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RobMoSys

Composable Models and Software for Robotics Systems

Deliverable 5.7: Final Report on Open call I Experiments

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Executive Summary

This document presents the final review of the six Integrated Technical Projects (ITPs) selected in the first RobMoSys Open Call over the final reporting period (12 months progress). This deliverable reports the progress of work package WP5 "Open Call" of the RobMoSys Project, related to task T5.5: "Monitoring and review".

The main topics of this report are:

- Background on ITP management and expected objectives.
- Global assessment in terms of performed activities and achievements.
- Individual ITP final reports and assessment.

This report is focused on evaluating the ITPs tooling developments through the fulfillment of objectives, measurements of Key Performance Indicators (KPIs) and success stories related to ITPs contributions to the RobMoSys ecosystem.

Conclusions of this deliverable are:

- The ITPs have fully achieved the objectives: All milestones have been completed, all deliverables have been completed, and all objectives have been reasonably achieved.
- The ITPs have reasonably achieved all the KPIs and provided success stories that contributed to the RobMoSys ecosystem.
- In general, the projects followed the planned schedule and the development plan. However, some issues have been noticed, mostly related to the difficulties of aligning the existing solutions with RobMoSys paradigm and difficulties in adoption of the new toolchains. This was to be expected and is due to the fact that RobMoSys brings about a paradigm shift, therefore not all impacts were to be foreseen during the writing of the ITP proposals.
- The key insight is related to the crucial role of individualized coaching by RobMoSys core partners. Coaches play a particular role to ensure the integration of the ITP contributions already while they are being developed and assist the ITPs in lowering the entry hurdle that comes with a paradigm-shifting approach such as RobMoSys.
- According to the general feedback given by ITPs, coaching is perceived very well and beneficial. This contributes to a constructive mood and atmosphere in the close collaboration between ITPs and RobMoSys: the integration of ITPs was successful and is a valuable contribution to community building.
- Therefore, the coaching approach is considered a mandatory success factor for Second Open Call. It must be reinforced during the Second RobMoSys Open Call and must be considered for further refinement in order to improve ITP productivity.

1 Introduction

RobMoSys's main goal is to create and consolidate an EU Digital Industrial Platform for Robotics to establish a common methodology for software development, improve tools and foster interoperability by model interchange and composability. The RobMoSys approach aims at solving critical issues observed in the industry and will draw a migration path for a stepwise adoption of existing systems for interested early adopters. It will consist of a specialized set of players with both vertical and horizontal interaction levels, providing both widely applicable software products and software-related services. This ecosystem will be able to rapidly address new functions and domains at a fraction of today's development costs.

The RobMoSys Open Calls are an essential means to achieve this goal. The First RobMoSys Open Call, which was open from July 2017 to October 2017, has funded six Integrated Technical Projects (ITPs) with a focus on strengthening the RobMoSys platform with better metamodels, tools, and models. They cover core technical aspects of the RobMoSys ecosystem, including behavior modeling, Quality of Service (QoS) management, functional safety, communication and control, and robotics performance benchmarking.

This report covers the evaluation of the ITPs of RobMoSys during the twelve months of experiments. The ITPs are six teams which were selected during the First Open Call for RobMoSys, with competences in tooling, development of models and generation of associated software (implementations that realize the models, and that are created/configured by the tooling) demonstrated on system-level prototypical scenarios e.g., navigation and manipulation. All the outcome of those ITPs will be made publicly available and will serve as industrial experiments as well as be available in the baseline of the Second Open Call.

This deliverable reports the progress of work package WP5 "Open Call" of the RobMoSys Project, related to task T5.5: "Monitoring and review". The description of the first open call is provided in the deliverable 5.1: Open Call I Preparation Documents, whereas the selection process is covered in deliverable 5.4: Open Call I Evaluation and Selection.

1.1 Scope

This report is focused on evaluating the six ITPs tooling developments by the fulfillment of objectives, measurements of Key Performance Indicators (KPIs) and success stories related to ITP contributions to the RobMoSys ecosystem.

1.2 Document Structure

The remaining part of this document is organized as follows:

- Section 2 provides background on ITP management and expected objectives, as well as a preliminary global progress assessment in terms of performed activities and achievements.
- In Section 3, we present individual ITP reports and assessments.
- The conclusions are discussed in Section 4.

2 Overall Activities and Achievements

2.1 ITP Management

The consortium ambition is to integrate not just the ITPs contributions into the body of knowledge of RobMoSys, but also the ITP teams themselves into the RobMoSys community. To meet this goal, an important condition is to achieve a close and meaningful interaction between these ITP teams and the RobMoSys consortium, beyond the pure monitoring of their progress.

In order to guarantee and maintain the strong integration of ITPs with RobMoSys activities, three mechanisms have been effectively set:

(1) fluid communication,
(2) active coaching,
(3) agile reporting.

Fluid communication with ITPs have been supported by an infrastructure composed of a Discourse forum, and a Tuleap repository and wiki. Such a communication configuration is used as a first proof of concept for the fully open communication infrastructure that will be released for the upcoming RobMoSys community.

An **active coaching** strategy has been developed from work package WP5 according to which individual members of the consortium have been assigned to each ITP. These so-called "coaches" were actively involved in the technical development of the ITPs taking the monitoring process a step beyond pure tracking of the project progress.

In order to achieve **agile reporting**, a monitoring digital platform was set up by TUM. This platform allows us to store project deliverables, bimonthly reports and keep track of milestones as well as offering a space for discussion about the project progress between the ITP members and the assigned coach. This platform was designed to ease the coaches' work in keeping track of their project progress and reporting.

2.2 Meetings and workshops

The **Kick-off ITP Workshop** for the ITPs selected in the first open call happened on 5th March, 2018, in Barcelona, Spain. A two-day event was organized with workshops towards having a first interaction between coaches and project teams. Presentations were made to share details on the RobMoSys approach and to explain the monitoring process. Each project was given the possibility of presenting their proposal so all the teams involved would have a global perspective of the topics being carried on in the first open call. This was thought to be important since such a meeting leverages synergies and prevents double work, especially if several projects share common topics (e.g., Behavioural trees). This approach has already proven to be fruitful since collaborations between projects have emerged.

A **Virtual ITP Workshop** for all the projects and the coaches was held on 27th June, 2018, organized by CEA. In this workshop the ITPs had the opportunity of asking the consortium about technical or non-technical issues in the implementation of their proposals and each of them were asked to elaborate on questions regarding: technical details on the implementation of their proposal and details on the connection between their contributions and the existing RobMoSys meta-models.

The event was very productive toward aligning views across different projects and to prepare the ground for the **RobMoSys Community and ITP Workshop**, which was hosted by KUL on 12th and 13th September, 2018 in Leuven, Belgium. Around 40 roboticists, representatives of the robotics and software engineering community and beneficiaries of the first set of ITPs discussed the challenges of RobMoSys. A structured dialogue and discussion with the audience about the challenges from the point of view of the robotics domain, the pain points from a robotics perspective and the views of the participants were valuable inputs for the ongoing work within the project, on its way to provide a tooling and software ecosystem towards an EU digital industrial platform for robotics.

As a final event for the ITPs, a **Demo Day for Robotics Software Ecosystem** was organized **by RobMoSys** on 11th April 2019 in Barcelona, Spain. Members of the consortium and of the ITPs, altogether about 30 people, were involved in the event. Each ITP shared the results of their projects and what it meant for the first demonstration with concrete examples of the RobMoSys approach.

It is also worth mentioning that throughout the duration of these projects, **individual ITP coaching workshops** (virtual and on-site) between coaches and ITPs have been set up per ITP to ramp-up and foster the collaboration between coach and ITP and to ensure the integration of the technical projects in RobMoSys.

2.3 ITP Coaching

As part of the efforts towards integrating not just the ITP contributions into the body of knowledge of RobMoSys but also the ITP members into the RobMoSys community, each of the ITPs was being individually coached by an assigned partner of the RobMoSys consortium as follows:

- EG-IPC – Herman Bruyninckx (KUL)
- MOOD2BE – Dennis Stampfer (HSU)
- CARVE – Matteo Morelli (CEA),
- RoQME – Dennis Stampfer (HSU)
- eITUS – Huascar Espinoza/Ansgar Radermacher (CEA)
- Plug&Bench – Eloy Retamino (TUM)/ Enea Scioni (KUL)

Overall coaching (master coach) coordination was performed by Huascar Espinoza (CEA).

The duties of these coaches included: active involvement in the technical development of their assigned ITP; aligning with RobMoSys background and to contribute in a consistent way; to be an external partner for discussions with a strong background in the RobMoSys methodology; to serve as main link between the ITP and the RobMoSys consortium for questions and requests or to trigger potential collaborations or interactions between ITPs.

Coaches worked closely with ITPs in conference calls and ad-hoc face-to-face meetings. Some of the meetings have been organized as hands-on meetings of up to one week duration. As a result, the ITP outcomes using RobMoSys pilots have been already published on a dedicated corner of the RobMoSys wiki (see Community Corner at the end of page https://robmosys.eu/wiki/community:start).

2.4 Overall Progress Assessment

The work plans of the six ITPs focused on the following technical objectives:

- Conceptual detailed specification of the technical work.
- Development of metamodels, aligned to the RobMoSys metamodels, covering their technical areas.
- Specification of case studies and user stories.
- Tool development with the proposed models.
- Testing of the tool with user stories.

During this period, the ITP consortia have pro-actively participated in the creation of the RobMoSys ecosystem and have achieved the following results:

a) ITP approach alignment with RobMoSys

ITPs proposed relevant contributions to the RobMoSys ecosystem as part of their submissions to the Open Call. However, the technical effort to align their conceptual approaches, implementation technologies and expected results was significant. During the very early phase of each ITP, the detailed specifications were released as a result of (i) intensive interaction with the RobMoSys consortium, (ii) coordination meetings with coaches and (iii) a set of core technical decisions to align their ITP plans to the RobMoSys principles and technologies. This includes terminology alignment, common understanding of software execution semantics, ITP metamodels preparation connected to RobMoSys metamodels, and implementation interfacing of ITP tools with RobMoSys toolchains.

b) Seamless link of RobMoSys with state-of-the-art middleware

As part of the alignment and integration of different execution platforms/middlewares with RobMoSys semantics, new mechanisms were proposed to allow for seamless interfacing of technologies. One concrete example is the link of RobMoSys component with YARP components in the context of the CARVE ITP. In a preliminary proof-of-concept demonstration, CARVE partners and RobMoSys partners used the so-called "Mixed-Port Component" concept to illustrate how the structures of RobMoSys can connect with YARP existing software components to ensure interoperability. Further information of this example can be found at: https://robmosys.eu/wiki/community:yarp-with-robmosys:start.

c) Development of solid user stories of RobMoSys usage scenarios

ITPs specified and developed user stories, describing specific user goals, tools usage procedure, and expected measures of success. The user stories were defined by ITPs but discussed with RobMoSys partners. The adoption of user stories has been an effective instrument to balance concreteness and technical focus in the light of concrete industrial usage of the RobMoSys platform. These user stories were demonstrated with the ITPs tools as described in the Community Corner of the RobMoSys wiki: https://robmosys.eu/wiki/community:start with links to the RobMoSys YouTube channel: https://www.youtube.com/channel/UCURqFtHgAPsXl9mB_QgbBow

d) Cross-fertilisation and openness of ITP results

ITP workshops helped to identify excellent opportunities for cross-ITP collaboration, which were boosted by the open source approach in RobMoSys. Among the collaboration opportunities in current exploitation are: (i) the use of the MOOD2BE tools for behavioral tree modeling by the CARVE project, (ii) the use of the contract-based approach for safety constraints between eITUS and CARVE, (iii) implementation of the runtime monitors between the RoQME and CARVE projects. This is also true for the development of the RobMoSys Pilots (managed by RobMoSys industrial partners, HSU, and CEA), which were aligned to ITP plans and results. Examples are the CEA Pilot on Safety Analysis, which has been integrated with the eITUS ITP user story and the HSU Industry 4.0/Intralogistics Pilot, which was used as a test-bed and demonstration baseline for MOOD2Be, RoQME and CARVE have developed demonstrations based on the HSU Industry 4.0/Intralogistics Pilot.

e) Community building in a coaching-oriented environment

The ITPs actively participated in the RobMoSys Discourse forum (https://discourse.robmosys.eu/), open community workshop (Leuven, September 2018) and provided useful feedback to refine the communication channels and community infrastructure in RobMoSys. This has been reinforced by the Coaching approach in RobMoSys, which helped to guide ITP partners in using the communication channels, provided a lively environment in Discourse and accelerated the information exchange; between ITP and RobMoSys partners.

f) Dissemination and publication

Some ITP partners were very active in the publication of the results. Some publications are joint work with RobMoSys core partners, which is an example of the tight and constructive integration of ITPs in RobMoSys. One of these is the RoQME ITP with at least 5 papers already published, as described below:

- "Managing Variability as a Means to Promote Composability: A Robotics Perspective" (Lutz, et al., 2018), New Perspectives on Information System Modeling and Design, by IGI-Global.
- "RoQME: Dealing with Non-Functional Properties through Global Robot QoS Metrics" (Vicente-Chicote, et al., 2018), Model-Driven Software Engineering Track of the XXIII Jornadas de Ingeniería del Software y Bases de Datos (JISBD 2018)
- "A Component-Based and Model-Driven Approach to Deal with Non-Functional Properties through Global QoS Metrics" (Vicente-Chicote, et al., 2018), The 5th International Workshop on Interplay of Model-Driven and Component-Based Software Engineering (ModComp 2018)

- "Towards the use of Quality-of-Service Metrics in Reinforcement Learning: A robotics example" (Inglés-Romero, Espín López, Jiménez-Andreu, Font, & Vicente-Chicote, 2018), The 5th International Workshop on Model-Driven Robot Software Engineering (MORSE 2018)
- "Towards the Application of Global Quality-of-Service Metrics in Biometric Systems" (Espín, Font, Inglés-Romero, & Vicente-Chicote, 2018) IberSPEECH 2018 Conference

Another example is the CARVE ITP which results were submitted to international conferences:

- Colledanchise, M., and Natale, L., Improving the Parallel Execution of Behavior Trees, in Proc. IEEE/RSJ International Conference on Intelligent Robots and Systems, Madrid, Spain, 2018.
- Giunchiglia, E., Colledanchise, M., Natale, L. and Tacchella A., Conditional Behavior Trees: Definition, Executability, Applications, submitted to ICRA 2019.

3 Individual ITP Results

The Integrated Technology Projects (ITPs) of RobMoSys were scheduled for a period of one year starting in March 2018. The results of each ITP are presented below and refer to the duration of the project, corresponding to months M01-M12. These reports are based on the final reports provided by each ITP and the perspective of the ITPs' coaches.

3.1 EG-IPC

The EG-IPC (EG-IPC - Architecture and Components for Reliable Control over Networks, using Intrinsic Passivity Control) project is conducted by Universiteit Twente and Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderoek (TNO). The coach assigned to the project by RobMoSys was Herman Bruyninckx (KU Leuven).

Project objectives

The main goal of the project is the development of all-time stable loop control components using Energy Guarded Intrinsically Passive Controllers. For the structure of these EG-IPC blocks, the development of metamodels that conform to RobMoSys is required. This entails the formalization of the generic IPC structure and adding energy guards on the interfaces of the components where needed as well as additional interfaces to communicate and synchronize the energetic state.

According to the proposal, the detailed objectives were as follows:

1. Development of the required metamodels:

- Formulation of a metamodel that describes the bond graph modeling language: Required to formalize the power port and power bond entities and energy exchange mechanisms among components of robotic applications.
- Formulation of an IPC metamodel that conforms to the bond graph and the RobMoSys' component architecture: Required to define the policies, mechanisms, and constraints of the IPC component architecture.
- Extend the IPC metamodel to incorporate passivity layers. Required to formalize the EG-IPC component architecture.

2. Design of the EG-IPC component architecture:

- Realization of the EG-IPC component architecture based on the previously formulated metamodels and the RobMoSys Component- Definition metamodel.

3. Development of the industrial-linked user story:

- Definition and development of the user story in the role of system developer to evaluate the usability of the EG- IPC model.

4. Dissemination:

- Ensure the RobMoSys community is aware of the efforts, potentials, and results of the project.

Reported results

1. Development of the required metamodels.

The formulation of a metamodel that describes the bond graph modeling language has been performed and will be disseminated as a conference paper.

The Intrinsically Passive Control metamodel has been successfully developed. As an IPC is a controller which behaves as a physical system, it conforms to bond graph and feedback control. By definition of the passivity property, an IPC has a constraint that indicates that the energy extracted from the system cannot be greater than the energy introduced to the system. In robotic applications, the stability property of passive systems is of particular interest when dealing with unknown environments. In order to overcome the loss of passivity due to delays, the role of Passivity Layers (PL) comes into play to enforce stability. Besides the metamodel, a pair of example datasheets of IPC components were generated. The datasheets are intended to provide diverse representations of the controller and information regarding its properties and parameters.

The Energy-guarded IPC metamodel is still under development. The EG-IPC metamodel makes use of the Bond Graph and IPC metamodels to simplify the definition of its entities. In addition, the EG-IPC metamodel also conforms-to the block-port-connector metamodel, fitting into the RobMoSys ideology. The Passivity Layer component monitors the energy entering and exiting the system, guaranteeing the passivity (and stability) by bounding the extracted energy.

2. Design of the EG-IPC component architecture.

The EG-IPC component architecture is still under development. The architecture in question is composed by entities defined in the bond graph and IPC metamodels. The definition of the Passivity Layers component is concerned with the EG-IPC metamodel. The proposed structure ensures the passivity of the block, regardless of the properties of the component between the passivity layers. A potential contribution of the EG-IPC component architecture to the SmartSoft environment has been identified. In order to achieve this incorporation, the toolchain requires the implementation of the bond graph and EG-IPC metamodels to define power ports, power bonds, passivity layer and other elements of the EG-component architecture.

3. Development of the industrial-linked user story.

To connect the developed models and metamodels to a real-world application, and thereby validate their usefulness, two user stories have been proposed. The user stories strive to demonstrate the composability, reusability, and stability of the EG-IPC components based on the metamodels. To limit the implementation effort, the two user stories are very similar. The first one features transparent bilateral teleoperation of a robotic arm by manipulating an identical arm. In the second user story the same components are connected in a different way, and two robot arms will be controlled by a single haptic controller, also taking into account the interaction between the two robot arms when pinching an object.

4. Dissemination.

A paper aimed at major conferences is currently under development. In the paper, a formalized metamodel for the bond graph language that captures the features of the energy-based modeling and control and relates them to the Block-Port-Connector paradigm is to be presented. Also, the identification of the entities, relations, and properties of the bond graph language will be tackled. The definition of these entities is critical to describe the power exchange between components under the energy-guarded component architecture.

Measurements of Key Performance Indicators

The KPIs were fine-tuned during the conducting of the project:

1.Benefit of EG-IPC and IPC (fully achieved). Performance tests were realized, comparing with and without (EG)-IPC.

2. Fit to RobMoSys ecosystem (fully achieved). The EG-IPC metamodels simplify the definition of its entities and created links of conforms-to another metamodel, fitting into the RobMoSys ideology. Also, a potential contribution of the EG-IPC component architecture to the SmartSoft environment has been identified.

3. Internal metamodelling approach in our project (fully achieved).

4. User story compliance (fully achieved).

User Stories

- Haptic Teleoperation: Manipulation Use Case. A setup was created to test the functionalities of EG-IPC in a teleoperation environment that involved the operator receiving haptic feedback over network communication. This setup involves a Franka Emika Panda robotic arm that serves as a haptic device (right robot in left picture), a video feedback system and a remote Franka Emika Panda robot that should perform a remote task. Between the two robots, an ethernet network with a possibility to increase communication delays was installed. The main task objective of this setup was to remotely open and close a door.

- Integration into RobMoSys Tooling: Navigation Use Case. In order to test our adherence to the RobMoSys ecosystem, we tried to recreate our metamodels using the SmartMDSD Toolchain, which is an IDE for robotics software conformant to the RobMoSys approach. In order to make use of existing modelling and simulation components provided by RobMoSys, we worked on a use case relating to navigation: platooning of small wheeled robotic platforms like the P3Dx or the Tiago.

Coach's perspective

The report is a good reflection of the work that was achieved. The cooperation between the RobMoSys project coach and the ITP members was very constructive and mutually beneficial. I have the impression that we now have the "final model" of what it needs to make safe network-driven motion control systems, because the ITP succeeded in the "separation of concerns" that is a major design driver for the RobMoSys project, but that was still not achieved in the literature about this topic.

3.2 MOOD2Be

The MOOD2Be (Models and tOOls Development for BEhavior design) project is conducted by Eurecat, Centro Tecnologico de Catalanya. The coach assigned to the project by RobMoSys was Dennis Stampfer (HS Ulm).

Project objectives

MOOD2Be project focuses on a very specific problem in the domain of Model-Driven Software Development - the Concern of Coordination and the Role of the Behavior Developer, as defined in the RobMoSys Wiki. This includes the definition of a comprehensive meta-model, compliant with the RobMoSys one, and the implementation of a specific set of tools and run-times which streamline the adoption of these models in real-world applications. One of the core objectives of MOOD2Be, fitting the overarching goals of RobMoSys, is the development of industrial-grade software tools which shall be easy to learn, to use and to integrate into legacy code bases.

According to the proposal, the detailed objectives were as follows:

1. Definition of a harmonized metamodel that is consistent with Behaviour Trees, Hierarchical Finite State Machines and SmartTCL.
2. Implementation of the software beta. It is planned to present this software package to the robotics community to receive feedback.
3. Refinement of the implementation, based on the feedback received by the robotic community and RobMoSys partners.
4. Verification of the effectiveness of the proposed metamodels and software tools, based on real-world user story.
5. Administrative coordination and dissemination.

Reported results

1. A document was presented that discusses how the meta-models and implementation were both designed from the ground up to achieve four main goals: modularity, composability, reusability and the ability to create reactive behaviors. To achieve these goals, they leverage multiple concepts and best practices from the domains of Model Driven Software Engineering (MDSE) and Component Based Software Engineering (CBSE); the "RobMoSys approach", played a key role in understanding how the solution proposed fits into the design of composable software systems.

2. An open source software has been developed and made available via public repositories[1]. In these repositories, the metamodels, methods, tools and technical documentation of MOOD2Be can be found.
3. A Webpage was created with tutorials and basic concepts explanations. The tutorials present step-by-step the use of MOOD2Be methods and tools with the intention that it is easiest for new users.
4. The open source software has been promoted to the community via the platform GitHub. It allowed to monitor interest in the repository, the number of downloads, feedback on improvements and bug correction. As the "impact in the community" is one of the key performance indicators of MOOD2Be, the project is considered satisfactory since at the moment the project finished the repository on platform GitHub has 274 stars and 63 forks.
5. Integration of MOOD2BE with one of the tools of RobMoSys - SmartMDSD Toolchain. This integration was documented on the RobMoSys wiki with a video and technical descriptions[2].
6. A collaboration with ROS2 developers has been started in order to build the "next generation Navigation stack". It resulted in the incorporation of parts of the MOOD2Be software in the ROS2 framework which underlines the need of this well-established community for a more flexible way to configure "recovery behaviors".

Measurements of Key Performance Indicators

The following Key Performance Indicators were proposed to enable proper monitoring and verification of intermediate accomplishments:

1. Agreement on a harmonized meta-model definition compliance with RobMoSys meta-models and methodology.

2. Compliance with RobMoSys Ethical Principles and EC guidelines.

3. Public release of MOOD2Be methods and tools available in public repositories.

4. Publication of documentation and tutorials for the use of MOOD2Be methods and tools.

5. Increase of productivity by reusability in software development measured by the net time saved by the software developers, considering the overhead of refactoring legacy code.

6. Demonstrated enhanced capabilities for debugging, validated by the ability of the user to record and replay all the state transitions of the system (off-line) and to correctly visualize all the input/output data that generated a certain state transition. The same must be true also in real-time.

7. Easiness of utilizing MOOD2Be tools measured by training time required by new users selected from two industrial partners of RobMoSys.

8. Adoption of these software practices and tools in the robotics community measured by the online activity derived (downloads, comments, etc.) from the public release of the results.

All the KPI were fully achieved.

User Stories

In the demonstrator video (https://youtu.be/aove2CH245Y), the execution of the behavior tree is first shown in simulation using the "Gazebo/Tiago/SmartSoft Scenario". The behavior tree is then executed on a FESTO Robotino Robot as part of the RobMoSys "Intralogistics Industry 4.0" Pilot. Finally, the video demonstrates the visualization of an automatically generated log file, that allows the user to analyze the execution of the behavior tree offline.

[1] MOOD2Be repositories: https://behaviortree.github.io/BehaviorTree.CPP/ and https://github.com/BehaviorTree/Groot.

[2] MOOD2Be on RobMoSys wiki: https://robmosys.eu/wiki/baseline:environment_tools:behaviortree.cpp and https://robmosys.eu/wiki/baseline:environment_tools:groot.

Coach's perspective

The ITP contributed RobMoSys-conformant meta-models for Behavior trees and established a link on the conceptual level. The link on the technical level has been established and demonstrated. MOOD2Be provided very good documentation for the stand-alone use of its developed software "BehaviorTree.CPP" and "Groot".

The objectives of the ITP have been fully achieved: All milestones have been completed, all deliverables have been completed, and all objectives have been reasonably achieved.

3.3 CARVE

The CARVE project is conducted by Fondazione Istituto Italiano di Tecnologia, Universitá degli Studi di Genova and United Technologies Research Center (UTRC). The coach assigned to the project by RobMoSys was Matteo Morelli (CEA). The technical assistance was provided by Dennis Stampfer (HSU) with respect to the RobMoSys Communication Patterns and Mixed-Port-Component (RobMoSys-YARP Bridge).

Project objectives

The main goal of CARVE is contributing to the development of the RobMoSys ecosystem by fostering its adoption in the research community and by presenting the Behavior Trees as a flexible, composable, and reusable hierarchical abstraction for modeling components orchestration in the ecosystem.
The CARVE project extends the RobMoSys ecosystem coverage by providing Behavior Developers an agile formalism for describing robot behaviors that are simpler to understand, maintain and adapt to different application domains, fostering the creation of a "behavior market" that will complement the "component" market envisaged in RobMoSys. Seamless integration of BTs in the RobMosys ecosystem —and specifically in the SmartSoft toolchain — is guaranteed with the development of a tool for automatic translation of BTs into SmartSoft DFSMs.

The main goals of the complete period of the project were as follow:

1. Formalism for modeling composable and reusable behaviors. Provide an approach for describing robot behaviors that aim at reducing development time by emphasizing composition and reuse of behaviors.
2. Develop a set of verification tools for increasing confidence in correct robot behaviors. This demonstrates the benefit of model-driven software engineering and increases confidence in the deterministic behavior of the robot. These tools can verify behavior invariants at design time, and generate runtime monitors to ensure proper operation.
3. Validation of the approach in a real-world scenario. Considering an assistive task in a domestic environment with a mobile manipulation platform that integrates object recognition, manipulation, and navigation.
4. Fostering the adoption of the RobMoSys ecosystem within the research community. Adopting the RobMoSys tools and the implementation of the validation scenarios on the target robotic platform, which is software-compatible with the iCub humanoid robot, making the toolchain readily available to the whole iCub community. Dissemination activities will facilitate the adoption of the RobMoSys tools and philosophy by the iCub community and the research community at large.

Reported results

1. The project concept has been refined by the team and ultimately has the following form:

- The user designs a behavior using BTs. Syntax and operational semantics for BTs have been defined by the ITP consortium.
- Using an automatic tool, the BTs can be compiled into executable code (BT execution engine). This engine is generated using the Coq proof assistant starting from the BT description and a well-defined BT operational semantic.

- Aforementioned engine is then loaded and executed as a RobMoSys component to orchestrate RobMoSys or YARP components.

Also, the incorporation of the off-the-shelf verification tools (OCRA) to statically verify the correct execution of the BT is suggested.

For the integration of the BT execution engine in RobMoSys a dedicated component that can execute the code extracted from the Coq proof assistant has been developed. Moreover, the interoperability between the SmartMDSD Toolchain and YARP (the middleware used on the R1 robot) has been achieved. To present the interoperability using the Gazebo simulator, the demonstration of the navigation of R1 using the RobMoSys "flexible navigation stack" was performed.

In order to improve the interoperability between YARP and RobMoSys, the RobMoSys communication patterns were mapped into their YARP equivalent. Current work focuses on the automatic generation of bridges in the form of mixed port components in tight collaboration with HSU.

2. A video that demonstrates the "Mixed-Port Component" approach for a system made up of RobMoSys and YARP components have been published.

3. The Groot GUI developed by the MOOD2Be ITP has been integrated with the CARVE BT engine.

4. Three user stories have been defined to validate CARVE methodology and tools. In all of them, the robot is presenting "fetch" behavior, with some deviations.

5. Two publications were submitted:

- Colledanchise, M., and Natale, L., Improving the Parallel Execution of Behavior Trees, in Proc. IEEE/RSJ International Conference on Intelligent Robots and Systems, Madrid, Spain, 2018.
- Giunchiglia, E., Colledanchise, M., Natale, L., and Tacchella A., Conditional Behavior Trees: Definition, Executability and Appliations, submitted to IEEE SMC 2019.
- Cardellino, A., Chevrie, J., Cicala G., Colledanchise, M., Natale, L., Soffia S., Tacchella, A. and Tacchella, A., Randazzo, M., Composable, Models and Software for Robotics Systems: Results and Lessons Learned from the CARVE project, in preparation, to be submitted to Robotics and Autonomous Systems.

Measurements of Key Performance Indicators

The following indicators were presented to evaluate the impact of the project:

1. Reuse of behaviors (target: 90%, achieved:90%)
2. Adoption of RobMoSys tools within Scenario 1 (target: 80%, achieved:80%)
3. Adoption of RobMoSys tools within Scenario 2 (target: 100%, achieved:80%)
4. Adoption of RobMoSys tools within Scenario 3 (target: 100%, achieved:80%)
5. Verification tool for static analysis (target: 100%, achieved:100%)
6. Run-time monitor (target: 100%, achieved:100%)
7. Validation Scenario 1 (target: 80%, achieved:80%)
8. Validation Scenario 2 (target: 80%, achieved:80%)
9. Validation Scenario 3 (target: 80%, achieved:80%)
10. Adoption of RobMoSys tools by the iCub community (target: 30%, achieved:5%)
11. Adoption of BTs by the iCub community (target: 30%, achieved:30%)

Almost all the KPIs were fully achieved, at exception of the KPI 10. For this KPI, the team have plans of promote the RobMoSys tool and Behavior Trees in the next edition of the iCub group's school.

User Stories

Three user stories have been defined to validate CARVE methodology and tools. In all of them, the robot is presenting "fetch" behavior, with some deviations:

- scenario 1: robot has to navigate to a given room, search for an object, pick it up and bring it back to the user (demonstrator video https://youtu.be/b7TeRX1uzoc).

- scenario 2: robot may ask the user to show the location of the room and follow him, if the room is not on the map; adding a human following behavior (demonstrator video https://youtu.be/q25uvU443Tg).
- Scenario 3: task involves picking up a bottle, a glass, and pouring a drink to add a safety constraint to the task (demonstrator video https://youtu.be/-wE457T0718).

Coach's perspective

CARVE studied the application of formal methods to the verification of robot behaviors described with BTs. The project took extreme care to be RobMoSys-conformant since day 1: they identified the entry points to link their extensions to the RobMoSys structures; they also studied a proper mapping of RobMoSys communication patterns to YARP, leading to the realization of YARP/SmartSoft mixed-port component. The CARVE team developed a number of toolchain components that allowed for the evaluation of the whole approach to meaningful use case scenarios. CARVE has achieved all its milestones and goals.

CARVE also pointed out some limitations of the current approach, that raise interesting questions for future research, such as scalability of contract refinements (contracts composition) and verification of properties strongly linked to the environment (resource usage, end-to-end timing properties).

The objectives of the ITP have been fully achieved: All milestone have been completed and all the goals have been reasonably achieved.

3.4 RoQME

The RoQME (Dealing with Non-Functional Properties through Global Robot QoS Metrics) project is conducted by Universidad de Extremadura (UEX), Universidad de Málaga (UMA) and Biometric Vox (BV). The coach assigned to the project by RobMoSys was Dennis Stampfer (HS Ulm).

Project objectives

RoQME wants to contribute to RobMoSys model-based framework for dealing with system-level non-functional properties, enabling the specification of global robot Quality of Service (QoS) metrics defined in terms of the (internal and external) contextual information available. The RoQME toolchain is intended to support the role of QoS Engineers, providing them with a specific QoS view. This view will allow them to model system-level robot QoS metrics according to the new RoQME meta-model. The concepts included in the RoQME meta-model will be linked to those already available in the RobMoSys meta-model (defined by other roles in different views). In order to guarantee the correct alignment and harmonization of the new role, view and meta-model with those of RobMoSys, a RoQME-to-RobMoSys meta-model mapping, linking both worlds, will also be defined. This mapping aims at promoting high cohesion and loose coupling among the different RobMoSys views, providing a non-intrusive way of extending the RobMoSys meta-model, i.e., modifying the RoQME meta-model would only imply adapting the mapping to RobMoSys (but not modifying the RobMoSys meta-model itself), and vice versa.

The detailed objectives of the complete period of the project were as follows:

1. Meta-models and RoQME-RobMoSys harmonization.

2. Support software development.

3. Tool-chain development.

4. Documentation and dissemination of the project's results.

Reported results

1. The following meta-models, implemented using the Eclipse Modeling Framework, have been developed:

- An Ecore-based RoQME meta-model enabling the specification of global robot QoS metrics on Non-Functional Properties (NFP). These metrics are specified in terms of reinforcing/undermining Observations based on Context Patterns; and
- An Ecore-based RoQME-to-RobMoSys mapping meta-model, linking the concepts in the RoQME meta-model to those available in other RobMoSys meta-models.

In order to achieve the desired harmonization between the RoQME and the RobMoSys metamodels, a visit to HS Ulm has been scheduled. This event allowed RoQME team to validate and complete the RoQME-to-RobMoSys mapping metamodel and outline an example scenario that aligns with HS Ulm work.

2. Support software for context monitoring, event processing, and probabilistic reasoning was developed. This software helped the development of the RoQME tool-chain.

3. The RoqmeDDS library, together with a document explaining how to install and use it has been delivered as an Eclipse plug-in. Also, a video documenting the RoQME pilot case and technical descriptions have been published in the RobMoSys wiki. Additional efforts were made focusing on the implementation of modules for:

- Automatically generating validation tests out of the RoQME model specifications,
- Visualizing the resulting QoS metrics (outputs) in terms of the context variable evolution (inputs).

This work was essential to provide this kind of mechanism for validating the correctness of the implemented software, in particular when actual robots were not always available for testing the developed solutions.

4. Regarding raising community awareness of RoQME results, several channels of communication were established including LinkedIn, ResearchGate and Twitter. The diversity of those means of dissemination ensures the coverage of different groups of the target audience.

Furthermore, a paper entitled "How well does my robot work? --RoQME: A project aimed at measuring quality of service in robotics" has been released in medium.com.

Moreover, the results of conducted work have been presented during conferences or workshops as follows:

- "Managing Variability as a Means to Promote Composability: A Robotics Perspective" (Lutz, et al., 2018) was submitted and approved for its inclusion as part of a book entitled: New Perspectives on Information System Modeling and Design, by IGI-Global. This book chapter is an extension of (Lotz, et al., 2014) and it was also written in collaboration with the RobMoSys HSU team. The main extensions included in this manuscript relate to the concepts at the core of both the RobMoSys Project and the RoQME ITP. Currently the book is in press and will be soon available.
- "RoQME: Dealing with Non-Functional Properties through Global Robot QoS Metrics" (Vicente-Chicote, et al., 2018) was submitted to the Model-Driven Software Engineering Track of the XXIII Jornadas de Ingeniería del Software y Bases de Datos (JISBD 2018), to be held in conjunction with SISTEDES 2018 on 17th-19th September 2018 in Seville (Spain). This contribution is available in open-access through the SISTEDES website [3] and via ResearchGate at: https://www.researchgate.net/publication/327239527.
- "A Component-Based and Model-Driven Approach to Deal with Non-Functional Properties through Global QoS Metrics" (Vicente-Chicote, et al., 2018) was submitted to the 5th International Workshop on Interplay of Model-Driven and Component-Based Software Engineering (ModComp 2018), to be held in conjunction with MODELS 2018 on 14th October 2018 in Copenhagen (Denmark). This contribution was accepted and will be shortly available in open-access through CEUR-WS.org (ISSN: 1613-0073). The camera-ready version of the paper is already accessible via ResearchGate at: https://www.researchgate.net/publication/328102310.
- "Towards the use of Quality-of-Service Metrics in Reinforcement Learning: A robotics example" (Inglés-Romero, Espín López, Jiménez-Andreu, Font, & Vicente-Chicote, 2018) was submitted to the 5th International Workshop on Model-Driven Robot Software Engineering (MORSE 2018), to be held in conjunction with MODELS 2018 on 15th October 2018 in Copenhagen (Denmark). This contribution was accepted and will be shortly available in open-access through CEUR-WS.org (ISSN: 1613-0073). The camera-ready version of the paper is already accessible via ResearchGate

[3] SISTEDES website: https://biblioteca.sistedes.es/articulo/roqme-dealing-with-non-functional-properties-through-global-robot-qos-metrics/

at: https://www.researchgate.net/publication/327243001.

- "Towards the Application of Global Quality-of-Service Metrics in Biometric Systems" (Espín, Font, Inglés-Romero, & Vicente-Chicote, 2018) has been submitted to the IberSPEECH 2018 Conference, to be held in Barcelona on 21-23 November 2018. If the paper is accepted, it will be presented as part of the IberSPEECH Projects Session and will be included in the online conference proceedings.

Measurements of Key Performance Indicators

1. No. of example models defined using the RoQME meta-model and model editor (target:2, achived: 2, fully achieved). Two scenarios have been developed that illustrate the modeling capabilities offered by the RoQME meta-model: (1) a scenario based on the HSU Intralogistics Industry 4.0 Robot Fleet Pilot; and (2) a scenario based on a Smart Clinic Assistant Robot, developed by UMA (among other partners) as part of the Echord++ CLARC Project (http://www.clarc-echord.eu/). These two scenarios have been included as part of deliverable D1.1. RoQME Meta-Models and RoQME-RobMoSys Harmonization.
2. No. of example models (defined with the RoQME tool-chain) linked to other models (target:2, achived: 1.5, partially achieved). Tool-chain interoperability has only been partially validated. However, the experiment carried out in collaboration with the HSU team in Ulm (Germany) in November 2018, and the tests carried out at the end of the Project, using identical input models as in those used in the previous experiment, provide good evidence of a correct tool-chain integration.
3. No. of downloads of the RoQME tool-chain from open-source repositories (target:20, achived: 10, partially achieved). The RoQME tool-chain was publically released in GitHub (https://github.com/roqme/robmosys-roqme-itp) at 10 April 2019. However, as soon as we announced it, it got more than 10 unique cloners in less than 1 week.
4. No. of page views (PV) and unique visitors (UV) entering the RoQME pages in the RobMoSys website (Wiki, etc.), (target:PV>100, UV>20, achived: fully achieved). The information published about the Project in different on-line publication media (e.g., Medium.com) and social networks (e.g., ResearchGate, LinkedIn or Twitter) has attracted considerable interest from the community.
5. Publications submitted to International conferences or workshops (target:2, achived: 5, fully achieved). Five papers have been accepted in different scientific publications and conferences.

Use Stories

An example scenario was implemented using the RoQME software on the HSU Intralogistics Industry 4.0 Robot Fleet Pilot, which was documented in a video, available in YouTube since 21st December 2018. The models and the components developed for this scenario are publically available in GitHub at https://github.com/dstampfer/RoQME.

The example scenario based on the Echord++ CLARC Project has not been implemented so far, although the RoQME models are fully operative.

Coach's perspective

The ITP contributed RobMoSys-conformant meta-models and contributed a new role to the RobMoSys ecosystem. RoQME established a link to RobMoSys on the conceptual level and implementation level. The approach presented by RoQME becomes usable via RobMoSys tools, thanks to its integration into the SmartMDSD Toolchain (an IDE for RobMoSys users). The state of

implementation is yet on a prototypical level. The ITP was encouraged to further work on the implementation and actively maintain the technical link to RobMoSys in their own interest. RoQME was actively disseminating RobMoSys through a number of scientific papers.

The RoQME project published software-related results via GitHub. The outcomes of the ITP are well described in the RobMoSys Wiki:

- Contribution to the "community corner" describing the general concept.
- A video showing RoQME in action: RoQME demonstrated its developed assets in the context of the RobMoSys "Intralogistics Industry 4.0 Robot Fleet Pilot".
- A description of the RoQME Plugins for the SmartMDSD Toolchain was added to the "RobMoSys

software" section.

The objectives of the ITP have been fully achieved: All deliverables have been completed, all KPIs have been reasonably fulfilled, and all objectives have been reasonably achieved.

3.5 eITUS

The eITUS (Experimental Infrastructure Towards Ubiquitously Safe Robotic System using RobMoSys project) is conducted by AKEOPLUS (AKEO) and Tecnalia Research & Innovation (TEC). The coach assigned to the project by RobMoSys was Ansgar Radermacher (CEA).

Project objectives

The eITUS project aims at creating a basic experimental infrastructure (models, software and tools) that enables robotic development stakeholders to assure system safety both at design time, using analysis and simulation-based techniques, and at run time, using safety monitoring algorithms.

eITUS integrated existing technologies as RobMoSys, P-RC2 (Platform for Robot Controller Construction) and AMASS (Architecture-driven, Multi-concern, and Seamless Assurance and

Certification of Cyber-Physical Systems) projects.

The main goals of the complete period of the project were as follow:

1. eITUS Specification. Definition of the business scenarios of eITUS including target markets, technology enablers, regulatory context, costs, and stakeholders.
2. A prototype of Robotics Models and Software Generation. This prototype will provide an extension of the RobMoSys metamodel to allow for contract-based design, along with model patterns of collaborative robotic solutions and tools to generate ROS/OROCOS compliant code to run on the robotics platform for demonstration.
3. A prototype of Safety Validation Tools. This prototype will provide an extension of the RobMoSys metamodel to allow for safety modeling, tool interfaces of RobMoSys platform with safety analysis tools (e.g. Sophia by CEA) and along with tools to simulate robotic systems with fault injection in the Sabotage and Gazebo simulators.
4. eITUS Demonstrator and Benchmarking. Test and validate eITUS solution and provide feedback for enhancements during the project and after the project. The demonstrator will be in the field of collaborative robotics and the robotics platform will be selected between an AGV and a robot manipulator.
5. Dissemination and Communication

Reported results

1. The methodology and conceptual approach of the eITUS project have been defined and are available in RobMoSys internal repository.
2. A prototype for the safety metamodel and the safety view was implemented as a Papyrus/SysML profile, which supports the design of safety-critical robotics systems. A safety view (FMEA, Fault Injection, and Safety Requirements Table) has been integrated into RobMoSys.
3. The FMEA editor was integrated. However, possible modifications and extensions might be needed to consider other techniques, such as HAZOP or Preliminary Hazard Analysis.
4. Two representative fault injectors have been implemented in P-RC2 on a simulated position sensor for a robot manipulator. Additional fault models and experiments have been implemented and run in simulation. Methodologies to automatically insert fault injectors and generate faulty controllers have been defined (corresponding code generators to be implemented). A demonstrator on a concrete safety validation scenario has been performed, demonstrating the complete eITUS workflow on a use-case[4].
5. Benchmarking plans were elaborated and placed in the RobMoSys internal repository.
6. The eITUS consortium has participated as invited speakers in some conferences such as ERF2018 and ERF2019. The eITUS consortium plans to publish after the project ending with the achieved results.

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[4] eITUS final demonstrator video: https://youtu.be/NH3NMACjRZk

7. AKEO has been disseminating the RobMoSys and eITUS projects to some of its existing R&D partners, customers, and trade fairs, like GLOBAL INDUSTRIE EXPO 2018, IDO 2018 and ROBOT 4 MANUFACTURING.
8. Training activities, both demos, and videos have been organized between the project members. Besides, the project results have been shown within both Tecnalia and AKEO.
9. eITUS has elaborated and published a use case in the RobMoSys Wiki Community Corner section entitled "Safety Assessment of Robotics Systems Using Fault Injection in RobMoSys"[5]. This use case explains how to use the safety related functionalities developed as part of the eITUS project via a safety analysis scenario.

Measurements of Key Performance Indicators

The eITUS benchmarking approach measures the estimated improvements considering two situations: Without eITUS technology and With eITUS technology. In order to evaluate the effectiveness of the eITUS technology, a set of metrics for evaluating each goal were defined, with the associated target and achieved values :

1. Effort for reusing safe robotics components in the global system design (target: 20% decrease, achieved: 15% decrease)
2. Effort for reusing safety validation for component (target:40% decrease, achieved:40% decrease)
3. Effort required in understanding safety-related decisions (target:60% decrease, achieved:50% decrease)
4. Effort for identifying consequences of robotics architecture on safety (target:20% decrease, achieved:20% decrease)
5. Effort for validating corner-case safety issues (target:40% decrease, achieved:40% decrease)
6. Lines of code generated based on models (target:40% gain, achieved:30% gain)
7. Capability to apply different tools in a transparent way for users (target:40% gain, achieved:50% gain)
8. Reuse of safety validation and assets between tools (target:80% gain, achieved:66% gain)
9. Identified risks related to seamless interoperability (target:40% gain, achieved:35% gain)
10. Discovered unknown risks related to seamless interoperability (target:20%, achieved:15%)

All the KPI were fully or partially achieved.

Use Stories

Nowadays, safety is becoming a crucial property of robotic systems. ISO 12100, ISO 13849 and IEC 62061 are some of the most accepted safety standards in robotics, covering aspects such as functional safety. Functional safety is the aspect of safety that aims to avoid unacceptable risks. The system should be designed to properly handle likely human errors, hardware failures, and operational/environmental stress. The safety analysis and validation steps are fundamental aspects to perform the safety assessment. Some of the commonly used risk assessment methods are Preliminary Hazard Analysis, Hazard Operability Analysis, Failure Modes, and Effects Analysis and Fault Tree Analysis. Furthermore, fault injection simulations complete these analyses by finding unexpected hazards (fault forecasting) and verifying the implemented safety mechanisms.

A video demonstrator of the eITUS project related to the eITUS Use Case has been recorded and published in the RobMoSys YouTube channel (https://youtu.be/YrwJ-GTVACw). This video goes through a demonstration of showing preliminary results on how to perform safety analysis in the context of RobMoSys by using and extending the Papyrus4Robotics toolchain and Gazebo.

Coach's perspective

The project developed an essential component of the RobMoSys tooling, in particular for the Papyrus4Robotics baseline. The eITUS results were well integrated into the RobMoSys approach, including the connection with the metamodels, the compositional way of describing safety aspects, and the link with other tools such as safety analysis (FTA, FMEA) developed in RobMoSys. The code generation part was

[5] eITUS in the RobMoSys Wiki: https://robmosys.eu/wiki/community:safety-analysis:start

partially completed, but it provides a good basis for further developments. There were a couple of missing aspects, such as the contract-based approach for modeling safety assumptions and guarantees and the implementation of runtime safety monitors. We agreed (ITP partners and the coach) to put the priority in the other aspects due to the limited resources and the unplanned use of resources to align the fault injection approach to the RobMoSys modeling approach.

The results are highly useful for follow-up projects and for direct usage in concrete use cases, demonstrated via available videos.

The projects achieved the key objectives, all the deliverables have been completed and most of the secondary objectives. eITUS ITP developed the fault injection tool environment as well as the code generation for the targeted software platform.

3.6 Plug&Bench

The Plug&Bench project is conducted by Politecnico di Milano (POLIMI) and Fraunhofer Institute for Manufacturing Engineering and Automation (IPA). The project coach initially assigned to the project by RobMoSys was Eloy Retamino (TUM), who from M21 (November 2018) was replaced by Enea Scioni (KU Leuven). The technical assistance was provided by Dennis Stampfer (HSU) with respect to RobMoSys software baseline "SmartMDSD".

Project objectives

Plug&Bench's main goal is to build on and unify those efforts by developing the models and tools necessary for standardized and easy-to-use benchmarks. Benchmarks defined using Plug&Bench models and tools will, in turn, allow meaningful comparisons between components offering the same functionality, and act as a foundation for the benchmarking of complete robot systems.

Plug&Bench also introduced a new role in the RobMoSys EcoSystem, which is that of a Benchmark Provider. An organization, which designs the benchmarks and publishes the results of the component, similar to the "Stiftung Warentest", a German consumer organization and foundation involved in investigating and comparing goods and services in an unbiased way.

The main goals of the complete period of the project were as follow:

1. Definition of the methodological foundations for the work of the project.

2. Development of the Plug&Bench Benchmark Engineering Tool (P&B-BM) and its description on the RobMoSys Wiki.

3. Development of a perception benchmark for localizing screw holes and a navigation benchmark for navigation.

4. Benchmarking

5. Documentation and dissemination.

Reported results

1. Documents supporting the Plug&Bench Benchmark Metamodel were written:

- "Methodological Foundations for the Benchmark Metamodel", describing the methodological background of the results of Plug&Bench.
- "The Plug&Bench Benchmark Metamodel as part of the RobMoSys Ecosystem", describing the connections between the P&B-BM and the elements of the RobMoSys Ecosystem.

2. The Benchmark Metamodel has been successfully developed and uploaded via RobMoSys' reporting platform.

- A first contribution to the RobMoSys wiki has been made publicly available, resuming the goals of the projects and links to both meta-models and software product.
- One additional outcome was achieved on top of what was foreseen in the project proposal: The improvement concerns the fact that the metamodel covers all 3 types of benchmark (dataset-based, simulation-based, physical) instead of the 2 considered by the proposal. This is a consequence of the fact that the P&B-BM incorporates in itself the elements required to model the different benchmark types, without need for separate extensions (as hypothesized in the proposal).

3. The Plug&Bench Benchmark Engineering Tool was developed and working with Eclipse EMF.
4. Implementations of both planned benchmark experiments (screw hole localiser and trajectory following) were realized. Those scenarios present the different approaches to software component benchmark (dataset-based, open-loop, simulation-based, closed-loop).
5. In the context of the Plug&Bench project, a new role in RobMoSys has been proposed and introduced: the benchmark developer. The benchmark developer plays the important role of developing benchmark scenarios and various metrics to test different functionalities.

Measurements of Key Performance Indicators

The following Key Performance Indicators were defined to evaluate the achievement of the objectives:

1. Number of Robotic Behaviours for which a benchmark model has been defined. The robotic behaviors considered were the following: 1) visual localization of screw holes on plates, in a factory scenario; 2) planning the trajectory for a mobile robot in a 2D map representing a real-world environment; 3) following a planned 2D trajectory by a mobile robot using (simulated) LiDAR data for obstacle avoidance.
2. Number of benchmarks implemented. The benchmarks implemented are: benchmark composition, Benchmark Engineering Tool and ping the Benchmark Benchmark Models.
3. Number of components definition for a benchmark. The components definition for benchmarked were uploaded to a document into the RobMoSys wiki. The tasks included are: task planning, 2D geometric mapping, 2D self-localization, robot path planning, robot path following, object/face detection, recognition and localization, arm path planning, arm path following, grasp planning, visual servoing and input from humans through speech

All the KPI were fully achieved.

Use Stories

The following user stories were presented by the ITP Plug&Bench:

• I want to measure the performance of a robot component which provides/contributes to a specific Skill;

• I need to represent the benchmark in such a way that all involved Roles are able to interface to it (according to their respective Tiers and Views) and unambiguously interact with it;

• I need to describe the benchmark in a sufficiently rich way to consider all the complexity involved in the chosen Skill, and all the significant aspects of the performance of the Component under test;

• I wish that the benchmark and its performance metrics are suitable for a scientifically sound performance evaluation (i.e., one that supports comparison, repeatability, reproducibility, justication)

Coach's perspective

The obtained results are positive and in-line with the expectations from the project proposal.

However, the execution of the project has not been smooth, especially during the first phase of the project: this is also due to the time required for understanding the RobMoSys structures and the proposed RobMoSys meta-models, a necessary step to guarantee the project success.

Even considering the delays on delivering some deliverables, the Plug&Bench consortium always reacted positively to any interaction with the coach, addressing each issue and constructively proposing solutions.

The original plan has been subject to few deviations during this execution: those deviations, always discussed and agreed with the coach in advance, have been taken to reduce the initial delays, but still guarantee a high final quality of the results. For example, a major decision was to focus mostly on two benchmark scenarios from the list originally planned, allowing to enter into the details of those. Another decision was taken regarding the concrete implementation of the benchmark cases, that is, having a partially RobMoSys-conformant set of functionalities. This was also possible thanks to the usage of the mixed-port component development, which was not considered in the original plan, since it became available during the beginning of the ITP project.

Apart from the technical aspects of the project's execution, Plug&Bench consortium has worked very intensively on the dissemination of both ITP results and the overall RobMoSys approach. As an example, the results of Plug&Bench has been submitted at IROS 2019 in form of scientific conference publication. Moreover Plug&Bench work has been presented, together with a general introduction on the RobMoSys approach, to the Robotics community during the workshop on "reproducibility research in Robotics" at ICRA 2019, in Montreal. In conclusion, Plug&Bench consortium has produced not only technical results, but also helped the RobMoSys consortium in the dissemination.

4 Conclusions

The final results of these projects are very positive. All the ITP teams achieved their key objectives and all the deliverables have been completed. The RobMoSys coaches ended up very satisfied with the work done by their ITPs.

Some issues have arisen during this period, with most of them related to the adaptation of the prepared solutions into the RobMoSys framework. Also, some projects experienced delays caused by unforeseen complexity of the goals presented in the original proposals. However, the issues have been solved due to the involvement of the coaches and their individualized approach to the ITPs.

The crucial role of individualized coaching provided by the experts of the RobMoSys core scientific members (described in section 2) is an important contribution to the ITP success. Following the RobMoSys approach entails a paradigm shift and requires deep understanding of the underlying RobMoSys concepts. Most of the ITPs teams did not have (and could not have) such an understanding during the proposal preparation. This was expected and the coaching instrument successfully minimized the negative impact due to the (initial) lack of understanding. Further effort to increase the accessibility of the RobMoSys approach and to lower the entry barriers is needed.

In order to facilitate the future spread of the RobMoSys approach, it is necessary to increase the awareness and understanding within the wider audience. Coaching turned out to be a very successful and important instrument. However, the resources available for coaching are limited. Therefore, the second open call has been shaped in a different way to take into account both the limited coaching capacity and its importance as a success factor of the open call. New instruments facilitating easy adoption have been defined.

This realization has led to shaping the second open call of RobMoSys in a different way – providing focused ITP areas and introducing new instruments. Those new instruments will enhance the RobMoSys consortium's capabilities in medialization of the results and training of new coaches.

The monitoring and coaching will be implemented also in the ITPs of the second open call. Hoping that the experience the coaches won in this first open call, will serve to facilitate entry into the RoboMoSys approach for these new ITPS.