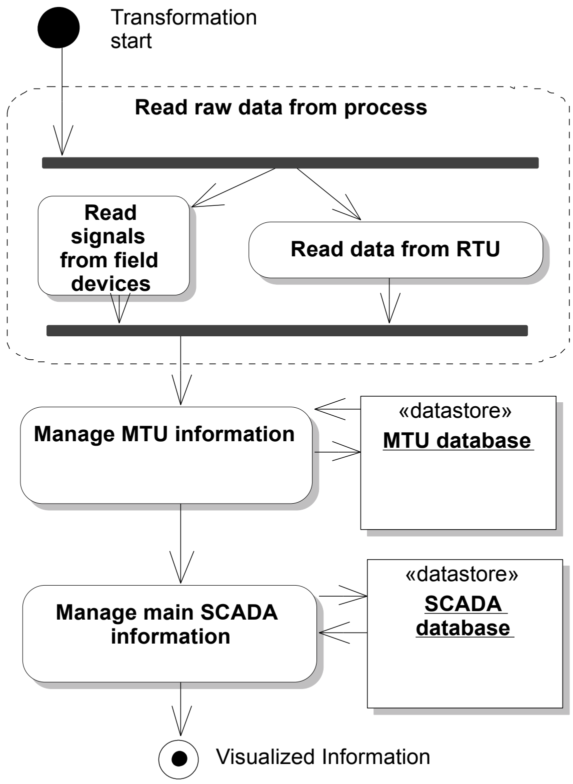

Fig. 3. Information generation in industrial process

An n-D visualisation is a promising and rapidly developing area, especially when it comes to application on new generations of SCADA systems. However, currently there is no open framework oriented on n-D process visualisations with the following features:

- process interoperability build on top of latest open standards,
- immersive visualisation capability (monoscopic as well

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as stereoscopic),

- open not only for a classical mouse/keyboard interaction but also support natural interaction paradigms used for different forms of display setups (power-wall, CAVE, etc.)

Fundamental requirements for the proposed system are written in Table I.

TABLE I
FUNDAMENTAL REQUIREMENTS FOR A HYBRID IMMERSIVE PROCESS CONTROL VISUALISATION SYSTEM

SYSTEM FEATURE	DESCRIPTION
hybrid data acquisition	usage of interoperability standards in order to support data acquisition from the real world industrial process as well as different data sources (e.g. process model simulation)
immersive visualisation	integration of real 3-D engines for creation of virtual environments; mandatory to enable definition of new process control data visual representations; the display output has to be configurable for the purpose of mono- and stereoscopic projection
open architecture	allow easy integration of different components; an advanced visualisation (based on a knowledge generation) has to be considered for the future development
interaction independent	not restricted to classical interaction devices; enable support for n-D interaction input
operators collaboration	allow multiple operator interaction while exploration of industrial process data (agent based visualisation)
security and permission of the control	when the natural interaction is employed, the system has to recognise user with permission to operate the process

III. DESIGN OF A HYBRID PROCESS CONTROL VISUALISATION SYSTEM

In this paper we are designing the architecture for a new generation of process data acquisition and visualisation systems. The provided solution should be considered as experimental and used as a platform for creation and evaluation of an immersive process data visualisation. In comparison to the classical SCADA desktop software, it will take advantage from different display setups and interaction scenarios. However the idea is not focused on replacing all standard visualisation approaches, but rather to create an extension, in order to enable better understanding of process variables behaviours in the complex industrial process control system. The diagram in Figure 4. shows a display and control information flow in proposed system. Main parts are described as follows:

a) Data generation: creates raw data. It could be the industrial process itself (with physical field devices etc.) or it could be a process simulation.
b) Data acquisition and storage: leveraging automation interoperability standards, data are collected from the data generation layer. They are transformed into data structures which are appropriate for providing uniform data access (raw and calculated real time data). For this purpose, typically a real-time distributed database system is used. Furthermore, the history is stored (usually in a relational database system).
c) Information generation: uniform data structures are analysed, in order to generate advanced information (knowledge). It could be done via utilisation of classical or online (reinforcement) machine learning algorithms.
d) Information visualisation: real-time, historical and knowledge data are combined. The concept of visualisation pipeline is used in order to transform these data structures into objects required by visualisation system.
e) Operator control: HMI (Human Machine Interface) is used in order to distribute control commands from operator to visualisation (control of the view) or to industrial process (control of the process).

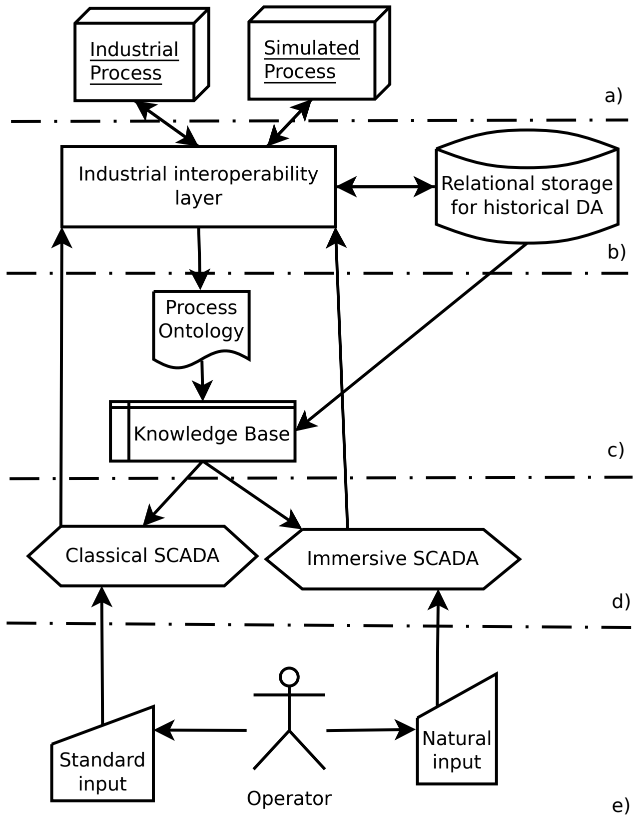

Fig. 4. A display and control information flow in the hybrid process control visualisation system. From up to down: data generation a) data acquisition and storage b) information generation c) information visualisation d) operator control e)

A. *Simulated and Real-World Industrial Process*

In order to handle interoperability issues, the decision was made to incorporate OPC UA (OPC Unified Architecture) [17] as a main inter-process communication protocol. OPC UA had been developed as an ancestor of a standard OPC protocol (sometimes denoted as OPC DA). In comparison to the classical OPC, OPC UA is leveraging SOA paradigm (Service Oriented Architecture). In the context of SOA the OPC UA server exposes all the functionality as special services. The communication is established via resolved via special purpose binary description (called UA Native) or the web services markup language (based on XML).

The address space model [18] is one of the main advantages of OPC UA technology. It is a high level description of an industrial system. Address space basically creates a

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meta-data ontology, which describes the industrial process. This makes the process description ubiquitous, mutually understandable by diverse systems [18]. OPC UA than could handle the problem of data acquisition from infrastructural level up to information provision of the most top ERP (Enterprise Resource Planning) software. Data generation layer (real-world industrial process or simulation) is hidden behind the OPC server which behaves as generic data access layer.

The meta-data description of an industrial process can have a form of the object model, similar to class/object UML notation from software engineering. However it is still compatible with a tree-like view (sometimes referred as a node model) as it is shown in Figure 5.

Simulation of industrial processes allows different types of visualisation scenarios. One of the most interesting applications is experimenting and operator training without the effect on real-world process. An example of OPC UA address space for the absorption refrigeration process simulation [7] is shown in Figure 5.

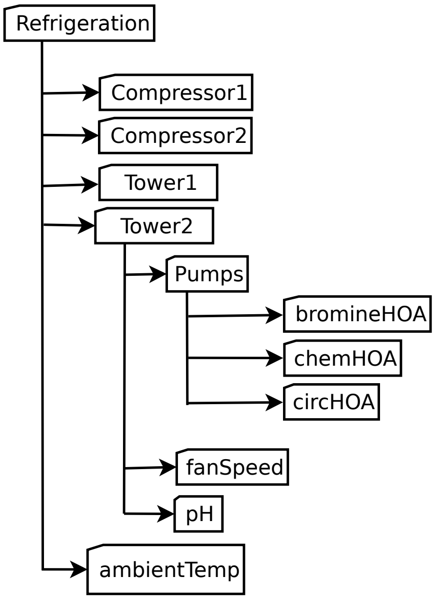

Fig. 5. Example of an address space tree-like representation of an absorption refrigeration process control simulation.

B. 3-D Industrial Process Control Visualisation

This section concentrates on the application of visualisation techniques to the industrial process control. Table II contains descriptions of identified basic visualisation concepts applicable on industrial process data. The resulting visualisation could contain photo-realistic as well as abstract representation of underlying industrial process. A disadvantage of strict realistic visualisation, as it is shown in Figure 6. a), is the fact that (depending on level of detail) some information could be lost in the 3rd dimension perspective. On the other hand it is useful in order to present the structure of industrial process itself. An abstract visualisation, see Figure 6. b), suits better for the cases when an operator is looking for a specific behaviour of visualised process. It shows data from other an one time step or a chosen historical time period.

TABLE II
3-D VISUALISATION CONCEPTS FOR INDUSTRIAL PROCESS CONTROL SYSTEM

VISUALISATION CONCEPT	DESCRIPTION
process data graph	is referring to the visualisation concept where real time values coming from process variables are displayed in the form of multi-dimensional graphs. Utilisation of more dimensions increase a number of displayed process variables at once, while the operator is still able to keep a track of them. This fact is important when especially when we are talking about the complex industrial process with many distinct variables.
process event	signalising ongoing alarms or another events presented in the industrial process
process ontology	graph or tree like ontology representation, helping with understanding the industrial process composition structure.
process knowledge	representing information about predicted alarm situations or a predicted behaviour for specified process variable (e.g. the process variable value will increase, decrease or hold the position in the future). The information could be displayed in form of artificial visual constructs (e.g. usage of glyphs).
integrated data	utilisation of GIS or another data to enhance raw information (e.g. real world location).

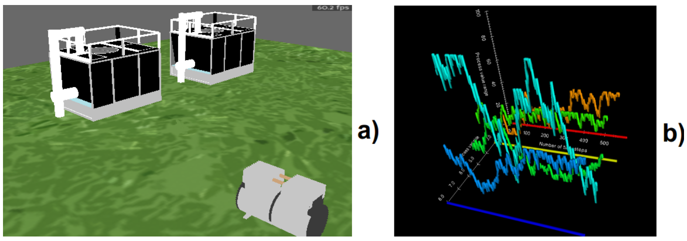

Fig. 6. a) an example of the 3-D photo-realistic visualisation b) an abstract visualisation representing process variables as 3-D lines (tube filter mapping).

IV. Experimental System Implementation

The proposed system architecture was used as a guideline for an experimental implementation of a hybrid immersive visualisation system. The component model of developed system is shown in Figure 7.

One example of supported visualisation is a 3-D line plot from process control data in Figure 6. b). The execution of a visualisation pipeline which is responsible for for this visualisation is defined as:

- Data Analysis: prepare the raw data obtained from the OPC UA address space ontology to structures which are required for the purpose of the visualisation. Namely the raw data about sensor value, sensor ID and time stamp, reported by OPC, are transformed into ordered lists which describe 3-D lines. Scalars representing colours for each process variable are also created.
- Filtering: a data sub-selection for the purpose of determining size of rendered visual information. Here we

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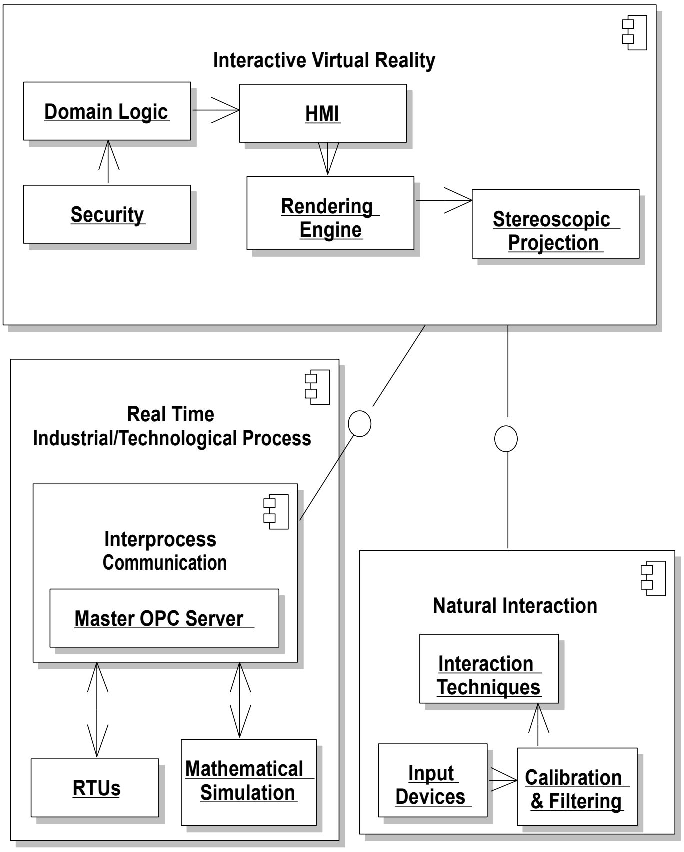

Fig. 7. A component diagram for the proposed system architecture implementation

are restricting a visible time step range of the process variable evolution.

- Mapping: the lines are created and colour is applied per process variable based on prepared visualisation data.
- Rendering: the final stage when the visual output is presented to the operator.

The core part of visualisation system consists of classes depicted in Figure 8. with following descriptions:

a) Display context: is the main class in the visualisation application. It is responsible for initialisation and execution of a configured visualisation. Additionally this is also the place where all services (callbacks) are registered in order to be executed in specified time intervals (e.g. OPC UA communication, etc.).
b) Data object algorithm: is executed automatically before the render event occurs. The main purpose of data object algorithm is to transform the raw data obtained from an OPC UA server into visualisation artifacts. If we have a look into visualisation pipeline described above, we can see that data object algorithm fits in the place of data analysis component.
c) Render callback: render configured visual output for predefined display setup (mono/stereoscopic). This is the last part of visualisation pipeline.
d) Visualisation: by utilisation of the *Strategy* design pattern, visualisations are independent from each other and an active visualisation could be changed even in run-time. In the context of visualisation pipeline, here the appropriate filtering and mapping techniques are applied.

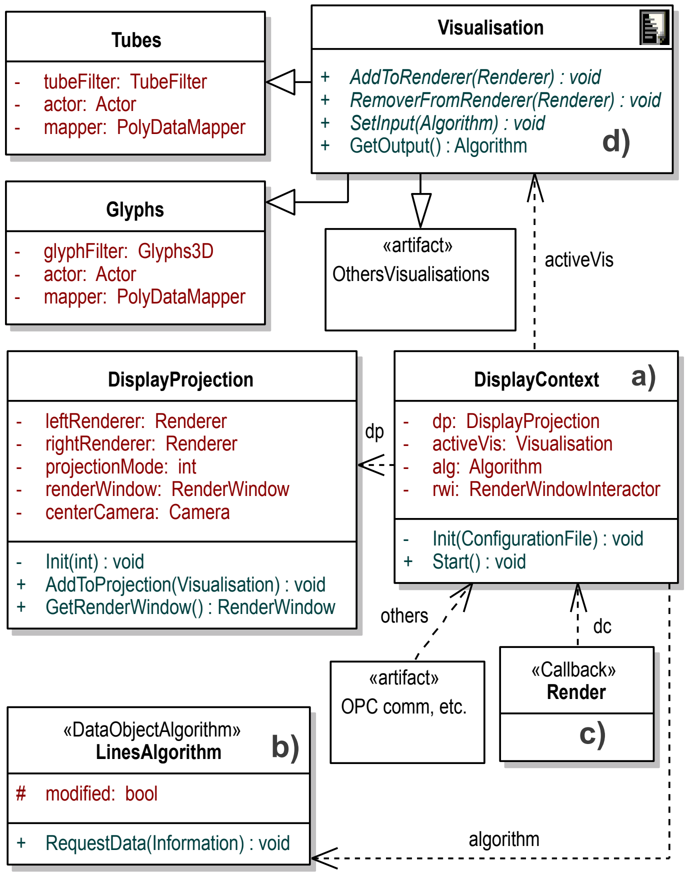

Fig. 8. Fundamental software architecture of the hybrid visualisation system depicted as UML class diagram. Display context a) Data object algorithm b) Render callback c) Visualisation d)

A. Example setup

The visualisation example setup consists from the back-projection power-wall and two polarised projectors. The visualisation workstation is running Linux as an operation system. C++ programming language was chosen for the purpose of a visualisation system development. The others third-party components used for the implementation of a visualisation system are listed below:

- Simulation (an absorption refrigeration process for the diary factory) and a OPC UA server provided by Inductive Automation [7].
- VTK (Visualisation Toolkit) as a generic purpose graphics library [19].
- OPC UA communication layer was developed with OPC UA SDK (Software Development Kit) from Unified Automation [20].

V. Conclusion

The paper examined a possibility of using an immersive virtual reality environment, in order to visualise more complex industrial processes with many process variables. The presented implementation of the proposed system is used as an experimental platform for discovering new types of industrial process data visualisations. The developed software solution is following latest trends in the field of applied automation, as service-oriented communication, in order to enhance interoperability between different layers of information and control systems in the modern factory. The plan is to further examine the possibility of visualisation based on the advanced knowledge generated (utilisation of reinforcement machine learning). Additionally for non desktop based display setups, the way of interacting with the system will be subject to change. That is why, a standalone NUI (natural user interaction) layer will be embedded into a future generation of the visualisation system. It will enable a direct natural exploration of the visualised process information.

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