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ON PRODUCTION CONTROL OF CMS ELECTROMAGNETIC CALORIMETER

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Abstract

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Some ideas concerning the object-oriented software for simulation, analysis, planning and control of production process at the CMS electromagnetic calorimeter are considered.

Аннотация

Битюков С.И. и др. К вопросу о контроле процесса производства электромагнитного калориметра установки CMS: Препринт ИФВЭ 96-77. – Протвино, 1996. – 8 с., 2 рис., библиогр.: 6.

В данной работе обсуждаются некоторые идеи, связанные с созданием объектно-ориентированного программного обеспечения для моделирования, анализа и контроля процесса производства электромагнитного калориметра установки CMS.

Introduction

Calorimetry plays a central role in CMS [1] physics by providing energy measurements of electrons, photons, jets, and estimating energy for noninteracting particles (neutrinos, photinos ...) by missing p_T. The CMS collaboration has decided to use lead tungstate crystals in electromagnetic calorimeter (ECAL). More than a hundred thousand crystals with photodetectors are to be produced, tested and assembled during several years. A large share of crystals are to be produced by the Bogoroditsk plant [2] in Russia. Other producers of crystals will be Shanghai Institute of Ceramics (China) and CRYTUR company (Chech Republic). It is suggested that the distributed control and data base system [3] would perform the quality control of produced crystals, photodetectors and other parts of ECAL. The information concerning the production, assembling, testing and moving elements of ECAL in production, regional and assemble centers will be stored to object-oriented database. Multiparameter monitoring and control of production process is vitally important in such system. There are some methods for scheduling and planning discrete events in manufacturing systems [4]. However, these methods don't allow one to construct control limits to monitor and control real process (once-off process) using well-studied time distributions (for each step of production process). We propose a simple procedure to determinate control limits for the given production process by using technique of simulation. The control limits are needed to check the state of process. If monitoring system indicates that process is out of control then the assignable causes should be sought for and a corrective action should be taken. This procedure, as supposed, will be part of Subsystem for Production Analysis and Control of the Electromagnetic calorimeter of CMS (SPACE CMS) in the frames of C.R.I.S.T.A.L.[1] system [5]. A sketchy description of such subsystem is given in Section 3.

[1]Concurrent Repository & Information System for Tracking Assembly and production Lifecycles

1. Scope of SPACE

SPACE has to be used during the production, assembling and testing of all the ECAL components. The main goal of SPACE is to provide the C.R.I.S.T.A.L. system with object–oriented toolkit that would help a user to simulate the detector production process, to optimize production process parameters as before the production (optimize center instruments, optimize number of center operators, ...) so in the course of production (optimize shipping, ...), to estimate the state of the real or simulated process and to find End of Production estimations.

The framework will provide a set of subsystems covering the following elements of the SPACE:

- simulator of the production process,
- analyzer of the single production process (both simulated and real),
- comparator of the production processes,
- visualization of any production related processes,
- interfaces with databases, etc.

2. Model of the ECAL Production Process

The following notations are used below:

- each element of ECAL (with identifier[2]) is Part,
- each assembly of some Parts is Superpart,
- Superpart is Part,
- unit of equipment for testing, shipping or assembling is Tool,
- each operation with Part and Tool is Task.

The principal application of simulation in the frames of SPACE is the estimation of time interval for each operation during production process (it may be the time interval from the first "PartRegistration" in C.R.I.S.T.A.L. system up to Detector installation to pit so the time interval of applying some Tool to the associating Part). Fig.1 illustrates subdivisions of the ECAL structure.

The production of electromagnetic calorimeter of CMS is a stochastic process.[3] Let we know the distribution of time for applying each Tool to the corresponding Part, that is the distribution of execution time for each Task. Then, knowing the order the tasks are done in, we can construct a modelling realization (trajectory) of the production process using a generator of random values (simulation experiment). The order of execution of each task is given due to the scheduling plan produced by hand, with the use of Petri Nets [6] or any other ways (for example, see Appendix).

While having accidental realization of stochastic process we can generate a number of trajectories of our process adequately to estimate mean times of completion of each

[2] A unique identifier usable with a bar-code read-out system.

[3] The real production process is one of possible realizations (and unique) of production process.

Task, its variances and other values needed to set control limits and to analyze production process in the frames of the given plan.

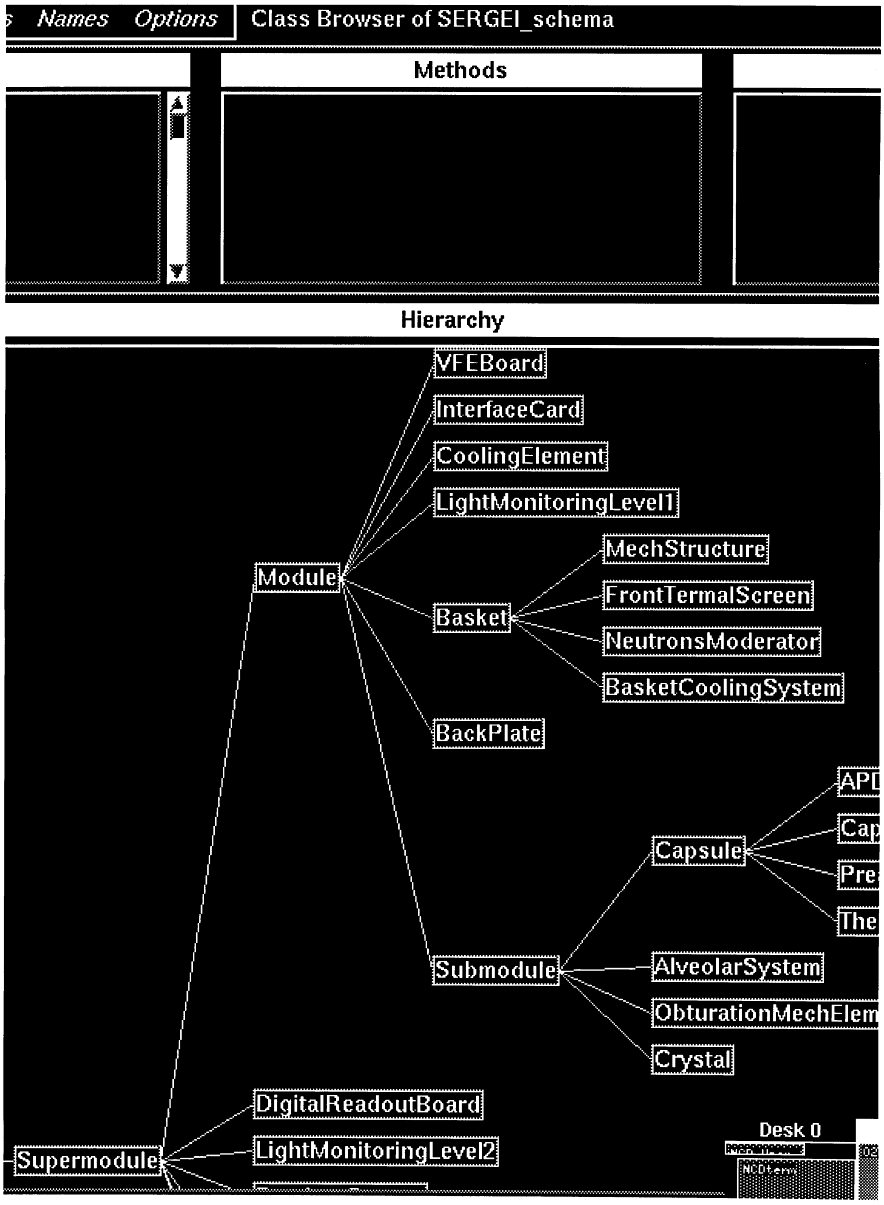

Fig. 1. Fragment of ECAL structure.

3. Class categories analysis for object-oriented simulation of the production processes

The SPACE class categories and their relationships are shown in Fig.2. A brief overview of the main SPACE components is given below.

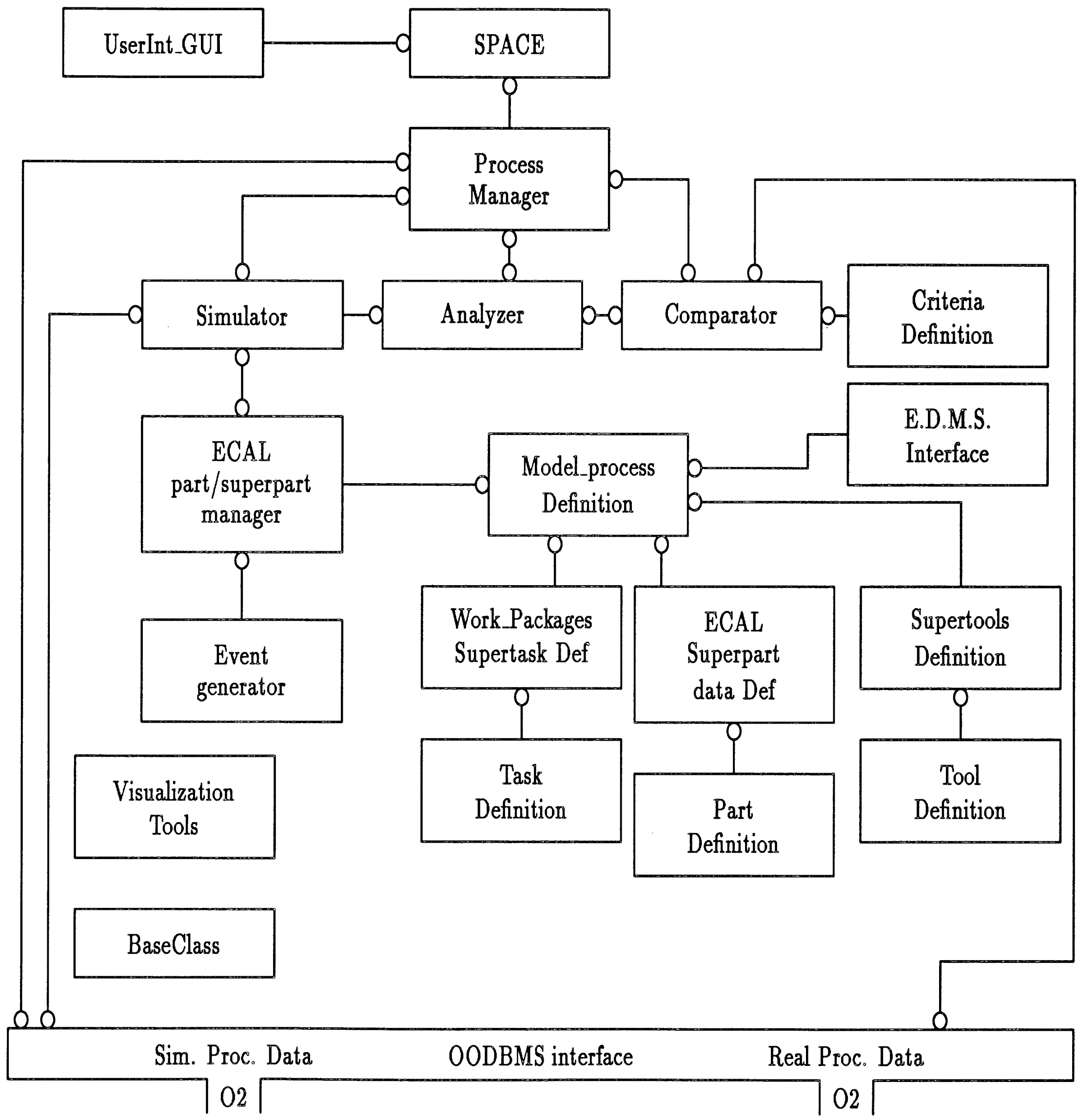

Fig. 2. Class categories diagram.

3.1. Manager

The SPACE has a number of support utilites:
Process_Manager, ECAL_part/superpart_manager and Event_Generator.

Process_Manager is a core subdomain of SPACE. At first this manager initializes the simulator, the analyzer and the comparator, and determines interface to OODBMS. Also Process_Manager serves any interruption signals from user and supports multiple threads in the system. This subdomain performs both simultaneous and separate management of processes in SPACE :

- process of the simulation of production process,

- process of the analysis of real or modelling production process,
- process of the comparation of real and modelling or two modelling production processes.

ECAL_part/superpart_manager is a manager of simulation process. Its main goal is generating the dynamical map of the production process. This manager will be able to process any interruption from Simulator at any moment. ECAL_part/superpart_manager uses information from Model_Process_Definition and some random values from Event_generator. This domain contains different convertors to transfer random numbers into any distributions. It should have a possibility to include correctly the convertor defined by an user. The main goal of the Event_Generator is to generate random sequences to be used in the ECAL_part/superpart_manager workspace.

3.2. Computation Kernel

This is the main intellectual part of the SPACE. It consists of Analyzer, Simulator and Comparator.

The subdomain Simulator simulates the passing of ECAL elements through the chain of tools from manufacturing to assembling in CMS setup or through part of this chain. The main goal is to generate a full map of the ECAL part/superpart dynamics to compare with the real process by Comparator or to store into the OODBMS for further analysis.

During the work Simulator sends a control sequences to the ECAL_part/superpart_manager using the information from the Model_Process_Definition. The results of simulation are stored in OODBMS in accordance with Process_manager control sequence where access rights for this operation have been granted.

Comparator performs the comparison of real/modelling production process status with the simulated one using one or many various criteria. This subdomain shall be able to analyse both full map of the process and some part of that map (maybe in the multithread mode, in parallel with process of simulation). Data for analysis may be transfered from OODBMS or directly from Simulator. All possible criteria of the comparation are taken from Criteria_definition. Final results may be stored into local user database by means of OODBMS interface, or directly transfered to user for next calculations and visualization with the Visualization_Tools. The analysis techniques build on statistical analysis, theory of the stochastic processes, self-organizing algorithms, fuzzy sets logic will be used in Comparator.

Analyzer will provide a full statistical and dynamical analysis of real or/and modelling production processes and will present the results of this analysis to the user with Visualization_Tools. Analyzer must be able to analyze:

- the statistical behaviour of every Tool, Task and Part,
- the statistical behaviour both of the model of production process and real production process at any level of detalization.

Analyzer will be able to provide the selection of the optimal model for the production process and to predict the behaviour of the real production process.

Analyzer will be able to detect (using outcome of Comparator) the unconditional variance of the production process and to provide the user with ability to perform steps to stabilize process.

Analyzer will use procedures based on the methods of the analysis for Dynamics of Discrete Event Systems, Queueing Models, Petri Nets, etc.

3.3. Definitions

This is a set of definitions of different variables used under SPACE work session. It consists of Criteria_Definition, and a lot of parameters and functions related to Model_Process_Definition.

Criteria_Definition will give a possibility to select some sets of the criteria to be used. Criteria will be used for statistical and dynamical analysis of the processes under investigation and for comparison between real and simulated processes. The main problem is to determine the confidence levels and limits for each of values, playing an impotant role in testing hypothesis.

Model_process_definition initializes the model of the production process according to the users requirements and serves the ECAL_part/superpart_manager with setting assosiations between Superpart/Part, Task and Tool. It will recognize various input formats from ASCII dump description up to the well designed graphical models from CAD/STEP systems or E.D.M.S (may be for the other OODBMS or RDBMS formats).

Task_Definitions characterize each step of the production process.

ECAL_superpart_data_definition subdomain contains the information on both physical details of the ECAL elements and other kinds of information (personality, timing, rejections and its reasons, etc...) related to each superpart. Part_definition is the elementary structural subdomain. It will contain full information on the analysis and visualization. This is an internal object of ECAL_superpart_data_definition.

Tools_definition contains the descriptions of different equipment units, applied to ECAL_superpart_part. It must contain the full information about equipment unit.

3.4. Interfaces

Determination of the framework for the production process is the main goal of the UserInt_GUI subdomain. It shall be able to determine:

- requirements on the production process,
- various process quotas and working regimes,
- the authorization level of the OODBMS usage during that task running (read-only, write-only, read-write, etc...)
- description of the intellectual part of the SPACE system (external criteria, user criteria, etc...)
- GUI for input startup (user control sequencies, ...) and output of the final results (ASCII dump, histograms, N-tuples, OODBMS structure, various graphical formats from CAD/STEP design, etc...)

UserInt_GUI allows a user to control the SPACE performance.

E.D.M.S._Interface will support possibilities for SPACE to use various graphics information (e.g. model process schema, etc...) so as to store any internal results into the files according to the E.D.M.S or CAD/STEP standards.

OODBMS_Interface is invoked to determine the access rights of SPACE to OODBMS (read-only, write_only, read_write, etc...) . It will support both user-supplied controlling of this access rights mechanism and a default mechanism.

Visualization_Tools will support a possibility to visualize any information in the system at any moment. It will support visualization of the partially stored information.

The common rule - each bit of the information may be visualized with the user-required level of visualization.

Conclusions

The conclusions from the results presented are :

- proposed method to set control limits for the monitoring production process of ECAL CMS by using technique of simulation,
- analyzed class categories for object-oriented simulation of the production processes.

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Appendix

A program for modelling and optimizing ECAL production process

The real process being very complex, both in terms of number of entities to be taken into consideration and the type of relations between them, it looks reasonable to consider a simpler model and then to try to apply results gained to the real process.

So, the following model was being considered. Let N be number of crystals to be produced, L be number of production phases. For each given i such as $1 \leq i \leq L$ let P_i be a total number of (identical) tools available at phase i, Q_i be number of crystals a tool at this phase can process up to simultaneously, R_i be the amount of time a tool takes to complete processing crystals loaded into it, S_i be the amount of time a tool takes to restore its ability to work. Each crystal should pass through every phase in a fixed order, being the same for each crystal. The crystals can be stored before each phase without any limitations. All the parameters listed above are positive integers.

Giving a moment of time, we can describe the state of the process as an ordered set of states of each phase. The state of phase i can be described by: the number of crystals being stored before this phase (U_i), the number of tools being ready to work, for each j such as $1 \leq j \leq R_i$ the number of tools loaded completely and having j units of time to complete processing and the number of crystals which must be loaded into the underloaded tool, for each k such as $1 \leq k \leq S_i$ the number of tools having k units of time to complete restoring.

The initial state of the process is the following: all the crystals are stored before phase 1 and all the tools are ready to work. The task is to minimize $T(N)$, the time it takes to complete the process by defining appropriate plan for each tool and crystal.

The following ideas were used when developing the solving algorithm. First, there is no need to hesitate while making a tool begin working as soon as it can be loaded completely. It means, in particular, that any tool that cannot process more than one crystal, should begin working at once just when it is able to load a crystal. So, the main problem with the solution is whether to make or not to make a tool work while it is underloaded. Second, it is possible to reduce the number of decisions, having noticed that the latter one should be made just when the number of crystals stored before the phase changes. Third, we can estimate the length of a solution and reject it as soon as it is found too long. Let $T(i, j)$ be the time it takes to process i crystals stored right before phase j and V_k be the number of crystals being processed before phase k. Then, for any given state of process, let $T_{min} = \max_{1 \leq i \leq L} T(V_i + U_i, i)$. This T_{min} is the time for the process to be completed.

By using these idea the program greatly reduces the incomplete tree of possible solutions and so enlarges its area of applicability. Without any doubt, it is not possible to find the best solution for any possible configuration of production line just because of great computational complexity of this algorithm in some cases. Nevertheless, it easily finds one of possible solutions and then all the solutions found are not worser than it. So, whenever it is interrupted, it gives a solution, but, maybe, not the best one. The first solution it finds corresponds to the one achieved by using "hungry" algorithm that never hesitates in making underloaded tools begin working.

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