Toward an incremental development for real time and embedded systems

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Abstract-This paper presents a new methodology to development complex embedded systems for hard real-time applications, based on incremental model in order to make the latter compatible with the particularities of embedded systems. In this paper, we first introduce the methodology proposed and describe it step by step, based on SART((Structured Analysis Real-Time) and MARTE (Modeling and Analysis of Real Time and Embedded Systems) profile for analysis and modeling of real-time systems.
The suggested methodology is illustrate with a two case studies for development of hydrostatic bearing lubrication system and triaxial appartus system.
Keywords—Incremental model, Triaxial appartus system, Hydrostatic bearing lubrication system , RTES.

I. INTRODUCTION

REEL Time and Embedded Systems (RTES) are now omnipresent, and it is difficult to find a domain where these miniaturized systems have not made their mark, such as: (a) consumer electronics (b) home appliances (c) office automation (d) business equipment (e) automobiles **[1].**
Furthermore, the development of these hybrid systems consisting of mechanical, electrical and software parts, that run in a physical world is a very complex challenge, comes from the fact that RTES must interact with the environment and their particularities.
Among life-cycle process used in the development of RTES are V-model **[17],** SW/HW **[16]** and W-Model **[9].**The
commonly used for the development of embedded systems is the V-model for example in **[21].**
The V-model is denoted as a linear life-cycle process that follows a top down approach shown at the left side of the V, while validation and verification takes place using a bottom up approach shown at the right side of the V **[14].**
The main idea to remember is that when any changes to the application at any level whether, it is necessary once again falling all stages of development.
To overcome this problem, we propose the principle of Incremental model takes into account the fact that software can be built step by step.
The objective with this model is to identify parts, which can be developed from specification to executable code. The development of an increment may follow either a waterfall model or a spiral approach. Incremental development means dividing the requirements into suitable parts during the specification allowing for independent development of the different increments. The design and coding of one increment are followed by testing of that increment, which makes it possible for the developers to start implementing the next increment while the testers validate, verify or certify the first developed increment. Here, it is assumed that development and testing are performed by different teams.
The incremental approach hence allows for a good deal of parallelism between development and testing. The benefit from this parallelism is not only the possibility to work in parallel, but also that the testers really start testing the software to be delivered at an early stage. This is what solves the previous problem figure in V-model.

The contributions of this paper relate to presenting a complete methodology for the development of RTES based of incremental model **[3][5] [13]** and improve this model to
fit the distinct RTES. The main benefits of this methodology
are:

- Each development is less complex;
- It is possible to deliver and enable each increment;
- It allows a better smoothing of time and development effort through the parallelization of different phases.

The rest of this paper is organized as follows: section II illustrates our contribution, followed by an introduction of methods used (SA-RT and MARTE) in Section III. While section IV presents our case study, with a Experimenting methodology on a case study. Afterwards, section V presents our discussion followed by a conclusion in section VI.

II. OUR CONTRIBUTION

In this section, we provide a brief overview of the methodology proposed, as illustrated in Fig.2, which aims to develop novel model life cycle, based on incremental model depicted in Fig.1, to

improve existing practices in development of complexes real-time and embedded systems.
The methodology consists of three essential elements: assets
activities (incremental model), New activities , and tools (with the methods and techniques used in each activity).

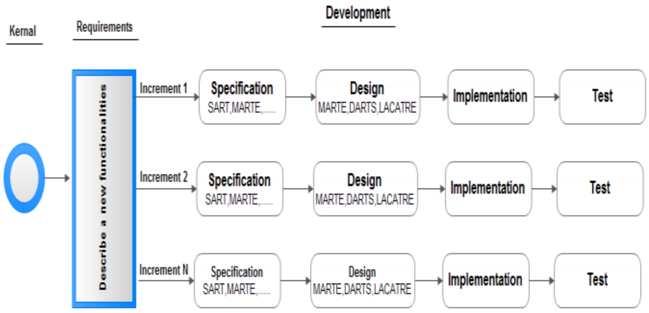

Fig 1**:** incremental model

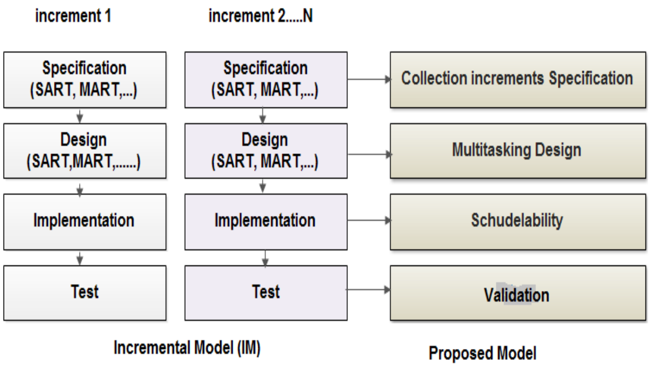

Fig. 2. An overview of our methodology

Initially, the left-level system design model are carried out using the Incremental model. When the developers execute the second increment the the right-level system design model
is starting, the third increment execute with IM model, then the proposed model therefore is carried out, until N increment the IM and proposed model are affected with consecutive manner.

Algorithm 1 Algorithm for our methodology

Begin
I=1; applied Incremental Model
For i=2 to N do
Begin
applied Incremental Model;
applied the proposed model ;(the novels activities)
I=I+1;
End
End

The main activities of this our methodology are:

The classical stages for incremental model: Specification,
Design, Implementation, and Test. with the activities proposed :
1. Collection increments Specification
2. Multitasking Design
3. Schedulability
4. Validation
Each of these stages must be followed by a phase designated her as shown in the figure, to confirm spell as follows: Collection increments specification followed by specification stage,
Multitasking design with Design stage and Schedulability followed by implementation, finally validation suited by Test stage.
Collection increments specification stage consists to add specification of increment i-1 (precedent increment) in specification of current increment to make a connection between the different increments. This stage allows the developers to see the common things between increments, like functions and avoiding non-recurrence, furthermore resources and try to reduce.
Multitasking Design stage offers to developers describe theirs multitasking application, and to express the architecture of system (the tasks, relation between tasks, access of critic resource).
Schedulability **[15]** stage is a primordial stage during all
development of RTES, it allows to verify the respect of times constraints.
Final validation will always be required in the completed system. This validation allows to valid all functionalities of system (all increments), when test valid each increment alone.
The aim of the Methodology-proposed is to provide a methodology that allows leveraging the productivity gains offered by incremental model. While the latter can contribute significantly to parrallized the different stages and minimize the faults of system from the minimization the need for re-validation activities.
The methodology enables developers to easily developed system for their own necessities with less complexity and allows the validation before next increment and total validation for all system.

III. PRESENTATION OF SA-RT AND MARTE METHODS

A. Presentation of the SA-RT method

SA-RT is **[9][22]** a short name for Structured Analysis Methods with extensions for Real Time.

The model is represented as a hierarchical set of diagrams that includes data and control transformations (processes). Control transformations are specified using State Transition diagrams, and events are represented using Control Flows.

Thus, SA-RT is a complex method for system analysis and design. This is one of the most frequently used design method in technical and real-time oriented applications adopted by various Case-Tools. It is a graphical, hierarchical and implementation independent method for top-down development (Fig.3).

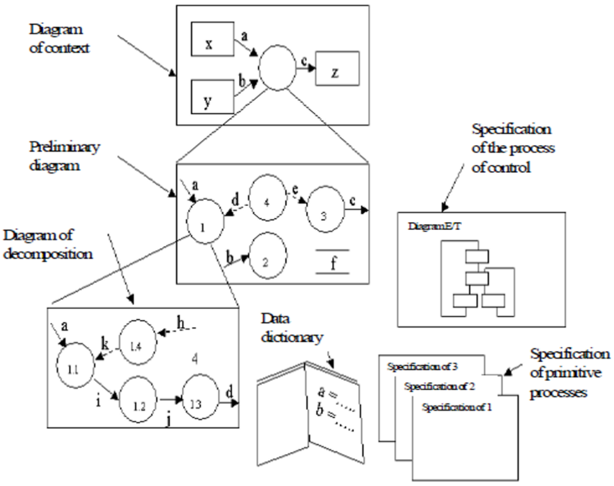

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Fig. 3. Organization of an SA-RT model

The symbols of the Diagram of Context (Fig.4):

- The terminator is the element in end, final element that encloses the action.
- The flot of data is the final element that opens up on a last action.
- The flot of control is generally a tie back of the process toward the terminator. It can be a main element of the process.
- The termination is generally a direct tie between a terminator and the process **[23].**

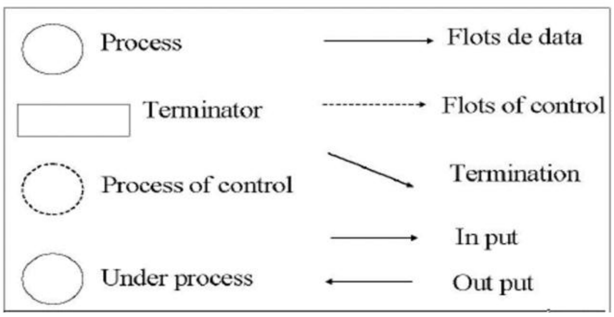


Fig. 4. Symbols of SA-RT method

B. Presentation of the MARTE profile

MARTE (Modeling and Analysis of Real-Time and Embedded Systems) **[2][24][25]** is the UML extension profile dedicated to the modeling of Real-time and Embedded Systems (RTES). Standardized by the OMG.

MARTE profile consists of three packages named "MARTE Foundation", "MARTE Design Model" and "MARTE Analysis Model", shown in fig.5.

"MARTE Foundation" package defines all basic foundational concepts required for design and analysis of real-time and embedded system. It provides model developers with constructs for modelling of non-functional properties (NFPs), time modelling, generic resource modelling (GRM), generic component model (GCM) and allocation modelling.

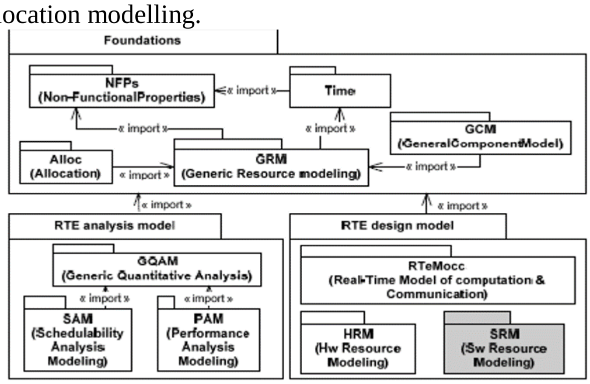


Fig. 5. overview of MARTE profile

"MARTE Design Model" package addresses model-based design, starting from requirement capture to specification, design and implementation. It provides high-level concepts for modelling both, quantitative and qualitative features of real-time systems/protocols. Further, it also provides means for detailed description of software and hardware resources used for execution of an application.

The package "MARTE Analysis Model" offers specific abstractions and relevant annotations that could be read by analysis tools. MARTE analysis is intended to provide trustworthy and accurate evaluations using formal quantitative analysis based on sound mathematical models. This package is sub-divided into three other packages, namely "Generic Quantitative Analysis Modeling" (GQAM), "Schedulability Analysis Modeling" (SAM) and "Performance Analysis Modeling" (PAM).

IV. CASE STUDY

To better illustrate the use of our methodology discussed in Section II, a case studies are presented.

A. Case study 1: Hydrostatic bearing lubrication system

Rotating machinery is commonly used in many mechanical systems, including electrical motors, machine tools, compressors, turbo machinery and aircraft gas turbine engines. Typically exogenous or endogenous vibrations produced by unbalance, misalignment, resonances, material imperfections and cracks **[6]** affect these systems**.**

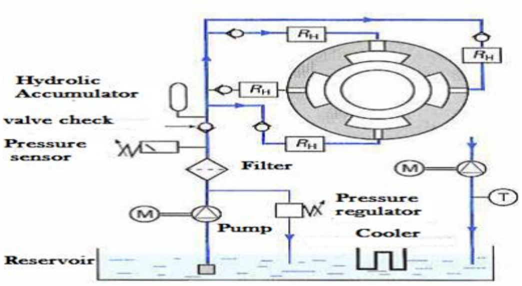


Fig. 6. Functionnement of hydrostatic journal bearing with four hydrostatic
Bearing.

To damp the vibrations has been proposed several methods: passive , active **[4][12]** and semi-active method **[11]** . Where passive methods are not enough to dampen the vibrations generated, a new smart hydrostatic journal bearing with four hydrostatic bearing flat pads fed by electrorheological fluid, has been designed to control rotor vibrations caused by imbalance and to reduce transmitted forces to the bearing **[8].**

So bearings are machine elements used to guide the rotating shafts **[7]**. The hydrostatic bearings can be used irrespective of the load and speed. They are used successfully in a large number of machines operating at low speeds and carrying heavy loads. Lubrication of hydrostatic bearings is an important process, but also complex. Because it consists of electronic and mechanical components that operate in a physical world.

This is what makes the development process is also difficult.

Functionnement :

Fig. 6 illustrate a functionnement of system. A pump supplies a bearing about 30 % higher than that required flow rate. The excess fluid returns to the reservoir via a pressure regulator. A pressure sensor is used to stop the rotor drive if the pressure reaches a value too low. Non-return valve and the hydraulic accumulator provide food bearing to a stop of the shaft. We can also provide a backup pump.

The flow is then derived to each cell on each portion of the circuit. Provision may be a check valve in case of overpressure in a cell. Resistance hydraulic HR should be placed as near the cell to avoid instabilities due to the pneumatic type lubricant compressibility. A pump may be necessary to ensure the return of the lubricant to the reservoir. A thermocouplee to control the temperature of the liquid at the outlet of the bearing and trigger stop if it becomes too large. Finally, a cooling system ensures a constant temperature on the power supply **[7].**

1) Experimenting methodology on a case study1: Here, we illustrate the various concepts present in our methodology by means of an effective real life RTES case study: hydrostatic bearing lubrication system.

After modeling of hydrostatic journal bearing lubrication system using the SA-RT method, we establish three diagrams as follows:

- Context diagram;
- Data flow diagram;
- Control flow diagram;

For this system, we carried out an increment(increment 1) to
verify the level of fluid tank. To achieve this increment, we
need to a sensor sends a signal when the low level (eg level
b), the sensor is considered a terminal send a data level low
= true or level low =false, finally needs an actuator here is that the pump will start.

- Specification /Design step

Figure 7 presents the context diagram of the SA-RT model of the system. In fact, the context diagram is constituted of one functional process « Control the level of liquid 0 » and 2 terminators (sensor and pump).

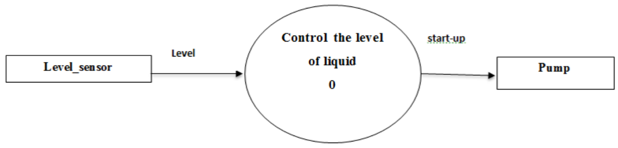


Fig. 7. Context diagaram

The Data flow diagram (Fig. 8) of the SA-RT model constitutes the first decomposition of the process presented in the context diagram. Then, we can break down the initial functional process of the application of control in three process: Acquirement process; Test process; command pump Process.

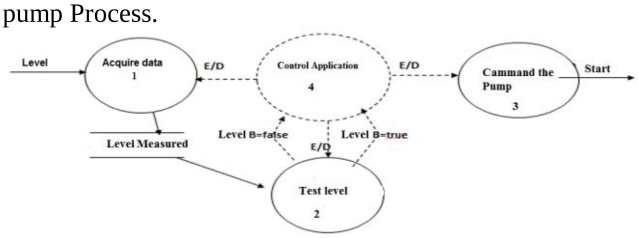


Fig. 8. Preminiraly diagaram

Now we pass in the second increment for control the pressure with the initial process « control the pressure » and 2 terminators
(the pressure sonsor and the regulator of pressure).Fig.9 present the context diagram of this and increment followed by the preliminary diagram (Fig.10).

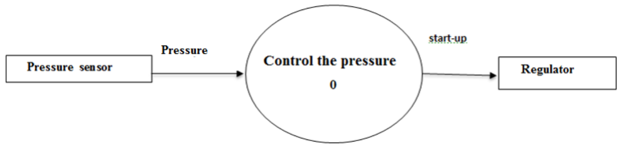


Fig. 9. Context diagram (Increment 2)

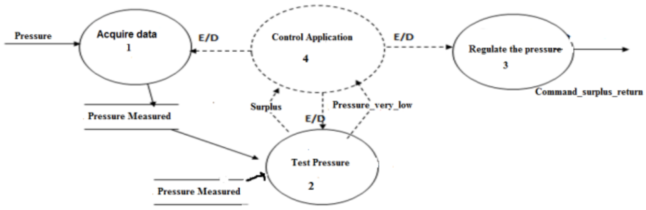


Fig. 10. Preliminary diagram (Increment 2)

- **Collection increments specification step**

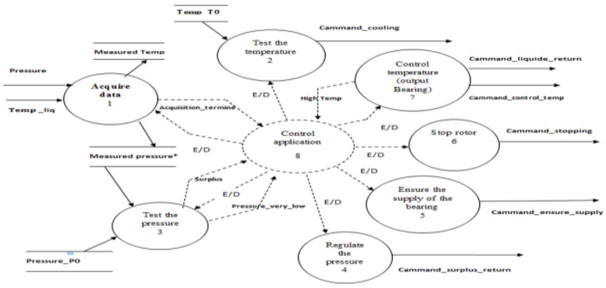
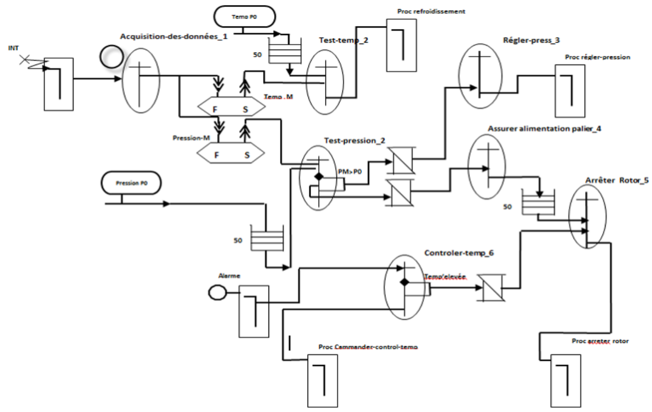


Fig. 11. Collection increment specification (context diagram).

After the implementation of several increments (acquisition data, test temperature, test pressure,...),the collection increments specification step is presented in Fig.11.



- **Multitasking Design step**

Fig. 12. Multitasking Design

Here the Multitaskig design step. Fig.12 illustrated the tracing of creation part of the application.

- **Development Systems /Environment**

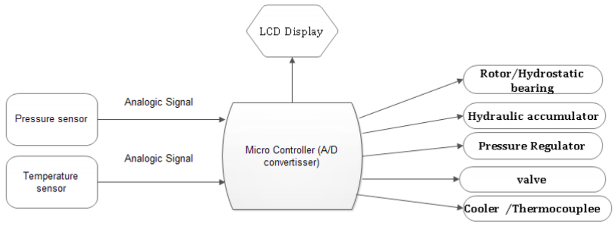


Fig. 13. Description of Hardware application

Fig.13 presents a description of the application.

This figure shows three parts: the inputs, and the microcontroller **[20]**. the outputs. The main role of the microcontroller is conversion A/D of the different inputs signals, and high level commands.

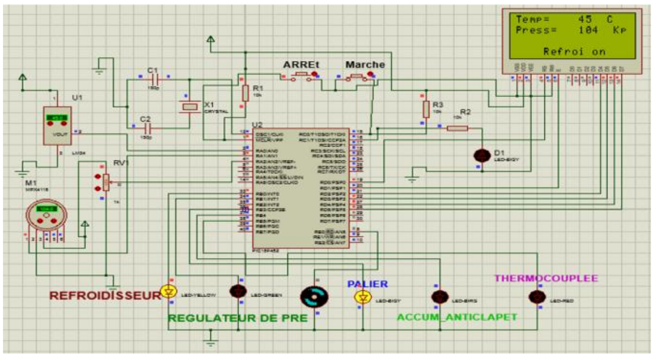


Fig.14 illustrates the simulation of the system.

Fig. 14. The simulation of application (case study 1)

2) Adaptation rules of SART method: We have established adaptation rules of the incremental method associated with SART:

a) Context Diagram

Rule 1: Each increment becomes a functional process numbered 0.

Rule 2: Data streams of each increment become input data for each process.

Rule 3: Results of each increment become sorties data streams for each functional process, or transformed for a given event.

Rule 4: Constant data types (standard liquid temperature) and the data must be recorded for each increment become storage units.

Rule 5: Entities outside of systems for each increment become endings (Terminals boundary).

b) Preliminary Diagram

Rule 1: If the increment requires functionality of pilotage then the process becomes a control process.

Rule 2: Increment is divided into several functions each function becomes a functional process numbered from 1 to n.

c) Decomposition Diagram

Rule 1: Each increment is decomposable becomes a decomposable process numbered X.Y or not decomposable is a primitive

B. Case study 2: Triaxial Appartus system

The triaxial test is one of the most versatile and widely performed geotechnical laboratory tests, allowing the shear strength and stiffness of soil and rock to be determined for use in geotechnical design. Advantages over simpler procedures, such as the direct shear test, include the ability to control specimen drainage and take measurements of pore water pressures. Primary parameters obtained from the test may include the angle of shearing resistance φ, cohesion C, and undrained shear strength Cu, although other parameters such as the shear stiffness G, compression index Cc, and permeability K may also be determined [**19].**

Fig.15 illustrate trixial appartus system:

Fig. 15. An overwiew of triaxial appartus system

The various realizable types of test are:

- Test UU (Unconsolidated-undrained): test unconsolidated not drained carried out on saturated material or not.
- Test CU (Consolidated-undrained): consolidated test not drained on saturated material or not.
- Test CU+u (Consolidated-undrained): consolidated test not drained on material saturated with measurement of the pore water pressure.
- Test CD (Consolidated-drained): consolidated test drained on saturated material.

The test apparatus comprises: a triaxial cell, a compression capacity of press 50 kn, and a measuring system (force sensor, displacement sensor, pressure sensor and a pore burette.)

The measurement Chain :

Our case study is available in the soil laboratory at the Department of Civil Engineering, it is often implied by the name, an automatic data acquisition system on the test performed. This system generally comprises various electronic sensors, an analog-digital converter and finally to a centralized computer acquisition. In our case, the electrode is "manual" as opposed to automatic. The operator must read the various sensors to derive the desired measurement.

Increments proposed

Increment 1: Data acquisition unit.

Increment 2: Display and acquisition software.

1) Experimenting methodology on a Case study 2: In this section we presented the experimenting of the second case study: triaxial apparatus system and illustrates the different phases of our developed design methodology. The design process started with the construction of a model using UML/MARTE.

Diagrams used in the model are Class diagram, Decompsition diagram.

For the development of case study, Modelio tool **[18]** is used. The Modelio is a development of Softeam group and provides an open source tool for development and maintain of MDA for UML through the profile technique. Modelio supports several UML diagrams, as well as additional diagrams such as Business Process, Requirement, SysML or Enterprise Architecture diagrams.

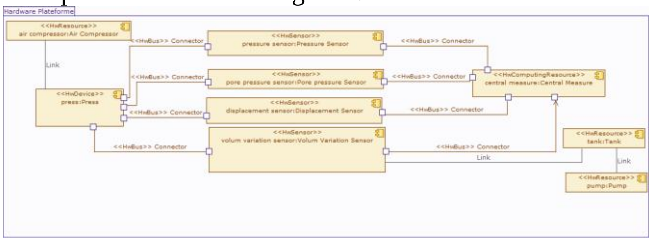
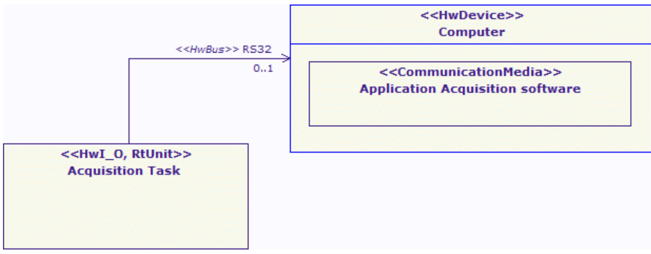


Fig. 16. Hardware plateform of triaxial appartus

We first illustrate the global structure of the triaxial apparatus system as illustrated in Fig.16, using a component diagram.

Our commitment to use MARTE HRM stereotypes here as the system is basically not traditionally hardware in the sense as it consists of electronic, electric and automotive components.

In the fig.16, the following nodes are present:
HwResource Air Compression,
HwDevice Press,
HwSensor Pore Pressure Sensor,
HwSensor Pressure Sensor,
HwSensor Displacement Sensor,
HwSensor Variation Sensor,
HwComputingResource CentralMeasure,
HwResource Tank,
HwResource Pump,



- **Specification Step (increment 1)**

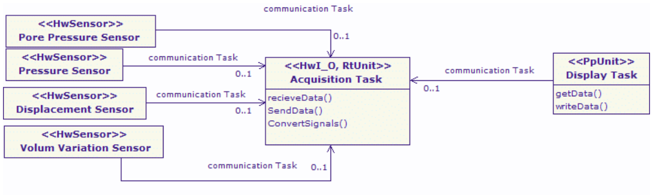


Fig. 17. Acquisition Task (Increment 1)

In Fig.17, the UML class diagram illustrates the communication flows between the different tasks of the execution platform.

- **Design step(increment 1)**

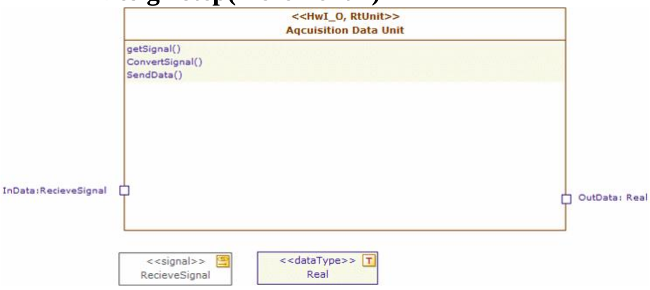


Fig. 18. Internal block structure of acquisition module

In the Fig.18, we first illustrate the internal block structure of the acquisition module. Which consists of an input InData port and an output OutData port.

- **Implementation step(increment 1)**

With respect to the environnent, we use also the microcontroller. Fig.19 present a simulation of my application.

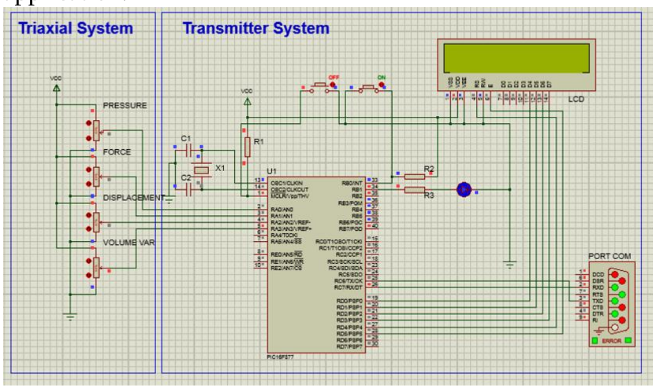


Fig. 19. the simulation of appliction

- **Specification Step (increment 2)**

Fig.20 illustrates the specification of increment 2 of software acquisition, we need an application for the reception of the data and compte the diffrents calculations,and a RS32 cable linked between the computer and acquisition unit.

Fig. 20. Class Diagram (increment 2)

2) Adaptation rules of MARTE profile: We have established translations rules of the UML/MARTE associated with c-microcontroller using the Sequences diagram.

Rules Translation

Rule 1: Each message of interaction becomes a sub-program.

Rule 2: Each repetitive structure becomes a variable, which corresponds to the number of repetition.

Rule 3: Each alternative structure becomes also an alternative structure with the same parameters.

Rule 4: Each observation of time becomes a variable.

Rule 5: Each time constraint becomes a condition treated by an alternative instruction.

Rule 6: Each object becomes a record structured by fields of specific types to store various information of the interaction between objects as well as the results of treatments and calculations.

V. DISCUSSION

This methodology allows gradually deploy functionality in a live environment to reduce the risk of a big deployment, when the system is analyzed as a whole, de-signed as a whole, implemented as a whole and tested as a whole .Feature interactions are often recognized in later development phases and it is very difficult, expensive and time-consuming to solve such kinds of problems . Another reason for applying our methodology is that teams can work more effectively.

On the other hand, our methodology is applicable when the developer system is a complex, contains at least three new complex increments, but if the system simple and contains a small functionalities, then this process does not work.

VI. CONCLUSION

In this paper, we proposed methodology of development based in incremental model for application complex real time and embedded systems.

The paper presents its contributions by proposing an effective subset of activities, forming the basis of our methodology and proposes set of concepts to increase quality of system developed, decrease complexity of system and promote synergy between the different teams working at different domain aspects of the global system in consideration.

Our methodology could inspire future researches of development RTES and may eventually aid in their evolution. Finally, the different activities and concepts and associated diagrams in the methodology have been illustrated in two case studies related to a hydrostatic bearing lubrication system and triaxial apparatus system.

VII. ACKNOWLEDGEMENT

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