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PHYSICS OF ELEMENTARY PARTICLES AND ATOMIC NUCLEI. EXPERIMENT

Construction Management Information System at JINR

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Abstract—The deployment and adaptation of an all-around Construction Management Information System (CMIS) was recently completed at the Joint Institute for Nuclear Research (JINR) from the collaborative work of the Laboratory of High Energy Physics (LHEP) and the Laboratory of Information Technologies (LIT). The system is particularly useful for the fine-grained control and continuous feedback of the production of complex multipart objects like the detector subsystems composing the experiments of the Nuclotron-based Ion Collider fAcility (NICA) at JINR's LHEP. Currently, the CMIS is used for the production of two different silicon tracker detectors at the LHEP, although it might as well be used by any other hardware production projects related to JINR whose complexity would make it very hard to fulfill their quality and timing requirements otherwise.

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1. INTRODUCTION

The production of silicon trackers for two of the major experiments of the NICA collider project at JINR, the Multi-Purpose Detector (MPD) [1] and the Baryonic Matter at Nuclotron (BM@N) [2], is led by one and the same department of the LHEP at JINR under the project names of MPD-ITS and BM@N-STS, respectively. These are complex setups that require the implementation of a precise workflow of components production, multi-stage assembly and tests to be coordinated between several institutions [3, 4]. For this reason, it was decided to implement for both projects a construction management information system (CMIS) that would allow for a tight control of the production process for the timely achievement of the goals of both projects. The system contains a Web application installed on an application server that is accessed by the clients through the internet and communicates with an Oracle database. It includes a user web interface as well as a web API collection, the latter allows direct interaction of the hardware with the database. As it is shown in Fig. 1 the system may be accessed both from inside JINR and from anywhere in the world. It uses the EOS distributed filesystem [5] for storing large files which may be accessed via ssh secure protocol. The authentication of the users to the web interface is done through JINR's Single Sign On (SSO) system within a role-based access rights scheme, while for the specific hardware-related software it is based on Kerberos credentials that are automatically renewed. The latter guarantees the continuous flow of information between the assembly/test hardware and the database without a need of human intervention.

The server part of CMIS infrastructure consists of two physical servers: a web server and a server for the database management system (DBMS). Both servers are located at JINR's LIT (Laboratory of Information Technologies) data center. The web-server is based on the x86-64 processor architecture with Microsoft Windows Server 2019 Standard installed as the operating system. The server interacts with external clients through Microsoft Internet Information Services (IIS) which is included into the Windows distributive. For security reasons the data transfer is performed

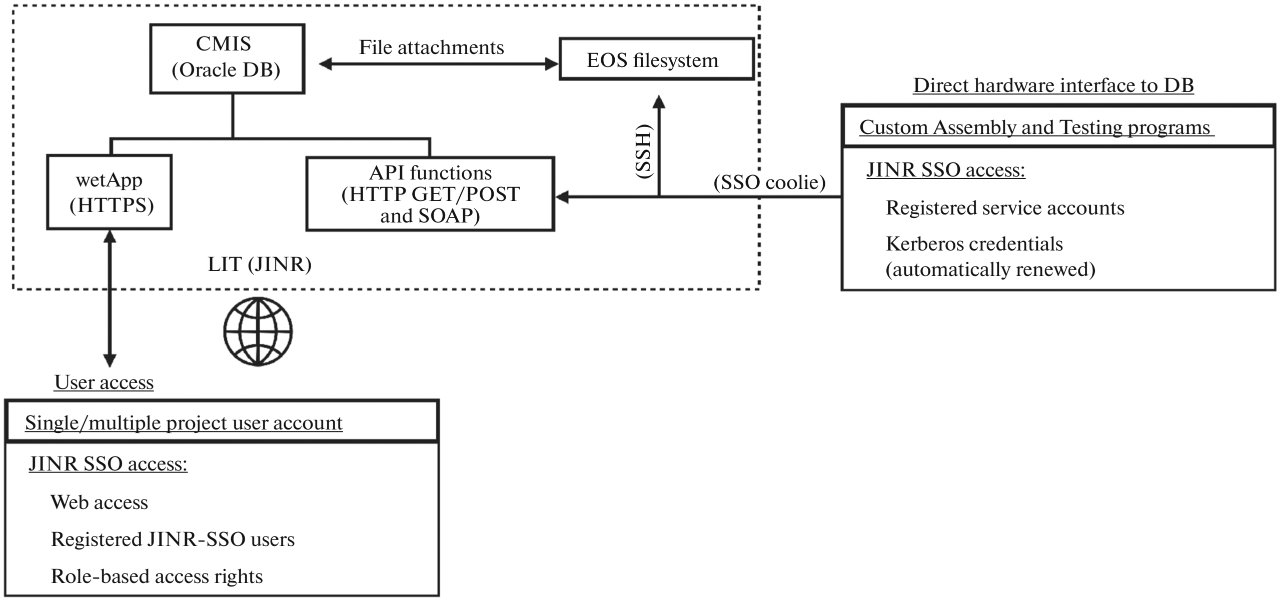

Fig. 1. CMIS implementation in LIT at JINR.

through the HTTPS protocol. The server backup is carried out using the Open-Source system UrBackup. The distributed file system EOS containing the CMIS project data files does not have the required protocols for exchanging the data with the Windows OS family. This limitation was solved by installing an additional gateway for transferring files from the web server to EOS using the SAMBA protocol. The DBMS server is also based on the x86-64 processor architecture and acts as the main object-relational data storage using Oracle Database v19. Oracle Linux 7 was chosen as the server operating system for being fully compatible with Oracle products. The backup is carried out using the built-in Oracle Database mechanisms as well as the Open-Source UrBackup system.

This was the first time that such a multicomponent construction management information system was deployed within JINR's LIT infrastructure integrating a web-based user interface with and independently accessible web API connected to an Oracle database and the EOS shared filesystem guaranteeing a secure access on demand for individual users (SSO) and continuously for the assembly hardware (SSH). For this, the two servers were provided with 10 Gbit/s Ethernet network interfaces with the possibility of further increasing this bandwith. Since the LIT infrastructure has a single user database that interacts with other services using the Kerberos and OAuth2 protocols, the access to the web components of CMIS was configured over the OAuth2 protocol while the rest of the components based on Linux OS were connected via the Kerberos protocol, including the access to the EOS filesystem. This approach allows to offer the same level of capabilities and accesibilities as the equivalent system deployed at CERN.

In the following sections the CMIS structure will be presented, followed by a brief description of the current implementation of this system for the construction projects of the silicon trackers for the MPD and BM@N experiments, respectively.

2. THE CMIS TOOL

CMIS is an Oracle-based all-around project management database system that allows the organization and follow-up of every aspect of a hardware production project. The system is produced and maintained by KYBERNETIKA s.r.o from Košice, Slovak Republic based on a similar product that this company developed for the upgrade of the Inner Tracking System of the ALICE detector at CERN. It allows the management of human resources, the project organization and planning, as well as monitoring of the current status and tests results history of every component of the detector. The direct interfacing of the assembly and testing hardware/software to the construction database is supported. Hence, the information ranging from the current location of a component in-transit to/from an assembly site down to the final position of a single chip inside the detector along with the results and test history of every component during the assembly process may be easily stored and consulted. It is a modular system that may hold several projects in parallel with independent role-based access for the different projects.

The mechanism for following and recording all the information related to the work being performed is based on the creation in the system of user-defined "Component Types" and "Activity Types" templates that correspond to the type of activities performed in

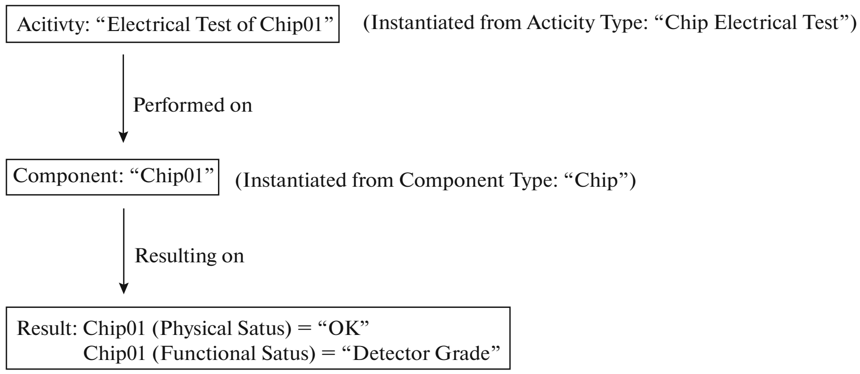

Fig. 2. Schematic representation of an Activity perfomed on a Component and its final result.

the real world on real types of components. These templates are then used for the creation in the system of the corresponding specific instances of “Components” and “Activities”. In practice, the “Activities” reflect *actions* (e.g. “Visual Inspection”, “Electrical Test”, “Component Assembly”, etc.) performed on “Components” that may result in a change of either its “Functional” or “Physical” status (or both) in the real world and these changes are correspondingly recorded in the system according to user-defined criteria. Figure 2 shows the example of how an electrical test that was performed on a specific chip (“Chip01”) is represented in the system and how the result of the test is recorded. In this case a specific activity named “Electrical Test of Chip01” is instantiated from a previously defined type of activity named ‘Chip Electrical Test’ which contains all the relevant attributes like, for example, name of the activity, type of components related to this kind of activities, the location where it could be performed and the possible results expected from this kind of activity. The specific instantiated activity is then performed on the specific component “Chip01” instantiated from a previously defined type of component named “Chip”. The latest allows for specifying the relevant attributes for a component like its name, composition, and the list of user-defined possible Functional/Physical statuses relevant to a specific type of component. The result of this Activity on the given Component is recorded into the system by updating its Physical and Functional status to one of the pre-defined possible values.

As for the Activity Type definition it includes the “Input” and “Output” components that will be part of this type of activity and may be the same (in case of a testing activity) or different (this is the case for an assembly activity). It also includes a list of user-defined parameters to be recorded for this type of activity, as well as a list of user-defined expected results, each of them being a combination of the Functional and Physical statuses previously defined for the type of component declared as ‘Output’. Additionally, when instantiating a specific activity of a given type, it is possible to attach to it any type of files that might be required. All the activities performed on a single component are recorded in the “history” of that component which allows the full follow-up and feedback in the production process.

3. APPLICATION OF CMIS AT NICA FACILITY

Following there is a brief description of the CMIS implementation for the management of the assembly process of two NICA projects (MPD-ITS and BM@N-STS) that are currently making use of this system. It should be noted that although these two projects are fundamentally different on the detector’s technology and on the assembly and QA process, the modularity and flexibility of CMIS allowed to implement equally functional construction management projects for each of them. Furthermore, in both cases the implementation of the data-recording into the DB was made an integral part of the assembly process, so that subsequent assembly steps are performed using the CMIS clients with graphical (GUI) or command line (CLI) operator interfaces that update the data and at the same time, act as a workflow plan of the assembly process. This was done in such a way that each new assembly/test step depends on the correct recording of the data from the previous one, minimizing the possibility of circumventing the system.

3.1. Application of CMIS in the Production of MPD-ITS

The Inner Tracker System (ITS) of the MPD experiment will be built as a joint effort of various institutions from Russia and China with the production split among JINR and at least 3 other production sites in China. This includes the shipping of detector components between the production sites, from individual chips to fully functional Staves (Detector supermodules composed by 14 individual Hybrid Integrated Circuits (HIC) modules each) and the precise testing and characterization of each part at different assembly

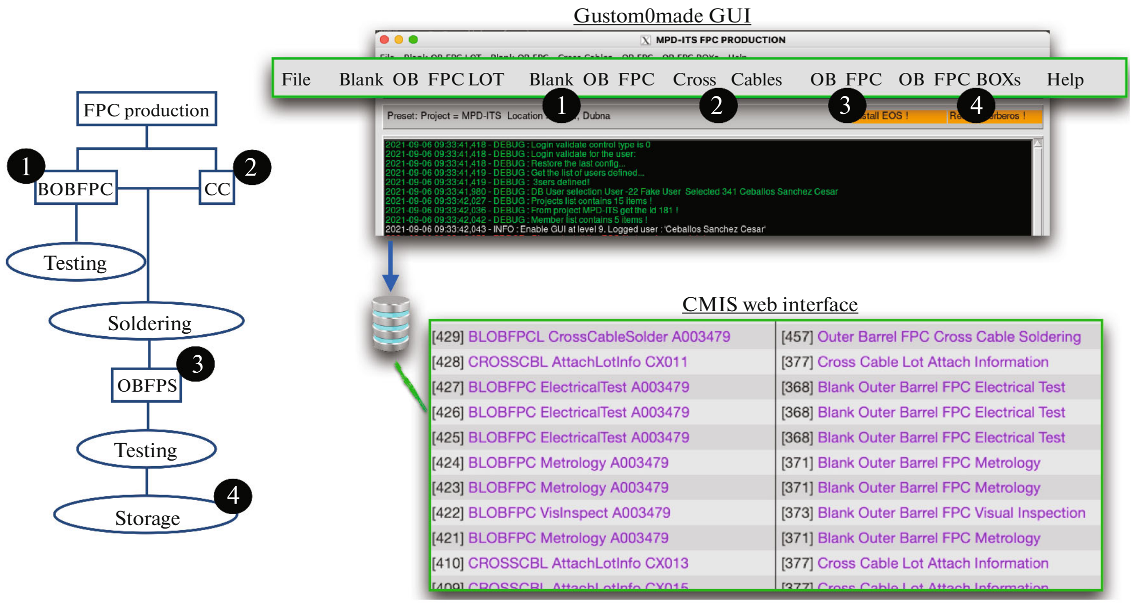

Fig. 3. (Left panel) Workflow of the assembly of the FPCs and (Right panel) the corresponding custom-made GUI to follow the process and record the activities into CMIS.

stages, aiming for a detector-grade yield of 75% for the Stave production and 85% for the HIC production.

The Outer Barrel alone will consist of 42 Staves holding 588 HICs for a total of 8232 MAPS chips (~4.3 Gigapixels) aligned with a precision within 5 μm.

The construction of this detector comprises the production, transportation, testing and assembly of components of different complexity, ranging from single sensor chips to large supermodules that demand a fine-grain level of control and continuous feedback. The complete workflow of production and testing at all levels has been implemented inside CMIS, and a variety of custom-designed software from scripts to full graphical user interfaces (courtesy of ALICE Collaboration) have been received and adapted at JINR to follow up the full production process of the MPD-ITS. Figure 3 shows an example of the implementation of the activities for the assembly of the Flexible Printed Circuit (FPC) to which the sensors will be bonded afterwards. It starts with the electrical test of a Blank Outer Barrel FPC (BOBFPC) to which a set of cross cables (CC) is then soldered resulting in a new Outer Barrel FPC (OBFPC) that will be subsequently tested and stored. As it can be seen, a custom CMIS client with GUI was developed in Python to reflect the workflow of this assembly process up to the storage of the FPCs with the corresponding creation of the activities in the database for each of the components involved. The collection of all CMIS clients developed for the full detector construction project allows both, the human interaction with the database and automatic and continuous interfacing of the database with the testing hardware at all levels of the detector production. In the given example the physical activities for the FPC assembly and testing process are concatenated via the dedicated CMIS client with GUI showed in Fig. 3 (upper-right panel) from where the operator gets the corresponding information for the selection of the available components to be used at every step, while at the same time the new information generated during the assembly process is automatically recorded into the DB.

3.2. Application of CMIS in the Production of MB@N-STS

The BM@N-STS detector as a whole will comprise 292 modules with double-sided microstrip silicon sensors having 2048 electronic channels each. Although the silicon tracker of the BM@N experiment is based on a technology completely different from the MPD-ITS it equally requires the precise and sequential assembly of different structures.

The workflow implemented for ALICE collaboration and used for MPD ITS could not be used and adapted in this case so the automation of the assembly process for BM@N silicon tracker via the CMIS tool should have been done from the scratch. Initially the assembly process was mostly manual (with the exception of some steps related to electrical testing of the components) and required the technicians to follow exactly several assembly steps and to record the intermediate results via the hard copies of dedicated assembly log documents, resulting in a stressful and error-prone process. Therefore, the initial step to implement the construction management system was the assess-

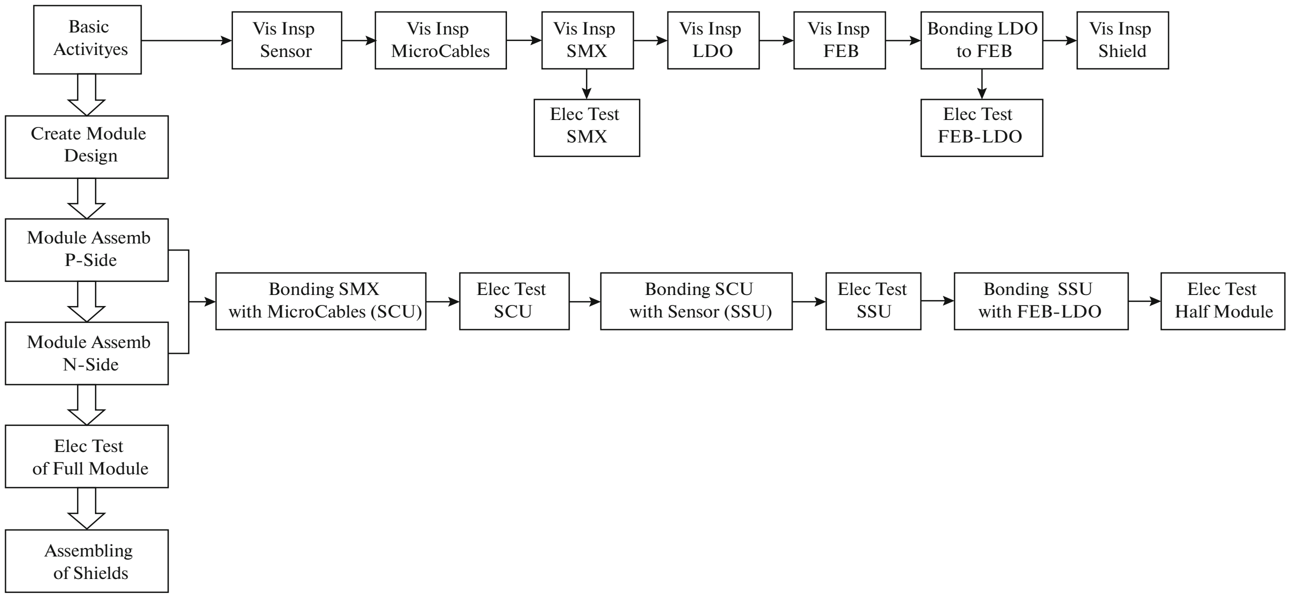

Fig. 4. Workflow for the module assembly of the BM@N-STS detector.

ment of the existing assembly process to systemize it, understand existing process issues and formulate improvement goals such as organizing the assembly data (intermediate and final) in a structured database that can be easily accessed and analyzed, minimize the risk of human mistakes, speed-up the process, etc. The resulting assembly workflow diagram is presented on Fig. 4. The next step was to create the DB model in the CMIS syntax containing the minimal required component types and activity types which can be used to organize each step of the process and avoid redundant objects. At this stage also started the creation of customized clients with GUIs for an easy and secure interaction with the DB. The first created DB model was iteratively refined while working on the implementation of the real-life assembly steps and testing activities until it fully satisfied the requirements from the operators. The clients for interacting with the DB were also repeatedly adapted to match the modifications of the DB model. The end of this process resulted in the storage in CMIS at JINR's LIT of all the information of the assembly and testing process for several modules for the BM@N experiment.

Python, Labview and C++ languages were used for the CMIS clients development. Most of client's GUIs were coded using Labview.

The CMIS Web application provides access to its API's with the following protocols: SOAP 1.1, SOAP 1.2, HTTP GET and HTTP POST. Appropriate libraries in each of the three programming languages have been developed to support the CMIS client interfaces. The structure of a CMIS client implementing an "Activity" is shown in Fig. 4.

The clients hardware interfaces were either embedded in a client and used hardware communication protocols directly, or implemented via synchronized file exchanges with corresponding independent hardware control applications using a common file system. In particular, in widely used visual inspections of components performed after various assembly operations, high resolution image files are produced with Carl Zeiss microscope by ZEN application in CZI format [7]. An additional application was developed to convert data from CZI-files to standard graphical formats for the specific configuration of the microscope, MS Visual C++ and open source libCZI [8] being used. The converted files are uploaded to CMIS by the corresponding clients.

A sample of some of the custom-designed client GUI windows for the interfacing with CMIS via the dedicated APIs are shown in Fig. 6. As it can be seen it also reflects the different steps of the assembly process. In addition to guarantee a safe interaction with the database, these GUIs were designed to guide the operator through the assembly workflow, taking into account that there will be different assembly operations going on in parallel at different stages of completion. As in the case of the MPD-ITS project, the data has been foreseen to be written/read either manually by the operators or directly by the software performing the component tests. The Pogo pin electrical tests, for example, are carried out at different stages of the assembly process using an in-house made dedicated C++ standalone application BondingTest [6] that automatically interacts with the DB.

In total, 21 CMIS clients were developed for the BM@N-STS, six of them to upload the results of the

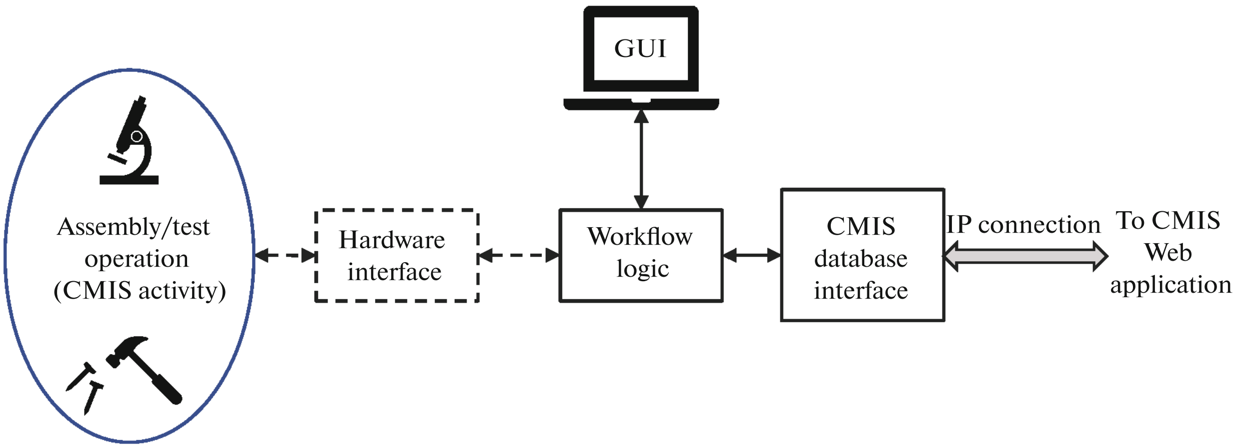

Fig. 5. Structure of CMIS client software.

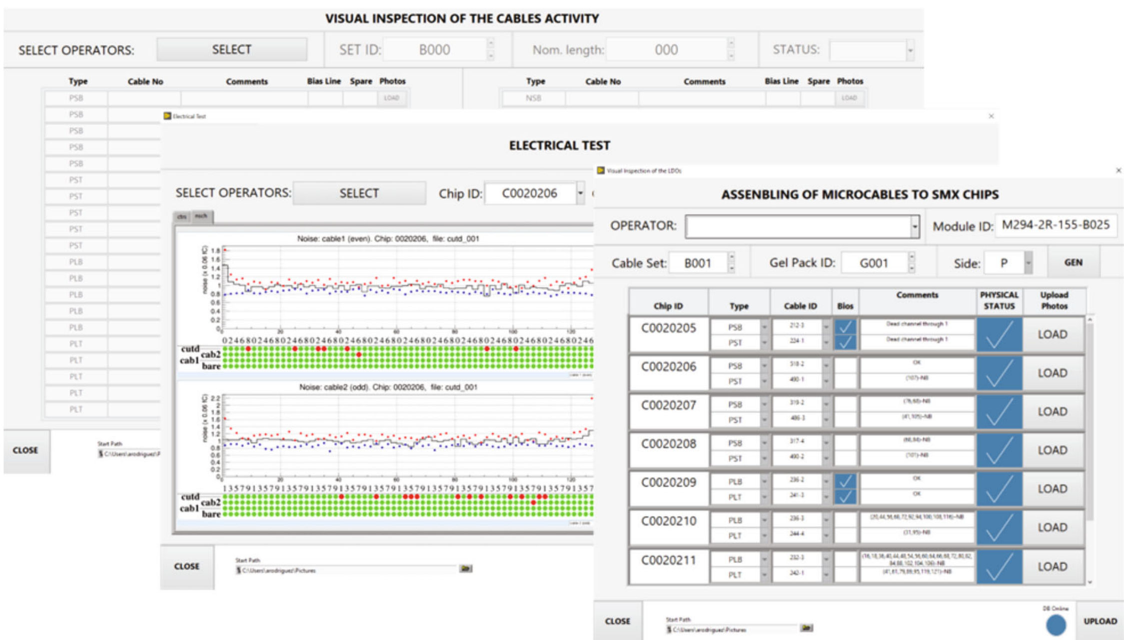

Fig. 6. Example of the LabView-based GUIs for registering the assembly operations of the BM@N-STS modules into CMIS.

visual inspection of the components, six more for recording the different assembly stages, two for implementing the electrical tests and uploading the results, one for uploading the results of the mechanical tests of wire bonding, three to generate reports on the state of the assembly for specific modules, two to organize the workflow and one Main Menu GUI application to have an easy access in one place to all the clients.

4. CONCLUSIONS

The deployment of the Construction Management Information System on the JINR's infrastructure represents a novelty for this institute since no such system had been used before. Despite this, the system was setup to offer the same level of functionalities as a similar system installed at CERN. The CMIS is particularly useful for the control and continuous following of the production of complex multipart objects like the detectors subsystems used in experiments of the NICA facility at LHEP. It offers the possibility of creating fully customized interfaces using any major programming language to better adapt to the structure and requirements of any project of this type. At present it is used by two of the NICA projects (MPD-ITS and BM@N-STS) but since it is centrally hosted at JINR's Laboratory of Information Technologies it might be used by any other project that could benefit from it.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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