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INTEGRATION OF MONITORING EQUIPMENT TO A SCADA SYSTEM

Degree Programme in Information Technologies
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This thesis was done for the HSE SEE Computing section of CERN. Its purpose was to integrate a radiation monitoring instrument to the REMUS SCADA system, document the integration process and create a procedure for further integrations.

The thesis is divided into four parts. The first part details the reasons behind the project and the underlying architecture. In the second part we go through some research methods and document the integration process and its different phases. The third part is a case study on the integration of a radiation monitor. The fourth part depicts the problems faced during and after the integration and the possible solutions for them.

The result of the thesis was a successful integration of the Berthold Technologies' LB 112 micro-gamma logger, and further improvements to the REMUS supervisory system. The integration process showed much room for improvement and inspired the creation of the REMUS development templates that could facilitate faster development and would provide a gentler learning curve for new members of the team.

VALVOMOLAITTEEN INTEGRAATIO SCADA-JÄRJESTELMÄÄN

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Satakunnan ammattikorkeakoulu
Tietotekniikan koulutusohjelma
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Tämä opinnäyte on tehty CERN:in HSE SEE Computing osastolle. Sen tarkoituksena oli integroida valvomolaite REMUS SCADA-järjestelmään, ja ohessa dokumentoida ja formalisoida integraatioprosessi.

Opinnäyte on jaettu neljään osaan. Aluksi käsittelemme projektin lähtökohtia, päämäärää ja projektin arkkitehtuuria. Toisessa osassa käsittelemme eri tutkimus menetelmiä ja käymme läpi yleisesti integraatio prosessia ja sen eri vaiheita. Neljäs osa on tapaustutkimus säteilyvalvontalaitteen integraatio prosessista. Viidennessä osassa käymme läpi projektin esille tuomia ongelmia ja mahdollisia ratkaisuja.

Tämän opinnäytteen tuloksena oli Berthold Technologiesin LB 112 mikro-gamma dataloggerin onnistunut integraatio REMUS SCADA-järjestelmään, sekä lukuisten parannusten tuominen järjestelmään itseensä. Integraatio prosessista löytyi huomattavasti parantamisen varaa. Kohdatut ongelmat inspiroivat moninaisten mallipohjien luomisen, jotka ovat auttaneet nopeuttamaan kehitystä ja helpottamaan uusien työntekijöiden koulutusta.

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Abbreviations

CERN	European Organization for Nuclear Research
HSE / DGS	Occupational Health & Safety and Environmental Protection Unit
SEE	Safety Engineering and Environment Group
RP	Radiation Protection Group
CO	Computing Section
EN	Engineering Department
ICE	Industrial Controls & Engineering Group
REMUS	Radiation and Environment Monitoring Unified System
EDMS	Engineering and Equipment Data Management System
LHC	Large Hadron Collider
ISOLDE	The On-Line Isotope Mass Separator (Formerly Isotope Separator On Line Detector)
SCADA	Systems Control And Data Acquisition [7]
HMI	Human Machine Interface
MS	Monitoring Station
CONTROL	Scripting language used by WinCC OA
JCOP	Joint Controls Project [8]
API	Application Programming Interface

1 INTRODUCTION

CERN is a European research organization located at the Franco-Swiss border near the city of Geneva. It operates the largest collection of colliders and accelerators, facilitating researchers from around the globe. The experiments at CERN produce ionizing radiation from collisions and interaction with the surrounding elements and run the risk of releasing noxious gasses to the environment, and while sewage and industrial wastewater is discharged to sewage stations in the area, some surface and cooling water is released to the nearby rivers. [1]

The Occupational Health & Safety and Environmental Protection Unit is tasked with monitoring these risks to limit the exposure of people and the environment to a reasonable achievable level [6]. As a part of this effort, the radiation protection and the environmental sections of the unit monitor the environment and radiation at the research facility and its immediate surrounding area. A collection of devices are distributed around CERN and outside its premises. Some of these devices come with software for remote control and possibly data acquisition, while others are strictly standalone devices [19]. A unified system would make working simpler, and by having the same look and feel the use would be more intuitive [7]. Previous attempts have been made to update and unify the supervision of monitoring instruments at CERN [6], but the outsourced effort was not a success. The end product did not scale well, had very poor performance, no reliability and negligible adaptability. Updates to this product are slow and expensive, and the maintenance disruptive. [19]

In late 2011 work was started on a new system by the HSE SEE Computing section of CERN. The system would be created with four basic pillars in mind; reliability, scalability, performance and adaptability. Reliability in this case would be paramount as false or missing radiation alarms and incorrect measurement data would be simply unacceptable. The system would have to scale massively, to facilitate the devices and the gargantuan amount of data acquired from them. CERN already utilizes tens of thousands of detectors and this number is continuously growing [10]. The Joint Controls Project had run extensive tests that found PVSS scalable and especially stable [11]. This made it a prime candidate for the new system. In addition REMUS was designed with a light interface, only loading what was necessary. This compartmentalization made it also highly adaptable and permitted the delegation of some of the administration effort to a few trusted end users. By building on top of WinCC Open Architecture, the section could leverage the organization’s prior experience and the existing support system. The system was named REMUS, a reverse acronym standing for Radiation and Environment Monitoring Unified Supervision.

In early 2013 I joined the team, taking over the function of integrating instruments requiring custom drivers. At the moment, one monitoring instrument was in the process of being integrated, but the person tasked with the integration was at the end of his contract and had no time to define a process of integration. Thus the secondary objective was to document a process of integration specifically for REMUS that could also work as a reference for new members of the team.

2 REMUS

2.1 WinCC Open Architecture

SIMATIC WinCC Open Architecture is an extremely flexible SCADA system that allows custom tailored SCADA solutions to be produced fairly quickly [8, 9]. The product used to be called PVSS (Prozeß-Visualisierungs- und Steuerungssystem) but after ETM got acquired and became a subsidiary of Siemens AG, PVSS was integrated to the SIMATIC HMI family and was renamed WinCC OA to simplify international marketing [2]. In this thesis, the terms WinCC OA and PVSS are used interchangeably.

For some time, CERN has used WinCC OA as the basis of their supervisory control and data acquisition systems, for which the EN ICE group has created the JCOP framework. By providing a higher level of abstraction, the framework reduces the development effort and the required resources for maintenance. The framework provides tools for structured device creation, CERN user authentication, database integration and additional support for common industrial application layer communication protocols. [8] Being built on WinCC OA, it has inherited some of the design decisions and is easily customizable for individual use cases. In addition the framework's modular nature allows projects to use only what is needed, thus creating faster and sleeker systems.

A WinCC OA application consists of several processes that are called managers. These managers are used to handle user interfaces, the internal database and communication. A single manager called the event manager is responsible for data flow between all other managers, including all client user interfaces, and for the synchronization of data between redundant servers. The event manager can become a major bottleneck as it is single threaded [3, 4, 22]. It is possible to run multiple instances of the event manager, even on separate servers to split the load. However the events must eventually be synchronized to the main event manager, thus only delaying the problem. It is wise to keep this in mind when designing and developing software with WinCC OA.

There are three major ways of extending WinCC OA. Simplest are the interpreted scripts written in CONTROL, WinCC OA's internal scripting language. CONTROL is quite limited as a language, but it is sufficient for simpler tasks such as manipulating data point element values. In combination with the built-in drivers, they can be used for communicating with equipment, but mostly they are restricted to handling user interfaces and running high level background tasks.

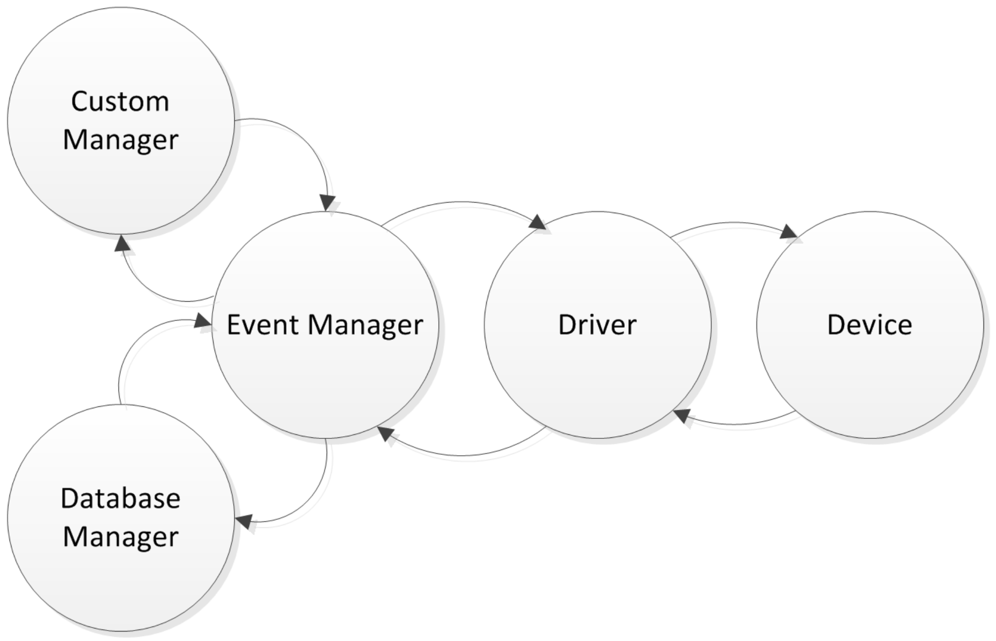


Illustration 1. Data flow with custom manager and an inbuilt driver

WinCC OA drivers are complex managers that, instead of being built with CONTROL scripting language, are fully fledged C++ programs leveraging WinCC OA API [3]. Their main purposes are implementing a specific protocol, low level filtering, data transformation, conversion and smoothing [23]. On REMUS we have offloaded some other functionality to them, including the writing of injection files, alarm generation, and the data acquisition logic. Data between the event manager and the drivers flow directly through API function calls, eliminating some overhead.

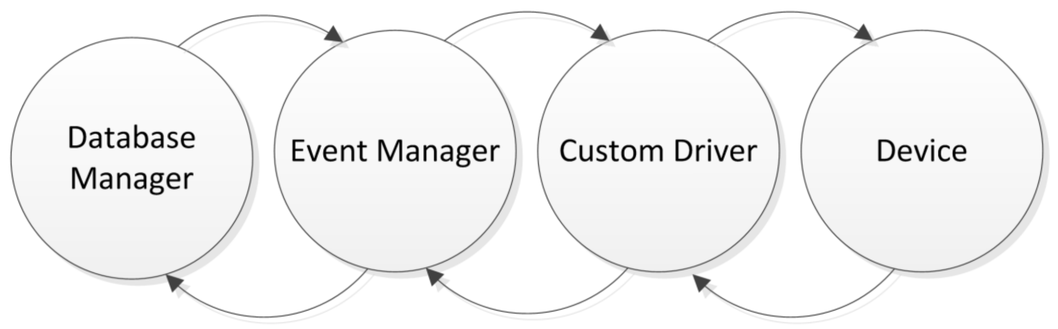


Illustration 2. Dataflow with custom driver

In addition it is possible to build so called API managers which fall in between. They are lighter than drivers, but still much more complex to write than CONTROL scripts [3]. The API managers have not been used in REMUS so far and will not be covered here.

The database manager mentioned on the above illustrations is a complex but internal manager that handles the application's internal database. The database consists of a collection of so called data point elements that hold values and their corresponding metadata such as addressing and connected functions. [3] This database should not be confused with the external database used for long term data archival. The internal database suffers from severe limitations due to the way it has been implemented. Each data point has an associated identifier, a running number that is incremented on each data point creation. Deleted identifiers are not automatically recycled, but manual reuse has been necessary in REMUS as the maximum identifier number is fairly limited. In any case, creation and deletion of data points is not fast and should be avoided. REMUS keeps a local copy of some of its database’s tables to ensure smooth operation during outages. To do this a pool of data points is used and reused, and a similar strategy is advised to avoid unnecessary deletion and creation of data points.

2.2 REMUS SCADA system

The REMUS software package consists of the base WinCC OA installation with a customized JCOP framework, a plethora of panels, scripts, managers and drivers, and an Oracle database.

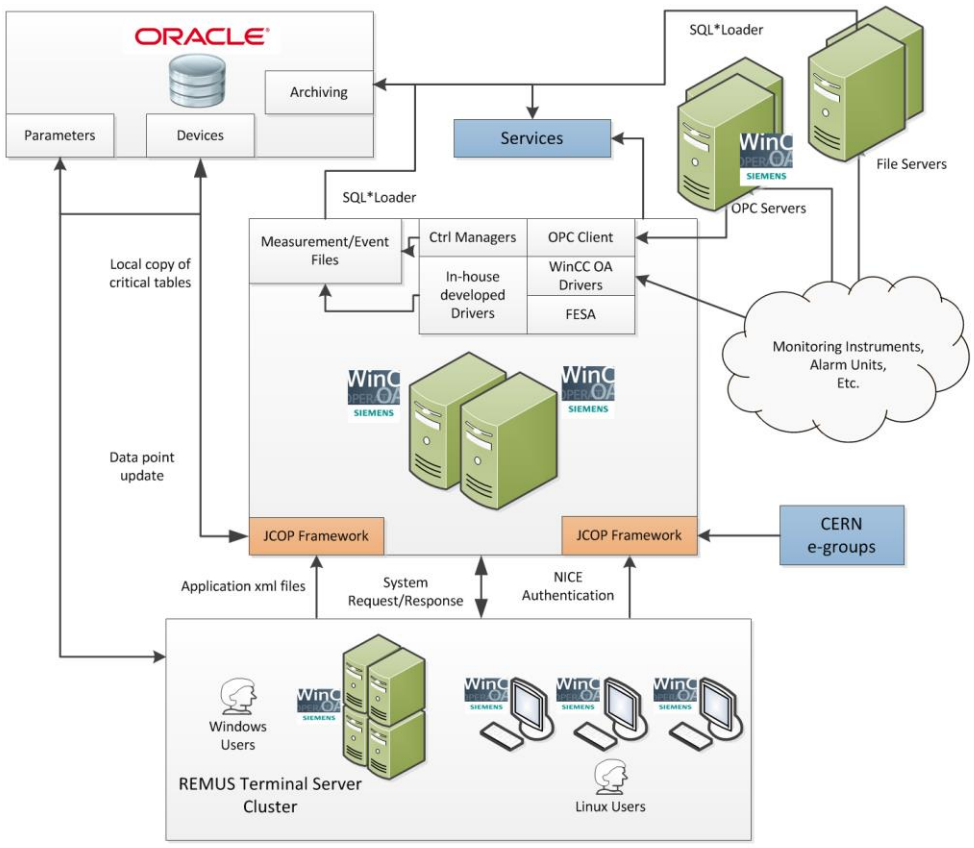


Illustration 3. REMUS Architecture

In the REMUS SCADA system the representation of each monitoring unit is split to three parts; the monitoring station, the devices and the channels. The unit as a whole is monitoring system or MS for short. A monitoring station encapsulates the devices and channels that make up that unit. A channel is a channel of measurement. It is an identifier that is used to store and map the events and measured values to their corresponding monitoring stations, devices and locations. A device is an actual, physical device. It may be the main monitoring device, or a sub device such as a detector. A monitoring system may have an arbitrary amount of sub devices and channels. In the below illustration one can see a possible structure of a monitoring station entity.

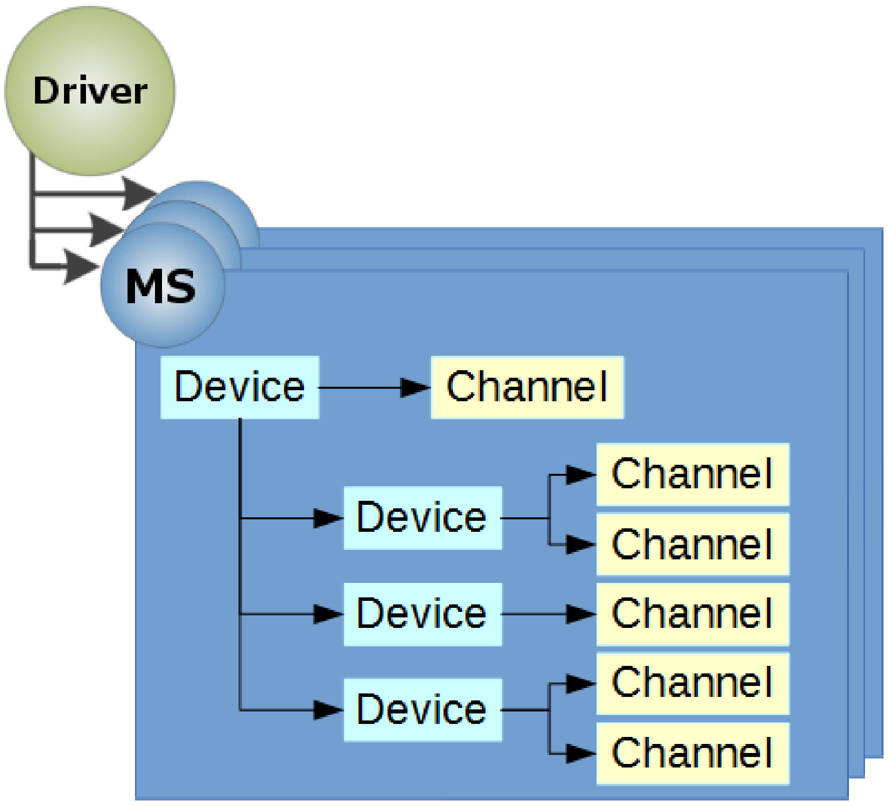


Illustration 4. Possible structure of a monitoring station

While WinCC OA provides a user interface for declaring data point types, that approach is not recommended [8]. Part of REMUS is the Oracle database that holds a record of the structure for each monitoring station type. This structure is used when creating new instances of that type. Each individual instance of a monitoring station type is then declared on the database to track changes to its configuration and events. [21]

Injection of data to the database is done either directly from WinCC OA or from injection files. In general events relating to user interactions such as requesting monitoring station mode and parameterizations have their events along with data injected directly to the database. Events and measurements acquired from devices can come in bursts or in quick succession exceeding the limitations of what a SCADA system can inject to the database [6] and are written to files. These files are then injected to the database with SQL*Loader once a minute [20]. The approach allows for batch insertion of data from multiple different sources and provides much better efficiency. This method of database injection was created for the previous, outsourced SCADA system and was extended for our purposes with only minor modifications.

2.3 REMUS Finite State Machine

The REMUS Finite State Machine (FSM) is used to track the state of each monitoring station as well as to trigger functions [30]. As REMUS can be accessed by multiple users at the same time, it was necessary to create a system to track the state of each device. Tracking the state allowed us to avoid problems that could rise from simultaneous operations. The FSM is a not a piece of software per se, but rather a specification of what state should the monitoring station report in any situation. Not all of the FSM states are implemented by every integration, but for those that are, the specification must be followed. The states of the FSM are unique, meaning that no two numbers should indicate the same state. The only exception are 4 and 16, which both indicate request error. This is due to historical reasons, as one device type that has been integrated may respond with either one. When implementing the FSM, number 4 should be used to indicate the request error state.

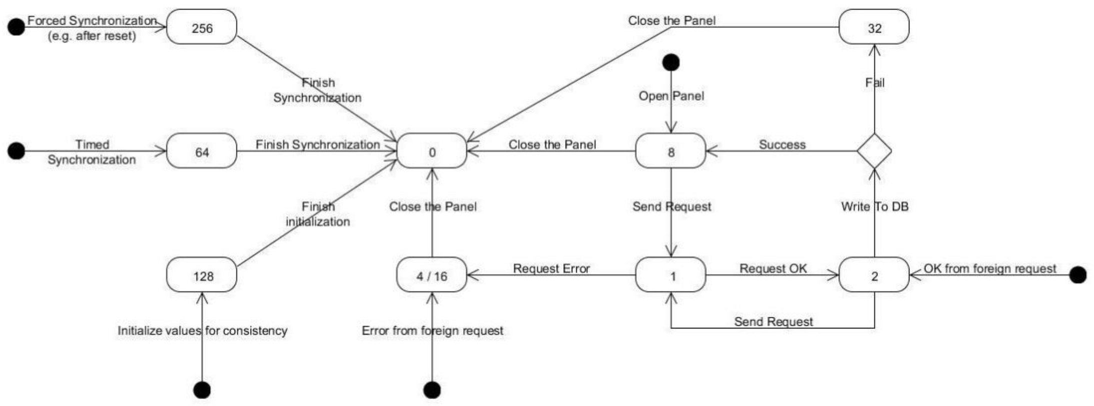


Illustration 5. REMUS Finite State Machine

The task of keeping the FSM in the correct state at all times is left to the developer. Commonly the state is changed directly, but certain events such as change in the monitoring station mode can have the side effect of changing the finite machine state. For example, the ‘Initialization’ (128) state is only allowed if the monitoring station is in either ‘Silent’ or ‘Off’ mode and setting the mode to anything else will set the state to 0, or ‘End’. Conversely setting the mode to ‘Silent’ or ‘Off’ will set the state to ‘Initialization’ as that is the only action possible in these modes. Further details on the REMUS FSM can be found in the REMUS Finite State Machine document on EDMS [30], and will not be discussed here.

3 RESEARCH METHODS

The research methods used vary from field to field and depend on the questions to be answered. The two main methods used in scientific research are quantitative and qualitative research. They are based in evidence and are thus part of what is called the empirical research method. Though starkly different, they are commonly used hand in hand as large amounts of qualitative work is often required for the quantification of phenomena. [32]

Qualitative method is used in many different fields. The aim may vary depending on the person or group utilizing the method, but in general it investigates the why and how of phenomena. It is often used to define hypotheses as it provides information only on the case studied, in contrast to quantitative methods that may find connections in data pertaining to cases not specifically included in the research. In scientific research, data is often gathered with observation, interviews, reflexive journals and analysis of document and materials. [33]

Quantitative research investigates phenomena using statistical, mathematical or computational techniques. It tries to find connections between observations, and can be used to prove or disprove hypothesis created using qualitative research. Though measurement is commonly stated as central to the quantitative research, it is accepted that it can’t be used as its sole basis. [32] Use of both qualitative and quantitative methods may provide more accurate results. Quantitatively produced conclusions can be better understood using qualitative methods, while quantitative methods can be used to produce precise and testable expressions of qualitative ideas. [34]

In software projects, both qualitative and quantitative methods are used. A recent development has been the growing popularity of a user centric approach that includes the end users in the project from the very beginning. The approach strives to identify the wants, needs and limitations of the end users that are then given extensive attention throughout the design and development process. [36] The users may be interviewed or asked to do self-documentation. Action research is done to identify the actions taken by users to achieve their day to day goals. In addition continuous feedback is given by the users throughout the project in the form of validation and testing. [35] Such an approach is often necessary as the developers are commonly not the end users of the product, making it difficult for them to intuitively foresee what are the end requirements and constraints. User-centered design lends itself well for software development when the end users are well defined, as is the case for REMUS.

4 THE INTEGRATION PROCEDURE

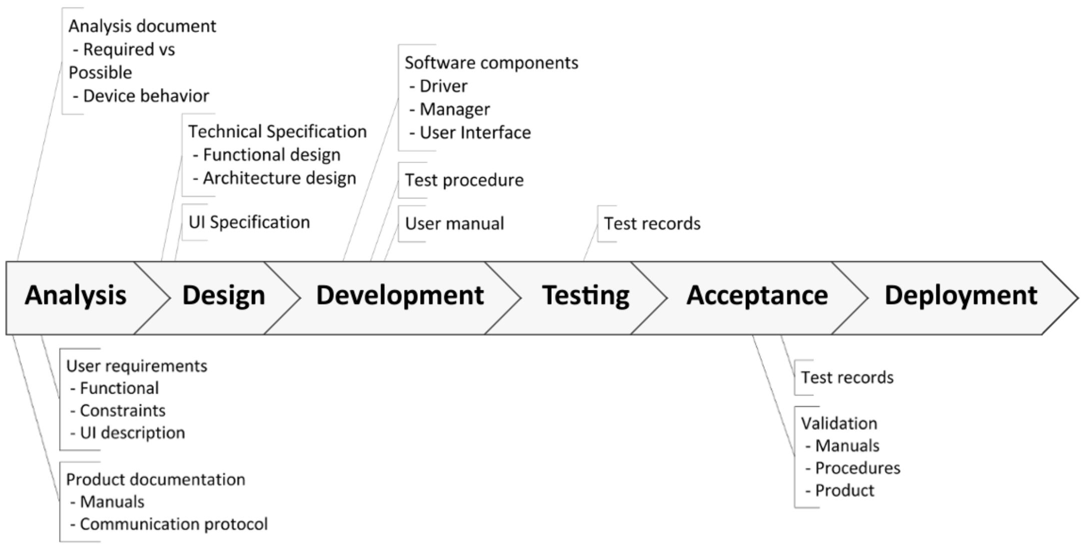


Illustration 6. Device integration process

The process of device integration follows a fairly straight forward pattern. Once the device has been chosen by the stakeholders, it is their responsibility to produce a requirements specification documenting the constraints, required functionality and the user interface. With the requirements and device's documentation in hand a feasibility analysis is made to match the required with the possible. After the proposal has been validated by the stakeholders, a technical specification is written to document the functional and architectural design. A specification of the final user interface is made which must also be validated by the stakeholders. Once development has finished, a user manual is created to help users navigate the system. A test procedure is created to verify that the end product is working as expected. This procedure is executed repeatedly, first by the developers, then by an impartial member of the team, until the product passes with no remarks. Same procedure is then followed by the users to validate the product for deployment. Users may add new test cases as seen necessary, and this phase can easily take a couple of months. Once the product has been validated, it will be deployed to production in the next scheduled production push.

At all phases of the integration, as well as in the maintenance phase, it is very important to maintain frequent communication with the users so as to really understand what the users want and expect. This can either make or break the whole project. In addition a technical contacts with the instruments manufacturer and the company developing the firmware can be extremely valuable and should be sought after.

4.1 User requirements

The stakeholders must provide a document specifying their functional requirements and constraints. Usually this is simply a listing of the devices functionality, with the added details on functionality that they would like to have implemented on top.

The devices might implement a large array of functions, but some of these will not make sense to be available remotely and for simplicity's sake some expert functions should be restricted to local modification. If a function is only used when the device is initially installed, it makes little sense to provide a way to change it remotely. In addition, as parameterization should check for data compliancy, the ranges of valid parameter values must also be specified.

Monitoring stations generate measurements at varying frequencies from once every few minutes to every 100 milliseconds [6], and aside from special circumstances such as exceeded alarm thresholds, these values can be averaged to save space after they lose their pertinence. In addition, the everyday usage of the system and devices can generate huge amounts of data, especially considering effects of scaling from one device to possibly hundreds or thousands of devices. Aside from few special events, such as alarms, most of them lose their value in a matter of years quickly and should not be retained longer than necessary. This point can be particularly hard to drive through to the stakeholders, but for the long term performance and cost efficiency it is very important.

In addition a separate user interface specification can be created. Sometimes it can be sufficient to include the UI drafts in the user requirements specification, but should the integration introduce multiple new panels or differ from the norm, a separate document may be useful. This specification should document the expected user interface and the experience of using it. This includes such things as the colours of status indicators in their various states, the format of numbers and dates, etc. REMUS has a colour coding system for these indicators [15], which should be followed, but on certain indicators it can be necessary to deviate from strictly following it, if only to reduce ambiguity in the specific case.

4.2 Analysis

From the user requirements, the device's manual and communication document; a feasibility analysis document is made to match the requirements with what is possible. In addition to the limitations and functionalities stated in the documents, the device must go through a strict analysis. Very often the limitations stated on manuals refer to an R&D environment with a single device and minimal outside elements. While the documentation of the device and its communication protocol are invaluable in understanding the functionality and the limitations of the device, they should not be trusted blindly. These documents very often takes a backseat during development, and is only created and updated almost as an afterthought, leaving room for outdated and sometimes downright false information.

During the analysis every function remotely available must be tested with both valid and invalid data. To make this testing faster, it can be useful to create a simple program to directly communicate with the device. As some protocols require valid checksums on messages, this might even be a necessity. This software may also be useful later on for debugging purposes.

4.3 Technical specification

The technical specification should document in detail what will be implemented and how it ties into the existing system. Any functionality that adds to, or diverges from prior integrations must be documented, as well as any functionality supported by the device that is not going to be supported. For an example, an instrument might support the measurement units becquerel and curie. REMUS has been built in a way that it is simple to add support for new measurement units, but as NIST actively discourages the use of non-SI units [5], support for curies can be safely dropped. Another example would be the device modes. At the time of writing REMUS supports nine modes. These are Off, Measure, Test, Simulation, Maintenance, Calibration, Without Mode, Silent and Degraded. However, one would be hard pressed to find any device supporting all of these modes, and even in that case, they would doubtfully call them by the same names. Thus the document must specify which device mode maps to which REMUS mode, and in addition what is the expected functionality in that state. For some devices maintenance mode may simply mean that the measurements are tagged with the mode maintenance, but others might not even do measurement in this mode. Similar details may come up with other modes too, especially on ones artificially introduced. This is an important detail and must not be forgotten.

In its appendices the document must include sequence diagrams of all complex functions, such as the acquisition of historical measurement data and alarms. Similarly a full list of data point elements with their data type, addressing string and their purpose has to be included. If the list of data point elements grows too big, it may be exported to a separate document and referenced on the technical specification. A separate document also makes it easier to add more details about the data point elements, such as the direction of data flow to the element, and the end points of data held within. It can be useful to know if the value originates from the driver or the device, and whether it is stored in the database or not.

4.4 Device type design

Devices in WinCC OA are represented as instances of data point types. REMUS makes use of JCOP frameworks template data point type creation process and the structure of each device type is stored in the REMUS database. The details of these structures can be refreshed from a special panel created for this purpose. The design consists of multiple levels. It details the amount of channels and sub devices that can be associated with the device, as well restricts the types of devices that can act as sub devices. In addition, it has the full structure of data point elements and the alarms related to this device type. Certain data points are grouped together under descriptive directories. The data points pertaining to the whole device are under directory *GLB*, while the channel specific data points are grouped under *CH**N*** where ***N*** indicates the channel number, starting from one. Furthermore, these directories have sub directories grouping data points for configuration, parameterization, and measurements under the directories Configuration, Parameters, and Measurements, respectfully. [18]

In addition to the data point elements uniquely required by different types of devices, certain data points are necessary for the operation of REMUS. These included the data points for the monitoring station name and its identifier, as well as the names and the identifiers of the channels attached. Data points for user name and station id, as well as date are necessary to track configuration, parameterization and control operations [7].

Functions can be bound to data points to do statistical operations on the data held or to dynamically call other functions. These statistical functions are limited to internal CONTROL functions, and cannot dynamically receive values from other data points. The function itself is written inline on the SQL statement, as opposed to dynamic function callbacks where just the name of the function is defined in the database. Dynamically called functions can be anything from internal functions to user created functions. These dynamic callbacks aren’t as efficient as inline data point functions, but allow complex functions to be executed from unsolicited driver messages.

4.5 Driver design

Each driver must be specified in the REMUS database, much in the similar manner as with device types, though their definitions are usually much shorter due to having less data points and alarms.

The drivers communicate between the event manager and the devices. This is done by passing HWObjects with derived classes inherited from the WinCC OA API library.

Changes to the data points with addressing to the driver will arrive as calls to the function HWService::writeData() [23] which must be implemented in the driver to receive them. By calling HWDrvManager::toDP() the driver can pass data to data points. [3] It should be noted that while it’s possible to write multithreaded drivers, the PVSS libraries are not multi-thread safe. [23] Driver designs must be made with this limitation in mind. In addition there are functions in the WinCC OA library that can be used to query singular data point elements, but these are not as efficient or thread safe, and are not used in REMUS.

All data in PVSS passes through the event manager, including data between other managers, the UI and the drivers. Calls to these functions should be restricted to the bare minimum to prevent congestion. This means limiting data point updates to only when their values have changed and for initialization purposes. The Event manager will periodically call function HWService::workProc(). This should happen every 10ms, but the timing is done by a dispatch call which can also suffer from congestion leading to variance of up to multiple seconds [3]. During this call the driver has the attention of the Event manager and it is safe to pass data to the event manager with the HWDrvManager::toDP() function.

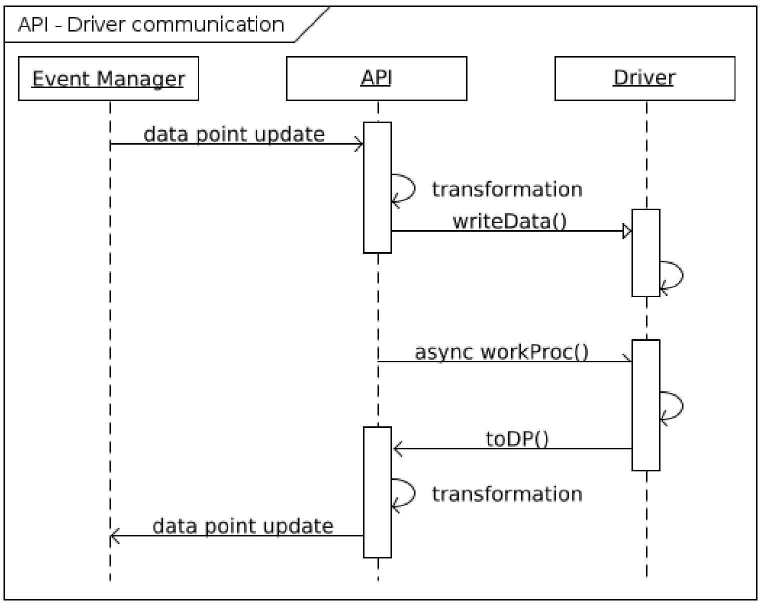


Illustration 7. API – Driver communication

HWObject is a WinCC OA API library class holding the data to be passed, as well as the information necessary to identify it. REMUS makes extensive use of the address property. Specified in the device type’s data point elements, it holds both a numerical identifier for the monitoring station and a textual identifier for the data point. For driver wide data points the numerical identifier is left to zero.

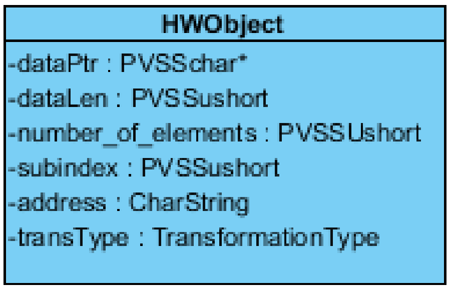


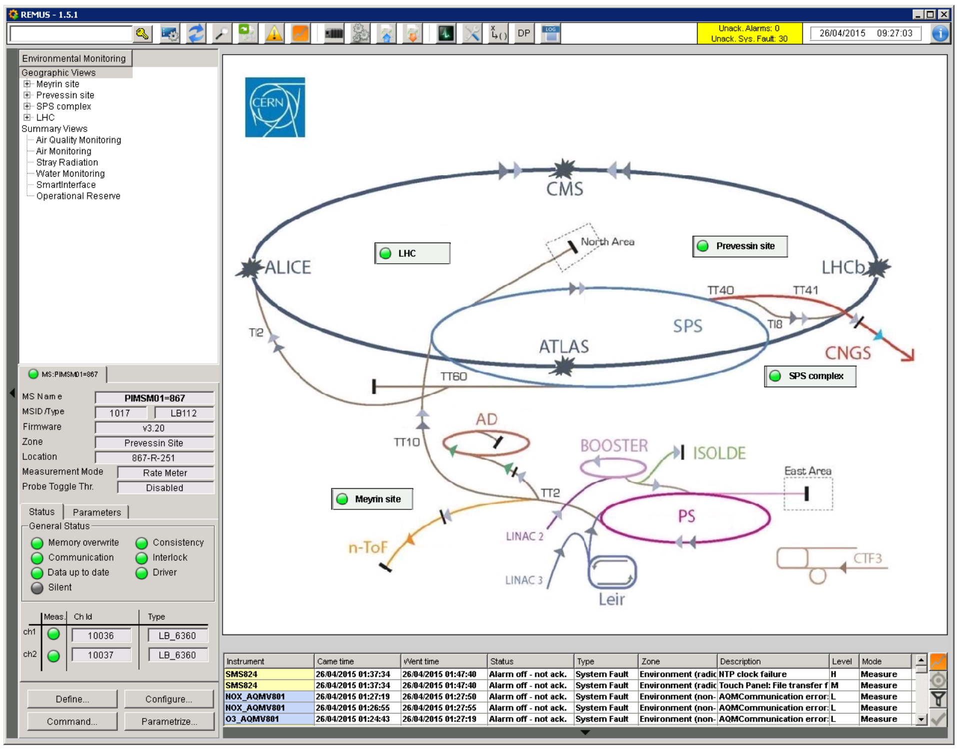
Illustration 8. Simplified HWObject class elements

HWObjects pass through transformation before arriving to the driver and after being sent to the event manager. A transformation is a custom class used to transform data from hardware format to WinCC OA data point element types and vice versa. On REMUS much of the measurement and event analysis is done by the driver and data is not directly passed to devices. Instead all data points are considered internal to the driver and thus the transformations are actually to and from C++ types. These transformations must be implemented for each type of data received and sent from the driver to the event manager. It is possible to have multiple values sub indexed on one address, but the number of elements must be same for all data points using the transformation. Should one not declare the amount of sub-indexed elements, API will try to free the same memory multiple times resulting in undefined behavior. Notably this will not crash the driver until the sixth element.

Every WinCC OA component, including the drivers, work in full redundancy on REMUS. During normal operation the event managers of both servers will keep their data points synchronized and consistent. Should one of the servers go down, either abruptly or for planned maintenance, the other will take over, seamlessly continuing from where the first left off. Data point updates are not communicated to the redundant driver during normal operation and when a redundancy switch occurs, the driver must be notified of the current values. The values must be updated on the driver but should not be propagated to the device. This is much the same as in the initialization and it is customary to use the ‘initializing’ FSM state during this process. If the REMUS FSM is used, great care must be taken to send the parameters in an order that would not disturb its state.

4.6 User Interface

The user interfaces of all REMUS integrations follow the same format [15]. On the left hand side of the user interface there is a faceplate showing real time values and state of the device. The faceplate also has buttons for defining, configuring, parameterizing and commanding the device. The layout of the state indicators and values is specified by the users, but that is as far as they have power over it. The format of configuration and parameterization panels depend on the amount of parameters, and the maximum number of sub-devices and channels associated to the device type. Inspiration for these panels should be taken from the previous integrations, with the top of the panel holding metadata and controls for requesting historical configurations and parameterizations. Bottom of the panel then holds controls for applying, refreshing and clearing the values on the panel. In addition a Retrieve button may be present in the bottom, to request latest values from the device. By keeping the experience consistent, less user training will be required and the overall user experience will be better.



MS:PIMSM01=867

MS Name	PIMSM01=867
MSID /Type	1017 / LB112
Firmware	v3.20
Zone	Prevessin Site
Location	867-R-251
Measurement Mode	Rate Meter
Probe Toggle Thr.	Disabled

Status | Parameters

General Status

🟢 Memory overwrite	🟢 Consistency
🟢 Communication	🟢 Interlock
🟢 Data up to date	🟢 Driver
⚫ Silent	

	Meas.	Ch Id	Type
ch1	🟢	10036	LB_6360
ch2	🟢	10037	LB_6360

Instrument	Came time	Went time	Status	Type	Zone	Description	Level	Mode
SMS824	26/04/2015 01:37:34	26/04/2015 01:47:40	Alarm off - not ack.	System Fault	Environment (radic	NTP clock failure	H	Measure
SMS824	26/04/2015 01:37:34	26/04/2015 01:47:40	Alarm off - not ack.	System Fault	Environment (radic	Touch Panel: File transfer f	M	Measure
NOX_AQMV801	26/04/2015 01:27:19	26/04/2015 01:27:50	Alarm off - not ack.	System Fault	Environment (non-	AQMCommunication error:	L	Measure
NOX_AQMV801	26/04/2015 01:26:55	26/04/2015 01:27:55	Alarm off - not ack.	System Fault	Environment (non-	AQMCommunication error:	L	Measure
O3_AQMV801	26/04/2015 01:24:43	26/04/2015 01:27:19	Alarm off - not ack.	System Fault	Environment (non-	AQMCommunication error:	L	Measure

Illustration 9. REMUS User Interface

The User Interface Specification must document the general appearance, explain the meaning of each element, states of each state indicator and the purpose of each button. While the user interface will see many changes throughout the project and this document will go through multiple iterations, an initial validation should be received from users before any real work on the user interface is undertaken. This validation is an insurance against users suddenly changing their minds later on in the project.

4.7 Development

The development phase of any integration will depend on the device, specifications and the designs made, but some general advice may be given.

When connecting data points to callback functions, data points that change rapidly should have their separate connection. The function WinCC OA uses to get data point values can cause serious performance problems and any update to a data point that is connected to a function will trigger an internal function to get the values of all the other data points connected to the same function. Furthermore, if the function is called again before the previous operation has finished, the operation is added to a queue. If the frequency of these calls is higher than what can be processed, the queue will keep growing and with it the consumed memory. Once maximum queue size is reached, a portion of queued calls will be dropped, leaving only the newest entries. [27]

At the end of development a user manual is prepared documenting how to access the functionalities provided by the product. A major part of this manual are the procedures how to install new devices of this type to REMUS, including the initial settings on the device and its communication module, if one exists, to ensure proper functioning of the devices. For most parts the manual is consistent with other integrations, and this is by design. Every integration should have the same flow, look and feel as the others, so that the user experience is consistent throughout REMUS.

It is very important to keep the code well commented and documentation up to date, and the importance of this is magnified at CERN with the extremely short contracts and high employee turnover. As the task of device integration is often given to a student, creating minute and accurate documentation is especially important.

4.8 Testing and validation

To ensure the quality of the product a rigorous test procedure is created and followed. The tests must be executable with no external programs so that users can perform them, provided they have the correct access rights. The tests should cover all of the requested functionality, ensuring data validity, and that alarms, faults and events are working correctly. It should be noted that slight variation will occur between the values stored on device, the driver, in the injection files, the database and displayed on the faceplates. This is due the differences in manner of storage of floating point numbers. How each device stores and transmits measurements, varies wildly and is out of our control. On the drivers, the values are stored as 64 bit double precision floating point numbers, but when they are sent to the event manager they must be cast to 32 bits, as WinCC OA does not support 64 bit floating point numbers. Similarly when the measurements are written to the injection files, only six significant figures are kept. In addition, the procedure must test for product robustness; that is how it will react in case of excessive load, networking issues and server crashes. While CERN infrastructure is very stable, some problems with communication do happen. Routers crash and supposedly routine maintenance from IT can have disastrous side effect. The end product must be able to withstand these situations without losing data or producing fallacious alarms or faults.

Having been tested by the developers the product must be tested by someone with little to no prior involvement to the project. After working on the product for an extended amount of time, it is easy to use the device and the software in the intended way, but it is important to also test how it behaves when one does not follow the expected pattern.

After the product has passed the test procedure with no remarks it must be validated by the users. Prior to the product validation process, the test procedure should be validated with the stakeholders, as they may want to add some test cases to it. This process takes a long time as they will have much less experience with REMUS.

4.9 Deployment and maintenance

Once the product is ready and it has been validated by the users, the code is frozen and the version number is incremented to 1.0.0. On REMUS the versioning scheme the first number is dedicated to the initial release and massive overhauls, second number for new features and last one for minor patches and bug fixes. Until the product is deployed the binary should be frozen to this version. The full process of deployment is covered fully elsewhere [17] and is outside the scope of this thesis.

5 INTEGRATING BERTHOLD LB 112 MICRO-GAMMA LOGGER

The Berthold Technologies’ LB112 Micro-Gamma logger is a radiation monitor, logger and alarm unit all in one. Up to two radiation detectors, either probes or radiation chambers can be connected to it. The device has an inbuilt MOXA modem and can be communicated with by serial over TCP/IP [16]. This device had been in use at CERN for some time but it had not been integrated to the previous unified supervisory system. It was the second device to be integrated to REMUS.

5.1 Analysis

Unfortunately in the case of LB 112 the users had not prepared any documents for us, and due to time constraints they were created by the team itself. One month was spent getting comfortable with the device. Users of the current software were then approached to acquire real life use cases. So far they had used MEVIS, the remote control and data acquisition software provided by Berthold, but due to the constant connectivity problems and the confusing user interface, they had often opted for local intervention instead. [29] This meant that there was effectively no log of parameterization changes or the users responsible for them. This also meant that the users had not gotten used to the functionality provided by MEVIS and removing unnecessary and dangerous functionality was fairly easy.

During the analysis and the formation of requirements and the technical specification, multiple mistakes were found on the device’s documentation. To quickly asses the actual constraints and responsiveness of the device, a java class was created. Developing this software helped us get better acquainted with the protocol, and the tool was also useful in later stages of the development for testing the product and for debugging the devices. During these tests we found additional limitations and some lacking constraints on the device. Values received by the device were not sanitized in any way and variables expecting numbers could be passed character values instead, thus bypassing the naïve range limitations [25]. The device also showed reduced responsiveness under active communication, leading to its internal clock losing time. [24]

5.2 Technical documentation

The Berthold LB 112 stores its measurements in a circular queue that is capable of holding up to 4000 entries. These entries are ASCII encoded strings holding a time stamp, device status at the time of measurement and both raw and integrated measurement values and their respective units from both probes. Access to the queue happens through an iterator allowing requesting the value of the current entry, and moving backwards and forwards, one measurement at a time. [16] If the queue is full new entries will overwrite the oldest ones and the iterator will be moved to the next one. However, if the act of reading an entry from the device happens at the exact same time as a new measurement is stored, the iterator will not be moved, and if the queue is full, the iterator will fall behind the latest entry, effectively losing all 4000 measurements in between [24]. To minimize the chance of this happening, it was decided to limit the maximum frequency of measurements to once per sixty seconds. This limit also meant that the 4000 entries now covered over two days and 18 hours of measurements, providing a pleasant buffer.

Although the device itself does not support modes, it was decided that three artificial modes were to be implemented on driver level. The driver would support measurement mode as the regular working mode, maintenance mode, and silent mode that would be used to simulate off mode and prevent any data collection including measurements, alarms or faults. [24] This would effectively leave the device in a standalone mode, and would allow swapping of devices without leaving fault events in the logs.

With REMUS the measurement data and events would now be stored in the unified monitoring database along with data from all the other device types. LB112 supports a wide array of measurement units, among which are mrem/h (milliroentgen equivalent in man per hour) and pCi/m^3 (picocuries per cubic meter) [16, 28]. Support for these two historical units was dropped as adding them to the supported units would have made little sense. On LB112 this ‘unit’ is really just a tag as the actual end unit depends on the calibration factor. The raw measurements are made with counts per second and the users must apply specific calibration factors to convert from cps to say µSv/h. These calibration factors depend on the instrument itself and on the type of radiation measured. The unit must still be known and supported so that the measured valued can be stored in a meaningful format, and to allow further conversion and calculations.

5.3 Driver and UI design

Inspiration for the driver design was taken from an older driver created for another device. For each monitoring station the driver would create an instance of a monitoring station class, and a thread running an infinite control and acquisition loop. The monitoring station class would hold measurement data and parameters held in data points, and the corresponding values held in the device to detect inconsistencies and to reduce unnecessary data transfer. The control and acquisition loop would read measurements and write commands to the device.

A number of reader classes were created to extract and transform values received from the device. Once a message was acquired from the device by the acquisition loop, the buffer would be passed to a reader factory. The factory would recognize the type of message by matching a part of it to known message types, and then returning the appropriate reader, with the message already fed to it. The reader would be then used to get the actual values received and to store them in the correct variables on the driver. Along with the data, these readers would hold addressing metadata to route the values to the correct data points, and after being fully analyzed, the readers themselves would be fed to an auxiliary function that would extract this information and pass the resulting data to be sent to the event manager. The multithreaded nature of the driver, in contrast to the single threaded API calls required the addition of auxiliary functions and static buffers. Data to be sent to data points was stored in a static queue from which one entry would be passed to the event manager each time it would call workProc().

As with previous drivers, measurements and events acquired or generated by the driver would be written to injection files. Another static queue was created to which each individual thread would add entries. Then a file writer loop was created that would get new entries from this queue, and would write them to files. The task of injecting them to the database is delegated to a cron job running SQL*Loader as before. The below architecture guaranteed better communication with the API and the file system.

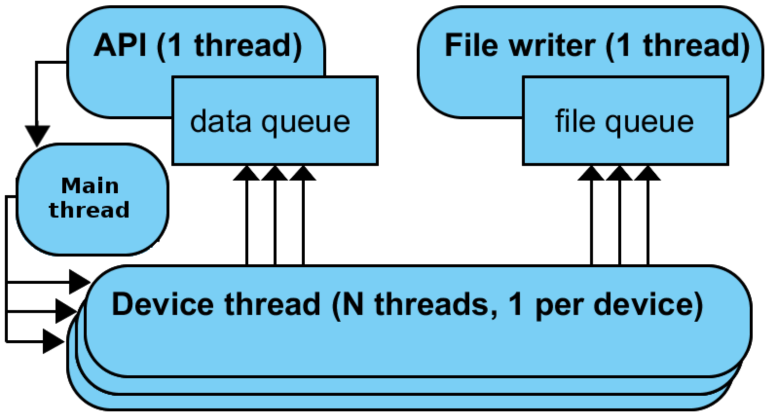


Illustration 10. Threads

As the users had not provided us a draft of the user interface, inspiration was once again taken from a previous integration. The user interface went through multiple iterations of minor changes, as users requested elements to be moved around. Finally an agreement was reached and work could start.

5.4 Development

During the analysis we had gotten very familiar with the device and subsequently there were very few surprises during the development. Some additional idiosyncrasies were found on the communication protocol, requiring additional constraints and safeguards to be added [25]. To gain more control over the driver state, the LB112 integration implemented a sort of a finite state machine [24]. This FSM has evolved to the REMUS Finite State Machine mentioned in the prior chapters.

LB 112 uses serial communication wrapped in TCP/IP packages, with the encapsulation being done by a MOXA modem. Communication is half-duplex, with the device requiring about 200 milliseconds delay between messages. Message collisions were not of much concern on earlier firmware, but later versions exhibited lockdowns requiring local intervention. At CERN these are not always possible. While active, certain areas of the complex can have high levels of radiation, rapidly fluctuating magnetic fields or temperatures near absolute zero. The control and acquisition loop was redesigned during the development to minimize the chance of collisions, on the expense of responsiveness.

In the later phases of the development it became evident that parts of the driver were less than easy to modify. Simple addition of a device variable required changes in no less than six places in the driver. As the number of variables grew, making all these changes became more and more complex as each additional variable would cause multiple cascading effects. Creating a procedure for these changes made it obvious that something had to be done, though it was too late for this project. It was decided that a more generic driver would be created, with the express purpose of simplifying modifications. This lead to the template driver project, which has been used in all later integrations requiring custom drivers.

5.5 Testing and Deployment

While internal testing was fast, it was difficult to get the users to take time of their schedules to validate the product. To emphasize the importance of their involvement we had to offer the test procedure as the final chance to make requests and changes. After deployment any and all changes would be released with respect to the release cycle of the entire monitoring system and would not have the same priority as the integration of new devices. In the end the product was accepted with little to very few changes necessary, and on time. [26]

5.6 Maintenance

Later on a problem was found when a new batch of LB 112 devices was delivered to CERN. This batch had a different wiring order for the relays used to control the alarm unit. On MEVIS setting up relay triggers happened simply by relay number, but on REMUS it was assumed that the relays would always be configured in the same order for the horn, the interlock and the three different colored lights. Unfortunately it was not possible to make a complaint, as the wiring order had not been stipulated on the contract. Prior wiring problems had not been noticed as a representative from the company had always done the trigger configuration on MEVIS after the devices had been installed, adjusting them according to the wiring of each device. It was decided that the wiring should be standardized and the expected mapping was then documented on the REMUS LB 112 User Manual's appendix on setting up the device for integration. [28]

In an effort to unify the devices, the radiation protection group gradually started to update all of the devices to the new firmware. The communication problems caused event logs to be flooded with faults, and for a year, continuous efforts were made to reduce them by working around the new limitations, and by increasing fault thresholds, thus masking shorter communication outages. In the end all devices were reverted to the previous version of the firmware as the problems exhibited far outweighed the benefits.

6 CONCLUSIONS

The purpose of this project was to investigate the process of monitoring instrumentation integration to the REMUS SCADA system, taking a broad view of the necessary steps and common pit-falls. The integration of one such instrument gave in depth view of the process and the challenges involved with interfacing with monitoring equipment.

By encouraging user participation, the project was finished on time and with minimal change requests. The methodologies used were sound, and played an essential role in the project’s success. No surprises were experienced in the final validation phase as the users had been continuously involved with the project. Without their involvement the testing and validation phase could have dragged on for much longer, as possibly drastic modification would have been postponed until then. The users have felt at home in the new SCADA system, leading to a sharp decline in the amount of support requests. Prior to the integration it would not be uncommon for the section to receive calls from the users, requesting help in navigating the other systems. This can be attributed to the more intuitive user experience that was achieved by letting the users participate in the design process.

One major problem encountered was the lack of responsiveness of the devices. The lifetime of monitoring equipment can be up to multiple decades. A class of equipment called ARCON that was designed and created at CERN in the 80’s is still in active use, and has been integrated to the previous SCADA systems [6, 14]. These are not the only legacy systems still in use, and most monitoring instruments are still not created with remote control or continuous data acquisition in mind. It is common to utilize a legacy industrial bus such as RS232, RS485 or Modbus [12] and then bridge it to Ethernet with a converter [13]. This severely limits the speed and robustness of communication with these devices, adds an additional point of failure and requires consideration when designing communication with devices.

Remus was created from ground up with the purpose of empowering trusted users by letting them add devices and create new views; tasks which had previously been left to system administrators. Delegating some of the administrative tasks to trusted end users meant that the team could concentrate on the integration of other equipment and in the general improvement of the software. However, the users lacking understanding of the limitations of the system ended up creating some unexpected views consisting of unforeseen amounts of devices. While the event manager is very stable even under extreme stress [11], the increased amount of devices and the rising amount of simultaneous users caused increasingly poorer performance as the callback functions started to get queued up. This has required us to frequently revisit the software in an effort to increase performance. A few different approaches have been tried, including low level comparison and caching in different stages to reduce unnecessary communication, and separation of volatile variables to separate function calls. These findings will be presented at ICALEPCS 2015.

The external process of injecting measurements and events to database from temporary files was recycled from the previous SCADA system, which foresaw the possible problems of drivers interfacing with the database directly. The first few devices integrated to REMUS produced measurements at a fairly low frequency, once every minute or two, and for these a single threaded file writer was more than sufficient. Later integrations have included devices generating measurements at much faster rates, up to one measurement every 0.1 seconds. With a rate as high as this, additional bottlenecks will require consideration. In addition to the aforementioned limitations of the event manager, the disk I/O might not always be able to keep up with the incoming flood of data. This development will require additional buffers, and possibly monitoring station specific file writing threads. In any case, changes in the file writing scheme are to be expected.

Integration of LB112 was done with the intent of supporting just that device type, and while the specialized code used was fast to write and easy to test, later modifications were difficult, and subsequently very little code could be recycled to later projects. The problems faced nearing the completion of development gave inspiration to the REMUS template project, which has helped shorten integration times. This can be seen in the evolution of project timelines as a student is now able to integrate two to three devices per year as opposed to being limited to one. The templates created range from CONTROL scripts for common panels, to a generic driver that can be easily extended to support most any type of device [31]. In addition, detailed procedures were created for each step of the integration, where possible. These templates and procedures have significantly eased the learning curve for new members of the team, making them productive much faster.

REMUS has been shown to be very adaptable, and with the in-house development and maintenance effort, all the problems encountered, including scalability, have been quickly resolved. Working closely with the end users has allowed us to integrate devices at much faster pace and to the user's satisfaction. As REMUS itself has matured, so has the integration process. The documents and procedures, in addition to the templates provide a straight forward path to follow, with few unknowns. Roadblocks and surprises are still encountered, but they are limited mostly to the devices themselves. The process allows for quick and predictable integration of various types, making it possible for technical students, who are usually employed for one year, to do at least two integrations of different devices, thus providing them with a broad experience in the area of SCADA systems and monitoring equipment.

7 END NOTES

A big part of the thesis was the actual integration of Berthold Technologies' LB 112 monitoring instrument. The documentation, the test results and the source code are available on request, but for liability and security reasons the requests must go through CERN Technology Transfer.

Similarly additional details on each step of the integration procedure from analysis to deployment is available on CERN EDMS document sharing system under the REMUS project documents.

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