Abstract—The development of cyber-physical system (CPS) is a big challenge because of its complexity and its complex requirements. Especially in Requirements Engineering (RE), there exist many redundant and conflict requirements. Eliminating conflict requirements and merged redundant/common requirements lead a challenging task at the elicitation phase in the requirements engineering process for CPS. Collecting and optimizing requirements through appropriate process reduce both development time and cost as every functional requirement gets refined and optimized at very first stage (requirements elicitation phase) of the whole development process. Existing researches have focused on requirements those have already been collected. However, none of the researches have worked on how the requirements are collected and refined. This paper provides a requirements model for CPS that gives a direction about the requirements be gathered, refined and cluster in order to developing the CPS independently. The paper also shows a case study about the application of the proposed model to transport system.

Index Terms—Requirements Engineering; Requirements Model; Cyber Physical System, Elicitation.

I. INTRODUCTION

Cyber-Physical Systems (CPS) integrate computing and communication capabilities with monitoring and control of entities in the physical world. These systems are usually composed by a set of networked agents, including - sensors, actuators, control processing units and communication devices. As a result, CPS conforms a complex system which leads difficulties in the requirements engineering process because requirements are also conflicting, redundant and and complex. The redundant and complex requirements increases the time and cost of developing the system. Elicitation phase plays a vital role of the requirements engineering process because it will act as a blueprint of the whole developments life-cycle. Elicitation phase is conformed by the activities - collecting requirements from multiple stakeholders and categorizing those requirements based on priority into normal, expected and exciting requirements. Normal requirements are those which must be accomplished by the developers. This type of requirements should be explicitly agreement between stakeholders and development team. Expected requirements are such those are necessary for the system to work correctly. This requirements are also explicitly documented. The third part, exciting requirements are extra features those can be provided by developers to give extra satisfaction to users/clients. This requirements are known as WOW factor in software requirement engineering.

The requirements for cyber-physical system are complex to identify and refinement of those requirements is also a difficult task as CPS is a complex and distributed system. The more appropriate way the requirements get collected and refined, the easier the development of the system. Existing works focus on requirements after collected, but they neither focus on the collection process nor the refinement process of the requirements for CPS.

Contribution

We propose a generic requirements engineering model for cyber-physical systems that serves as the basis for requirements engineering at elicitation phase and documentation having suitable categories based on priorities. This model helps developers to work independently in each of the subsequent development phases - designing, implementation, testing, etc. to develop CPS system as the requirements model forms multiple clusters based on CPS computation, communication, control, etc.

Paper Organization

The paper is organized as follows. Section II discusses the existing work related to requirements for CPS, Section III introduces the proposed requirements model, while Section IV discusses a case study based on the model. Finally, Section V concludes the paper with a outlook of future work.

II. RELATED WORK

Physical components of CPS are qualitatively different from object-oriented software components. As a result, requirements engineering process for CPS also varies with respect to traditional software development process. Some existing researches have been worked on the requirements engineering process or only on some specific requirements that should be consider during CPS development. The existing works can be divided into two major categories: Time related requirements and generic requirements.

A. Time Related Requirements

Time is an important requirement for developing CPS system which should be make the system deterministic and predictable [1]. This paper has examined the challenges in designing CPS systems and in particular has raised the question of whether todays computing and networking technologies provide an adequate foundation for CPS. Edward A Lee has advised in the paper to incrementally improve technologies and computer OS (Operating System) architecture to ensure time requirement.
CPSs need to conduct the transmission and management of multi-modal data generated by different sensor devices. In [2], a novel information centric approach for timely, secure real-time data services in CPSs has been proposed. In order to obtain the crucial data for optimal environment abstraction, L. H. Kong et al. [3] have studied the spatio-temporal distribution of CPS nodes. H. Ahmadi et al. [4] has presented an innovative congestion control mechanism for accurate estimation of spatio-temporal phenomena in wireless sensor networks performing monitoring applications. A dissertation on CPSs discusses the design, implementation, and evaluation of systems and algorithms that enable predictable and scalable real-time data services for CPS applications [5]. However, time is not exactly predictable due to the hardware configuration and programming language nature. This only requirement can not ensure and focus the whole requirements engineering process.

B. Generic Requirements

Requirements engineering for systems of systems faces extremely distributed requirements engineering activities that involve a multitude of stakeholders. This often results in isolated requirements engineering approaches which, in turn, lead to requirements that can hardly be integrated with the other units of the SoS in order to keep them consistent [6]. Penzenstadler et al. have provided a content model for CPS system requirements engineering. Méndez et al. [7] has shown fundamentals and lessons learned in requirements engineering from developing a meta model for artefact-orientation. They have reported on a case study with a street traffic management business unit from Siemens on the application of an artefact-based requirements engineering approach [8].

Berenbach et al. [9] has described requirements engineering (RE) artifact modeling and name the key components to be a measurable reference model, a process tailoring approach, and respective process guidelines. Berenbach describes each of these elements and suggests practices for their elaboration. In [10], Jan Oliver et al. described design requirements for robotics systems only using I/O automata. However, none of these researches have not focused on how the requirements will be collected and how the requirements are organized as well as optimized in the requirements engineering process for cyber-physical systems.

III. PROPOSED REQUIREMENTS MODEL

Requirements engineering for CPS is a challenging task as there are many requirements conflicting each other of complex CPS systems. Elicitation part of the requirements specification is focused in this paper as it is one of the most vital parts of the engineering process. Collecting requirements and removing the conflicts depends on how appropriately the requirements are gathered and categorized. In addition, it will make development easier by reducing time and cost at elicitation phase as well as it will affect positively in the subsequent development phases. The following requirements model is developed in this paper for CPS system requirements engineering process at elicitation phase (figure 1).

1) Business Domain Analysis
2) Collect System Requirements
3) Remove Conflict Requirements and Grouping the Requirements as
   a) Normal/Essential
   b) Expected
   c) Exciting
4) Cluster the Requirements

![Flow Chart of Requirements Model for CPS](image)

Each part of the model is described briefly in the following contents.

1. Business Case Analysis

   Business case (BC) of a system consists of certain contents such as - problem statement, mission/vision statement, Objectives of the system, rationality of the approach, benefits of all relevant stakeholders, performance measurement, risk management, work plan and time-line, team role, cost estimation and fund, etc. The topics of a BC provide us a useful source for analyzing requirements after collecting the requirements from stakeholders. Even we can generate such necessary requirements from mission/vision and objectives part of the BC that some of those might not be collected during collaboration with stakeholders.

2. Collect System Requirements

   In the inception phase during collaboration with stakeholders, system requirements to be collected and listing those requirements. The list contains conflicting requirements such
as - response time vs output data volume, and common requirements such as - system protection from other accesses and authentication. These types of requirements should be managed carefully in order to optimize the requirements so that it will be more easier to handle the requirements as well as it will reduce a lot of development time and cost.

3. Remove Conflict Requirements and Grouping the Requirements

In the requirement list, common and conflict requirements are found. It is necessary to remove the conflict requirements and merge the common ones. As a result, the list would be so optimized that it will be easier to handle the requirements and fulfilling those ones for such a complex cyber-physical systems. After getting the optimized list, it is necessary to refine the requirements in order to grouping those ones into the following three categories.

(a) Normal/Essential: This type of requirements is explicitly described by the stakeholders and must be met in the system development.

(b) Expected: This type of requirements is collected from the system and business case analysis and through collaboration with stakeholders. Although these are not explicitly defined by stakeholders, these should be identified clearly and explicitly as without these requirements, the system will not functionally be correct or complete. So these requirements must also be met in the CPS product.

(c) Exciting: This category of requirements are provided by the developers only as an excitement feature. This is not mandatory to work the CPS system correctly, but it will give extra satisfaction to clients. This is known as WOW factor in Software Requirements Specification. These requirements are completely dependent on the developments team whether to provide or not.

The requirements can also be divided into two groups:

(a) Functional: The three categories described above fall into the functional group as each of the requirements will be a function (or feature) of the system.

(b) Non-functional: It is also important to identify non-functional requirements at the elicitation phase for CPS. This requirement might be collected through business case analysis. Reliability, throughput, response time, performance, etc. are the example of non-functional requirements.

4. Cluster the Requirements

Since CPS is a complex system having multiple modules like - computation, communication, control, the requirements are needed to be clustered based on the modules in order to distributing the workloads among the developers. As a result, each developer can work independently of other modules. So development goes faster. Three tire architecture can be applied here to cluster the requirements -

(a) Requirements related to business logic (computation logic)
(b) Requirements related to user interface (UI)
(c) Requirements related to data access/database

IV. Case Study: Transport System

We provide a case study of transport system to apply the proposed requirements model. To understand the model easily, we assume that the system consists of a set of cars and a traffic signal on the center in which several roads are connected. The scenario is pictorially represented in figure 21. The cars receive signals by their sensors from the traffic signal locating at a predetermined distance. These cars also sense information about the road’s two sides range and other cars at a specific distance range. According to the above business scenario, a portion of requirements collection and refinement using the proposed model have described in the following parts.

1. System Requirements

The following requirements are listed through collaborating with stakeholders.

(i) Object identification range 10 meters
(ii) Sense data through headlight and backlight of a car
(iii) Avoid Crash
(iv) Move the car when no object is found
(v) Stop the car when an object is found in front of the car or get signal to stop
(vi) Wait when an object is at a specific distance
(vii) Detect the road line/range
(viii) Count time
(ix) Accident should not occur
(x) Alert when other cars get closed to the car
(xi) Alarm to find any object suddenly
(xii) Control car speed
(xiii) Monitor vehicle speed
(xiv) Automatically track vehicle location in real-time
(xv) Automatically determine schedules and efficient route
(xvi) Provide safety and security
(xvii) Move fast at free road

11Fig. 2. Transportation System

11Full resolution of picture online: http://1.bp.blogspot.com/_eccQJKQcXab/Svlonj6HKJI/AAAAAAAAlmg/VEhicle – Communication – lg.jpg
2. Remove Conflict Requirements and Grouping the Requirements

To refine the requirements stated above, we need to merge the common requirements and remove the conflict ones. The requirements (iii) and (ix) both are related to avoiding crash and hence these should be merged into one requirement. The requirements (xvi) and (xvii) are conflicting as it is not possible to move fast and get higher safety. So we emphasis on higher safety instead of fast moving. Requirements (x) and (xi) point to the same requirement alert when necessary. Requirements (xii) and (xiii) can be merges into one monitor and control speed. However, the final requirements are categorized into the three categories:

Normal Requirements:
(i) Object identification range 10 meters
(ii) Sense data through headlight and backlight of a car
(iii) Avoid Crash
(iv) Move the car when no object is found
(v) Stop the car when an object is found in front of the car or get signal to stop
(vi) Wait when an object is found at a specific distance
(vii) Detect the road line/range
(viii) Provide safety and security

Expected Requirements:
(i) Alert when other cars get closed to the car
(ii) Count time
(iii) Monitor and control car speed
(iv) Automatically track vehicle location in real-time
(v) Automatically determine schedules and efficient route
(vi) Provide safety and security

Non-functional Requirements: The following non-functional requirements are identified through business case analysis.

(i) Reliability whether it work properly or not
(ii) Safety measurement
(iii) Performance measurement with respect to real time data collection

3. Cluster the Requirements

Cluster the requirements based on sensors’ data collection and functional business logic as so the developers can work independently to each cluster.

Cluster-I: Requirements Related to Data Collection:
(i) Object identification range 10 meters
(ii) Sense data through headlight and backlight of a car
(iii) Detect the road line/range
(iv) Monitor car speed
(v) Automatically track vehicle location in real-time

Cluster-II: Requirements Related to Functional Business Logic:
(i) Avoid Crash
(ii) Move the car when no object is found
(iii) Stop the car when an object is found in front of the car or get signal to stop
(iv) Wait when an object is found at a specific distance
(v) Provide safety and security
(vi) Alert when other cars get closed to the car
(vii) Count time
(viii) Control car speed
(ix) Automatically determine schedules and efficient route
(x) Provide safety and security

V. Conclusion and Future Work

A. Conclusion

The requirements process for CPS is a challenging and important task for CPS on which the subsequent development phases depends. The proposed requirements model provides a strategy of collection and refinement of the requirements. Clustering requirements is a vital part of the model as it provides developers to work independently of other clusters of requirements. As a result, the model facilitates parallelism which reduces development time and cost dramatically.

B. Future Work

The proposed model provides a complete approach of requirements engineering at elicitation phase. However, there is a possibility to work on scenario based modeling including usecases generation using this requirements model as future work.

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