Educating Internet of Things Professionals: The Ambient Intelligence Course

# BREEDING INTERNET OF THINGS PROFESSIONALS THROUGH EDUCATION: THE AMBIENT INTELLIGENCE COURSE

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The Internet of Things (IoT) is nowadays a well-established paradigm for a network of all kind of tangible and concrete things interconnected by exploiting the existing Internet infrastructure, over a variety of protocols, domains and applications. Beginning over 10 years ago in the context of pervasive and ubiquitous computing research, IoT currently counts more than 13 billion Internet-connected devices ranging from mobile phones to plant watering tools. According to Cisco's Internet Business Solutions Group [1], IoT will steadily grow up to over 50 billion of devices by 2020. These devices will be used in application domains that promise to change many aspects of everyday life, and the study of the whole integration, and interaction, of IoT systems with end users is tackled by the Ambient Intelligence (AmI) research field, that sets the focus on transparently and intelligently supporting people.

IoT challenges and technology break-through are attracting increasing efforts from the research community and higher attention from the business world, with big players seeking new market opportunities. This hype will increase the pressure on higher education and training programs, to breed an entire, new, generation of IT professionals and engineers. Some signals can already be perceived in some courses, like the Ambient Intelligence [2] course of the Technische Universität Darmstadt, Germany, the Mobile Computing and Internet of Things [3] course of the Karlsruher Institute für Technologie (KIT), Germany, or the Ubiquitous Computing [4] course of the University of New Hampshire, USA.

## WHAT IS AMI?

Ambient Intelligence (AmI) is defined as *"a digital environment that proactively, but sensibly, supports people in their daily lives."* [10]. As a research field, it lies at the intersection of Artificial Intelligence, Human-Computer Interaction, Ubiquitous Computing, and Sensor Networks.

Four main cyclical steps compose an Ambient Intelligence system, typically: *sensing* from the environment, from the users, from the Cloud; *reasoning* about sensed data; *acting* upon the environment, towards the users; and *interacting* with the users, to always keep them in the loop. An AmI system must be: sensitive, responsive, adaptive, transparent, ubiquitous, and intelligent (see [10]).

The educational framework and the skills that future IoT engineers need to acquire are much wider than before. The complexity and heterogeneity of IoT call for new educational approaches breaking the silos between scientific and humanistic courses and experiences. Future IT professionals will need to learn new ways to work in multidisciplinary teams and to communicate effectively with persons that are not IT experts. The reasons are evident: (a) IoT impacts people's life, in almost all aspects from the private sphere to public relations and occupation; (b) Designing for users requires understanding user needs, in different domains, a skill to which young engineers are typically under-exposed; (c) IoT systems involve several aspects, often strictly intertwined and spanning over ambient intelligence, mechanics, industrial design, physics, etc.

Educational challenges brought by these new opportunities are not limited to redefining curricula; also the means to transfer knowledge from educators to students need to evolve. Knowledge can no longer be confined to isolated disciplines and learners must be accompanied in the process of understanding the multidisciplinary nature of AmI systems. Current teaching programs must be complemented with new advanced courses that, building upon skills acquired in each technical field, tackle realistic design problems with a multifaceted approach.

With this goal in mind, Politecnico di Torino[1], one of the leading technical universities in Italy, in 2014 started to offer a new course, "*Ambient Intelligence: technology and design*". The course applies a new, team-based and design-driven paradigm to teaching the design and prototyping of AmI systems, with the aim of preparing students to the upcoming IoT scenarios. Proposed by the Department of Control and Computer Engineering, it is an elective course held in English and available to all Engineering students enrolled at the third (and last) year of the bachelor degrees at the Politecnico. To our knowledge, it is the first and only course in Italy, at the university level, about Ambient Intelligence applied to IoT.

This paper summarizes almost two years of teaching experience in this new course, by applying the mentioned integrated design approach. The adopted teaching methodology, the lessons learned and the feedback received from both students and the industry are discussed, with respect to the educational goals. By sharing our experience on this course, we aim, on one side, at stimulating and exchanging best practices with other universities and higher-level education institutes. On the other hand, by getting in touch with the worldwide community of IT professionals, we aim at better distilling needs and at reflecting them in improved educational programs.

## AMBIENT INTELLIGENCE: TECHNOLOGIES AND DESIGN

The course tackles IoT system design by applying principles and methodologies stemming from the Ambient Intelligence (AmI) research field, with the aim of guiding learners to effectively design systems "*in which the actions of numerous networked controllers (controlling different aspects of an environment) is orchestrated by self-programming pre-emptive processes (e.g., intelligent software agents) in such a way to create an interactive holistic functionality that enhances occupants experiences.*" [5] The overall educational goal is to outline the multidisciplinary nature of IoT design and to provide a strong set of competencies, both in terms of teamwork and technology awareness, which will enable future engineers to address the upcoming challenges of an increasingly connected world of humans and machines.

### OVERVIEW

The course spans 14 weeks in the second semester (spring to summer) of the third year of the bachelor degrees, with four-and-a-half hours of classes per week divided in three blocks of 90 minutes each. Classes are video recorded, and the lectures are visible by enrolled students. A freely available version of the video lectures is also available as a YouTube playlist[2].

The course is strongly based on active learning [6] [7], with a lessons deployment biased towards practical design activities and supervised work (65%). The distribution of theoretical and experience-based lessons is carefully planned, with a higher density of the former in the first half of the course, where students need to gain knowledge about IoT, and AmI, and to bootstrap teamwork activities. Four types of teaching activities are employed during the course: 1) "traditional", direct, lectures in class (35%); 2) hands-on lessons and exercises in class (30%), in which students are actively involved in defining solutions to proposed problems; 3) guided exercises in laboratory to experiment with topics discussed in class (15%); and 4) supervised work group in laboratory (20%).

Learners are enrolled in different academic programs, mainly Computer Engineering, Electrical Engineering, Mechanical Engineering, and Industrial Design. Internationality is deemed as relevant to fertilize ideas and above-average results, as a consequence, the course is taught in English and hosts a noticeable (around 20-25%) group of

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[1] Politecnico di Torino has, currently, 22 bachelor degree programs: 3 programs in Architecture and Industrial Design, and 19 in Engineering, with more than 2000 students enrolled in the final year (of the bachelor degrees).
[2] See the course website at http://bit.ly/polito-ami for further details (e.g., useful links, materials, and calendar).

students coming from foreign universities (Table 1 and Table 2 report enrollment statistics for the 2014 and 2015 editions).

**TABLE 1. STUDENTS BACKGROUND.**

| Academic Program | 2014 (52 students) | 2015 (70 students) |
|---|---|---|
| **Computer Engineering** | 46% (24) | 55% (38) |
| **Electrical Engineering** | 33% (17) | 29% (20) |
| **Mechanical Engineering** | 11% (6) | 8% (6) |
| **Industrial Design** | 10% (5) | 8% (6) |

**TABLE 2. STUDENTS NATIONALITY.**

| Nationality | 2014 (52 students) | 2015 (70 students) |
|---|---|---|
| **Foreign students** | 21% (11) | 24% (17) |
| **Italian students** | 79% (41) | 76% (53) |

Course topics are quite diverse and aim at providing a wide view on IoT systems. The general structure of direct lectures is almost constant, with adjustments made based on received feedback. After two years of experience, the course setup is quite settled and it includes notions about:

- Internet of Things and Ambient Intelligence (AmI): definitions and available approaches for smart homes, smart buildings, smart cities, etc.
- Overview of application areas (home, building, city, traffic, etc.) and types of applications (monitoring, comfort, anomaly detection, ambient assisted living, control and automation, etc.).
- Requirements and design methodology for AmI, including requirement analysis and software specification formalisms.
- Design, analysis and specification of requirements and functionalities related to user interacting with AmI settings.
- Practical programming of AmI systems: the Python language, the Raspberry Pi computer, Web protocols (HTTP and REST) and languages, Android development, Web-based APIs and collaboration tools (e.g., Git and GitHub), and interaction with various kinds of smart home and IoT devices.

Throughout the entire course, students are exposed to realistic and/or real design problems. Even in pre-assigned lab activities, they are always required to deal with intelligence applied to environments where real devices (both commercial and custom built) and humans need to interact and/or cooperate. Notions about programming technologies are typically provided in form of hands-on tutorials, with students actively involved in defining solutions to proposed problems, and teachers showing how to exploit particular technologies and languages to tackle the issues under examination.

Starting from the early beginning of the course, students form teams of 3 to 4 persons, and they are guided to define the requirements, design and implement an IoT system by applying Ambient Intelligence principles (briefly summarized in the sidebar “What is AmI?”, for readers’ convenience). This IoT system and the “deliverables” produced throughout the teaching period are the objects of the course exam, which also consists of a presentation of the team projects and an oral discussion on the same topic. Each team is responsible to find an idea, at the beginning of the semester, which is suitable for the course and in line with the typical features of AmI systems.  Every year a common theme for projects is proposed to better enable students to focus on ideas in-line with the course educational goals. As an example, the 2015 course edition was about the “Smart University Campus” and students have been required to identify, design and prototype systems bringing AmI features inside the Politecnico di Torino campus. Target environments could be classrooms, libraries, offices, hallways, open spaces, bars, laboratories, etc. The main requirement for developed ideas is to bring tangible benefits to students, teachers, staff and/or visitors.

After approval by the teachers, the teams start developing their ideas according to the proposed design methodology, which follows four main steps: 1) visions and goals definition, 2) functional and non-functional requirements elicitation, 3) system architecture design and component selection, and 4) practical realization of the prototypical system.
Each of these steps correspond to a project milestone, and has to produce a document (deliverable, publicly available on the Internet), or an artifact, and is evaluated for the final exam. The teaching team provides feedback and guidance on these parts throughout the whole course lifespan, with explanations during the lectures and practical exercises in class. Teams are encouraged to develop open and reusable solutions, which involve sensing (e.g., environmental, user, social, cloud), actuation and interaction (e.g., on the environment, user, social, cloud), and intelligence (i.e., should not be simply deterministic or preordained). Projects cannot be mobile-only, software-only, or hardware-only solutions, but must exploit different platforms and mix hardware with software and user interaction. All the projects must implement all the four main steps of an AmI system, as well as include most AmI features (see the sidebar "What is AmI?" for a quick look on the AmI steps and features).

Activities are not limited to "traditional" study and homework, but they also require exercising "soft skills" and communication. In fact, students are forced to be pro-active and teams are required to give presentations in at least one lecture during the course, to publish and keep updated a (public) website that presents their work (and all the deliverables for the exam), to prepare a pitch-like video for sharing the idea underlying their work, etc. Each group is, moreover, required to put and maintain the source code related to its project in an assigned Git repository, kindly hosted by GitHub that provided the course with a fair amount of private repositories. Project repositories are part of a dedicated GitHub organization and must have a corresponding public website created by using the 'GitHub Pages' hosting.

The 52 students enrolled in the 2014 edition of the AmI course formed 13 teams, while in 2015 the 70 students split in 17 groups. All but three groups passed with success the final examination (see Table 1 for an overview on the completed team projects) in 2014, whereas in 2015, 15 out of 17 teams passed the exam.

## INVOLVEMENT WITH INDUSTRIES

The ultimate goal of this course is to form a new generation of IT professionals able to effectively deal with challenges brought by the IoT world, and by increasingly complex and interconnected technologies. As such, the course must, on one hand, be successful in exposing learners to realistic scenarios, involving real devices, and on the other hand, must involve industries in the loop, and possibly adapt based on received feedback. To achieve these goals, a two stages strategy has been applied, based on support and feedback.

### SUPPORT AND SPONSORSHIP

A continuous and quite intense activity to gather sponsorships and donations in terms of IoT devices and materials has been carried, in both 2014 and 2015. Prior to the 2014 edition of the course, we contacted two Italian companies developing IoT devices and/or smart systems, especially in the home domain (selected as common theme for the 2014 edition): BTicino and Telecom Italia, the latter as a representative of the European Energy@home industry association [8]. Both companies agreed to sponsor the course, through a donation of materials, and accepted to hold a seminar about their products and their vision for the future of smart homes. BTicino, in particular, donated a developer toolkit with some of their smart home products, while Telecom Italia provided some ZigBee Home Automation components and gateways. In 2015, BTicino provided another demo kit, in the form of three booth display panels typically used in tradeshows, whereas the innovative enterprises incubator (I3P) of the Politecnico di Torino held a seminar, on how to move the prototypical projects and the underlying ideas to a startup-level initiative. Moreover, the Telecom Italia Joint Open Labs, the Istituto Superiore Mario Boella (ISMB), and CSP, three ICT research and innovation centers of the Turin area, provided access to some of their research projects, thus further widening the possibilities of students to get guidance, and support to their ideas.

In addition to donated devices, students have access to additional commercial and industry-level materials and devices provided by our university. In particular they can work with: one Philips Hue kit (six bulbs and a LED strip), various Z-Wave home automation components, two Pebble smart watches, several Raspberry PIs, spare hardware components (e.g., breadboards, LEDs, resistors, etc.), a few Android 4.x tablets, and various computer peripherals (e.g., webcams, microphones, speakers, etc.). Since 2015, RFID/NFC tags and readers, LCD touchscreens for the Raspberry Pi, and Bluetooth beacons have been added. Moreover, students can use their own material, if they prefer. For each technology, the relevant APIs and libraries (e.g., accessible through Python, or through REST/HTTP) are illustrated in the course hands-on sessions.

### FEEDBACK

To gather direct feedback from the industry and from small and medium companies operating in Piedmont, as well as in Italy, the course organizes a final, open, presentation event kindly hosted by the I3P incubator [9]. All student teams who passed the exam by September 2014 (and 2015, respectively) have been invited to participate and share their achievements, and projects, with a wide audience composed by local companies, startups, and research centers. The first presentation event, named AmI Showcase 2014, took place on September 30, 2014, with eight former AmI teams presenting their projects. The showcase saw over 100 people attending the event. Participants were almost equally distributed between students, Politecnico staff and faculty members, and industries.

**FIGURE 1: AMI PUBLIC SHOWCASE**

The eight teams were supplied with a table, a poster holder, power supply and network connection, and all “smart” materials needed to perform a demo of their ideas. A couple of local startups incubated at I3P, were also invited to present their works in the IoT area. Telecom Italia sponsored the event by donating a gift (mobile phone credit) to the members of the eight AmI projects.

For the 2015 edition of the showcase, scheduled on September 29, we aim at gathering an even higher level of participation, with the goal of feeding a virtuous feedback cycle between educational offers, teachers, learner and industries working in the IoT domain.

## RESULTS

The first edition of the course (2014) was very demanding and very satisfying, both from the teachers’ and from the students’ standpoint, and the second one (2015) was even more intense, with higher student numbers and additional logistics to solve. All students, in their final evaluation questionnaires, acknowledged that the course “*was very hard,”* but that they “*learned a lot*” about handling a complex project and about IoT systems. Some of the students said that the course "*was the best ever taken during all their bachelor degree*". Teachers, on the other hand, were positively impressed by learners' maturity (in both editions), by the variety of generated ideas and by the commitment shown by students both during the course and for the final projects. Given these results and the interesting topic, the Ambient Intelligence course has been proposed again for the 2016 academic year.

Projects presented in the two course editions, are briefly summarized in the following, and show how students have concretized learned notions to automate, accelerate and augment people lives in their everyday life.

### Year 2014 projects

Presented projects targeted different application areas in the Smart Home / Smart Environment domain, and are visible at http://ami-2014.github.io/. In particular, the eight showcased projects were:

- *DoorOnPhone*, an intercom transformed in a powerful home-station that can be controlled from a smartphone;
- *Set App*, a system to help improving the efficiency of a computer lab by controlling the power of the workstations and the lights based on user presence;
- *Smart Butler*, a system able to help users in daily routines as a human butler may do, by providing an always-on voice-computing platform.
- *Smart Gardener*, an easy, though advanced, system that takes care of user plants (see the box "Spotlight on... Smart Gardener" for further information);
- *Smart Notifications*, a system able to fetch, filter, prioritize notifications from online and real world applications, and to present them in a unified and easy-to-access way. Messages are conveyed to users by means of a simple and user friendly interface and through vocal and light alerts sent at the right moment, in the right way;
- *Smart Pet Feeder*, for healthy and in-time, automatic feeding of your pets;
- *Smart Raise Your Hand*, a system for intelligently call a teacher in an overcrowded lab, by simply "raising your hand";
- *Treasure Hunting*, a multiplayer, cooperative game that consists in competing against an "evil" AI while finding checkpoints in your city (aka university) thanks to the clues the app gives you.

## Spotlight on… Smart Gardener

Smart Gardener is an innovative system that integrates modern computing and the natural beauty of gardening. Nowadays it is increasingly difficult to find the time to take proper care of your plants. Every time you leave the house for vacation there is always the unwanted hassle of forcing unwilling neighbors to water your plants while you are away.


The project goal is to create a system, which will take care of plants for you, watering them at the perfect moment, and leaving you free to enjoy them. Smart Gardener is easy and intuitive right out of the box. It also cares about the environment: it activates itself only when needed, saving water and electricity - and thus saving you money. Smart uses self-learning algorithms to intelligently manage a plant watering system in an unobtrusive and efficient way, without requiring complex setup procedures and expensive accessories. Its decision-making algorithms use a wide range of information to determine the best course of action: current and forecasted weather conditions, status of plants, etc. By learning from its previous actions, the system is able to make the best decision possible to efficiently and effectively water your plants.

### Year 2015 projects

Presented projects targeted different application areas in the Smart Campus domain, and are visible at [http://ami-2015.github.io/](http://ami-2015.github.io/). In particular, the fifteen projects that already passed the exam, and that will be shown in September, are:

- *Adaptive Online Radio*, a system that automatically play music based on the taste of users in a canteen or in other spaces, and constantly adapt according to the audience composition;
- *ItsYourTurn*, a system that will help students and professors to get in touch more easily and efficiently;
- *MarcoPoli*, for knowing which places inside the campus have critical settings, in terms of humidity, temperature, people congestion, light, and noise level;
- *NeverLate*, a smartwatch for students that would like to never miss out a lecture and enjoy breaks during long lessons;
- *NoNoise*, a system that help you find a place with the desired noise level, for every student activity;
- *SmartClassSchedule*, which aims at improving the classroom schedule by putting contextual information in front of each classroom;
- *TrackDown*, a system that uses indoor tracking to lower the possibilities of losing valuable items inside the university campus;
- *Wc INfo*, a system for warning students about out-of-order bathrooms and waiting time (updated in real time);
- *MyGuide*, a system for guiding visually impaired users in the campus, through voice interaction with a mobile phone and obstacle detection with a vibrating cane;
- *EasyPark*, to direct university staff to the closest parking lot with available space, and check license plates upon entrance;

- *WellCleaned*, for enhancing bathroom maintenance by constantly monitoring the levels of deployment of soap, toilet paper, trash cans, and informing students and maintenance staff;
- *SmartMakeYourBag*, that uses active tags to remind the student which items to add or remove from her bag, depending on daily class schedule;
- *MyBikePlace*, that proposes a sensor-enabled bike parking slot, to enable intelligent parking finding, and theft detection;
- *PoliRoute*, that offers a turn-by-turn internal campus navigation system, based on smart bracelets and dynamic signposts.

# CONCLUSIONS

As IoT will further evolve over the years, upcoming IT graduates exposed to courses similar to the one presented here will be better versed in handling the complexity of involved systems, while, at the same time, devising solutions centered on end user needs.

The main lesson learned in the two editions of the course is strongly motivating students, by giving them the support they need, in terms of both technical information and feedback on project development. One of the crucial points for success is offering to the learners the possibility of developing a project of their choice. Many students could in fact realize, and get academic credits for systems they have been conceived from the beginning (possibly even before the course started). The second lesson learned is about student interaction: when students are given freedom of choice on ideas and work planning, they improve their own self-recognition in the project results. Finally, we insisted much on agile, yet sound, development methodologies, by imposing deadlines and mitigating their desire of rushing to code. In the end, they appreciated the time spent in elaborating system requirements and system architecture, as it resulted crucial for achieving successful designs.

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