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Tool Support for a Method and a Language Integrating Model Refinements and Project Management

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Abstract

Complexity of Embedded System (ES) development is increasing due of several cumulative sources. Some of them are directly related to constraints on the ESs themselves, like computing power, resource constraints, and multi- or many-core programming, while other are related to the industrial context, like teamwork and parallelisation of concurrent development. In this paper we present CanHOE2, a Model-Driven Engineering (MDE) tool that addresses two issues of ES development: expression of parallelism by means of objects and Hierachical State Machines (HSMs), and teamwork synchronisation.

1 Introduction

Embedded System (ES) development teams have to cope with usual constraints of industrial organizations: (1) End-to-End Engineering: the full development cycle goes from requirement formalization to the final integration and assessment of the application on its platform. (2) Incremental & collaborative development: To organize efficiently the work of large teams, it is critical to regularly distribute and integrate work, and to measure progress towards the objectives. (3) Moreover, at any level, models should be executable and instrumented: executable to check them against requirements, and instrumented to get continuous qualitative and/or quantitative feedback to drive engineering decisions.

Another important factor of ES development efficiency is the set of modeling and programming languages used in a project. Ideally, we would rely on a single high-level modeling language that: (a) Can model hardware as well as software; (b) Is not tied to any hardware architecture like Field-Programmable Gate Array (FPGA), Digital Signal Processor (DSP) or General Purpose Processor (GPP); (c) Is parallel-friendly; (d) Provides a clear path to generate efficient code.

Lastly, the wide variety of modern platform patterns like manycore platforms with distributed memory based on Globally Asynchronous, Locally Synchronous (GALS) and Network-on-Chip (NoC) are increasingly heterogeneous and thus much more difficult to program than classical shared memory architectures. For these new architectures, parallelism has to be exposed; their distributed architecture requires strong partitioning of the code and calls for message-passing style of programming. At the same time, modern embedded applications cannot be divided between data/computational parts and control parts anymore. Instead, they are made of a number of layers that include both parallel computations on large data sets and data-dependent control as well.

In this context, we developed a Model-Driven Engineering (MDE) approach named "Highly Heterogeneous, Object-Oriented, Efficient Engineering" or ⟨HOE⟩² for short. The approach is made of:

- A *method* that provides modeling concepts necessary to describe heterogeneous embedded systems. The ⟨HOE⟩² method provides a set of related project management entities and metrics to organize, track and report on the development efforts [1, 2, 3].

- An *action language* that seamlessly combines association-based data parallelism and operations on compound data [4]. The ⟨HOE⟩² language preserves the expressiveness of Statecharts [5], and captures a layout – and implementation – neutral description of data organization, extends message passing with an intuitive semantics for this additional parallelism and provides strong foundation for array-based optimization techniques.

- A *canonical tool* named CanHOE2 that combines textual and visual programming while enforcing

the principles of $\langle$HOE$\rangle^2$ for efficient management of projects. It is canonical in the sense that it aims at illustrating the main points of the method.

This paper is structured as follow. We review some related works in Section 2. Section 3 introduces the context of our approach. In Section 4, we present the CanHOE2 tool, its main features, design choices and implementation. Section 5 presents its application on a specific case study, and we conclude in Section 6 with perspectives and future work.

2 Related Work

Over the past years, many methods and tools were proposed in order to model embedded systems [6, 7, 8].

ACCORD/UML is a model-based method proposed to model real-time application models in the automative area [6, 7]. It is organized around waterfall lifecycles and implies several stakeholders such as car and parts manufacturers.

BIP (for *Behavior, Interaction and Priority*) is a framework for composing hierarchical systems [8]. It permits to build composite systems by hierarchically assembling atomic components that are described in terms of behavior and interactions. BIP defines an activity-based process in which a few set of activities is defined, for designing application models, integrating platform's constraints, generating code and for verifying the system.

MopCom is a model-based development method for designing ESs [7]. It proposes a top-down process divided up into two flows for enhancing the development parallelism, and several iterations to refine an application model onto several abstraction layers of a platform.

In all these methods, processes are defined alongside generic or specific tools. Tools are used in order to support both the language used for modeling ESs, and the process with its different features (parallelism, multi-roles, etc.). However, there are several drawbacks. Tools are often generic and do not cover all the activities of an ES process. Coupling several tools can permit to cover the whole process, yet is inefficient for modeling ESs. Using non-dedicated tools hinders the development as they do not provide a global and coherent view of the developed system throughout the whole process. Hence, they allow designers to digress from the canonical process. In addition to that, they do not integrate any project management features a project manager could benefit from in order to have a global understanding of a current development and to monitor it. There is now a need of developing Integrated Development Environments (IDEs) that address all these issues in one go.

On the tool side, "IBM Rhapsody", from IBM/Rational, provides an IDE to develop UML or SysML models that is widely deployed in the industry [9]. The dynamic behavior of an object is captured in a flavor of Finite-State Machine (FSM) where the transitions' actions are called by external libraries developed in a general-purpose language. The FSM can be translated into C++ code, compiled and executed. During development, this code calls back into the IDE for debug and animation of the execution, *e.g.* with sequence diagrams. Several Board-Support Packages (BSPs) are also available such that the generated code can be compiled, uploaded and executed on various embedded platforms. Other tools from IBM, such as "Rules Composer" permit to define specific code generators from Rhapsody models [10]. The mixed semantics of these tools, with FSM and C++ libraries, do not allow for symbolic reasoning at the model level, be it for optimization, correctness analysis or model refinement. Although they do support MDE, they main target is executable code production.

"Papyrus MDT" [11, 12] is a component of the Eclipse Model Development Tools (MDT) project. It is a complete solution for UML modeling and is fully compliant with the latest versions of the UML standard. It supports the definition of profiles, and their applications to tailor UML models to a particular domain. Papyrus provides some tools to customize the whole modeling environment of Eclipse (i.e. editors, palettes, the model explorer and the property panel) according to the definition of the profile. Thus, designers can design models in a dedicated environment using specific profiles. However, the customization is only performed regarding the dedicated language and disregarding any process that could be combined to the dedicated language. Hence, Papyrus could be tailored to a specific language, but not to a specific method. From the model execution side, Papyrus provides code generation engines for C++ and Java. However, it focuses on structural elements and only provides a limited support for code generation from behavior models through "Qompass Designer" [13]. That means, as the authors state [14], Qompass Designer only supports simple FSM models and it is currently not possible to produce code from hierarchical FSM models.

3 Context

CanHOE2 supports and implements the $\langle$HOE$\rangle^2$ method.

3.1 The $\langle$HOE$\rangle^2$ Method

$\langle$HOE$\rangle^2$ stands for Highly Heterogeneous Object Oriented Efficient Engineering. The $\langle$HOE$\rangle^2$ method is organized around four models and three refinements, that defines a set of successive activities with clear inputs and outputs – See Fig. 1 [1, 2, 3]. These models are built as follows: (A) The informal requirements are formalized in the *Requirement Model* by means of *System*, *Actors*, *Use Cases* and *Scenarios*; (B) This requiement model is then refined into an executable, platform independent, *Analysis Model*. This is done by means of *Hierarchical Opening* of objects: replac-

ing an object viewed as black box with several object that represent a more detailed version of the orginal object while collectively exhibiting the same apparent behavior. This transformation can be applied recursively to new objects. (C) The *Platform* is partially introduced by declaring its *Worlds* – See (1) in Fig. 1. A world is an abstraction of an execution domain that can *Hosts* objects – like a set of processors and their shared memory, a FPGA, or a dedicated hardware Intellectual Property (IP). Once the platforms's worlds are known, the *Design Model* is built. For this, each object from the analysis model is split in smaller objects that are *Distributed* over the platform's worlds. (D) Further platform details are introduced into the application: for each world, its *Containers* are provided. Each container embodies a set of coding rules, with a trade-off, to implement an object semantics on the target world. The *Implementation Model* is built by *Injecting* each object of the design model into a container.

In terms of associated process management, we define the following concepts:

- *Task*, *Phase* and *Task Sheets*: A task is an atomic modeling activity: one of the three refinements applied to a single objet. A phase is the set of tasks that captures all the refinements that build the phase's model. A task sheet is an instance of a task.

- *Participant*: A participant may be either a Project Manager (PM) or a Developer. A PM creates and drives the project by (a) defining and assigning tasks to Developers, and (b) by integrating, or rejecting, the models they produce. A Developer can modify models only according to a task sheets provided by the PM.

- *Project*: A project contains its task sheets and the four phases of the process. A project is led by a single PM and built by several Developers.

- *Iteration*: An iteration is a collection of tasks. It is the smallest entity of project management.

Table 1 illustrates an example of a consistent planning using the iterations as a diagram similar to a

Table 1: Consistent Planning of developments

		RA	SA	SD	SI
UC_1	SN_1^1	T_1^1	T_1^2	T_3^6	
UC_2	SN_2^1				
UC_3	SN_3^2		T_2^4		
	SN_3^3				
UC_4	SN_4^1				T_4^8
UC_5	SN_5^1	T_2^3		T_3^7	
	SE_5^2		T_2^5		
	SE_5^3				
UC_6	SN_6^1				

Figure 2: $\langle$HOE$\rangle^2$ Action Language

Gantt where T_j^i denotes the ith task of iteration j. The same kind of planing can be declined for the development of the platform. As can be seen, the iterations form rectangles and squares in the table schedule: Each iteration starts from a consistant state and ends by a consistant state of the system. However, this kind of representation does not illustrate the refinements within a single iteration.

3.2 $\langle$HOE$\rangle^2$ – A New Action Language for HSM

The $\langle$HOE$\rangle^2$ language build on a number of concepts from Unified Modeling Language (UML) such as objects and associations [4, 15]. $\langle$HOE$\rangle^2$ Objects communicate through exchange of messages. Their behavior is captured by Harel's Statecharts [5, 15]. The $\langle$HOE$\rangle^2$ language proposes a number of extensions to UML:

- A new *Action language*. The $\langle$HOE$\rangle^2$ action language separates actions into two sequentially ordered parts: First the parallel updates of associations, followed by a parallel sending of messages – See Fig. 2.

- Using associations to define *Iteration domains* and *Indexes*. $\langle$HOE$\rangle^2$ introduces a syntax for the specification of parallel iteration domains for associations updates and sending actions.

- *Indexed regions*: Iteration domains can also be used to enumerate parallel regions. Each region is identified by its own index.

- *Transaction*: The concept of interface is extended with the ordering and direction of messages exchanged.

These extensions are detailled by Llopard et al. [4].

4 The CanHOE2 Tool

As we explained previously, CanHOE2 serves to support the $\langle$HOE$\rangle^2$ process and language. We choose to develop our tool with the several Eclipse technologies [16, 17, 18]. Eclipse offers a set of convenient user-interface components in the context of meta-modeling (Perspective Management, Common Navigator Framework, Ecore Standard, etc.). It provides some tools to easily display multieditors in the editor area, navigator and views. CanHOE2 can create models and diagrams associated to these models. Models are created using
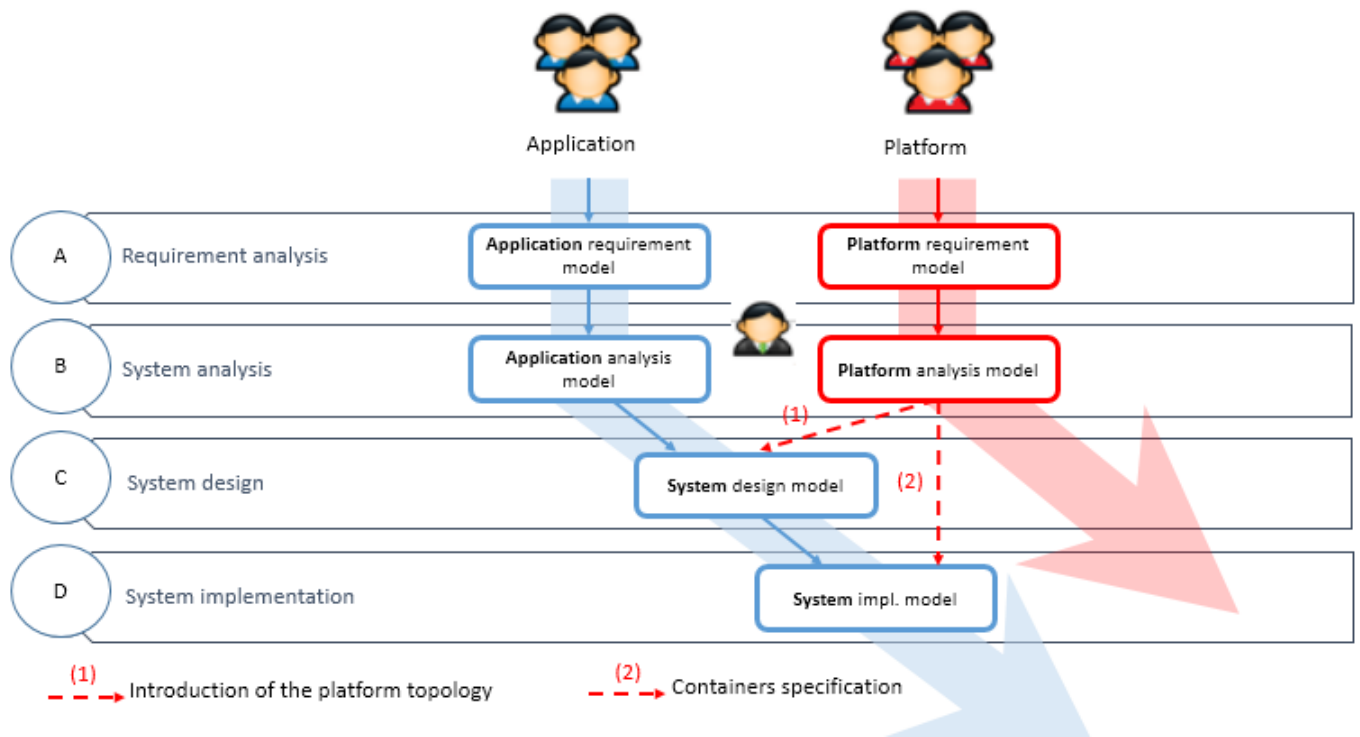
Figure 1: $\langle$HOE$\rangle^2$ a Collaborative Top-Down Dev. Process for Embedded System Design: Application and Platform Tracks

the Eclipse Modeling Framework (EMF) tool. It allows to instantiate models by providing a meta-model and save them in XML Metadata Interchange (XMI) markup language. It is suitable for metamodels and model exchanges. CanHOE2 also offers a textual editor for the $\langle$HOE$\rangle^2$ language. In this section, we detail the implementation choices, interface design and contributions of our tool.

4.1   Tool Design

CanHOE2 provides four editors corresponding to the four models described in the $\langle$HOE$\rangle^2$ method (see Fig. 1). Navigation in the models is based on the logical ordering of refinements within models. The project management tool supports consistent planning and definition of iterations obeying the model refinement dependencies. The iteration history is navigable. The user interface is split into three areas at a minimum (see Fig. 3):

- The *Navigator Area*, that allows the designer to intuitively navigate inside a streamlined hierarchy of $\langle$HOE$\rangle^2$ artefacts.

- The *Editor Area*: where the developer can write program using graphical elements or textual coding.

- The *View Area*, dedicated to project management and teamwork tools. It implements dedicated views to update information about the entities selected in the active editor.

As illustrated in Fig. 4, the developer may either write its program directly in $\langle$HOE$\rangle^2$ textual language or describe it graphically, assisted by a palette and a property panel: a palette is displayed and the developer is able to drag and drop entities from it. Information about graphical entities can be modified in the graphical editor, or in a property panel. Graphic and textual development can be complementary. Indeed, the developer can mix user friendly textual and graphics solutions, they will be automatically synchronized to each backup (see Fig. 4). By double-clicking on any graphical element, an embedded $\langle$HOE$\rangle^2$ language editor open up and let the programmer modify the actual code (see Fig. 5).
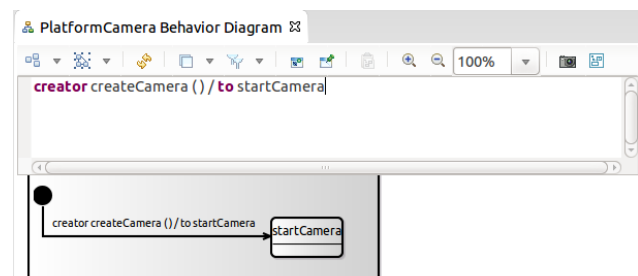

Figure 5: Embedded Editor for Transition

4.2   Tool Implementation

The first step is to derive a well-formatted Ecore metamodel from our canonical one. This step is fundamental since we need to consider the Ecore and its associated tool specificities. Once we have produced our
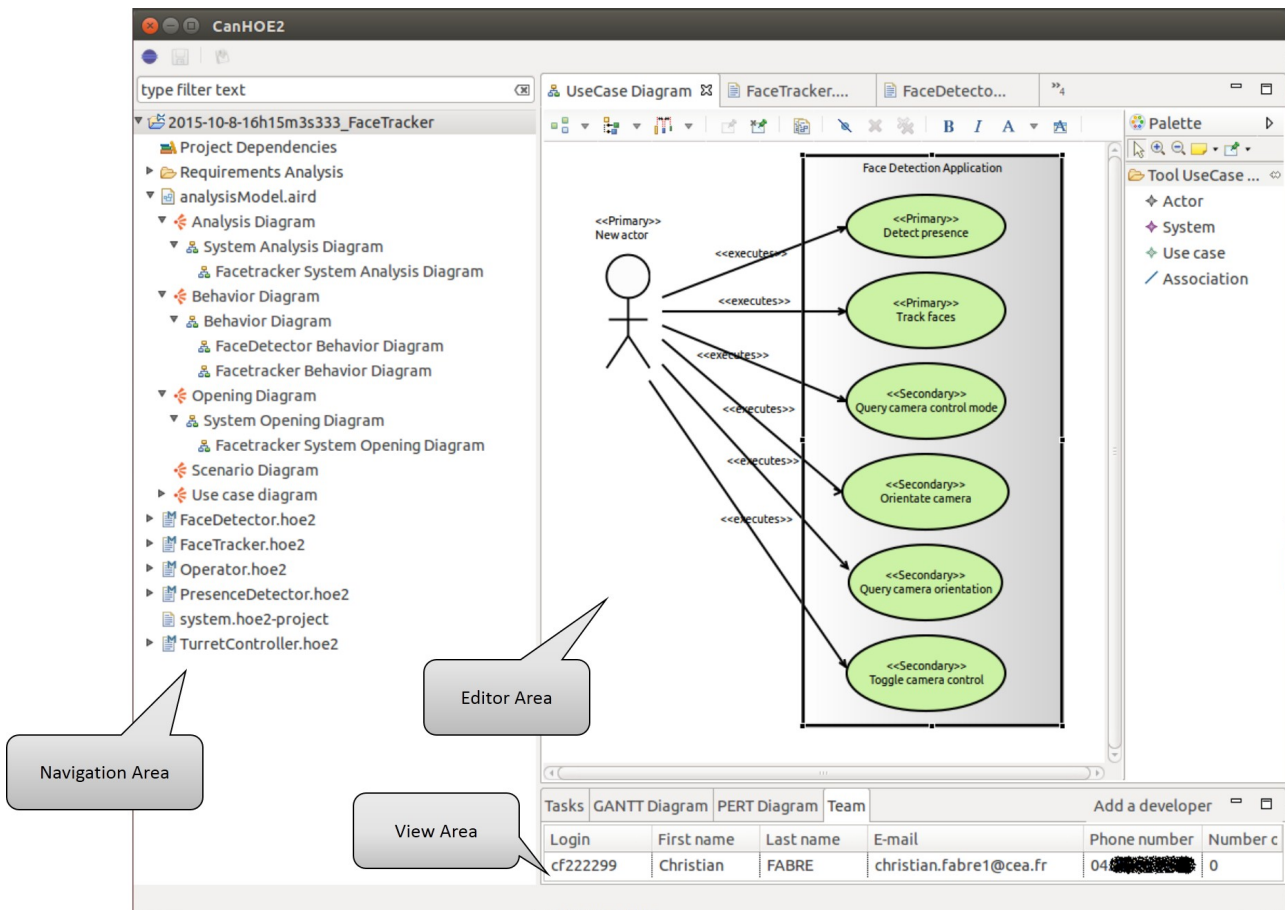
Figure 3: The CanHOE2 Interface Dedicated to the $\langle HOE\rangle^2$ Method and Language

Ecore metamodel, we defined the $\langle HOE\rangle^2$ language syntax using Xtext/Xtend technology from the above defined Ecore model [17]. Xtext provides a set of tools for the implementation of domain-specific languages. From the $\langle HOE\rangle^2$ metamodel, we derived a full concrete implementation of it. The compiler components of our language are independent of Eclipse or OSGi and can be used in any Java compliant environment. Xtext automatically generates the parser, a type-safe builder of our Abstract Syntax Tree (AST), the serializer and code formatter, the scoping framework and the text editor. The editor integrates syntax highlighting and error checking, among many other things. To achieve graphical models, we rely on the Sirius framework [18]. Sirius enables the visual design of complex systems (software, business activities, physics, etc.) and guarantees the consistency of the corresponding data (architecture, component properties, etc.).

4.3 Support Tools for Project Management in CanHOE2

CanHOE2 offers several tools to support project management. Indeed, it can manage the authentification and collaborative work providing a global view on the progress of the project.

Authentication. In a regular work environment, an employee can only access the projects to which he has been assigned. In CanHOE2, once authenticated, the user accesses a personal dashboard that lists the projects in which he is involved. From this dashboard, he can also create new projects as a PM. According to his role in the project, one of two perspectives is opened: "Project Manager" or "Developer" perspective. A perspective is a window with adapted views to the user. Eclipse RCP can easily manage these perspectives and allow us to show a proper layout of the available views. The views in CanHOE2 are based on Java SWT [19].

The user authentication process goes through Lightweight Directory Access Protocol (LDAP). LDAP is a network protocol for accessing an electronic directory where you can reference the users (name, login, phone ...), machines or applications. Access to LDAP server is done via Java Naming and Directory Interface (JNDI) [20].

Collaborative development. Such a collaborative environment needs a database to capture all the artifacts manipulated and their evolution over time. CanHOE2 uses centralized Git repositories to this end that are accessed by CanHOE2 on behalf of each participant [21]. CanHOE2 uses two types of repositories:

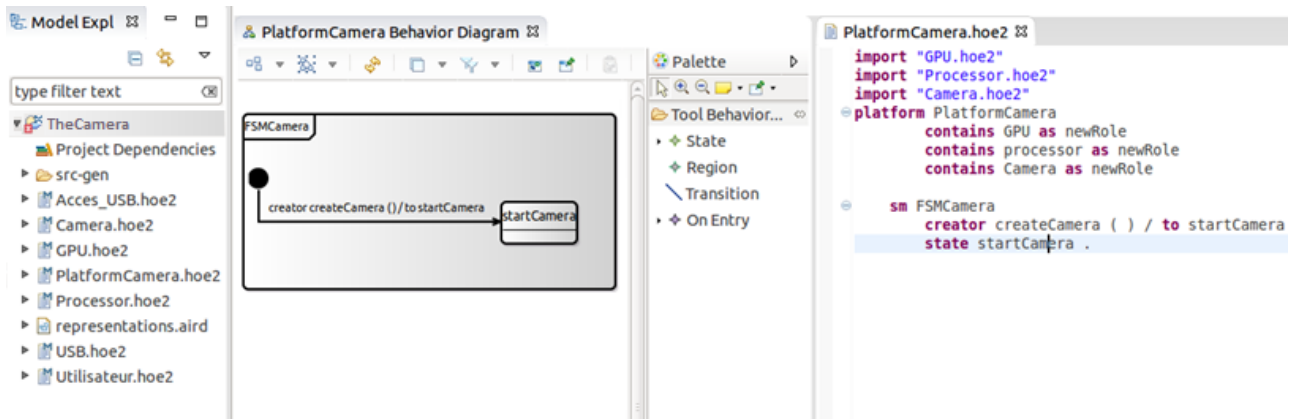- A configuration Git repository contains the infor-

Figure 4: CanHOE2 Synchronized Text and Graphical Editors

mation that CanHOE2 uses to connect to LDAP and the list of all CanHOE2 active repositories.

- Several project-specific Git repositories, where we store additional information about the project (task sheets) and resulting patterns of the Can-HOE2 application (model use cases, scenarios).

Project monitoring. In order to help the project manager to monitor the project development and to plan different iterations on it, we implement traditional diagrams for project management such as GANTT and PERT diagrams. Internalized project management reduces development time and provides a monitoring interface to better manage the development team.

5 Case Study

In this section, we introduce a Face Tracker system. The face tracker system consists of application for face detection, which is hosted by an Oriented Camera platform. This platform includes a general purpose processing unit, a Passive InfraRed (PIR) sensor and a bracket on which the camera is attached. Two servo-motors orientate the bracket for pan and tilt.

Fig. 3 illustrates use cases diagram of the Face Tracker application . Tables 2 and 3 show multiple use cases and scenarios, respectively, that formalizes the requirements. From these use cases and scenarios, we can now define a task list and its corresponding order of execution. We present hereafter a non-exhaustive list of tasks that have to be performed:

- T^1: Refinement of UC 1 & 2

- T^2: Initiation of the system analysis

- T^3: Refinement of UC 3, 4, 5 & 6

- T^4: Refinement of the system analyis for UC 3 & 4

- T^5: Refinement of the system analyis for UC 5 & 6

- T^6: Initiation of the system design

Table 2: Usecases of the Face Detection Application

Id	Causality	Name
	Description	
1	Primary	Detect presence
The actor wants to know when somebody enter the monitored zone.		
2	Primary	Track faces
The actor wants to track faces of people entering the monitored zone.		
3	Secondary	Toggle camera control
The actor wants to switch between manual and automatic tracking modes		
4	Secondary	Query camera control mode
The actor wants to know the current tracking mode		
5	Secondary	Orientate camera
The actor set the camera's orientation.		
6	Secondary	Query camera orientation
The actor wants to know the camera's curent orientation.		

- T^7: Refinement of the system design

- T^8: System implementation

Once this list is completed, we can define the execution priority of tasks and hence the list of our different iterations.

- $I_1 = T^1 + T^2$: Refinement of the use cases 1 & 2 and system analysis initiation

- $I_2 = T^3 + T^4 + T^5$: Refinement of requirements and system analysis

- $I_3 = T^6 + T^7$: System design

- $I_4 = T^8$: System implementation

Table 1 illustrates our iterations planning. In what follows, we will focus on I_1 and I_3 iterations. However, before the beginning of the design phase (i.e. iteration I_3), the platform development team have to start to work on it. We will call that iteration I'_1. We named our platform, "The Oriented Camera platform".

Table 3: Scenarios of the Face Detection Application

Id	Nature	Name
		Description
1-1	Nominal	Presence detected notification
The actor subscribes for updates of presence in the monitored zone. The application notifies to the user when somebody enters or exit the monitored zone. The actor unsubscribes when he does not want updates anymore.		
2-1	Nominal	Face tracking notification
The actor subscribe to people's faces and the position in the monitored zone. The application notifies to the user with the position of a face in the monitored zone every 2 s. The actor unsubscribes when he does not want to track people faces anymore.		
3-1	Nominal	Switching to automatic mode
The system is in manual mode. The user toggles it to automatic mode.		
3-2	Nominal	Switching to manual mode
The system is in automatic mode. The user toggles it to manual mode.		
4-1	Nominal	Querying control mode
The actor asks for the camera's control mode. The system answers wether the camera is in automatic or manual mode.		
5-1	Nominal	Manually orienting the camera
The system is in manual mode. The user wants to move the camera relative to the curent position. The camera is moved by the requested *pan* and *tilt* angles.		
5-2	Error	Manually orienting while in auto. mode
The system is in automatic mode. The user wants to move the camera relative to the curent position. The system refuses because the camera is in automatic mode.		
5-3	Error	Manually orienting the cam. hits a stop
The system is in manual mode. The user wants to move the camera relative to the curent position. The camera is moved by less than the requested *pan* and *tilt* angles as it hits a hard stop.		
6-1	Nominal	Camera position query
The actor asks the system about the camera position. The system answers with the position.		

Iteration I_1: Refinement of the use cases 1&2 and system analysis initiation

During this iteration, we can detail the use cases identified but also initiate the analysis phase. Fig. 6 illustrates an analysis model of the Face Tracker system : the system is composed by three objects (1) a presence detector for detecting a presence in a specific area, (2) a face detector for detecting a face and its position from a video stream and (3) a turret controller for controlling the orientation of a camera a controllable turret two angles.

In this iteration we have also to model the behavior of our application, and its response to exchanged messages (See Fig. 7).

Iteration I'_1: Requirements and system analysis of the platform

Tables 4 and 5 gives a list of use cases and scenarios of the platform. These lists can be completed and refined with theirs corresponding diagrams.

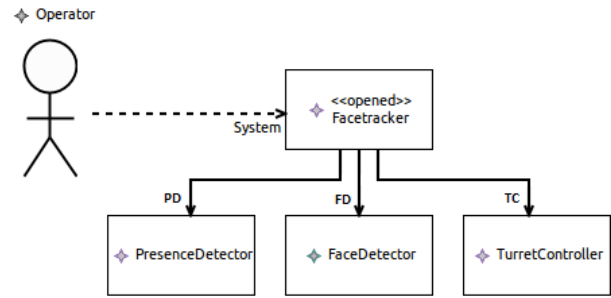To model the platform, we use the same diagram for
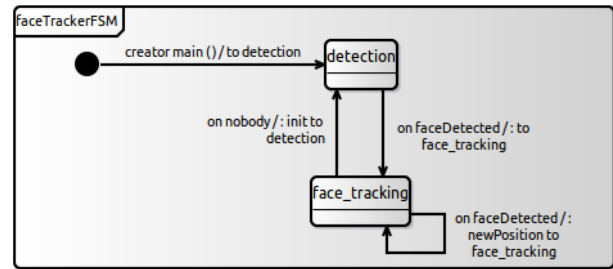

Figure 6: Face Tracker system opening diagram

Figure 7: Face Tracker system behavior diagram

modeling the application with a particular notation for the different elements of the platform. Fig. 8 shows the analysis model of the platform. This platform allows the hosted application to control, via two engines, the position of the camera by orientating it around two axes. The model is composed by two worlds a Processor and Microcontroller. They are provided with resources in terms of computing and memory, and communication. They also provide different containers allowing access to the communication resources and to the peripherals of the platform.

The technical choices for the platform design are:

- The Raspberry PI platform: It is adapted to the field of image processing and allows installing and uninstalling Python programs running one program at a time. It allows also the update of time and date settings.

- The turret control platform: This platform provides the use cases (1) subscribtion to presence detection, and (2) turret orientation. The turret can be used to support the sensors or actuators, such as a camera, an ultrasonic radar, a projector, etc.

- The Arduino UNO platform: It is a prototyping platform for the control of sensors and, digital or analog actuators.

From these three platforms we have designed the composition diagram (see Fig. 9). From this level of modeling we can start the system design.

Iteration I_3: System design

Table 4: Use cases of the Oriented Camera platform

Id	Causality	Name
	Description	
1	Primary	Install Firmware
The actor installs a new firmware in the platform.		
2	Primary	Toggle the application on/off
The actor turn on/off the application.		
3	Primary	Time & date settings update
The actor sets the time and date settings.		
4	Secondary	Time & date settings query
The actor gets the time and date settings.		
5	Secondary	Firmware version query
The actor gets the firmware version.		

Table 5: Scenarios of the Oriented Camera platform

Id	Nature	Name
	Description	
1-1	Nominal	Firmware installed
The actor installes a new firmware.		
1-2	Error	Firmware installation error
A firmware is already installed on the platform. The actor wants to install the same version or an older version of the firmware. The firmware cannot be installed.		
2-1	Nominal	Toggle the application on/off
The actor turn on the application. The application runs till the actor decides to turn off the application. The application is switched off.		
3-1	Nominal	Time & date settings updated
The actor sets the time & date. The platform reset its clock to the entered time & date.		
4-1	Nominal	Time & date settings query
The actor asks the system about the time & date. The system answers with its internal time & date.		
5-1	Nominal	Firmware version query
The actor asks the system about the firmware. The system answers with the firmware version.		

The I_3 iteration initializes and starts the system design phase satisfying the separation of objects, into the two worlds of the platform (See Fig. 10).

6 Conclusion & Perspectives

The $\langle HOE \rangle^2$ method defines a single process used to develop both applications and platforms. It defines precisely what information is sent from the platform model to the application model during development. Its companion language suports parallelism and is amendable to polyhedral analyses. It is made of (1) a new action language limited to association updates and sending of messages, (2) domains, iterators and indexes based on associations.

In this paper, we presented CanHOE2, a modelling and process management tool for the $\langle HOE \rangle^2$ method and its language. Its main contribution is that not only does it supports the $\langle HOE \rangle^2$ language, as any modelling tool, but also the associated process. The
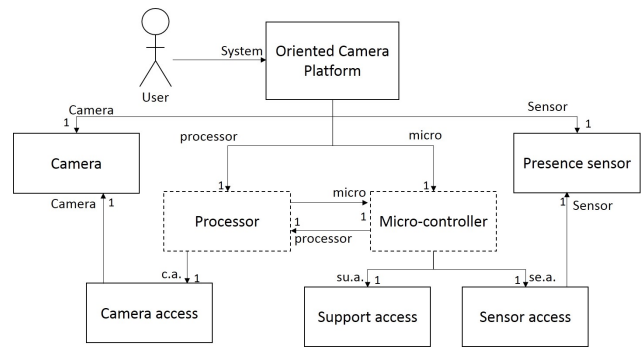

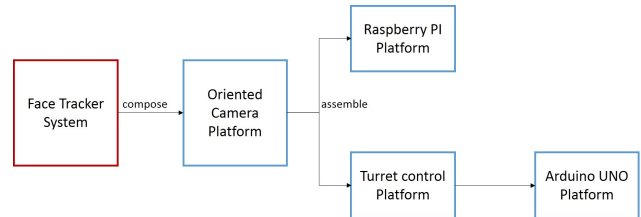Figure 8: Oriented Camera Platform Analysis
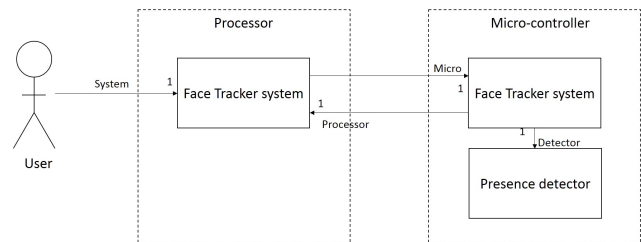

Figure 9: Oriented Camera Platform Composition

Figure 10: Face Tracker system design

support of management and cooperation is deeply integrated with support of modeling.

In future work, we want to extend CanHOE2 with more support for the method, in particular towards the models simulation and $\langle HOE \rangle^2$ model-to-model transformations.

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