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# Innovative Engineering: Developing Laser Manufacturing and Optical Detection Systems

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***Abstract***

*The Master's Degree in Industrial Engineering at Escuela Técnica Superior de Ingenieros Industriales, Universidad Politécnica de Madrid (ETSII-UPM) integrates a series of compulsory subjects known as INGENIA (ENGINEERING). These subjects aim to cultivate students' ability to design and construct systems and products that address societal needs, emphasizing a project-based learning approach. The Laser Manufacturing and Optical Detection Systems INGENIA topic, introduced in the 2017-18 academic year, focuses on applying theoretical knowledge in optics, electromagnetism, and mechanical engineering to practical scenarios. Students work in teams to develop and implement innovative laser manufacturing or optical detection systems. Beginning with proposal development and culminating in system fabrication and testing, students engage in hands-on learning experiences guided by faculty. This paper outlines the methodology and outcomes of the Laser Manufacturing and Optical Detection Systems topic, highlighting its role in bridging theoretical knowledge with real-world engineering applications.*

***Keywords:*** *Laser Technology; Optics; Industrial Engineering; CDIO.*

## 1. Introduction

The curriculum of the Master's Degree in Industrial Engineering (MII) of the Escuela Técnica Superior de Ingenieros Industriales, Universidad Politécnica de Madrid (ETSII-UPM) incorporates a type of compulsory subjects that have been generically called INGENIA (ENGINEERING). The basic guiding principle of these subjects is to develop in the student the ability to design and build systems and products that solve the needs of society. It could be said, in a simple way, that these subjects are based on the engineering student doing engineering.

This initiative, approved by the Spanish Agency for Accreditation (ANECA) and the Accreditation Board for Engineering and Technology (ABET), gathers the learning competencies of this level of expertise by combining the project-based learning strategy with the learn-by-doing focus (Hernández Bayo et al., 2014).

These types of subjects have an important international reference within the CDIO initiative, which has been promoted by MIT in the United States and by Chalmers University and other Swedish universities in Europe (Kjersdam et al., 1994; Crawley et al., 2017). The acronym CDIO refers to the starting point of this initiative, according to which engineers should be able to Conceive, Design, Implement, and Operate engineering systems in modern team-based work environments (CDIO, 2023).

To achieve these objectives, students must master a complex and changing body of technical knowledge. Young engineers must also possess a broad set of personal skills that will enable them to successfully work in companies and organizations. To achieve this, CDIO member institutions advocate the incorporation into their curricula of learning experiences that lead to the development of the required personal and interpersonal skills in students, while developing their ability to conceive, design, implement, and operate products or systems, see ABET 2023. The INGENIA courses of the Master's Degree in Industrial Engineering have a conception that is very much in line with the CDIO approach (Mtz. Muneta et al., 2020).

The principle that defines the INGENIA courses is that they are based on the student's approach to the realization of a project, system, or product in the field of engineering, taking into account a series of restrictions or requirements previously defined and working and taking into account situations similar to those that may occur in a real professional environment.

These are, therefore, subjects in which the realization of projects or developments within the field of engineering is addressed from the first phase of conception and design to the final phase of implementation and operation. Depending on the complexity of the proposal, some courses may decide to limit the activity to the design phase or to reserve implementation only for the best designs.

This type of approach should facilitate the transition from theory, taught in other subjects of the curriculum, to practice. On the other hand, it is based on posing open-ended problems that deal with complex situations in which there is no single predetermined correct answer.

It is made up of different topics, although each year new topics are proposed, and some disappear or change their scope, and new ones are added. The following topics were offered in the 2022/23 academic year: Industrial Applications of Acoustic Engineering, Computer-aided Engineering, Development and management of industrial construction projects, Design of intelligent systems with robots and AGV, Bioengineering Design, Design and Simulation of a Pressurized Water Nuclear Reactor, Circular Engineering, Engineering an electrical system, Automotive engineering. Design, manufacturing, testing, and demonstration of a vehicle for Formula SAE competition, Systems Engineering, The School of the Future - Smart ETSII, Motor-Gen: Design and manufacture of a thermal engine, Machine project, Traditional forging manufacturing, and Laser manufacturing and optical detection systems.

The present contribution is aimed at the last of these topics: Laser Manufacturing and Optical Detection Systems which was started in the 2017-18 course.

This topic is oriented to enhance the practical application of knowledge acquired throughout the degree, especially concerning topics of Optics, Electromagnetism, and Mechanical Engineering, using a project-based learning approach. Students will work in teams living the complete process of development of the machine/system proposed and designed by themselves, not only from the technical point of view, but also from the economic one, addressing all its phases, from the choice of the process (and its study in bibliography), the conceptual design of the machine/system with its specifications booklet, the integration and manufacture of the same, and its final test to verify compliance with the specifications initially raised.

## 2. Materials and methods

In order to start this course, there is an initial outlay to acquire equipment (from calls for equipment and from the department's own funds), but the material is reused every year (except for consumables, electronic components, plywood, paint, etc.) and the annual cost is less than €500. The course also uses calls for teaching equipment and the existing infrastructure at the university (mainly the UPM Laser Centre).

The Laser Manufacturing and Optical Detection Systems INGENIA topic aims to provide students with a systematic methodology for the development of these systems.

Students will have a first phase of training to complement the training received in the Degree, they will be introduced to the operation of lasers with a reminder of Optics and Modern Physics, and they will be introduced to the different Types of Lasers and Laser Systems (laser together with the beam and part delivery system) available in the industry and a brief introduction to the physics of Laser-Matter Interaction. This training allows them to take a course on "Laser Safety Training" which enables them to work with lasers in the laboratory. Finally, they are introduced to Industrial Applications of Lasers and Optical Characterization Techniques to provide them with ideas and examples on which to base their system.

At the end of the first month of fundamental classes, students will be grouped into teams of 2-3 members, each tasked with developing a proposal for an innovation. During this phase, they will receive limited guidance from professors, encouraging creativity in identifying the innovation's purpose rather than focusing solely on technical details.

Following this, presentations will be conducted, and students will vote on the best ideas, which will proceed to the next phase. The feasibility of selected ideas will be analyzed by the faculty, and students whose ideas are not chosen may join other teams. Subsequently, students, divided into groups of 5-7 individuals, will work collaboratively on the laser fabrication or optical detection process proposed in the previous phase, developing a complete system for the intended process.

Drawing inspiration from literature, including patents and designs of similar machines, students will design cost-effective, simplified versions of the proposed machines while adhering to their specifications.

Once the desired laser process/optical device is selected, students will proceed to work on its design. They will be guided through a series of steps, including understanding the process, determining the necessary laser/lighting source, defining the beam handling system or movement system if necessary, designing the optical path, and establishing safety elements.

Following the conceptual design, students will present their designs, specifications, and estimated costs. The faculty will then suggest simplifying the systems for scale models, ensuring they retain key features while reducing costs and risks.

After simplification, students will proceed to fabricate the system, which involves designing the scaled system, selecting components, integrating and assembling the system, and conducting tests to validate its performance and adherence to specifications.

Upon obtaining the demonstrator, students will present it to their peers along with specifications, validation test results, and the final system cost.

The final grade consists of two parts: Team grade (80%) – obtained from different tests and presentations given to assess the progress of the teams and from the assessment linked to the final project and Individual grade (20%) - based on individual performance in the development of the system and peer evaluations to assess how individuals perform within the teams.

Since the beginning of this subject, no student has failed it (except in cases of abandonment for reasons unrelated to the subject) and most of the groups have achieved an excellent result.

## 3. Projects completed along this INGENIA years

Since the beginning of *this* Ingenia, several ideas have been brought to fruition. Far from building a fully industrial system, the idea behind the INGENIA goal is to develop project-related skills - such as strengthening teamwork or improving project presentations - as well as some engineering skills - planning and developing a design and implementation project.

These student-led projects fall into three main categories related to the focus: External Problem Solving, Process Implementation, and System Development. Two projects in each category were selected from the different years of this INGENIA.

### 3.1. External Problem Solving

These projects focus on finding a solution to an external problem, usually proposed by the students because they are aware of it. The main difficulty is in finding a solution, and the focus is not on obtaining the best process parameters or developing a final system. Two projects have been selected to illustrate this category:

LaserDry (2017-2018) was a two-stage station for studying laser drying in the automotive paint process. As the automotive industry moves to water-based paints, the drying process must use large ovens that consume a lot of energy. The proposed solution was to use local drying with lasers. The system is a combination of paint spray and laser heating. Electronic control allows the part to be moved from the painting stage to the laser curing stage. This project was designed for 2D top patterns in a first approach.

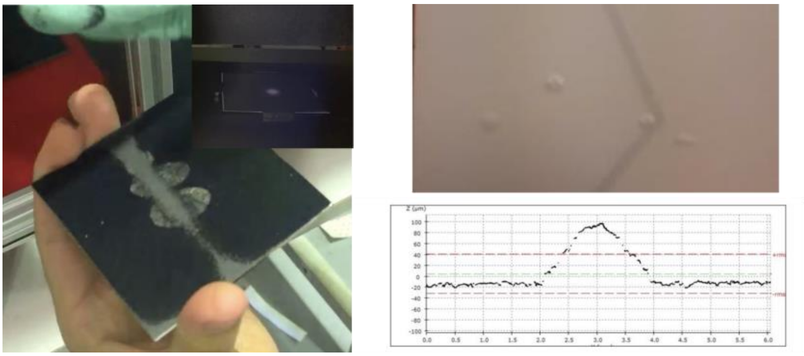

*Figure 1. Left. LaserDry (2017-2018 course) shows that the laser-treated area has dried the paint. Right. Braisser (2019-20) example of Braille dots created by the laser.*

The Braisser (2019-20) team focused on finding a solution to write Braille to help teachers with students suffering from visual problems to be able to generate study material without the need for an external organization (in the case of Spain, this was done by ONCE). The project worked on finding a material and a laser process that would allow the generation of a 3D dot (with the specifications of the Braille system). The chosen solution was a foaming process: the interaction of a laser beam with a material (typically a polymer) can cause it to inflate in the shape of a small bubble - can be used to write in the Braille system, taking advantage of the flexibility that a laser beam gives.

### 3.2. Process Implementation Projects

These projects focus on extending the capabilities of existing equipment to meet the needs of a specific application, usually requiring some adaptation and incorporation of new elements. The main difficulty is in finding the process parameters and there is less focus on system development. Two projects have been selected to illustrate this category:

LaserJeans (2018-2019) project is an alternative to traditional denim distressing processes commonly used in the apparel manufacturing industry. Currently, the predominant method used worldwide to achieve this distressing effect is sandblasting, which is associated with significant water consumption and a notable risk of silicosis. However, a Spanish company has introduced the innovative approach of using lasers for this purpose. This project achieved the desired distressing effect on denim fabric using a 5W CW IR laser (a very cheap laser with specifications worse than those used in the industry), see Fig 2 left.

The Laserust (2021-22) team worked on laser rust removal, which is a superior alternative to manual and chemical cleaning methods. Laser cleaning produces minimal airborne dust, which can be easily removed with an exhaust system, minimizing cleanup time and maintenance. In addition, the process eliminates the need to replace cleaned items, promoting reusability. Utilizing fiber laser pulses ensures minimal energy consumption, contributing to environmental sustainability by replacing chemical-intensive methods and reducing material waste and energy consumption, see Fig 2 right.


*Figure 2. Left. LaserJeans (2018-2019) example of laser drawing on denim fabric.*
*Right. Laserust (2021-22) example of laser rust removal showing their logo.*

### 3.3. System Development Projects

System development projects focus on the industrial implementation of a technology, either at full scale or scaled down as a prototype. The main difficulty is the design and implementation of a working system, as the process parameters are already known or not very time-consuming. Two projects have been selected to illustrate this category:

BraccioBeam (2017-2018 course) (fig.3 left) resembles the processes in the automotive industry involving a robotic arm for 3D parts processing. In this approach, the students built a scaled workstation for laser engraving –which is, in brief, a downscaled process for cutting and welding–. The pattern was predefined in CAD software. The project not only involved the laser system but also the safety parts surrounding the laser equipment, such as the enclosure, an electronic interlock, an optical window to oversee the process… Though the electronic control was not smooth, it was enough to engrave patterns onto sensitive materials.

A permanent laser marking system was designed for the project Movilaser (2019-20), but they were not able to finish it due to COVID-19. The final design and construction were done the following year by the Laserange team (2020-21) (fig.3 right). Traditionally, laser engraving machines are heavy and difficult to transport. Through this idea, a nanosecond fiber laser was mounted on an aluminum profile structure to build a desktop engraving machine. Its size and weight have been specifically optimized to have a portable machine that can be used as a demonstrator in the industrial fairs done in ETSII-UPM. The machine is fully functional, including a laser and a scanner, a safety enclosure, and some aesthetic elements such as LED lighting strips. It is used by new teams to develop processes and to upgrade the system (safety elements, cameras, ...).

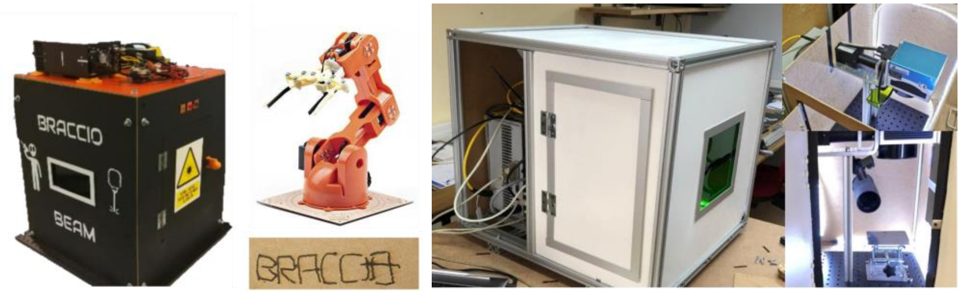


*Figure 3. Left. BraccioBeam (2017-2018 course) laser with a robotic arm for 3D parts processing Right. Movilaser (2019-20) and LASERANGE(2020-2)1 laser engraving machine.*

## 4. Conclusions

In conclusion, while the Industrial Engineering curriculum at ETSII-UPM covers a broad spectrum of industry-related science and knowledge, the intricate details of technologies such as laser technology cannot be fully expounded due to constraints in curriculum planning. Despite this, laser technology plays a significant role in industry, with only a fraction of its potential being addressed within the curriculum.

The formation of interdisciplinary groups comprising engineering students from various specialties offers a broader perspective when tackling complex problems. This approach encourages students to identify challenges and devise innovative solutions, thereby honing the skills demanded by the industry.

Engaging in hands-on, learn-by-doing subjects provides invaluable opportunities for students to navigate the professional process of product or service development, while also delving into topics not typically covered in the standard curriculum.

The Laser Fabrication and Optical Detection Systems INGENIA course enriches the educational journey of engineering students by immersing them in optics, electrical and electronic design, programming, business acumen, and communication skills within a collaborative learning environment. Furthermore, the students also acquire indirect competence in laser technology. Feedback from course evaluations consistently reflects high levels of student satisfaction across all these years.

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