A Masters Degree in Embedded & Cyber-physical Systems

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ABSTRACT
A group of faculty in The Henry Samueli School of Engineering (HSSoE) and the Donald Bren School of Information & Computer Science (DBSICS) are proposing an Interdisciplinary Masters degree of Embedded & Cyber-Physical Systems (MECPS). In this paper, we are presenting our systematic way of creating a new MS degree through conducting a survey among applicants and current MS students in both the EECS and CS departments. Moreover, a market study by the University Extension was conducted to see the CPS-related job market in USA for the program's graduates.

1. MOTIVATION

In a key report commissioned by NIST[4], it was stated that *"... a key visionary element of the future of education for CPS is the availability of recognized educational programs that offer the fundamentals of CPS though a multi-disciplinary curriculum.*" The report goes on to recommend several transformative ideas, one of which is to *".. reward Masters' programs in CPS".* The report also points to a major barrier which is the *"...Lack of a CPS degree that cuts across multiple disciplines, hindered by stove piped nature of university structure."* This degree will be a first in the US to focus on both Embedded and Cyber-Physical Systems (ECPS). Being managed by a center that falls at the intersection of Engineering and Computer Science disciplines is likely to overcome the hindrances observed by the NIST report. Graduates are expected to have an integrative knowledge of systems fundamentals that include software, hardware, sensing, and actuation control and hands-on knowledge through practical projects in a targeted application domain.

The proposed program will complement our undergraduate degree offerings quite well. Graduates of undergraduate programs in EE, CpE, CS, and CSE are ideally suited to apply and enter the MECPS program. In recent years, we find that as these undergrads work on senior design projects they get familiar with Embedded and Cyber-Physical Systems and gain an appreciation for the domain. Indeed, many of these students state that hands-on knowledge of systems is a highlight of their educational experience at UCI, and want to see more of it in the future. The proposed MECPS program directly addresses that point through the project students are required to do to fulfill their MECPS graduation requirement.

As systems grow in scale, complexity, and integration levels, there is a need to move towards a science of embedded systems, addressing the foundational aspects of design. Now that we have a better understanding of the basics of embedded systems, it is equally important to branch out to the application of such systems. This requires addressing domain-specific issues and the scale-up in complexity introduced by what is referred to today as Cyber-Physical Systems. Generally speaking, Cyber Physical Systems (CPS) are systems-of-systems that tightly couple their cyber (i.e. computation, communication and control), and physical components (sensing and actuation) in the context of applications such as (but not limited to): automotive and transportation, manufacturing, power distribution grid, medical and healthcare, robotics, civil infrastructure, avionics, etc.. Thus, these Cyber Physical Systems marry knowledge from the fields of embedded systems, networking, sensors, real-time systems and control as well as domain-specific knowledge to realize systems that are of untapped complexity and scale. At the national level, CPS has been promoted in major funding initiatives as presented in several reports from funding agencies (e.g., [4,5,6,7], and on a global scale, the European Union has allocated over $7 Billion to fund research in the area of embedded

and cyber-physical systems as part of their Vision

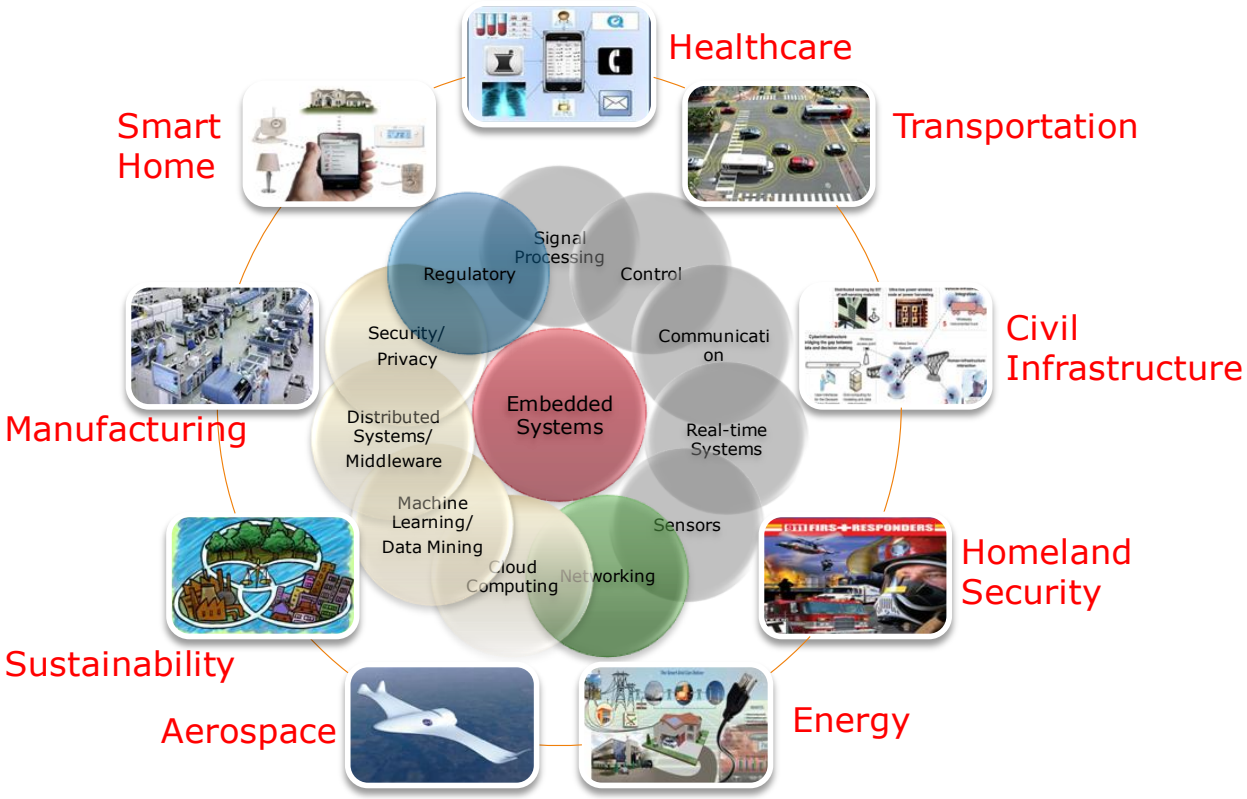

Figure 1. The Interdisciplinary nature of ECPS

2020 initiative. Japan has also launched similar initiatives. Essentially, the following domains have been identified as major thrust areas in CPS (although other areas are constantly being added to the list).

1. **Advanced Manufacturing:** smart production equipment, processes, automation, control, and networks; new product design.
2. **Transportation/Automotive:** intelligent vehicles and traffic control, intelligent structures and pavements.
3. **Smart Infrastructure:** smart utility grids and smart buildings/ structures, civil infrastructure, smart homes.
4. **Health Care:** body area networks and assistive systems, elderly home care and monitoring, networked implantable devices.
5. **Emergency Response and Cyber-Enhanced Security:** detection and surveillance systems, situational awareness, communication networks, and emergency response equipment.
6. **Sustainable development:** Water, pollution, waste, etc..

The CECS-managed Interdisciplinary self-supporting Masters Degree in Embedded & Cyber-Physical Systems (MECPS) consists of a pre-sequenced pace of 7 foundational courses plus two project courses leading to a final project. Courses will carry 4 units of instruction and will be developed specifically for this program and delivered in a blended format. The courses comprising the degree will be a mix of on-ground and online components. To begin the program, all the courses will require a residential component. In the future, we will consider the possibility of having some courses in a blended or online format if deemed pedagogically sound. The blending format will vary from course to course depending on the amount of foundational versus hands-on components in each course. Ideally, much of the foundational knowledge will be delivered online while hands-on sessions will be face-to-face. Depending on the class size, some of the face-to-face sessions may be held using group interaction systems such as Google hangout.

Students can apply to the program from anywhere and can be either domestic or international. The program is recommended for early to mid career professionals or new graduates wishing to expand their expertise into systems. Based on current trends worldwide, we anticipate having about 30 students at the start, then ramping up to over 50 eventually

2. Student demand for the program

Our target pool of applicants is from EECS and CS departments. The number of applicants to the graduate programs in the Electrical Engineering & Computer Science department in the Henry Samueli School of Engineering has more than doubled in the past 4 years. About 2/3 are MS applicants. Only 5% of these applicants are admitted to the MS program. A quick search showed that about ¼ of the Fall 2014 applicants indicated ECPS as one of their interests *even without having an ECPS program in place*! Thus it is clear that there is significant demand for the program and there exists an excellent pool of applicants to which this program can be marketed. We will specifically seek out those applicants who have some industry exposure (whether as working professionals or interns, or having done practical work in their undergraduate years). Additionally, the degree will be marketed to local industry through our affiliates and contacts.

The applicants and current MS students in both EECS and CS at UCI were surveyed to indicate how attractive such a program would be to them. 34.1% responded as "very attractive", another 52.0% responded as "somewhat attractive". To frame this in the proper context, the EECS and CS applicants and students' interests cover an extremely wide scope, from computer algorithms to solid-state devices. The fact that over 1/3 of them rated such a program as very attractive is quite indicative of the expected popularity such a program would have once implemented.

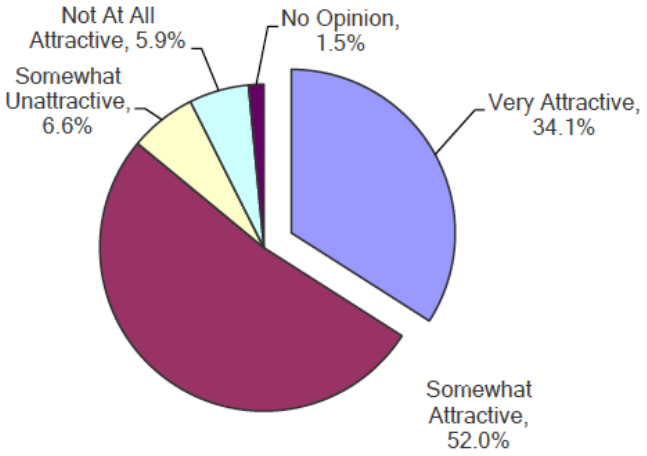

Figure 2. Survey Question 1: Based on the program description above, in your opinion, how attractive would the described Master's degree program in ECPS be to a prospective student

2.1 To online or not to online:

When prompted to provide feedback about the desired proportion of on-campus classroom instruction versus online instruction, most respondents favored a majority of face-to-face instruction. This lead us to proposed blended format courses which are heavily technology enhanced, but not eliminating classroom interaction.

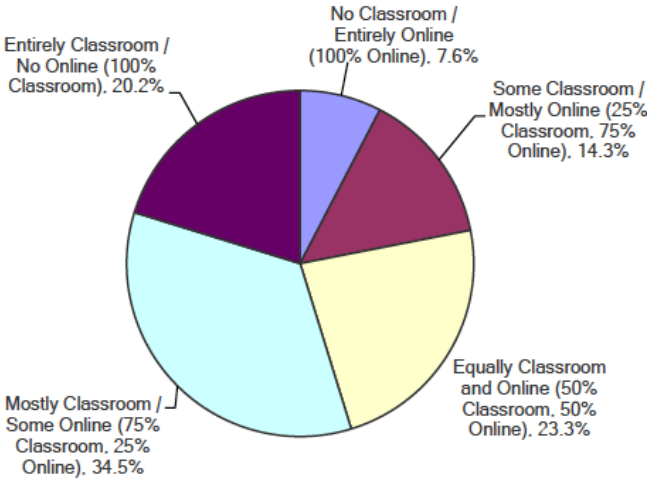

Figure 3. Survey Question 5: If the Master's degree in ECPS were offered with an online instructional component, how much of the program would you expect to be conducted in a traditional campus/classroom format on campus, and how much would be offered in an online format? Please select the response that most closely represents your opinion

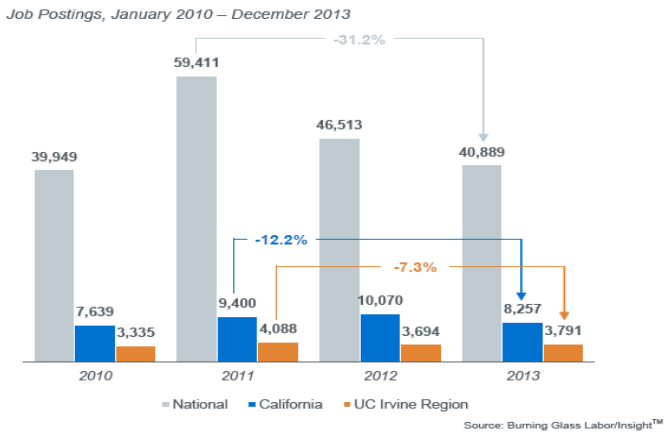

Figure 4. Historic trends in demand for CPS and related skills

3. Opportunities for placement of graduates.

We expect students to have an integrative knowledge of systems fundamentals that include software, hardware, sensing, and actuation control. Students will also acquire hands-on knowledge through practical projects in a targeted application domain. Owing to its interdisciplinary nature, program graduates will be able to seek employment in electronics, aerospace, automotive, biomedical, manufacturing, robotics, defense, and construction industries.

The placement market for the program's graduates is quite attractive. A market study was conducted by the University Extension. The graph in Figure 5 shows historic trends in demand for CPS and related skills. These skill include: systems engineering, embedded systems, robotics, mechatronics, control system design, or data communications. While a decline is observed nationwide in job demands, it is still a very healthy field with over 40000 job postings nationwide in 2013. More importantly, the job market in the local markets (California and UCI region) shows an even healthier trend with jobs in the UCI region increasing between 2012 and 2013 to around 4000 postings. Figures 6-9 highlight the skills, companies regions and industries that are likely to hire MECPS graduates. The marketing report further expects that 50-75% of the enrollees to be international students. This resonates with the applicant pools in EECS and CS where the vast majority of students are from India and China. With the economies of these two leading BRIC [8] countries growing at phenomenal rates, many of the program's graduates may be candidates for the global job market, where even more significant growth is expected.

Salary information further accentuates the attractiveness of the proposed degree. The same market study concludes that "..students receive higher starting salaries, over $100,000 at jobs that require CPS skills…".

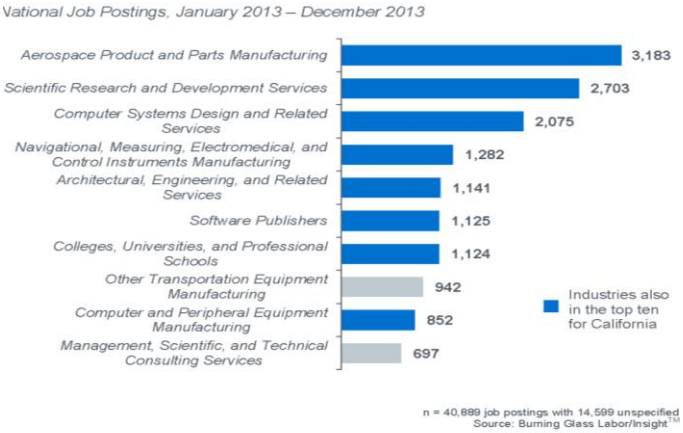

Figure 5. Top industries in the US for CPS and related skills

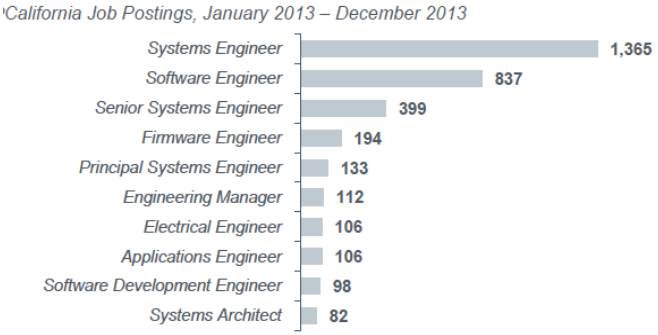

Figure 6. Top titles for jobs that require CPS an related skills

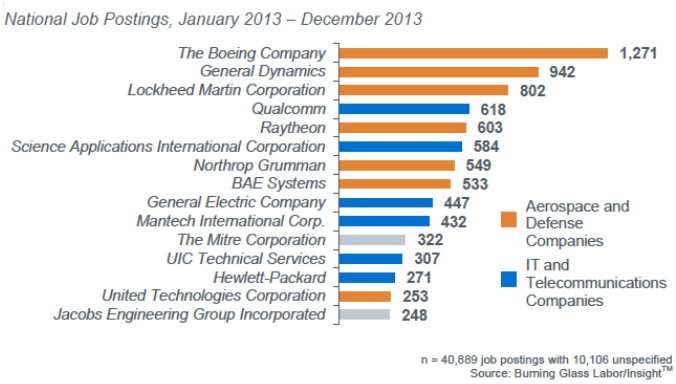

Figure 7. Top employers in the CPS for CPS and related skills.

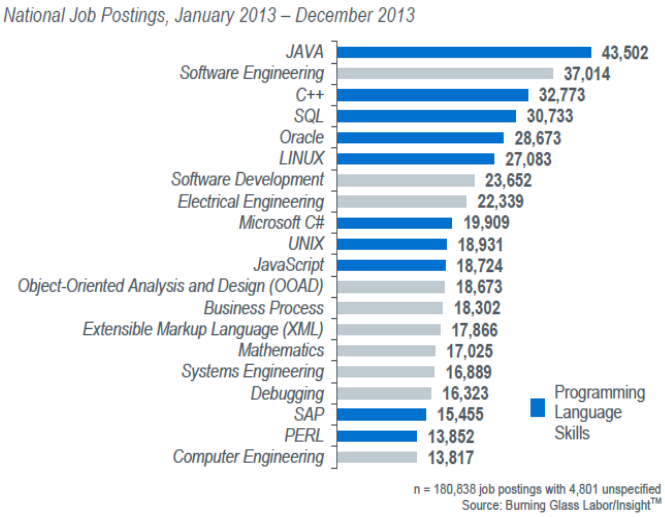

Figure 8. Top specialized skills for potential occupations for CPS program graduates.

3.1 Importance to the discipline.

Embedded systems are not apparent as computing apparatus but control the functioning and features of systems that exist around us in almost every appliance or device that is powered through an outlet or battery. Cyber-physical systems are built around embedded systems and can be found in cars, for example, controlling almost every subsystem: breaks, steering, entertainment and many other. They are also found in set top boxes, airplane automatic pilot, pacemakers, building thermostats, and robotic manufacturing system to mention but a few. Today 90-95% of computing devices are in embedded systems and are expected to grow by 10% per year, reaching 40 billion computing devices in 2020, or 5-10 devices per every living human on the planet! The value of embedded systems is correspondingly increasing as more functions are migrated to these systems. Today, they comprise 20% of car's value but will increase to 35-50% by 2020.

The significance of embedded and cyber-physical systems on the economy is hard to overlook, the worldwide market for embedded systems in 2010 was about $100 billion, and $121 billion in 2011, and increasing at 7% CAGR per year to about $195 billion in 2018.

According to the Bureau of Labor Statistics, Network and Information Technology is projected to account for about 55% of all STEM jobs between 2008-2018, and amounting to over 760,000 jobs. The expected growth rate is twice the rate for all occupations in the US economy.

3.2 Ways in which the program will meet the needs of society.

The importance of ECPS in serving the needs of society cannot be overstated. Figure 1 highlights the pervasiveness and ubiquity of such systems. Today it is hard to imagine a moment in as person's life on this planet where he or she is not interacting with such a system. Dubbed as systems that "you can trust your life to," cyber-physical systems are present in our everyday lives and are slated to become ubiquitous in the foreseeable future. From the smart grid that powers homes, to medical and health care monitoring systems, to electric vehicles and automotive telematics, to civil infrastructure, emergency response systems, and manufacturing, the need for skill sets in ECPS to help design, maintain, improve, use and assess such systems is an indispensible component in society's quest for a safer, more dependable, comfortable and generally happier status. As we increasingly entrust our well-being to automated systems, the need for integrative skills in ECPS will become more acute.

4. THE PROGRAM OF STUDY

The CECS-managed Interdisciplinary Masters Degree in Embedded & Cyber-Physical Systems (MECPS) consists of a pre-sequenced pace of 7 foundational courses plus two project courses leading to a final project. As a prerequisite, students are expected to have completed a BS in EE, CS, CpE or CSE as shown in Figure 11. Courses will carry 4 units of instruction and will be developed specifically for this program and delivered in a blended format. The courses comprising the degree will be a mix of on-ground and online components. To begin the program, all the courses will require a residential component. In the future, we will consider the possibility of having some courses in a blended or online format if deemed pedagogically sound. The blending format will vary from course to course depending on the amount of foundational versus hands-on components in each course. Ideally, much of the foundational knowledge will be

delivered online while hands-on sessions will be face-to-face. Depending on the class size, some of the face-to-face sessions may be held using group interaction systems such as Google hangout.

Figure 10 shows a one year plan of study. A two year plan will be phased in one year later while the program builds up its infrastructure. The two year plan is a part-time program for industry professionals.

5. CONCLUSION

A masters degree in Embedded and Cyber-physical systems is proposed to address the industry demands. The MECPS program proposed here is developed, in part, to serve the needs of domestic and international students, and working professionals among whom the leaders of the Embedded & Cyber Physical Systems are especially likely to come. In future, lessons learned from the operation of this degree program will be shared with the ECPS community so that other universities worldwide may benefit from our experience.

6. REFERENCES

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[6] http://cps-vo.org/

[7] http://sites.nationalacademies.org/CSTB/CurrentProjects/CSTB_084351

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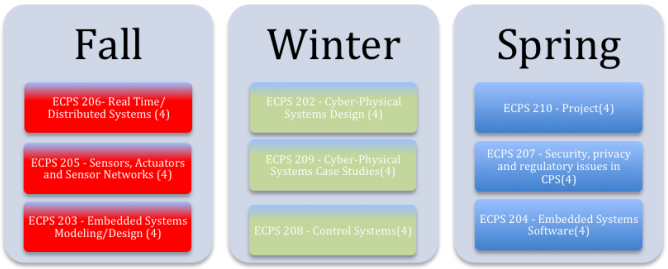

Figure 9. Sample program of study

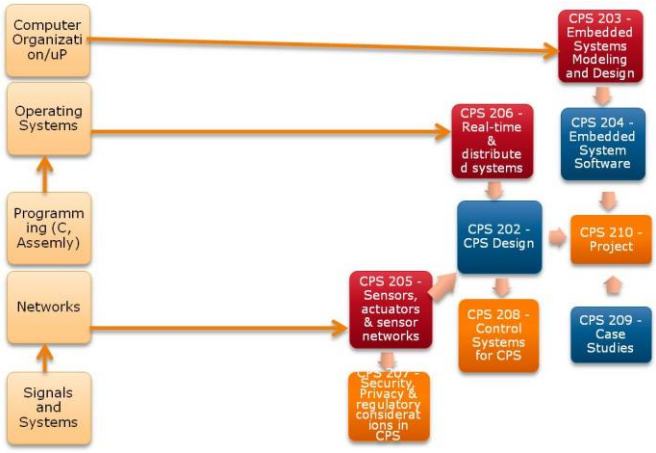

Figure 10. MECPS courses and prerequisites

Figure 11. Program timeline and milestones.