An Ecosystem for E-learning in Mechatronics: The CLEM project

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Abstract— This paper describes some results of the CLEM project, Cloud E-learning for Mechatronics. An interesting development has been the creation of remote laboratories in the cloud. Learners can access such laboratories to help with their practical learning about mechatronics without need to set up laboratories at their own institutions. On the other hand the cloud infrastructure enables multiple laboratories to come together virtually to create an ecosystem for educators and learners. From such a system, educators can pick and mix materials to create suitable courses for their students. This means that learners can experience different types of devices and laboratories through the cloud. The paper provides an overview of the CLEM project, presenting results so far. In addition to the remote laboratories set up using a Raspberry Pi and Arduino microprocessor structure, this paper also presents information on the results of a survey and the development of static learning material. It also explains how a holistic e-learning experience can be obtained through use of static and dynamic material together with facilities for collaboration and innovation.

Keywords— mechatronics; e-learning; cloud; virtual laboratories; remote laboratories; community; ecosystem

I. INTRODUCTION

Mechatronics combines the disciplines of electronics, mechanics and computer science. The fusion of techniques from these disciplines enables fantastic technological advances with many practical applications. Example application areas include the medical field and increasingly intelligent industrial automation with sophisticated use made of highly-calibrated sensors and complex control systems. A workforce with relevant skills is essential if the potential of these technologies is to be realised. Highly trained individuals with relevant skills in mechatronics will be increasingly sought after by emerging industries in the new technological and information age.

A need has been identified in Europe for vocational skills development in the area of mechatronics [1, 2, 3]. The objective of the FP7 Leonardo project in Cloud E-learning for Mechatronics (CLEM) is to develop an infrastructure for e-learning based on cloud services which will satisfy this need [4]. The authors and institutions listed above are all partners in the CLEM project. The approach of CLEM is to develop a method and exemplar to enable learning providers to create and deliver suitable courses in mechatronics, tailored to local needs, in a scalable and sustainable way.
Training, and in particular, vocational education and training (VET) has in recent years gained an important status on the European social and political agenda. Demands for a highly skilled workforce for the European economy are challenges for the teacher and training community. Various surveys and research studies indicate that the continuing professional development (CPD) of teaching staff and trainers is a key element in meeting the demands of industry for highly skilled workers. Skilled educators are needed to train the workforce. Through this project we hope to inspire educators and trainers so that the potential of Mechatronics can be more widely communicated and exploited to make graduates of training and vocational education programmes industry-ready. To do this, we will produce a resource base in mechatronics tuned to the needs to VET teachers which will be hosted in the cloud and accessible to VET teachers.

The emerging technologies, cloud computing and service-oriented computing, allow resources to be interoperable and shareable. This enables the facilities and materials for e-learning to be modelled as services and managed in the cloud. The advantage of this is that the users can obtain their required services without being concerned with technical issues. In addition, teaching materials can be easily composed to meet the users’ requirements. Teaching or training materials developed in this way become accessible and sharable.

Many educational programmes display a trend towards increased cooperation, not only between different departments in the same organisation but also among the many different organisations involved in national VET systems. These include schools, training institutions, companies and local and central government. Often, cooperation takes the form of what we have called bottom-across coordination, with individual teachers cooperating directly with teachers, researchers, administrators and policy-makers outside their own organisation. This trend is embraced in CLEM which provides the means of community building and resource sharing.

In this paper we describe the approach taken in order to deliver the CLEM objective. We present our results so far and we also take a glimpse at future research directions in this field. The paper is organized as follows. Section II provides an overview of our approach. Section III reviews the state of the art in e-learning and virtual laboratories. Section IV presents our results so far. Section V concludes the paper.

II. OUR APPROACH

The local needs of vocational education providers in mechatronics are vast and varied, especially when targeting a large community such as Europe. The approach we have adopted is therefore, rather than to provide a ready-made and complete system, we will provide an exemplar and method so that sustainable systems can be built in the future and tailored in a timely manner to the needs of local areas. Our high level architecture is shown in Fig. 1.

![Fig. 1. High-level Architecture of CLEM System](image1)

The architecture consists of a server which holds static learning resources, such as e-books, power point slides and lecture notes. The server links to a number of virtual laboratories and contains a booking system so that virtual laboratories can be booked by teachers or learners. In the system, we use the term virtual laboratory to cover both virtual and remote laboratories. We have so far concentrated our work on remote laboratories but virtual or combinations of virtual and remote could also be included. We recognize that rigorous distinction between the terms is not always followed in the literature, although ‘virtual’ tends to be used to refer to laboratories where the experiment is simulated or recreated and ‘remote’ refers to real laboratories that are connected to from a distance, for instance through the internet.

![Fig. 2. The CLEM Ecosystem](image2)
The server also hosts forums and expert channels so that trainers can access expert advice and also help each other as knowledge and experience grows. The idea is that the system will become self-sustaining through the community approach. Trainers can add their own materials and laboratories if they are prepared and able to make these public. It is also possible to build the system in a scalable way by adding links to new servers and services. Private clouds built in the same style can also be made as the CLEM approach aims to divulge the method for creating such a system as well as providing an exemplar platform. Fig. 2 shows the vision of an active community sustaining a service-based E-learning infrastructure in mechatronics and also illustrates the concept of a private similar cloud, which may be required by individual training organisations.

The most interesting parts of the project from a research perspective are the developments of the infrastructure, through services for the creation of a scalable and sustainable community, and also the development of the online laboratories. We will look in more detail at these areas in the next sections.

III. RELATED WORK

E-learning is becoming very important in higher education as a means of reaching wider audiences as well as as a convenient way to supplement traditional learning. Students like to see learning materials online as well as being presented in a classroom as it gives them more opportunity to learn and greater location freedom. Various principles for e-learning have emerged, an important one being the development of a community of inquiry [5]. A community of inquiry is the idea of groups of learners and instructors communicating or collaborating in order to increase understanding or solve a problem. This idea is better supported in e-learning rather traditional learning because of the ease with which communications can be made in an online setting. An online community of inquiry can be supported through a cloud infrastructure, which is the approach taken in CLEM. Another important development in e-learning has been the provision of virtual or remote laboratories [6].

The idea of virtual laboratories in science and engineering has prevailed for some time now, ever since computers became very networked and ubiquitous. In 1986 National Instruments launched LabView (Laboratory Virtual Instrument Engineering Workbench) which is a software platform for interfacing to laboratory instruments enabling control and visualization. Many different types of instruments and buses are available for inclusion. In 2000, Ertugrul provided a review of virtual laboratory implementations that had been created using LabView [7]. He described the basic structure of a virtual laboratory as being a device under test which can be controlled electronically. Various seniors gather data from the device. The data can be captured and analysed remotely. The analysis results can determine control commands which can be sent to the device via a control interface. The experimenter can decide which control instructions to send or what environmental factors to change depending feedback. The experimenter can set hypotheses and test these to by analyzing the data that is gathered. Ertugrul’s review describes industrial and education applications in various areas of engineering and science.

One of the main advantages of virtual laboratories used in education is that learners can have access to laboratory equipment and data that we would otherwise be beyond their reach, because of cost, time, distance or rarity. Ertugrul observed that the roles of teachers and students were changing and that new methods of learning were still to be discovered. Since then there has been much further effort and interest in virtual or remote laboratories in both education and industry. For instance, in 2003, Bistak and Zakova discuss organizing tele-experiments for control education [8]. The paper describes the authors’ experiences in building remote laboratories. It also illustrates the various architectures for providing real experiments via the internet.

In 2005, Martin and Munoz [9] describe a distance learning course on virtual laboratory implementation for high school science teachers. The simulation environment used to implement the virtual laboratories in this case was Easy Java Simulations (EJs), an open-source tool for teachers who do not need complex programming skills and which enables easy building of interactive visualisations based on mathematical models. The intended audience was high school teachers who wished to make use of interactive simulation in their classes. The course gives the skills to design and implement virtual laboratories for educational purposes using EJs.

Remote control of experiments via Matlab was presented in 2006 [10] and in 2008 Zilka, Bistak and Kurcik described a hydraulic plant remote laboratory [11]. The authors discussed the means in which the hydraulic system could be integrated into a virtual laboratory. In 2009 Rojko described a system for e-training in mechatronics [12]. The system consisted of standard modules in the form of static learning material and also a virtual laboratory which was made through LabView. More recently Chaos et al. [13] have used EJS, Matlab and LabView to create virtual and remote laboratories.

In 2013, the Open University UK launched their OpenScience initiative [14]. OpenScience consists of a number of virtual laboratories accessible via the web covering various areas of science. The approach of OpenScience is recreation rather than simulation. This means that data and images recorded from experiments previously carried out by researchers is captured and used as a foundation for the virtual laboratory. The group prefer this approach as simulation and rendering of complex experiments can take massive amounts of processing time and can be error-prone. Examples of OpenScience applications are the virtual microscope through which moon dust can be viewed; a histology laboratory where samples can be analysed through a virtual microscope; a chemistry laboratory where reactions of chemicals in various experiments are visually reproduced; and an animal science laboratory where users can conduct experiments on rats. The applications are being used in some university classes and also could be used in schools. The OpenScience project wishes to
co-opt more providers from various organizations who might wish make a virtual laboratory application available as part of the holistic system.

There are a number of other initiatives that aim to bring virtual laboratories together. The Global Online Laboratory Consortium (GOLC) focuses on promoting the development and sharing of research in remote laboratories for education [15]. Library of Labs (LiLa) was a European project which ran from 2009-2011 and involved eight universities and three companies [16]. The project aimed to provide an integrated platform for remote experiments and virtual laboratories [17]. The iLab project is an MIT based project which based on the premise that online laboratories can enrich science and engineering education [18]. The iLab project links users to remote laboratories over the Web. The architecture consists of a Lab Sever, a Lab Client and a Service Broker which mediates exchanges between the Lab Server and the Lab Client over the Web. It also provides common administrative services such as authentication and data storage. The iLab project has partners from around the world but appears not to have been active since 2011. The iLab project recognized three main types of remote experiment. These are shown in Table I. From the literature review it is evident that there is currently much interest in developing systems for distance learning which include online laboratories. Table II shows the three main approaches to providing online laboratories.

It has been recently recognized that cloud infrastructure can provide the scalability and facility for collaboration that a number of the above-described projects do not have [19, 20, 21, 22]. Through using a cloud infrastructure, more learners can be reached and larger communities can develop bringing greater ranges of knowledge and expertise. As this is a fairly new concept, there are as yet no well-embedded and, as far as the authors are aware, just a few developing systems that embrace the concept.

<table>
<thead>
<tr>
<th>TABLE I. THREE TYPES OF REMOTE EXPERIMENT</th>
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<tbody>
<tr>
<td>Type</td>
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<tr>
<td>Batched</td>
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<tr>
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<tr>
<td>Interactive</td>
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<td>Monitoring</td>
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<tr>
<th>TABLE II. APPROACHES FOR ONLINE LABORATORIES IN DISTANCE LEARNING</th>
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<tbody>
<tr>
<td>Approach</td>
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<tr>
<td>-------------------------</td>
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<tr>
<td>Recreation (Virtual Lab)</td>
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<tr>
<td>Simualtion (Virtual Lab)</td>
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<tr>
<td>Actualisation (Remote Lab)</td>
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<tr>
<td>Community Support and Innovation (Added Value)</td>
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<table>
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<th>Characteristics</th>
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<tr>
<td>• Data from real experiments is collected</td>
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<tr>
<td>• Real images are collected</td>
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<tr>
<td>• Data and images used to recreate the experiment</td>
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<tr>
<td>• Mathematical models provide foundation</td>
<td></td>
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<tr>
<td>• Graphics and visualisations controlled by mathematical models according to user input</td>
<td></td>
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<tr>
<td>• Real Devices connected to software controllers</td>
<td></td>
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<tr>
<td>• Real Devices operated by instructions provided through the software</td>
<td></td>
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<tr>
<td>• Camera may be used to show device in action in real-time</td>
<td></td>
</tr>
<tr>
<td>• Services provided to enable uses to set up add laboratories, materials or set up own Cloud</td>
<td></td>
</tr>
<tr>
<td>• Expert Channel</td>
<td></td>
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<tr>
<td>• Facilities provided to enable users to tailor and set up courses easily</td>
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</tbody>
</table>

In embracing the cloud ideal, CLEM has another important difference from much of the work described above. In sharing its method and providing other user support, CLEM will play an important part in promoting the approach. We use web-based cloud services to deliver both the static and dynamic material. Additionally, we provide services to enhance cooperation and stimulate innovation.

IV. RESULTS

A. Trainer Survey
A survey was carried out amongst 80 trainers or potential trainers, mainly from the Italy area to establish trainer needs. The survey found that, at present, little use is made of online resources in teaching/training sessions (see Fig. 3 and Fig. 4). Only 38% used any sort of technology in the teaching/training sessions and of those that did, few had a media-didactic approach (see Fig. 5). This indicates that there is room for education and training in this area so that better use can be made of technology amongst grass-roots trainers. When it came to looking at how the treacher/trainers looked after their own training needs, the survey found that, trainers use mostly conventional training courses, although there was some internet research and learning through new books (see Fig. 6).
Question: “What kind of material do you use for your teaching/training sessions?”

Fig. 3. Responses to question about material used

Question: “Which media do you use for teaching/training?”

Fig. 4. Responses to the question about media

Question: “Do you have a specific media-didactical approach using technology?”

Fig. 5. Responses to question about media-didactic approach

The trainers had little connection with channels for learning about innovation and new technologies (see Figs. 7 and 8). This is not good as it is essential for trainers to update in order to impart the latest knowledge to learners. This finding validates an objective of the CLEM approach which is to provide forums and expert channels.

As well as indicating a need, the survey also indicated an interest from the majority in an e-learning system in mechatronics (see Fig. 9). In a further question about what resources should be provided in such an e-learning system, respondents showed an interest in exchange of resources, free resources, assessment of progress, library of examples and movies.

Question: “How do manage your own professional skills enhancement and personal/professional competence in today’s fast moving technological world?”

- Regarding new items evolving
  - Internet research 15%
  - Purchase of new books 14%
  - Training courses 59%
  - No response 12%

Fig. 6. Responses to question about managing trainer training needs

In terms of topics that should be covered, respondents highlighted topics related to industrial applications, technological innovations and specific examples. In summary, the survey indicated a need for and interest in a community based e-learning system in mechatronics. The main desired features was resource sharing, again indicating a need for a community.

Question: “Are you in touch with organizations/individuals, that are responsible for transferring innovations and/or best practices on a local, regional, national or international level?”

Fig. 7. Response to question about contact with innovation channels
Question: “Do you use certain networks/communities of practice when delivering the teaching/training (providers, companies, scientific resources)?”

Answer

[Diagram showing responses with percentages]

Fig. 8. Response to question about communities of practice

Question: “Would a new e-learning technology in mechatronics through which you can both update your knowledge and skills and build courses be useful to you?”

Answer

[Diagram showing responses with percentages]

Fig. 9. Response to question about interest in e-learning system in mechatronics

B. Static Modules

The next task of the project was to put together an exemplar of online static modules. The static modules are in the form of PowerPoint slides on relevant topics in mechatronics. Each module has meta-information associated with it giving information such as objectives, learning time and prerequisites. We used the learning environment Moodle as a platform and decided on the following five modules as a suitable introductory course to the topic of Mechatronics:

- Introduction to Mechanical Systems Design
- Sensors and Transducers
- Actuators and Control
- Robotics and Biomechanics
- Intelligent Control

A module was also provided on how to set up a cloud infrastructure for mechatronics e-learning. Figs. 10 and 11 show examples of the static modules. The modules provided are intended as examples. The expectation is that when the ecosystem is established and running well, there will be many and varied static learning materials available. An issue then will be how to discover, index them and recommend them for specific purposes.

C. Dynamic Online Laboratories

The Digital Systems and Media Computing (DSMC) laboratory of the Hellenic Open University has created a web-based remote laboratory for mechatronic control using Arduino [23]. Our approach extends this concept in terms of examples, architecture and in scalability. A crucial CLEM principle is the community aspect and the idea of multiple laboratories which can be booked through a single system. We have created dynamic online laboratories in four of the partner institutions. The architecture of our online remote laboratories is shown in Fig. 12. It consists of the CLEM Server linked to remote PCs, some of which are Raspberry Pis. The remote PCs are linked to an Arduino microcontroller, which in turn controls devices such as LED switches and Servo motors.

Fig. 10. Example of part of a static module on cloud technology

Fig. 11. Example of part of the static module of Actuators and Control

Fig. 12. CLEM Architecture
Users of the remote laboratories can book a slot though the CLEM server. Since there are a number of virtual laboratories linked in, if a slot is not available at one the user can be directed to another. When a user has a slot in a remote laboratory, he/she can interact with the controllable devices by loading up Arduino programming code. Some ready-made examples have been provided so the learner can start by using and altering code that is already there. Figs. 13, 14 and 15 show some screenshots from a remote laboratory. Some of the coding examples already provided in the remote laboratory are listed in Table III. Some of the sample sketches have previously appeared in the Arduino remote laboratory of the Digital Systems and Media Computing (DSMC) laboratory of the Hellenic Open University [23]. Sample code for the Stepper Motor test is shown in Table IV.

**TABLE III. EXAMPLE PROGRAMS OF THE REMOTE LABORATORY**

<table>
<thead>
<tr>
<th>Program</th>
<th>Basic Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bare minimum</td>
<td>Contains void &quot;set up&quot; and &quot;loop&quot; routines which can be used as a framework for other programs</td>
</tr>
<tr>
<td>Blinking LED</td>
<td>Turns on an LED on for one second, then off for one second, repeatedly.</td>
</tr>
<tr>
<td>Serial Hello</td>
<td>Writes Hello on the display unit</td>
</tr>
<tr>
<td>Sensor Light, LED,</td>
<td>Light is actuated according to sensitivity of environment</td>
</tr>
<tr>
<td>Controls a DC Motor</td>
<td>Controls DC Motor</td>
</tr>
<tr>
<td>Stepper Motor Test</td>
<td>Controls a Stepper Motor</td>
</tr>
</tbody>
</table>

**TABLE IV. CODE EXAMPLE: STEPPER MOTOR TEST**

```c
// Adafruit Motor shield library
// copyright Adafruit Industries LLC, 2009
// this code is public domain, enjoy!
#include <Stepper.h>

// Connect a stepper motor with 48 steps per revolution (7.5 degree)
// to motor port #2 (M3 and M4)
AF_Stepper motor(48, 2);

void setup() {
  Serial.begin(9600); // set up Serial library at 9600 bps
  Serial.printn("Stepper test!");
  motor.setSpeed(10); // 10 rpm
}

void loop() {
  Serial.println("Single coil steps");
  motor.step(100, FORWARD, SINGLE);
  motor.step(100, BACKWARD, SINGLE);
  Serial.println("Double coil steps");
  motor.step(100, FORWARD, DOUBLE);
  motor.step(100, BACKWARD, DOUBLE);
  Serial.println("Interleave coil steps");
  motor.step(100, FORWARD, INTERLEAVE);
  motor.step(100, BACKWARD, INTERLEAVE);
  Serial.println("Microstep steps");
  motor.step(100, FORWARD, MICROSTEP);
  motor.step(100, BACKWARD, MICROSTEP);
}```
D. Rapid Course Developer and Ecosystem Services

The next stage of the project is the development of instructions and software through which teachers can build courses quickly using a pick and mix approach. This facility will involve building textual instructions, a directory of materials and providing services to link these materials quickly to make a suitable course according to the needs of the particular trainer. Services will also be developed for browsing and exchange of materials, collaboration, networking, innovation stimulation and expert channels. This part of the project is currently ongoing.

V. CONCLUSION

The CLEM project aims to establish a cloud-based ecosystem for e-learning, resource-sharing and support for mechatronic vocational education teachers and learners. Our research indicates that such a system is needed and desired. The approach we have taken centres around providing an exemplar system and method that others can add to or replicate. So far we have carried out a survey and developed a static material part and a dynamic part consisting of bookable, remote laboratories. Future work will involve more detailed evaluation and the development of further services for community engagement and material sharing.

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