Workpackage	Deliverable ID
WP8	**D8.4 Training Activities Report**

Summary

This document reports on the training activities carried out during the I-MECH project (Task 8.3). Training material has been prepared and activities have been performed, according to a plan that has been defined in the consortium, with the aim of spreading the knowledge acquired during the project between the partners and also in order to show the benefits of the I-MECH methodologies to any potential user.

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Keywords

Training; Dissemination; Communication; Knowledge transfer; Webinars, Training materials; Tutorials

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Table of Contents

List of Figures

List of Tables

(Open) Issues & Actions

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ID	Description	Due date	Owner	IAL ID

Document Revision History

Revision	Status	Date	Author	Description of changes	IAL ID / Review ID
R01	1st Draft	05-February 2020	Antonio Visioli (UNIBS)	Initiation the document	
R02	2nd Draft	06-March 2020	Antonio Visioli (UNIBS)	Addition of EMC, PHI, UNIMO contribution	
R03	3rd Draft	10-April 2020	Antonio Visioli (UNIBS)	Addition of many contributions	
R04	Final version	28-April 2020	Antonio Visioli (UNIBS)	Minor modifications	

Contributors

Revision	Affiliation	Contributor	Description of work
R01	UNIBS	Antonio Visioli	Initiation of the document
R02	UNIBS	Antonio Visioli, Siranush Akarmazyan, Mart Coenen, Harry Mansvelt, Marco Solieri	Minor corrections, addition of various contributions
R03	UNIBS	All partners involved in training	Addition of various contributions
R04	UNIBS	Antonio Visioli	Minor revisions according to the suggestions of internal reviewers

Document control

Status	Draft	FInal							
Revision	03								

Reviewer Name	Role	Selection							
Noud Mooren	Reviewer (TU/e)	X							
Kaspars Ozols	Reviewer (EDI)	X							
Siranush Akarmazyan	WP8 leader (ITML)		X						

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1 Introduction

This deliverable focusses on the activities carried out during Task 8.3 Training. The spread of the knowledge acquired during the I-MECH project is important in order to promote the use of the I-MECH platform among enterprises. In fact, it is essential to show how advanced motion control systems can be implemented and the advantages they provide.

Training activities play therefore a crucial role in making the general public aware of the progresses made in the project, and in promoting the applicability of the I-MECH Building Blocks in the context of motion control systems developed in both large and small and medium enterprises. Eventually, showing the benefits provided by the I-MECH methodologies will also promote the usefulness of the I-MECH centre.

Task 8.3 is part of WP8 and therefore its activities have been coordinated in that framework. In particular, part of the training activities has been disseminated through the typical dissemination channels used in the I-MECH project with the aim of reaching the widest possible audience (see Deliverable 8.5)

In this document, we provide a description of the training activities of the consortium. As they are related to the use of advanced methodologies developed in the project, these activities have been carried out mostly in the last part of the project.

The rest of the document is structured as follows:

- Description of the training plan
- Description of the training activities
- Conclusions

2 Training plan

After some fruitful discussions between the partners during the first f2f meetings of the project, it has been decided that the training activities should have been divided mainly in three categories. They all allow eventually a more thorough dissemination of the building blocks features and of the I-MECH platform/centre in general (although at different levels).

1. Internal training activities: these are activities performed in order to make the employees of a company aware of the progresses made by the company itself in the project so that the whole company is involved in the dissemination of the project and of its results.
2. External training activities: these are training activities that are performed in general by one partner versus other partners of versus a general audience with the aim of explaining a methodology developed in the project. In some case the activity is related to a specific new design tool, in other cases to the explanation of an advanced general design approach, so that the main idea of the usefulness of advanced solutions is conveyed.
3. Specific training activity related to the I-MECH platform. This is the core of the activities performed in Task 8.3 and they are related to the specific explanation of the features of the specific building block and how they are finally integrated into the I-MECH platform. In particular, for each building block a webinar has been created and made available through the I-MECH website so that a general audience can be reached. Instructions related to the webinar preparation have been given to the BB owners (or delegates) in order for the webinars to have a unified style and a unified viewpoint related to the use of BB in the I-MECH platform. In the webinar the tangible assets, holding methods and algorithms have been emphasized. It has been agreed that the structure of the webinar is in such a way that, after the

explanation of the context of the BB in I-MECH framework, an explanation of the HW & SW framework is given before providing an explanation of the developed algorithms and what advantages they can bring. Application examples are also provided in order to prove the effectiveness of the proposed approaches. In this way, the webinars represent a public training material (available through the I-MECH website) that can be used by the partners to describe the use and the functionalities of the overall I-MECH platform.

3 Fulfilment of I-MECH training activities through KPIs

Despite the problems related to the coronavirus situation that has occurred at the end of the project, the I-MECH consortium has achieved the Key Performance Indicators (KPIs) related to the training activities and these are shown in Table 1.

Table 1: I-MECH Key Performance Indicators for training activities.

Number of trainee lessons to be organized (with active participation of attendees)	- 5 lessons (30 participant per lesson in average)
Number of educational seminars to be organized	- 5 seminars to be organized (50 participants per seminar in average)

4 Training activities

As mentioned in Section 2, the performed training activities can be divided into three main categories. The list of the different activities with their explanation is given in the following subsections.

4.1 Internal training activities

The training activities that have been performed for employees by some partners are outlined in the following subsections.

4.1.1 Philips course for employees

At Philips Healthcare in Best two individual I-MECH training sessions were organized.
Session 1 was organized on March 1st, 2019 as a carousel poster presentation session. The carousel, composed out of 5 sessions, was given at Philips Healthcare in Best to groups of 6 participants (thus covering 5x6=30 participants in total). Below picture shows one of the poster presentations, which highlighted the relation of the different building block elements and especially about the integration of the building blocks 3 & 6 into Pilot 5. The poster sessions had a high interactive content leading to good discussions on progress, delivered content from the partners and current status of the integration and challenges encountered during their integration.
On November 26th ,2019 a second carousel poster presentation session was held with the topic “Robust condition monitoring and predictive diagnostics”, which showed more in-depth details and the recent learnings from the integration.

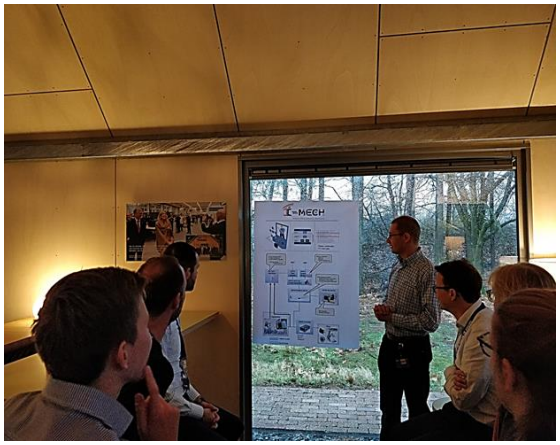

Figure 1: Training activity at Philips Healthcare.

4.1.2 Reden course for employees

A course related to model order reduction training using developed GUI in Abaqus was held on October 9, 2019 for 16 attendees.
Within the I-MECH project a method was developed to efficiently reduce the order of linear finite element models and convert these to a FMU. One of the main developers, Ronald Kampinga, has given an in-depth presentation on the fundamental principles behind the method and has also given a demonstration of the dedicated ABAQUS plug-in software. In the second part of the presentation a short overview on the reduction techniques that are applicable for non-linear models has also been considered (BB8).

4.1.3 Nexperia course for employees

Within the I-MECH project, iterative learning control techniques (BB9) were developed for Nexperia's semiconductor assembly equipment. The potential of these techniques as a means for on-line and adaptive machine tuning was demonstrated in terms of improved servo performance. Furthermore, the developments have led to important insights related to the existing feedforward control and calibration methods and strategies.
A session, scheduled in May 2020, is organized to familiarise mechatronics and software engineers (about 10 participants) with the new tools and the updated insights gained during the project. The session will have the form of a presentation of the results and tools, after which mechatronics colleagues can gain some hands-on experience on a real machine.

4.1.4 Ingenia course for employees

On February 14, 2020, Francesc Marlasca, from Ingenia, presented the BB5 outcome to all Ingenia R&D staff (25 participants). Pictures are shown in Figure 2. This training session was trying to contextualize the building block approach inside the I-MECH project together with highlighting the final features achieved in the building block. After the introduction of the I-MECH project main objectives, the results of the integration of BB5 were reviewed, showing videos of the pilots and demonstrators incorporating the module as well as discussing the challenges appeared during the integration.
After the presentation, a Q&A session was opened.

Figure 2: Training activity at Ingenia.

4.1.5 BUT seminar for academics and students

On March 12, 2020, Bohumil Klima has given a seminar entitled “Predictive maintenance toolbox in the context of I-MECH BB3” to academics and PhD students of BUT CEITEC and BUT Department of Control and Instrumentation. In the seminar, basic terms and definitions were provided and predictive maintenance algorithm development workflow was explained. An example of condition indicator identification and fault classification model training was demonstrated during the seminar using dedicated MATLAB toolbox. A relation of MATLAB predictive maintenance toolbox and I-MECH BB3 was presented as well. The 20 people who attend the seminar have learned a general predictive maintenance tasks and workflows and got an overview on methods used in condition monitoring and predictive maintenance.

The seminar form was changed to Webex conference as a measure against Coronavirus spreading.

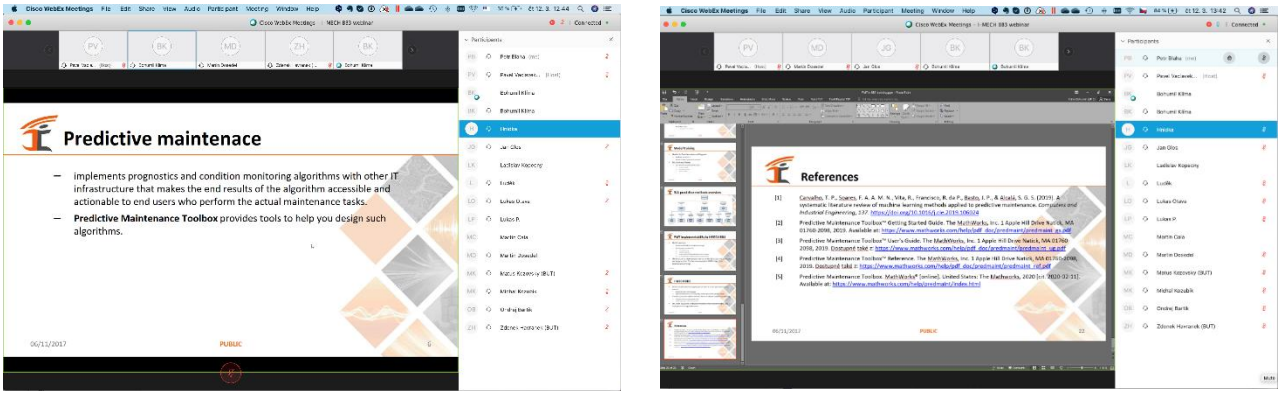

Figure 3: Training webinar at BUT.

4.2 External training activities

The training activities that have been performed for other partners of for a general audience are outlined in the following subsections

4.2.1 EMCMCC training about EMC for motion systems design

A three days course called “EMC for motion systems” with the contribution of EMCMCC was originally scheduled on April 6-8, 2020 in Eindhoven for 10 participants, that is, R&D engineers from various companies / research labs. The course has been postponed to November 2020 because of the coronavirus lockdown. The main topic is related to disturbances on signal lines and sensor systems caused by magnetic fluxes from motors and other kind of energy transfer. Power factor correction, leakage currents and asymmetric loading of a 3-phase system are the main enemies in power distribution systems with respect to unpredictable resonances and current flows. In the course these disturbances and their consequences will be discussed and analyzed. Then, solutions based on a high level of ‘good engineering practices’ will be also discussed.

4.2.2 GEF seminar to UNIBS students in industrial automation engineering

A seminar entitled “Industrial control design for mechatronics applications” has been given on May 19, 2019 by Davide Colombo of Gefran to the students of the Industrial Automation Engineering students of the University of Brescia (Figure 4). Almost 20 graduate students attended the seminar, in which the model-based approach for the design of motion control of mechatronics systems has been outlined. In particular, the use of HIL has been highlighted. Results obtained in the context of the I-MECH project (in particular, those related to BB6 and BB7) have been presented. Students have learned how the problem of designing motion control systems is tackled in industry and they have understood the new challenges in this field that they will soon face in their career.

Figure 4: Training activity performed by GEF at UNIBS.

4.2.3 TEK course on wind turbine control

On October 11, 2019 TEKNIKER provided a seminar related to the control of wind turbines for 18 attendees of industrial companies (e.g. SENER). In the course, I-MECH related concepts like wind turbine dynamics, critical modes damping (BB7), and energy production management were covered. The course had two main objectives: the maximization of energy production during normal operation and the minimization of loads to the systems under high load conditions. Attendees have learned how proper

knowledge and dedication to the control field will lead to a better understanding of their systems and performance improvement.

4.2.4 UNIMORE/EVI seminar to graduate students in computer science

On December 11th, 2018, EVI and UNIMORE hosted a seminar for master students in computer science and computer engineering about Erika Enterprise, the RTOS included in the CPU version of BB11. Paolo Gai, founder and CEO of EVI exploited the very Erika's origin to gradually introduce to more than 30 students concepts of RTOS in general and Erika-specific APIs. The interaction and appreciation have been tangible in the audience (Figure 5).

Figure 5: Training activity performed by EVI at UNIMORE.

4.2.5 EDI seminar to graduate students of University of Latvia

On April 21, 2020, Rolands Savelis presented a practical lecture on "BLE wireless sensor network library in the context of I-MECH BB2" to the students of Faculty of Computer Science of the University of Latvia. In the lecture, introduction to BB2, description of Bluetooth low energy (BLE) wireless sensor network library, and information on the developed BLE wireless sensor were presented. Several examples on building the models, their simulations and the obtained results were explained as well as saving the parameters of BLE devices for their use for identical configuration of real-world devices was demonstrated. The 13 students who attended the lecture learned how to use the library for building the models for simulating the communication between multiple BLE devices.
The lecture was presented using the videoconferencing tool Zoom to prevent Covid-19 spreading (see Figure 6).

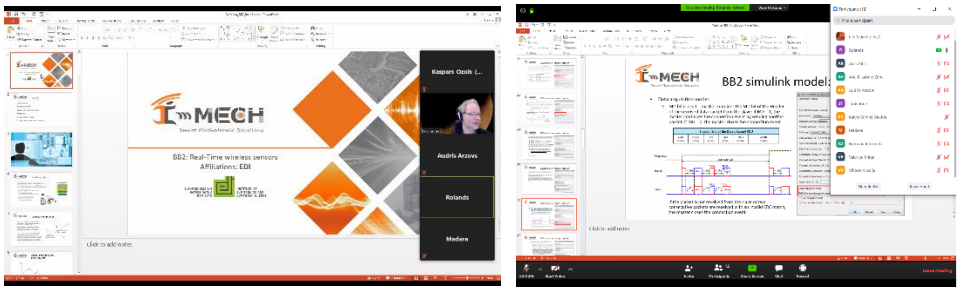

Figure 6: Training activity performed by EDI at University of Latvia.

4.2.6 SIE webinar on Amesim Centre

On November 20, 2018, Olivier Schmidt, from Siemens, presented Simcenter Amesim under the form of a webinar (Figure 7). There was an attendance of 8 people.
The presentation consisted in a brief introduction to Simcenter Amesim as a mechatronic simulation platform. The global workflow for creating a simulation model and exploiting the results has been demonstrated. The multi-physics libraries of components have been roughly described.
The model consisted in a control loop connected to a rotary mechanical mass-spring model, to stay in the context of I-MECH project.
Then the model has been split into 2 parts: a “control” part and a “plant” part. The plant model has been converted into a FMU block. A co-simulation has been created between these 2 Amesim models. This knowledge has then been fully exploited by other partners in the I-MECH project, for different building blocks.

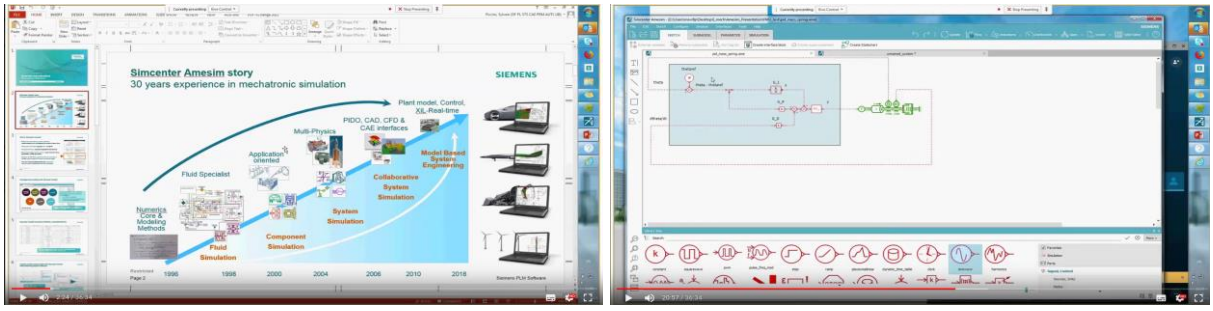

Figure 7: Pictures of the SIE webinar about the use of Amesim.

4.2.7 TU/e course on motion control tuning

The course was held for 10 attendees at the Eindhoven University of Technology in the following dates: 13-20 June 2018, 6-13 Feb. 2019, 2-4 Dec. 2019. Another edition will be held on 22-16 June 2020.
The performance of controlled mechanical servosystems in an industrial setting is generally achieved by using PID controllers. In systems that suffer from dynamics and vibrations it is often useful to use additional filters, like notch-filters. The course dealt with the application of frequency domain techniques, which are very useful for analyzing requirements, describing controllers and carrying out experiments to find the optimal settings.
Starting with the time domain, the complete basis of control has been repeated, placed in a modern framework, validated experimentally and applied to mechanical servo systems. During the course all aspects of 'motion control' have been covered, including the use of feedforward steering.
This course is highly related to, and can be considered as preliminary knowledge, for the content of I-MECH BB8 on 'robust and multivariable control'. The course focusses on how to tune simple PID controllers in practice, which contributes to understanding more complex multivariable controllers.

4.2.8 TU/e course on advanced motion control

The course has been held on 18-22 November 2019 at the Eindhoven University of Technology and it has been attended by 10 people. Another edition will be held on 26-30 October 2020.

The performance of controlled mechanical servosystems in an industrial setting is generally achieved by using PID+ controllers, which are designed using time and frequency responses. In drive systems with more than one axis, it is important to understand if one needs to consider interaction between the axes in the design, and if so, who to tackle the controller design challenge.
Therefore, the course started with a short recap of the basic course 'Motion control tuning' for a SISO (single axis) situation, followed by the analysis and control of the multivariable situation including an in-depth treatment of the interaction analysis, de-coupling and MIMO control. The knowledge has been applied to the hands-on case of a mechanical (2 axes) servo problem and all relevant aspects including advanced feedforward have been treated.
After completion of the course, the attendees were capable of analyzing an industrial multivariable servosystem and designing an adequate control. Based on measurements, they could determine if and to what extend the interaction between the axes is a problem. They were able to apply a stepwise approach to find adequate settings of a multivariable controller, to determine the achievable performance of the controlled system and to understand what limits this performance.
The content of this course is related to I-MECH BB9 on Iterative learning control and repetitive control, which are both part of the course material.

4.2.9 TU/e webinar on repetitive control

During this webinar, which has been held on September 24, 2019, Noud Mooren (TU/e) presented to 10 people the work that has been performed together with Joep Kooijman and Ibrahim Açan (Sioux CCM), on (position domain) repetitive control for the substrate carrier system.
Due to the rotating nature of the substrate carrier (Pilot 1, Sioux CCM), it suffers from periodic disturbances that vary with the operating velocity. Traditional Repetitive Control (RC) is not effective for such period variations. The webinar presented the work that has been done in the direction of position-domain repetitive control, i.e., benefit from the fact that the disturbances are repeating in the roller position domain, which is again a part of BB9.

4.2.10 TU/e AMC frontier tutorial lecture

The tutorial is related to Iterative Learning Control and it should have been given by Tom Oomen on April 20, 2020 at the AMC conference in Kristiansand, Norway (200 participants) but the conference has been postponed to September 2020. A general learning framework will be presented that exploits measured error signals from previous tasks. By employing very simple models, both fast and safe learning is achieved, guaranteeing a reduction of the error in each experiment. Typically, perfect performance is achieved in only five to ten iterations. A complete design framework for motion systems will be provided, while at the same time touching upon the essential theoretical foundations, including non-causality of the optimal design and the connection to traditional feedback and feedforward designs. Finally, recent approaches will be explored that facilitate the implementation on industrial systems, including flexibility for a large class of tasks and multivariable systems.

4.2.11 TU/e tutorial on advanced feedforward and iterative learning control for precision mechatronics

The tutorial will be held in virtual mode (because of the coronavirus situation) at the ASPE Conference in Cambridge (USA) on May 6, 2020 and it is for 150 participants. Tom Oomen (Eindhoven University of Technology) will explain the use of advanced feedforward and iterative learning control (ILC) algorithms to improve the performance of a system (BB9). The tutorial consists of several topics.
First, traditional ILC algorithms can learn from measured error signals of previous tasks. After just a few iterations, such algorithms can compensate any repeating disturbance perfectly. Applications that are suitable for ILC and how a very simple test allows you to immediately determine the achievable ILC performance of your system will be explained. A complete design framework that resembles standard loop-shaping control techniques is presented, which guarantees fast and safe learning. Essential technical aspects such as robust and monotonic convergence as well as non-causal filtering are explained in an intuitive and directly usable manner. An overview of optimization-based ILC techniques is outlined, as well as their advantages and disadvantages.
Second, advanced feedforward is investigated. Indeed, ILC algorithms achieve exceptional performance for repeating tasks, however, they are far from standard in industrial practice. One of the key reasons is that iterative learning control cannot deal with varying tasks. Even a small variation can lead to disastrous performance deterioration. Many industrial systems perform such very similar yet slightly different tasks, necessitating new concepts for advanced feedforward control, including high-order feedforward (snap, jerk, etc.), input shaping, automated tuning, etc. These new concepts have been developed in recent years, whereas most of these ‘iterative learning control’ (ILC) techniques have been developed in the past two decades and many successful industrial applications have been reported, in particular in precision mechatronics such as printing systems, additive manufacturing, wafer scanners, pick-and-place machines, etc.
Throughout, extensions of the design framework to multivariable systems are outlined, as well as several recent connections to machine learning techniques.

4.3 Specific training activities

A set of webinars has been realized and, with the permission of the partners, will be made available for the general public through the I-MECH website. It is believed that, in this way, the general audience will be trained in the use of the single building blocks and in the use of the general I-MECH platform. Further, the I-MECH centre will be more attractive. In each webinar, the main concepts (algorithms, hardware components, etc.) are described in such a way that also people who do not have a strong background in the specific field will be able to understand the core features of the building block and to understand the advantages that the methods can yield for their application. A short description of each webinar is provided in Table 2.
An introduction to the project and to the I-MECH platform and I-MECH centre has been given by the project coordinator in an online public event on digitalization and Industry 4.0 organized on April 16, 2020 by The Mathworks. There were 60 people watching the presentation. This webinar complements the single building blocks webinars giving a complete overview of the platform and of the benefits that the I-MECH centre can give to external users.

Table 2: Content of BB training webinars.

BB	Webinar developer	Content
I-MECH platform/centre	SCC	Overview of the project and introduction to I-MECH platform and I-MECH centre
BB2	EDI	1)Introduction to BB2 2)Description of Bluetooth low energy (BLE) wireless sensor network library 3)Information on the developed BLE wireless sensor
BB3	BUT	1) Introduction to condition monitoring and predictive maintenance and BB3 2) Smart vibration sensor and i2t condition indicator integration in Use Case 1.1 3) Park vectors analysis method for Pilot 5
BB4	SCC	Low-cost high-speed vision-in-the-loop
BB5	INGENIA	Part 1: BB5 Presentation & main features. Part 2: How to use BB5 in current amplifier mode.
BB6	UNIBS/GEF	Automatic tuning techniques for motion control systems
BB7	UNIBS/GEF	Open-loop control for oscillations compensations in overhead cranes
BB7	TEKNIKER	Closed loop techniques for vibration compensation in mechanical systems: damping through conventional cascade control, acceleration feedback and summary of the application in Use Case 2.1
BB10/11	TU/e	1) Introduction to BB10/11 FPGA 2) Description of three developed simulation configurations 3) Demonstration of the features of the configurations

5 Conclusion

In this deliverable the training activity performed in Task 8.3 of the I-MECH project has been reported. The aim of the activity is to spread the knowledge acquired in the project at different levels. In particular, the knowledge has been spread both inside the partner organizations (which has also fostered the cooperation between different teams) and to the general public. This is important for the results of the I-MECH project to be exploited in general by the large and small and medium enterprises. For example, students who learn the relevance of advanced motion control solutions will boost their applications in the companies where they will be employed. The use of webinars to illustrate the building blocks components will allow the training activity to go on also after the end of the project, contributing to the promotion of the I-MECH platform/centre. Of course, the activities of Task 8.3 have been coordinated with the other activities of WP8 and their synergic effect should be considered in making the results of the I-MECH project exploitable as much as possible.

Acknowledgement

This project has received funding from the Electronic Component Systems for European Leadership Joint Undertaking under grant agreement No 737453. This Joint Undertaking receives support from the European Union's Horizon 2020 research and innovation program and Netherlands, Czech Republic, Latvia, Spain, Greece, Portugal, Belgium, Italy, France, Ireland