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Joint International Master in Smart Systems Integration
University Collaboration for Improved Education

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Abstract—The Joint International Master in Smart Systems Integration (SSI) graduates candidates for the ever-growing industry of Smart Systems, ubiquitous in all sectors of society including healthcare, transport, environment protection, energy and security. SSI is given jointly by three universities in three European countries: Heriot-Watt University (HWU) (Edinburgh, Scotland), University College of Southeast Norway (HSN), and Budapest University of Technology and Economics (BME) (Hungary), utilizing the complementary expertise and laboratory facilities of the three partners to create a unique programme with a more holistic approach than a single university could give. The programme is run in close collaboration with industry, to assure its relevance. SSI has Erasmus Mundus status, and the graduates receive a Joint Degree.

SSI students benefit from the extended competence the consortium can provide, as well as from the extended socio-cultural knowledge obtained by living in three different European countries that represent distinctively different aspects of the diverse Europe. The students in the programme show excellent performance, and the employability of graduates has proven to be very high. The partner universities benefit from the high performance of the students, and from the intimate interaction with the partners allowing exchange of best practice in education, teaching and evaluation.

Keywords—Joint master; Joint Degree; Erasmus Mundus; Smart Systems; Microtechnology

I. INTRODUCTION

The Joint International Master in Smart Systems Integration (SSI) is an MSc degree covering tomorrow’s technologies in Smart Systems such as intelligent biomedical devices, cyberphysical systems, Internet of Things, sensors and actuators, with a special focus on how such systems are designed and manufactured through integration of microsystems with microelectronics. All aspects of how Smart Systems interact with their environment (mechanical, electrical, optical, biological, chemical, acoustical) are included. The subject is truly cross-disciplinary within engineering, and a single university would typically only be able to cover parts of the relevant topics for such a degree. SSI is given jointly by three institutions: Heriot-Watt University (HWU) (Edinburgh, Scotland), University College of Southeast Norway (HSN), and Budapest University of Technology and Economics (BME) (Hungary), each providing one full taught semester. The SSI programme uses the complementary expertise and laboratory facilities of the three institutions to provide a unique programme that truly offers a system-level approach to Smart Systems Integration. Each institution contributes with its special expertise, giving the graduates from SSI a much better basis for their professional career than any of the institutions could provide individually. SSI has obtained Erasmus Mundus [1] status in the European system, and provides the graduates with a Joint Degree Certificate [2] issued jointly by the three institutions. The first students were admitted autumn 2013, and graduated summer 2015. Three cohorts of students have graduated so far. A revised programme with up-to-date syllabus will be launched autumn 2018.

The programme addresses the pressing industrial needs for qualified graduates in the field. Smart systems, integrated from microsystems and microelectronics, combine data processing with multi-modal sensing, actuation and communication. Examples are self-driving cars, artificial organs, Internet of Things (IoT) and wellness armbands, ubiquitous in all sectors of society including healthcare, transport, environment protection, energy and security. Current research in SSI is global and dynamic, responding to these urgent needs. There are however far not enough young graduates to sustain this exponential industrial growth [3-5]. The Joint International Master in SSI aims at filling this gap. The study programme covers all aspects of the SSI process, in particular both design and fabrication issues are central parts of the study programme.

II. ACADEMIC CONTENT

A. Structure of SSI

The structure of the master degree follows a defined mobility scheme, where the whole class moves together in the first three semesters. The first semester takes place at HWU, which is also
the Co-ordinating Institution. The second semester is at HSN while the third semester is at BME. The master project (thesis) is carried out in the fourth semester, where the students select their project at one of the three institutions, and the students are split in three groups each with a similar number of students. The master thesis may also be carried out at an external partner (either industrial or academic organization), but always associated with one of the three partner institutions. This ensures involvement from the consortium in external projects, as well as being an excellent way to enhance or initiate collaboration between the University and the external partner (industrial or academic). The internal master projects are always part of ongoing research projects, hence exposing the students to cutting-edge research.

B. Course Programme

The MSc programme is developed jointly, with courses given at each institution set together in order to optimize the learning outcomes, and to best utilize the complementary expertise and laboratory facilities of the three institutions.

The mobility scheme is chosen to allow each institution to contribute its special expertise in the most appropriate timeframe for the study progress: In the first semester at HWU, all the fundamental aspects of design, manufacturing, packaging and applications of smart systems and IoT are taught, together with hands-on laboratory training in prototype-based manufacturing. The physical system integration is taught in this semester, building on the HWU special expertise in packaging and integration. HSN teaches smart systems specialization in the second semester. Starting from the 2018 cohort, the students may choose their specialization into Smart Biomedical Systems or Cyberphysical Systems. This implies choosing courses either in Micro- and Nano-Biological Systems or in Microsystem Design, both being subjects where HSN has a long history in research and teaching. For both tracks, the mass-production platform of silicon processing for microsystems is taught, together with laboratory work where the students manufacture a microsystem. This complements the prototype-based manufacturing taught in the first semester. BME teaches design for system integration in the third semester, covering microelectronics and its integration with microsystems, sensors and actuators. The main focus is on their world renowned speciality in design and integration to create complete smart systems with integrated sensing, actuating and signal processing functionalities. The specialization selected by students is deepened through project work in the third semester, either in Smart Biomedical Devices Project or in Intelligent Sensor Devices Project.

Figure 1 presents the SSI Education Model, demonstrating the integrated learning approach across the study programme and across the three partner institutions.

C. Transferrable skills

Apart from the sheer academic syllabus, the development of transferrable skills are encouraged during the study programme: Such as the ability to work in a team, the ability to work independent in a research-oriented setting, communication and presentation skills and innovative thinking. Also courses in local language and the culture of the three host countries are included in the curricula, to better prepare the graduates for working in an international environment. The three partners represent three different European countries (Scotland, Norway and Hungary), strongly representing the cultural, historical, socio-economic and linguistic diversity of Europe. The students in the programme spend at least one semester in each of the partner countries, and are thus intimately exposed to this diversity.

The ability to work in a team is highly valued in all the three partner countries, and the students are trained in teamwork throughout the study programme, with particular emphasis during the group projects carried out in the third semester. There is some diversity as to what kind of transferable skills are most valued in the culture of the three partner countries, and hence the students are exposed to a broader range of these than a student in a single country would get. Examples of such are leadership ability, ability of independent work, and quality thinking; transferrable skills somewhat higher valued in Scotland, Norway and Hungary, respectively.

In semester 1, a course in Advanced Writing Skills, Research Preparation and Entrepreneurship prepares students for research methodology, scientific writing and how to start up a Company. The topics in Entrepreneurship will cover the fundamental aspects in business startup: Intellectual Property, Writing up of a Business Plan, the eco-system of investments from Angel Investors and VC, understanding Technology Readiness levels, How to create a start-up company. These topics will be led by Prof. Marc Desmulliez, who is winner of the £45K Converge Challenge award, the most prestigious prize in Entrepreneurship in Scotland [6].

In semester 2, students write laboratory reports in the format of scientific publications, as a further training in scientific communication. Thus, they apply the knowledge gained in Advanced Writing Skills from the first semester. They are further trained in scientific writing in their project reports in the third semester, getting a firm basis for writing skills to be applied when writing their master thesis in the fourth semester. In addition to their written master thesis, the students shall also present the master project orally, or in poster format, thus expanding their presentation skills.

The teaching language for the programme is English (all three taught semesters). Students are strongly encouraged to improve their English language and writing skills, particularly while studying the 1st semester course “Advanced Writing Skills, Research Preparation and Entrepreneurship”. This will not only aid non-native English-speaking students to improve their English skills, but for all students to improve their scientific writing to be used in assignments and in their dissertation report. As the 1st semester will take place in Scotland, the students also get informal English training in their daily life.
For the 2nd and 3rd semesters, taking place in Norway and Hungary, the programme contains mandatory courses in national language and culture, introducing the students to Norwegian and Hungarian language while studying in the respective countries. These courses also have a culture and society component, and the 1st semester has a specific course in "Introduction to Scottish Society". This helps the students to better understand the country they are staying in, and how each country contributes to shaping the diverse Europe, since the three countries indeed represent different parts of the complex history of Europe. In Scotland, emphasis is put on the history: how the relation between traditional Scottish Culture and the British society and politics impacts today's society. In Norway, the students are introduced to the socio-economic "Nordic Model", crucial in explaining the high living standard and societal participation in the Nordic countries. In Hungary the students learn about the specialities of the Central European countries, and how the large variations in political systems over the centuries impact societies. In total, these courses allow the students to better understand the socio-economic differences between these three distinctively different countries of Europe.

Furthermore, the students are exposed to the local culture of the three host countries as part of the study programme: In Scotland, the students attend a ceilidh (traditional dancing session), and visit Edinburgh castle as well as Glasgow. In Norway an on-campus skiing session is arranged, as well as a sailing trip for the SSI students on the Oslo Fjord. In Hungary, the students are introduced to traditional dance and music, as well as Hungarian cuisine and visits to the Buda Castle and the exceptionally multicultural capital, Budapest.

D. Education methodologies

The students in the programme spend at least one semester at each of the three partner universities, meaning they will experience the different teaching methods and university structures of the different partners. This contributes to a more independent learning approach, where the students learn to use a wider range of learning methods than a student in a single-university degree would do.

The teaching methods for the Joint International Master are a combination of traditional and innovative teaching and learning methods:

- Lectures, for the fundamental understanding, basic concepts, and relation to current research,
- Laboratory exercises, for gaining practical experience and hands-on knowledge of processes and characterization techniques, as well as training in reporting the student’s individual work,
- Projects, for enhancing the student’s capability to work independently and as part of a project group,
- Tutorials, for deepening the understanding from the lectures and training the students in problem-solving,
- Visits to industrial companies, tying the connection between the academic topics and the industrial needs,
- Master thesis, and Individual Design Project, training the student in research and in project organization,
- Traditional lecture delivery combined with self-study periods.
Innovation in teaching and learning includes:

- Peer-to-peer correction of assignments (students correcting their colleagues’ answers)
- Guest lectures and seminars given by researchers, visiting scholars and from industry, ensuring that the students get up-to-date training with respect to cutting-edge research and industry,
- Group-based projects whereby students allocate themselves the various tasks to implement a project (GANTT chart, minutes taking, division of technical labour, marketing) and jointly contribute to the final report. Each of the students will present weekly the contribution of the team, enhancing thereby their communication and presentation skills,
- Research-inspired reporting mechanism: Lab reports written in the form of IEEE journal articles, master project summaries to be written as scientific articles, and a literature review article to be written as part of the first semester course “Advanced Writing Skills, Research preparation and Entrepreneurship”,
- Projects carried out in team work are reported using the reporting approach of H2020 research projects, evaluation meetings are held in the mentality of R&D projects
- Summer School as a part of the study curriculum: workshops and topic proposals from invited innovative SMEs, lectures from industrial and academic experts and an open discussion with the Alumni students about project opportunities
- E-learning materials and open access materials, online exams and tests [7]
- HSNExpo: Exposition of student projects to a general audience: For SSI students in second semester and for those doing their master project at HSN.

III. INDUSTRIAL RELEVANCE

The MSc programme is carried out in close collaboration with industry: Relevant industry clusters at European level (European Platform of Smart Systems, EPoSS) as well as on Norwegian level (Norwegian Centre of Expertise- Micro and Nanotechnologies, NCE-MNT) are Associated Partners of the MSc programme, providing master projects, guest lecturers, company visits and internship possibilities. EPoSS includes major multinational European companies (Bosch, ST Microelectronics, Infineon, EADS) that manufacture or use integrated microsystems. NCE-MNT includes most of the major Norwegian industrial companies involved in microsystems and microelectronics. Most are located in the Vestfold region close to the SSI partner HSN. The Department of Microsystems at HSN is indeed a central actor in the NCE-MNT.

Prior to launching the SSI in 2012 a thorough industry survey was performed by EPoSS. One of the co-authors, Prof. Marc Desmulliez, was also involved in the preparation of the EPoSS SRA (Strategic Research Agenda) [8] and the later enhanced version of the SRA [9]. This document demonstrated clearly the need for a programme such as SSI, and details have been used as inputs for the design of the programme structure and for the courses selected for the programme. A similar and more recent survey was performed in collaboration with EPoSS in November-December 2016, with replies from 26 industrial companies in Germany, UK, Hungary, Norway, Sweden, France, Netherlands and Spain. Again, the survey demonstrates a clear need for the SSI programme, and details were used as input to the revision of the course programme. When asked to grade the importance of topics and sub-disciplines of Smart Systems Integration, the highest scores are for “Sensors and Actuators”, “System integration” and “Measuring microsystems”. Each of these topics corresponds to specific courses given as part of the programme (“Sensors, Actuators & IoT” being taught the first semester by HWU, “System Level Design” being taught in the third semester by BME, and “Measurements & Characterization” being taught in the second semester by HSN), as well as being components in other courses. “System Integration” is indeed at the core of the programme, and most of the courses contribute to System Integration understanding. High score is also given for “Assembly and Packaging” (which corresponds to a first semester course), “modelling microsystems” and “Internet of Things (IoT) technology”. The two latter topics are now brought stronger into the revised study programme: A new elective course in “Microsystem Design” (where modelling is an important aspect) will be given in the second semester. IoT technology will be taught in the subject “Sensors, Actuators & IoT” (first semester) as well as in “System Level Design” (third semester). The lowest average priority in the industry survey is given to “Micro/ Nano biological systems”, however for a certain number of companies this is the top priority. This may not be a surprise, since the topic obviously is important for the biomedical industry, but may appear too specialized for other sectors. The consortium interprets this result as “Micro/ Nano biological systems” being an important subject, but that it need not be taught for all the students. This is implemented in the revised study programme: Whereas “Micro/ Nano Biological Systems” is currently a compulsory course (given by HSN in the second semester), it will be an elective in the revised study programme, where the alternative elective is “Microsystem Design”. The two courses are regarded as complementary, and initiates the specialization in the two study tracks “Smart Biomedical Systems” or “Cyberphysical Systems” with different third semester subjects (“Smart Biomedical Devices” or “Intelligent Sensor Devices Project”), and correspondingly different set of topics for the master thesis.

IV. STUDENTS/GRADUATES

The students admitted to the programme has been a truly international class. Typically more than ten nationalities has been represented in each class, covering a wide specter of world cultures. This, together with the fact that the class moves together the first three semesters, natures a strong class feeling and allows an excellent learning environment. The students themselves call themselves “the SSI family”. The number of applications for admittance has been very high every year, allowing the Consortium to select students of excellent quality. SSI students perform significantly better than the regular master students at the respective institutions, which we interpret as a
consequence of the fierce competition to be admitted, together with the excellent learning environment provided by the strong personal relations between students.

The employability of the graduates has been very high, demonstrating the societal need for those graduates. A survey was performed in January 2017, covering two graduated cohorts. This showed an employment rate of 94%, with SSI graduates employed in 12 different countries (mostly in Europe, but also in Asia and North America). Positions include hardware and IC design engineers, senior product engineers and researchers. Both small, innovative start-up companies as well as large multinational companies have employed SSI graduates. 40% of the students found positions in one of the consortium countries (Scotland, Norway or Hungary). 88% of the students declared that the prestige of the SSI degree doubtlessly helped them in getting their actual position. A large proportion (55 %) of students pursues Ph.D. studies in the field of Smart Systems, showing the academic excellence of the graduates. We expect that these students, when obtaining their Ph.D. degrees, will achieve leading positions in the Smart Systems industry worldwide.

V. CO-ORDINATION OF JOINT DEGREE

To establish a Joint Degree, a high level of interaction between the three institutions has been necessary. A joint Consortium Agreement is established, and a joint Academic Board that oversees all aspects of the execution of the Joint Master. The selection of students to be admitted is done in face-to-face meetings, and similarly the Exam Board is taking place with academic members from all three institutions in place.

A yearly Summer School is organized in Hungary, right before the start of Semester 3. This is mandatory for the students transferring from Semester 2 to Semester 3, and academic and administrative staff from all three partner universities will be present. Besides academic presentations, this is also an occasion for Consortium Meetings, Academic Board Meetings and Exam Board, important for all co-ordination efforts for the Joint Master. No less important is the Summer School as an informal meeting-place between the academic and administrative staff of the three partner universities, which has allowed the development of a mutual understanding and trust within the consortium. The importance of such relations cannot be underestimated when explaining the success of the Joint Master. At the Summer School, also newly graduated students are asked to come to present their master projects, and also some graduates from previous cohorts are present.

VI. GRADING SYSTEMS

Special emphasis has been put into comparing evaluations from the three national grading systems. This is important, since the graduates will receive a Joint Degree Certificate. At HWU, the students get marks in percentages, which are transferred to ECTS grades through an official conversion. At HSN, grades are given as ECTS grades only, as implemented in the Norwegian national system. At BME, the Hungarian grading system 1-5 is used, where the grades 5-2 are transferred to ECTS grades A-D, and the grade 1 to ECTS F.

The graduates receive transcripts from each institution for the semester they studied there. Since the study follows a predefined mobility scheme, this ensures equal judgement of all students in the cohort, independent of varying national implementation of the ECTS scale. The overall distribution of the grades for each course is detailed in the Joint Diploma Supplement.

When graduating, the graduates may obtain an “MSc” or an “MSc with distinction”. The consortium agreed to use the different local systems as basis for the Joint Distinction criterion. Hence, there is a need to compare these systems, in particular how students are evaluated across the institutions. At HWU, several requirements must be fulfilled to obtain a “distinction”, the most important being that the weighted (with respect to the number of ECTS credits) average mark throughout the MSc is $\geq 70\%$. Similarly, at BME the corresponding requirement is that the weighted average grade is $\geq 4.5$. At HSN, and in Norway in general, there is no procedure in place for awarding Distinction. However, there is an established requirement for an MSc to be eligible for admittance to a PhD programme: That the weighted average shall be B or better (averaging performed numerically by converting A-F to the numbers 5-0). Since the PhD admission requirement overlaps with the intention to award a Distinction, this was selected as the Norwegian equivalent to a Distinction award. When the decisions of award of Distinctions are taken at the joint Exam Board, these three national systems are used as basis for the decisions.

Data from the graduated cohorts show a very high correlation in the performance and evaluation across the three institutions. For the three cohorts graduated this far (46 graduates), the number of students passing the local Distinction criteria in the individual semesters has been monitored. Whereas the Distinction is awarded based on the overall performance throughout 120 ECTS credits, such a breakdown per semester gives a good indication on the performance and the evaluation across the institutions.

The table below shows the number of students passing the local distinction criteria, for each semester.

<table>
<thead>
<tr>
<th>TABLE 1. NUMBER OF STUDENTS PASSING DISTINCTION CRITERIA (ALL STUDENTS IN 3 COHORTS)</th>
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</thead>
<tbody>
<tr>
<td>Sem 1</td>
</tr>
<tr>
<td>HWU</td>
</tr>
<tr>
<td>Distinction</td>
</tr>
<tr>
<td>Not distinction</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

The correlation between semesters 1 and 2 is remarkable, taking into account the different traditions and different grading scales in Norway and Scotland. The number of students passing the distinction criterion for semesters 3 and 4 is significantly higher. It is not surprising that this number is highest for the last semester (the master thesis), since students tend to put more effort and dedication into their own project. Semester 3 also has a significant component of individual projects, partly explaining the higher number of students passing the distinction criterion in
semester 3 compared with the two first semesters. Also, better performance in the last part of the study may be expected, since students are then more mature. They have also gained experience in the extended mobility this particular study requires, which may take some focus in the earlier stages of the study. The higher number in semester 3 may therefore have various explanations, and cannot be explained directly by a possible difference in evaluation between the institutions.

The close correlation in numbers of students passing the distinction criteria the various semesters does not in itself reveal the progress of individual students. A more detailed investigation looking into the grades of individual students shows that 17 students pass the distinction criterion in all 4 semesters, and 5 students pass the distinction criterion in 3 of the 4 semesters. This demonstrates that the performance, and evaluation, of individual students is consistent throughout the study and across the three partner institutions. Furthermore, those passing the criterion in 2 or 3 semesters are typically only marginally below the limit in the remaining semester(s). The overall result is that 24 students were awarded distinction. This corresponds to 52% of the graduated students, a result substantially higher than for other programmes at the partner institutions.

VII. CONCLUSION: SYNERGY OBTAINED

The Joint International Master in Smart Systems Integration combines complementary expertise and laboratory facilities from the three partner universities to create a unique master degree with a holistic, system-level approach to Smart Systems. As a result, the graduates obtain a wider knowledge than any of the individual universities would be able to provide. The success of the programme is evident from the large number of applicants, the excellent academic results the students obtain, and the high employability of graduates.

Since the Joint Master requires the students to spend at least one semester in Scotland, Norway and Hungary, the graduates obtain a cross-cultural experience giving a far better insight in the variety of European societies than a single-university degree would give. This is extremely important for the graduates to work in an international working environment. Furthermore, the students’ exposure to three different university systems and learning environments will benefit them in their careers, to easier access new knowledge and easier adapt to changes in their working environment.

For the three partner universities, the benefit of the Joint Master has most of all been the possibility to graduate excellent candidates. Furthermore, the intimate relations between the institutions has given detailed knowledge of each other’s university systems, teaching approaches and evaluation methods. In this way it is possible to bring back “best practice” to the home institution, for improving each partner’s education system.

REFERENCES