Identification of Trends for Model Based Development of Embedded Systems

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***Abstract*—Model Based System Engineering (MBSE) approach has been frequently put in to practice for the development of embedded systems in order to achieve the business objectives like productivity and time-to-market factors. However, the selection of appropriate UML profile for system modeling is a complicated process. Furthermore, it is also critical to apply the appropriate model transformation technique to get the desired outputs. Therefore, keeping in view aforesaid challenges, this paper investigates the usage of UML and its SYSML/MARTE profiles for embedded system development through Systematic Literature Review (SLR). In addition, various model transformation techniques have also been analyzed and presented. It facilitates the researchers and practitioners of the domain to discover the latest MBSE trends for embedded systems development.**

Keywords*— *MBSE; SYSML; MARTE; modeling; transformation; embedded systems

1. INTRODUCTION

The development of embedded systems is always challenging. The risks of design errors are significantly increased due the broad behavioral and temporal aspects of embedded systems. Consequently, productivity and time to market have been badly affected due to design uncertainty. To overcome these problems, it is essential to incorporate some mechanism for early design verification and validation of embedded systems during development. Model Based System Engineering (MBSE) approach is highly supportive for the development of embedded systems as it provides early design verification and validation capabilities. Therefore, it has been commonly researched and put into practice for the development of embedded systems [11-12], [18-19], [21-23]. The MBSE approach has four main activities for the development of embedded systems as shown in Fig. **1**

The primary MBSE activity is to specify embedded systems requirements. Both structural and behavioral aspects of the system are modeled. UML and its SYSML / MARTE profiles are commonly used to specify embedded systems requirements in latest research practices [1-20]. Property specification techniques have been frequently used [31-32][55-57] to specify behavioral / temporal aspects of embedded systems by using different UML, SYSML and MARTE diagrams. After the requirement specification, different model transformation techniques have been used to get the output model of choice for further verification and validation. The two most common transformation approaches are: Model-to-Model (M2M) transformation [2-3] and Model-to-Text (M2T) transformation [17-18].

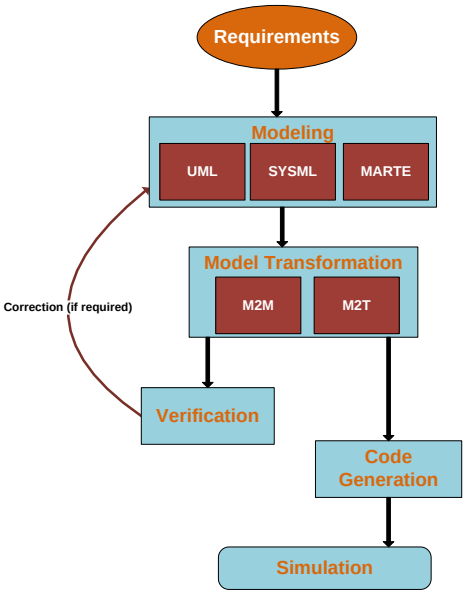

Fig. 1. *Major MBSE Activities for Embedded Systems*

The verification activity is carried out to evaluate the correctness of the model / system. Normally, behavioral / temporal aspects of the model / system have been evaluated by using different formal verification techniques [47-49]. If model fails to satisfy verification requirements, then alterations have been performed to rectify the design errors as shown in Fig. **1**. The simulation is used to perform validation of the model / system. It is a common practice to generate the source code by using model transformation technique which is then used for simulation.

Although researchers frequently propose various modeling approaches based on UML and its SYSML/MARTE profiles [1-20], it is still difficult to select appropriate UML profiles for specifying requirements of complex embedded systems due to their diverse behavioral / temporal aspects. Moreover, there are certain issues while integrating UML and its SYSML /

MARTE profiles [30][34]. Furthermore, selecting appropriate transformation approach (i.e. M2M or M2T) to get desired output model is a demanding activity.

Keeping in view the current state of affair, this paper investigates the practice of UML and its SYSML / MARTE profiles in latest research works for the development of embedded systems through MBSE approach. In addition, the application of M2M and M2T transformation approaches in latest researches has also been analyzed for the development of embedded systems. Consequently, we try to get the answers of three research questions given below:

Research Question 1: What important researches have been reported from 2008 to 2014 where MBSE approach has been utilized to support the development of embedded systems?
Research Question 2: Which of the UML and its SYSML/MARTE profiles are more frequently utilized to model embedded system requirements during 2008 to 2014 researches?
Research Question 3: Which of the Model-to-Model and Model-to-Text transformation approaches are more frequently utilized during 2008 to 2014 researches?

Systematic Literature Review (SLR) [64] has been used as a research methodology. Six categories have been defined to improve the accuracy of our research objectives. The overview of research is presented in Fig. 2.

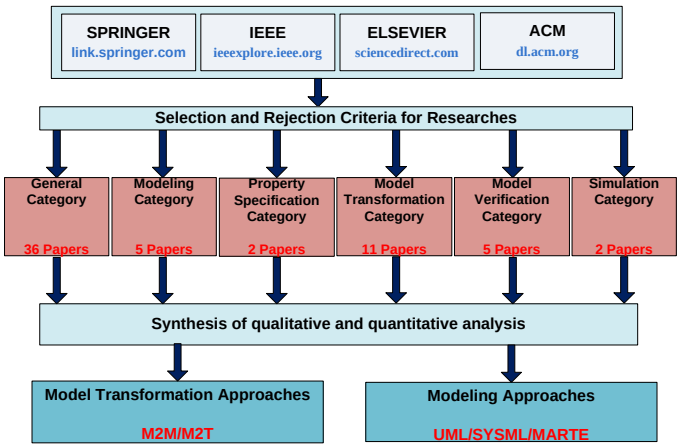

Fig. 2. *Overview of Research*

A Review protocol has been developed (Section 2.2) that incorporates selection and rejection criteria (Section 2.2.2). The search process (Section 2.2.3) is carried out by using four scientific databases as shown in Fig. 2. We define six categories (Section 2.1) to classify 61 selected researches. The important data extraction elements (Section 2.2.5) have been defined to perform comprehensive analysis. The results are summarized in Section 3 and answers of the research questions are given in Section 3.4. The important findings of this research have been discussed in Section 4. Conclusion and future work are described in Section 5

2. RESEARCH METHODOLOGY

Systematic Literature Review [64] has been used to carry out this research. This research incorporates various stages: 1) Categories definition 2) Review protocol development 3) Selection and rejection criteria 4) Search process 4) Quality assessment 5) Data extraction and synthesis.

2.1 Categories Definition

Six categories have been defined to classify selected researches. This categorization significantly improves the accuracy of our research objectives:

General Category: The general category contains all research works providing solution of more than one MBSE activity (e.g. modeling, model transformation and verification) simultaneously for the development of embedded systems.
Modeling Category: Modeling embedded system requirements is the primary MBSE activity. Therefore, there is a fair possibility that all other categories might contain some modeling related information. However, modeling category contains research works where only modeling aspects of embedded systems are discussed / researched by making use of UML and its SYSML / MARTE profiles.
Property Specification Category: This category contains research works where only property specification techniques / languages have been discussed / researched for specifying behavioral / temporal aspects of embedded systems.
Model Transformation Category: This category contains research works where only model transformation techniques / approaches have been discussed / researched. Particularly, the application of M2M and / or M2T transformation approaches has been discussed / researched for the development of embedded systems.
Model Verification Category: This category contains research works where only model verification approaches (both formal and informal) have been discussed / researched to ensure the correctness of behavioral / temporal aspects of the model. .
Simulation Category: This category contains research works where only simulation approaches / tools have been discussed / researched in order to validate the model.

It is important to mention here that the *General Category* contains a number of researches where solutions are either provided for all MBSE activities or at least two MBSE activities simultaneously for the development of embedded systems.

2.2 Review Protocol Development

Once the categories are defined, we develop review protocol on the basis of predefined SLR standards [64]. Consequently, the developed protocol defines the background, research questions, selection and rejection criteria, search process, quality assessment, data extraction and synthesis of the extracted data. The details are given in subsequent sections:

2.2.1 Background and Research Questions

Background and research questions are already given in Section 1 (Introduction).

2.2.2 Selection and Rejection Criteria

We develop concrete selection and rejection criteria in order to get the answers of our research questions. The

selection and rejection of a particular research work is based on the six parameters given below:

Subject-Relevant: Select the research work only if it is relevant to one of the six predefined categories (Section 2.1). Otherwise reject the research work.
2008-2014: Select the research work only if it is published from 2008-2014. Otherwise reject the research work.
Publisher: Select the research work only if it is published in one of the four renowned scientific databases i.e. IEEE [62], SPRINGER [66], ELSEVIER [63] and ACM [67].
Crucial-effects: Select the research work only if it has significant positive effects regarding embedded system development through MBSE approach. Otherwise reject the research work.
Results-oriented: Select the research work only if its proposal and ultimate outcomes must be supported by solid facts and experimentation.
Repetition: All the researches in a particular research context cannot be included. Consequently, reject researches those are identical in the given research context and only one of them is selected.

2.2.3 Search Process

We select four renowned scientific databases (i.e. IEEE, ELSEVIER, SPRINGER and ACM) for search process as given in selection and rejection criteria (Section 2.2.2). These scientific databases provide high quality journal and conference proceedings. We have also studied technical reports, white papers and books for sustenance of our study and investigation. We use different search terms like MBSE, SYSML, MARTE, embedded systems etc to accomplish the search process. We also use AND / OR operators to get the most relevant search results. The details of search terms and relevant screenshots can be viewed at [68]. The following steps have been performed during the search process (depicted in Fig. **3**):-

1. We specify various search terms in four scientific databases and analyze approximately 8862 search results as per selection and rejection criteria.
2. We discard 5290 researches by reading their Title as per selection and rejection criteria.
3. We discard 2176 researches by reading their Abstract.
4. We perform general study of 1396 researches by reading different relevant sections of each research. We discard 984 researches those do not meet selection and rejection criteria. We select remaining 412 relevant researches for detailed study.
5. We perform detailed study of 412 researches and discard 351 researches.
6. Finally, we select 61 researches, fully compliance with the pre-defined selection and rejection criteria

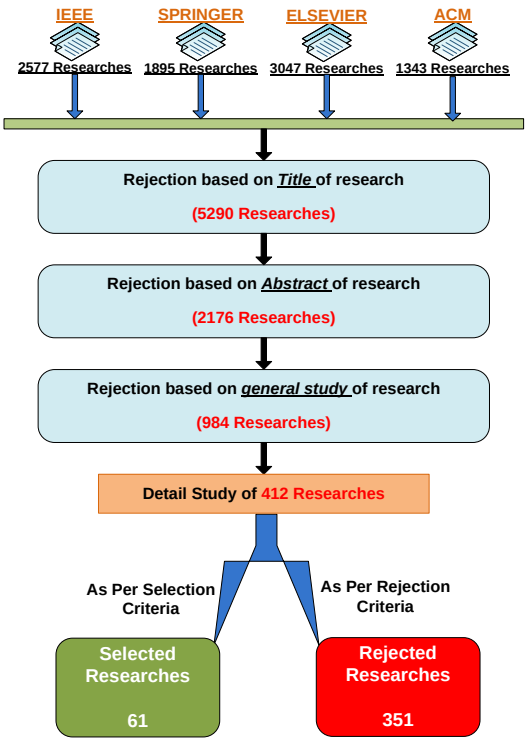

Fig. 3. *Search Process*

2.2.4 Quality Assessment

We have developed quality criterion to understand the important outcomes of selected researches. The developed criterion also defines the credibility of each selected research and its decisive findings. The details of quality assessment can be viewed at [69].

2.2.5 Data Extraction and Synthesis

We extract relevant data from each selected research work in order to get the answers of our research question. The data extraction elements are defined in TABLE I.

We extract bibliographic information of each selected research work as given in TABLE I (serial # 1). For data extraction, defined from serial # 2 to 6, we extract significant details of each selected research work to ensure its compliance with the selection and rejection criteria. . For data synthesis, defined in serial # 8 and 9, we perform detailed analysis of each selected research work in order to extract the accurate information regarding UML profiles utilization and transformation type.

3. RESULTS

We have identified 61 researches and classified them into six categories. The summary of classification is shown in TABLE II.

TABLE I. Details of data extraction for each selected research work

SR. #	Extracted Data	Details
1	Bibliographic information	Title, author, publication year, publisher details and type of research i.e. journal or conference publication
Extraction of data		
2	Overview of research	The basic proposal and objective of selected research
3	Result of research	Results acquired from the selected research
4	Data collection of research	Quantitative or qualitative
5	Assumptions	Assumptions (if any) to achieve or validate the results of the selected research
6	Validation method of research	Validation method used in the selected research to validate its proposal
Synthesis of data		
7	Classification of research	Relevance of selected research to one of the predefined categories (Section 2.1)
8	UML profiles utilization	UML and its SYSML / MARTE profiles used in the selected research (TABLE III)
9	Transformation type	Type of transformation used in the selected research i.e. M2M, M2T or both (TABLE IV)

TABLE II. Classification of selected researches

Sr. #	Category	Number of Researches	Relevant Researches
1	General	36	[1][2][3][5][6][7][8][9][11][12][13][14][15][16][17][18][19][20][21][22][23][24][25][26][27][29][33][44][52][53][55][56][58][59][60][61]
2	Modeling	5	[10][28][30][34][57]
3	Property Specification	2	[31][32]
4	Model Transformation	11	[37][38][39][40][41][42][43][45][46][50][51]
5	Model Verification	5	[35][47][48][49][54]
6	Simulation	2	[4][36]

TABLE III. Results pertaining to UML and its SYSML/MARTE profiles utilization

Sr. #	Profiles	Number of Researches	Relevant Researches
1	UML	7	[1][13][14][16][17][24][53]
2	SYSML	14	[2][3][4][5][6][7][8][9][33][44][52][55][57][61]
3	MARTE	0	
4	UML and SYSML together	2	[15][27]
5	UML and MARTE together	12	[18][19][20][21][22][23][26][28][29][56][58][60]
6	SYSML and MARTE together	4	[11][12][30][59]
7	UML, SYSML and MARTE altogether	3	[10][25][34]

TABLE IV. Model transformation statistics

Sr. #	Transformation Type	Number of Researches	Relevant Researches
1	Model to Model (M2M)	14	[2][3][8][14][15][37][38][39][40][41][45][46][51][59]
2	Model to Text (M2T)	9	[9][17][18][20][21][29][42][43][52]
3	Both M2M and M2T	12	[1][6][12][19][22][23][26][27][44][50][58][61]

We identify 36 researches where more than one MBSE activities are researched simultaneously to provide complete development solution for embedded systems. We further analyze that modeling is the primary MBSE activity and commonly discussed along with other activities. For example, Takashi et al. [4] propose simulation of SYSML model through SIMULINK [65] tool. However, they also provide sufficient SYSML modeling information in the context of simulation. We identify five researches where "only" modeling aspects are discussed. Similarly, we identify two researches where "only" property specification techniques have been discussed. However, various property specification techniques are also proposed along with other MBSE activities. For example, Daniel et al. [55] propose TEPE for property specification but they also provide complete solution for transformation and verification activities. Consequently, we put such researches under the general category as shown in TABLE II. Similar is the case with the model transformation (e.g. [1][12]), model verification (e.g. [11][33]) and simulation (e.g. [6]) categories.

3.1 UML/SYSML/MARTE Utilization

To get the answer of our research question # 2, we investigate each selected study to find which of the UML and its SYSML / MARTE profiles are used / discussed. We also analyze that UML and its SYSML / MARTE profiles are frequently used individually as well as simultaneously to model the requirements of embedded systems. The results are given in TABLE III.

Although we select 61 research works through SLR, we identify only 42 research works in which UML and its SYSML / MARTE profiles are used / discussed as shown in TABLE III. The primary reason is that there are few research works particularly in model transformation (e.g. [41][43]) and model verification (e.g. [47-48]) categories in which UML and its SYSML / MARTE profiles are rarely used / discussed. Consequently, we exclude 19 research works those are irrelevant to our research question # 2.

3.2 Model Transformation Techniques

We analyze the practice of model transformation approaches in each selected research work. The results are given in TABLE IV. We identify 35 research works in which model transformation approaches have been used as shown in TABLE IV. We list relevant research works against each transformation type i.e. M2M, M2T and both. The model transformation activity is not performed / discussed in remaining 26 research works.

3.3 Overview of Selected Researches

We extract relevant data (TABLE I) from each selected research work in order to get the answers of our research questions. However, we cannot include the details of data extraction in the article due to length restrictions. Therefore, the data extraction details of all 61 selected research works can be found at [70].

3.4 Answers of Research Questions

Research Question 1: What important researches have been reported from 2008 to 2014 where MBSE approach has been utilized to support the development of embedded systems?

Answer: The 61 important researches, published from 2008 to 2014, have been identified and classified into six predefined categories (Section 2.1) as given in TABLE II. The overview, publication year, validation method and description of each selected research work can be found at [70].

Research Question 2: Which of the UML and its SYSML/MARTE profiles are more frequently utilized to model embedded system requirements during 2008 to 2014 researches?

Answer: From the results given in TABLE III, it has been concluded that SYSML profile is more commonly used / discussed in the context of MBSE for embedded systems. Further details are available in TABLE III.

Research Question 3: Which of the Model-to-Model and Model-to-Text transformation approaches are more frequently utilized during 2008 to 2014 researches?

Answer: From the results given in TABLE IV, it has been concluded that the M2M approach is more frequently used as compared to M2T approach. It has also been analyzed that simultaneous use of both transformation approaches (i.e. M2M and M2T) is also very common in latest research practices. Further details are available in TABLE IV.

4. DISCUSSION AND LIMITATIONS

Discussion on Modeling Embedded Systems Requirements: It has been analyzed that modeling is the core MBSE activity for the development of embedded systems. The model transformation, verification and validation (simulation) activities are highly dependent on modeling activity. Consequently, various verification and simulation aspects are also considered during the modeling activity. To model embedded systems behavioral / structural aspects, UML and its SYSML / MARTE profiles are most frequently used individually as well as simultaneously (TABLE III). The integration of these profiles provides additional flexibility to model diverse behavioral and structural aspects of embedded systems. However, there are certain problems those should be resolved while integrating UML and its SYSML / MARTE profiles [30][34]. In addition, selection of appropriate property specification approach to specify constraints and properties in the models is always a demanding task. Temporal aspects / timing constraints are well supported by MARTE profile but it is insufficient to handle all behavioral and structural aspects of embedded systems. Therefore, MARTE profile is rarely used alone but frequently used along with UML and SYSML as shown in TABLE III. On the other hand, SYSML has feature sets to handle both behavioral / structural aspects of embedded systems alone. SYSML parametric, activity, block definition and state machine diagrams are frequently used in latest research practices [3-7]. Finally, it has been concluded that

modeling activity for large and complex embedded systems can be well managed by systematically integrating UML and its SYSML/MARTE profiles.

Discussion on Model Transformation: The model transformation approach is the key for further verification and validation of the model / system. Model transformation is used to achieve various objectives; however, the most important outcomes are executable source code for simulation and domain specific model for formal verification. From the results given in TABLE IV, it has been concluded that M2M transformation approach is more frequently used as compared to M2T transformation approach. The primary reason is the transformation accuracy of M2M approach as transformations errors are significantly reduced. However, implementation complexity is the key issue of M2M approach. On the other hand, the transformation accuracy of M2T approach is not as good as that of M2M approach. However, it is easy to implement M2T approach. Further, it is highly flexible and can easily be customized according to transformation requirements. Consequently, the researchers frequently used both M2M / M2T approaches simultaneously (TABLE IV) to perform complex transformation tasks for large embedded systems.

4.1 Limitations of Research

Although, SLR guidelines are observed to perform the research in this paper, there are still few limitations. For example, few search terms produce thousands of results so it is not possible to completely scan all results. Moreover, several works have been rejected by reading their titles and it is possible that research contents are not properly defined in the title. Furthermore, we select only four scientific databases (i.e. IEEE, ELSEIVER, ACM and SPRINGER) for our research. Although selected databases provide high quality research works in the given domain, there are various other scientific databases those may also provide latest research works. Therefore, there is a fair probability that we miss some relevant research works from other scientific databases. However, ultimate findings of the research should not be affected as selected scientific databases provide plentiful research works.

5. CONCLUSION AND FUTURE WORK

This paper explores latest developments of modeling and model transformation techniques in the context of embedded systems. Systematic Literature Review (SLR) has been carried out to identify 61 research works where Model Based System Engineering (MBSE) approach is used for the development of embedded systems. Identified researches are analyzed to present the UML and its SYSML / MARTE profiles utilization. In addition, the practice of Model to Model (M2M) and Model to Text (M2T) transformation techniques has been investigated. This facilitates researchers and practitioners of the domain to look inside the latest developments of modeling and model transformations techniques.

This research provides the basis for students, researchers and practitioners to investigate various MBSE aspects in the context of embedded systems development. For example, this research can be extended to further explore the UML and its SYSML / MARTE diagrams for modeling structural and behavioral aspects of embedded systems. Similarly, this research can also be extended to investigate the latest MBSE tools in the context of embedded systems development.

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