Developing Innovative and Attractive CVET programmes in industrial shoe production

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Developing Innovative and Attractive CVET programmes in industrial shoe production

Train-the-Trainer Manual

STEM

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Content

1 Introduction

1.1 Aims of the DIA-CVET Project

The aims of the Erasmus+ project «Developing Innovative and Attractive CVET programmes in industrial shoe production» are

- to develop, pilot and implement comprehensive courses for the Spheres of Activity (SoA) of foremen in industrial shoe production on European level; available in English (EN) as well as in DE, RO and PT,
- and to develop a sector qualification framework level 5 and 6 and to reference existing or newly drafted national qualifications from Germany, Portugal and Romania.

1.2 Manuals to Guide Tutors and Trainers

The purpose of the manuals is to prepare designated trainers for their role and to provide content and support. Due to the nature of the SoA of foremen, they do not include specific forms of training; but we suggest a blended approach. Successful Continuous Vocational Education and Training (CVET) programmes combine theoretical lessons with application of the acquired Knowledge, Skills and Competences (KSC) in real work environments. The tasks of a trainer are to

- impart SoA-specific KSC,
- demonstrate operations which the learners are expected to learn to perform,
- introduce the learners to each new task and supervise them during their first approaches,
- organise and supervise blended activities (i. e. projects),
- guide them towards an independent performance of the tasks of the respective SoA.

The manuals are not meant to replace a textbook. They are meant to provide support to the trainers to plan and execute their teaching. The trainers are invited to gather more information from other sources.

1.3 Refer your training to the business process of industrial shoe production

Industrial production is a complex process, where the Sphere of Activity, described in this manual, is embedded in the business process. Before you start the training on a specific SoA, please make sure that the learners are familiar with the other SoA of industrial foremen in shoe production.

For example, the learners should be introduced to the types of products the company manufactures and their intended use, the different customer segments, the distribution channels etc. They should be aware of the product creation and manufacturing processes, i.e. product design, pattern making, purchasing department, production planning, and all production departments to warehouse and logistics.

The production process (not part of DIA-CVET, for insights see: http://icsas-project.eu/) is in the core of the business process; the SoA of DIA-CVET play a preparatory, supporting or accompanying role (see Fig. 1).

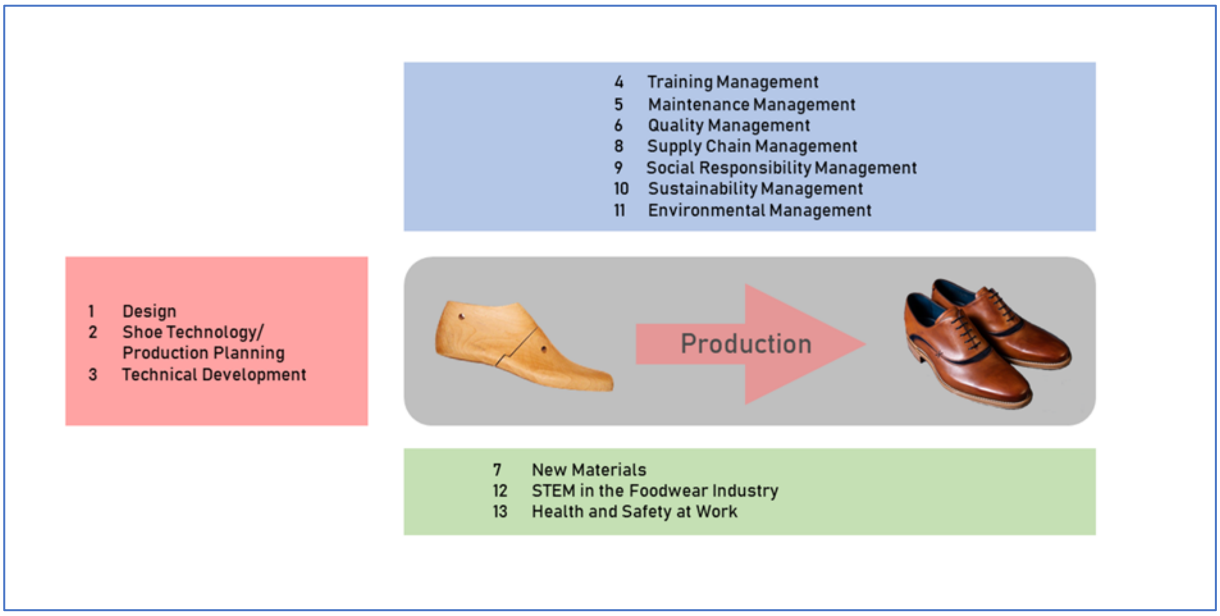


Fig. 1 Spheres of Activity of DIA-CVET and their relation to the production process.

2 STEM in the Footwear industry

2.1 Introduction

The adidas Speedfactory™ is a famous project of a German footwear manufacturer, where the use of robotics and automated processes has received a high amount of press coverage. For people unfamiliar with the shoe industry, it looks like the use of numerical controlled robots is something new and revolutionary. But it isn't!

In 1996 Brightwood, a Florida based manufacturer of athletic shoes, has invested in three Staubli RX90 robots which perform in roughing and cementing processes. Those robots where capable of processing 1800 pairs of lasted shoes in eight hours. This was a necessary step to compete with the off-shore production of his competitors, where manual labour is doing similar tasks. But even earlier, in 1980, the Scandinavian shoe brand Eccolet SKO had partnered with Klockner DESMA for directly moulding soles onto the uppers of their products. In 1984 they installed the first robotic helper in one of their factories.

Although machines are very effective in some tasks, and can easily outrun human capabilities, some other tasks, which are trivial for a human hand, are a challenge for robots they haven't mastered till today. A perfect example for that is the lacing of a finished shoe.

3 Automation and Robots

3.1 What is a robot

A robot, in particular an industrial robot is a programmable system used for repetitive tasks in manufacturing processes. Typical applications of robots include welding, painting, assembly, disassembly, pick and place for printed circuit boards, packaging and labelling, palletizing, product inspection, and testing; all accomplished with high endurance, speed, and precision.

In the year 2020, an estimated 1.64 million industrial robots were in operation worldwide according to International Federation of Robotics (IFR).

Fig. 2: 6-axis robot with gripper © PFI

Definition by VDI-Richtlinie 2860

[DE] „Industrieroboter sind universell einsetzbare Bewegungsautomaten mit mehreren Achsen, deren Bewegungen hinsichtlich Bewegungsfolge und Wegen bzw. Winkeln frei (d. h. ohne mechanischen bzw. menschlichen Eingriff) programmierbar und gegebenenfalls sensorgeführt sind. Sie sind mit Greifern, Werkzeugen oder anderen Fertigungsmitteln ausrüstbar und können Handhabungs- und/oder Fertigungsaufgaben ausführen."

[EN] "Industrial robots are universally applicable automatic movement machines with several axes, the movements of which are freely programmable regarding the sequence of movements and paths or angles (i.e., without mechanical or human intervention) and, if necessary, are sensor-controlled. They can be equipped with grippers, tools or other production means and can carry out handling and / or production tasks."

– VDI-Guideline 2860

Definition by Robotic Industries Association

"A robot is a reprogrammable, multifunctional manipulator designed to move material, parts, tools or specialized devices through variable programmed motions for the performance of a variety of tasks"

Definition by JARA (Japan Robot Association)

Manual Manipulator: Non-automated Handling device, directly controlled by the user.

Fixed Sequence Robot: Handling device with a fixed movement pattern. Changing of this pattern is relative laborious

Variable Sequence Robot: Handling device, as previously described, but with the option of changing the sequence of movements quickly and easily.

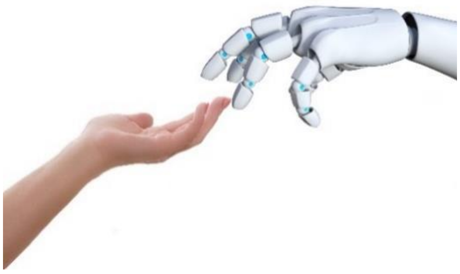
Playback Robot: The motion sequence is demonstrated to this device once by the operator and is saved in the program memory. With the information contained in the memory, the sequence of movements can be repeated as required.

Numerical Control Robot: This handling device works in a similar way to an NC-controlled machine. The information about the movement sequence is entered numerically into the device via buttons, switches or data carriers.

Intelligent Robot: This highest robot class is intended for devices that have various sensors and are therefore able to automatically adapt the program sequence to changes in the workpiece and the environment.

Despite the various definitions, the actual common understanding of a robot is a <u>programmable device that has at least three freely movable axes</u>.

3.2 Robots and Humans



In the past, robots and humans mainly worked separately from each other. This separation is still relevant today in many areas of production and is made clear by complex barriers and safety precautions. These are intended to prevent a person from entering the working area of an active robot and being injured or even killed by its movements. The various options for securing work areas of robots against unauthorized entry include, for example, cages with monitored security doors, light barriers or even access restrictions for entire rooms or halls. Triggering these protective measures generally means stopping the affected machines immediately in conjunction with an optical and / or acoustic alarm.

Despite the danger that robots pose to humans, there are various solutions to enable humans and machines to work collaboratively. In this case it must be ensured that the robot is either physically incapable of injuring the human or several different intelligent safety measures must ensure that the robot does not perform any movement that could result in a harmful collision with the worker.

These safety measures can be:

- Proximity sensors
- Touch sensors
- Laser distance sensors
- 3D-Scanners
- Video Systems paired with machine vision

Additionally, the robot can be equipped with force or torque sensing units, which deliver force feedback to its control unit. This way it can detect if the user interacts with it and respond to its partner accordingly.

But: Such systems are highly complex, and even small errors can cause a complete halt of the machine, since human safety always comes first. This complexity is also reflected in the price, both in terms of purchase and maintenance. In terms of the definition by JARA this would be called an *intelligent robot*.

3.3 Different types of robots

If you think of industrial robots the most common model you can imagine will be similar to the one shown in the chapter "What is a robot". It's a five to six axis arm like structure with a tool at the tip. This type is the most versatile construction and can handle various tasks from handling parts and feeding other machines to assembly of products or even milling, welding or (3D-) printing. A six-axis robot can reach any point in its space with its tool oriented in any direction necessary. With five axis the orientation of the tool is partially limited and depends on the position the robot is reaching for.

Fig. 3: Scara Robot © PFI

Another common model is a so called scara robot. It's mostly used for pick and place tasks, where speed and precision must be achieved at moderate costs. The kinematic of a scara robot is limited to a plane, with a height adjustable manipulator. With this limitation it's easier to reach a high degree of stiffness and precision, while maintaining speed and moderate costs.

The last typical participant in the field is the delta robot. Like the Scara robot, it is mainly used for pick and place activities where speed and cost efficiency are more important than precision and versatility. Like the scara type the tool axis is fixed and remains perpendicular to the working plane.

Fig. 4: Delta Robot © PFI

3.4 How does a robot function?

The task of nearly any robot boils down to the positioning of a tool or workpiece in 3D-space. To do so, the robot has several arms connected with joints in a defined manner. This chain is known as the kinematic and is mathematically represented in the software for controlling the machine.

All transformations and rotations of the joints can be expressed in Matrices which makes it easy to calculate the exact movements of all the axis in the chain. Many of these calculations are necessary in every step the robot moves. Although most robot axis are rotational ones, a rotation in one axis results in rotation and, most of the time, a translation of all joints further down the chain. Luckily modern computers have more than enough processing power, and all the complex mathematics hide under a nice and intuitive user interface, which makes it easy to control and program the robot for various tasks.

But all the mathematics and software would be of no use, if there wouldn't be an electrical and electronical network of sensors and actors (motors), that translate all the bits and bytes into real world actions. So, there are the sensors which tell the controller where the robot actually is. The controller compares these actual values with the setpoint values specified in the running program and regulates the motor output accordingly. This control loop runs all the time the robot is active, either in the case of a complex movement or just while holding a position.

And last but not least there is the mechanical part of the robot. That's what we see. Usually, a very stiff and stable assembly made of steel and plastic, wrapped with numerous cables and compressed air lines. This construction takes the loads, forces and torques of the different actions. The effort in this discipline is to create a construction that is rigid enough to handle the loads but not to heavy so it would slow down the machine too much. This mechanical appearance also defines the possible handling area and the space required for the installation.

3.5 Programming a robot

There are different methods to tell a robot what to do.

Manual Programming

A specialised programmer codes all the actions of the robot manually. This is often accomplished in a special programming language called G-Code. G-Code is a universal language for CNC-machines and consist of a long list of commands which tell the machine what to do next. Although there are some shortcuts and helpers for some typical actions, this a very tedious task and a simple typo can cause anything from a slight misalignment to a total disaster.

Teach in

The teach in process is an intuitive method to program an industrial robot. A user controls the robot directly and records the positions and activities manually, so the robot can repeat those actions. This process normally doesn't require a high level of training and can be done without programming knowledge.

CAM supported programming

A software supports the user while defining the robot's actions. This can be a simple tool which simulates the robot, and the user can combine teach-In and manual programming techniques to create an action. But there are also way more complex situations where a whole production line is simulated in the software and the users can program and simulate the combined actions of all sorts of machines. This is the most sophisticated kind of programming and the way to go in a complex construction environment. The robots can be programmed while they are still working.

Fig. 5: CAM-System DEScom by DESMA; Programming of a roughing cycle based on 3D-CAD data; visualizing of tool path and orientation. (Picture by DESMA)

3.6 Existing processes in the industry

One of the earliest participants in the field of automation and robots in the shoe industry was the company DESMA. As stated in the introduction, in 1980 the installed the first machine for moulding soles directly onto the uppers. Meanwhile they offer complete automation solutions for the shoe industry, as seen in the picture below. A carousel with multiple stations for injection moulding is fed by robots with the uppers, and the finished product is also automatically removed and placed on a conveyor band for further processing.

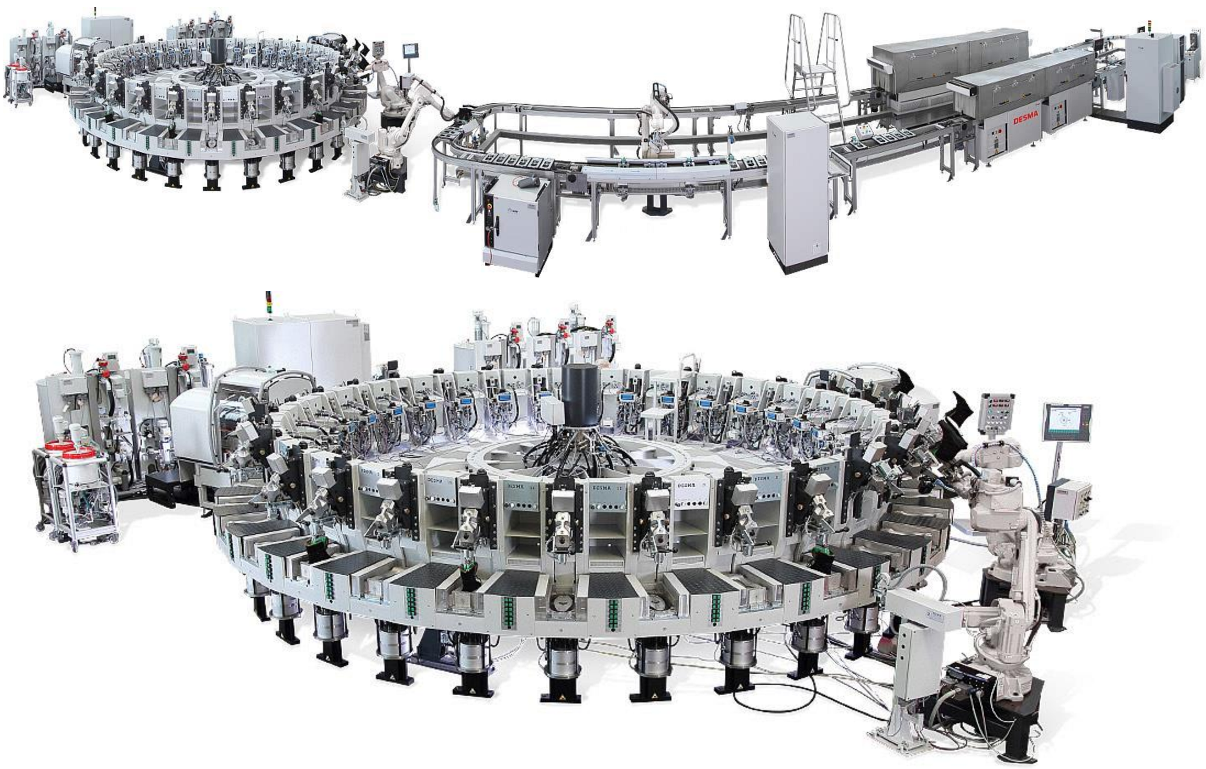


Fig. 6: Highly automated injection moulding system by DESMA (Pictures provided by DESMA)

4 3D-Printing – Additive Manufacturing

Only some time ago, manufacturing processes in industry were mainly subtractive processes in which the desired geometry is extracted from an existing raw stock by removing material. Probably the best-known processes are turning, milling and cutting. But in recent years, additive processes have increasingly come to the fore, both in the industrial and private sectors. The decreasing costs for 3D printers and the improving materials are making additive processes more and more attractive for a wide range of applications. 3D printing is an additive process in which material is applied layer by layer to create the desired geometry. The raw material can be in various forms, such as wire, powder or liquid. The solidification of the material at the desired positions takes place either thermally or chemically. The major advantage of 3D-printing is the short amount of time needed from the cad-model to finished part, especially for high complex geometries. It also offers a new degree of freedom for the designers cause the complexity of the part is nearly irrelevant for the manufacturing process, even interlocking parts or complex inner structures are possible.

Fig. 7: left: subtractive process (dark blue: desired Part, light blue: removed material) | right: additive process (dark blue: base layer, green: added up layers) © PFI

4.1 Overview of different techniques

In the field of 3D-printing, there are different approaches to target the material application.

Stereolithography

Probably the oldest method is the so-called stereolithography, which was patented in 1984. In this process, a photosensitive medium is selectively cured by a laser beam in order to create the desired structure layer by layer. This method was often used to create physical models out of CT-Data in the medical sector. Nowadays the laser is partially replaced by an LCD-screen that selectively blocks a UV-light source or an UV-projector to cure the material. After printing the parts must been washed and post-cured with UV-light

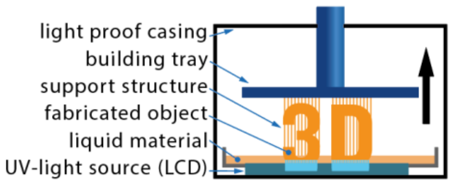


Fig. 8: Schematic of an SLA-printer with LCD-light source © PFI

This method can produce highly detailed parts with a nice surface finish, but the used photopolymers are toxic and harmful for the environment. The physical stability depends strongly on the used chemicals but can be quite good. Also, flexible materials are possible. Various companies in the shoe industry experiment with this method to print soles with specialized structures dedicated to variable damping properties.

Best for: Functional prototyping, patterns, molds and tooling

Fused Deposition Moulding

Maybe the most common 3D-printing method uses molten plastics to create the part. The raw material is fed into a heated extruder, where it melts and can then be pressed through a nozzle at the desired position. The extruder and the nozzle are guided by a cnc-like machine, which could also be a robot. A heated base plate serves as the printing surface for the first layer. All other layers are applied on top of each other. So, the printer needs something to print on and in the case a part has overhangs, the printer needs so called support structures. Those structures are calculated automatically in the printer software but can also be modified by an experienced user to speed up the process. The removing of those structures after the print has finished is part of the manual post processing and can be a tedious but necessary task for the final product.

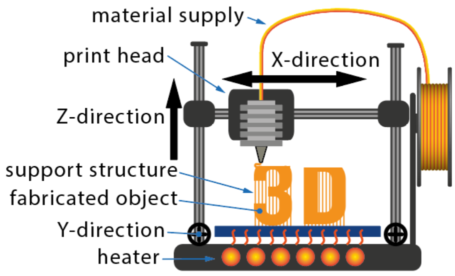


Fig. 9: Schematic of an FDM-printer © PFI

The quality of the parts depends heavily on the settings used for printing. For optimal settings the user needs some experience especially if many different materials are used. A few degrees Celsius more or less on the extruder can mean the difference between good parts and a failed print. This is the cheapest entry into the world of 3D-printing, with entry level printers in a price range between 200$ to 500$.

BEST FOR: basic proof of concept models and simple prototyping.

Selective Laser Sintering or Selective Laser Melting

This is an additive manufacturing processes in which selective areas of a powder bed are fused together using thermal energy. After the desired areas are fused, the bed is lowered, and a new layer of powder is applied. The required energy is introduced into the preheated powder material by means of a laser, which scans the current cross-section of the component. A great advantage of this process is that the unfused powder serves as a support structure for the upper layers and can easily be blown away after printing. Therefore, no special support structures need to be printed and the laborious removal of these elements is not necessary. Also, metals are processable, but a proper post sintering procedure is necessary to achieve real metal-like material properties.

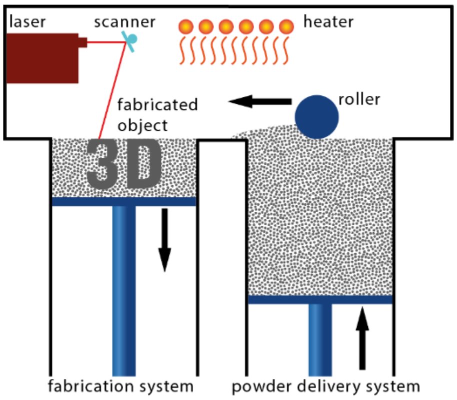


Fig. 10: Schematic of SLS / SLM system © PFI

The surface of SLA / SLM -printed structures is grainy but can be sanded in post-processing for a smooth surface. The overall stability of the parts is one of the best possible and the layers are nearly invisible. Depending on the used powder material properties from flexible to rigid are possible. Because of the small tolerances and the stability of the process these parts can be used as functional elements in various types of products. But all these advantages have a price, and that's the cost of the machines and the surrounding infrastructure. A single machine starts at around 100.000$ and needs 10 or more square meters of place with a high current energy connection. The additional equipment for powder recycling and post processing of the parts is not included.

BEST FOR: functional prototyping and end-use production.

Material Jetting

This printing principle is similar to a common ink jet printer, but instead of ink a photosensitive polymer is printed, and cured by uv light. Like a typical desktop printer, which usually prints with four colours (cyan, magenta, yellow and black) a material jet printer also has separated printing heads which can be utilized in different ways. This can be the same material in different colours but can also be materials with different properties. For example, it can use a hard and a soft material and even mix them together to create varying flexibility in the part. Another advantage is the use of a special support material which is typically easy to remove after the print has finished. Therefore, no explicit support structures are necessary, what makes the post processing of the parts much easier.

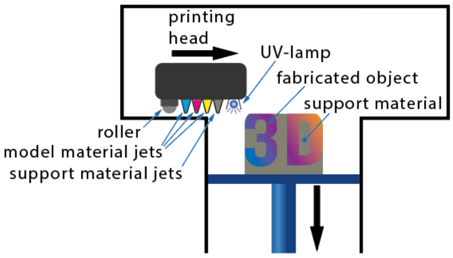


Fig. 11: Schematic of material jetting printer © PFI

Although this is an expensive procedure, the possibility of digitally mixed materials or even photorealistic colours is a property that most other printing procedures can't offer. Therefore, this technique is mostly used for design or haptic focused prototypes of consumer products.

BEST FOR: functional prototyping with focus on haptic and design

Binder Jetting

The binder jetting technique is something like a combination of selective laser sintering and material jetting. In this case a printing head is injecting a binding agent layer by layer in a powder bed to form the final part. Like other powder bed procedures, no support structures are needed. This procedure is faster than the SLS, while capable of photorealistic colouring but the parts are brittle without special postprocessing. Also, metals are processable, but a proper post sintering procedure is necessary to achieve real metal-like material properties.

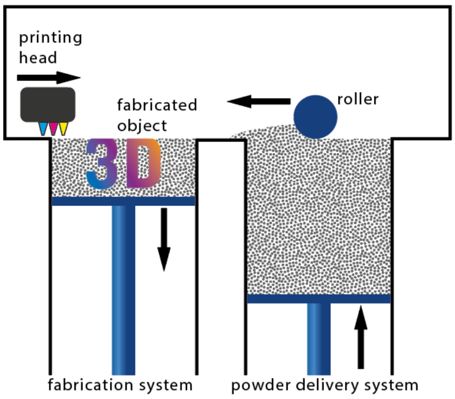


Fig. 12: Schematic of a binder jetting printer © PFI

BEST FOR: functional prototyping with focus on design and end-use production

4.2 Print preparation / slicer

The preparation of a 3D-part for printing is relatively simple but can have a big impact on the required printing time and quality of the part.

The first step is to import the desired part and place it inside the printing volume. The printing software (the slicer) normally choose a good orientation for the part itself. *For demonstration purposes, the T-like structure is deliberately brought into an orientation in which a high proportion of support structures is required (blue). But as you can see a small amount of overhang is possible without the need of a support.*

Then you adjust the printing settings as needed. The most important settings in terms of quality and print time is the thickness of the layers.

Thin layers → fine details but slower

Thick layers → fast but more coarse structures

Depending on the used printing technique there are many other settings to adjust and finetune. Especially the FDM procedure has many parameters like temperature, cooling fans, amount of infill (material inside the part), material feed-rate, printhead velocity, etc. Good software will give you a number of pre-sets dedicated to your printer, like “Draft”, “Normal” and High quality”

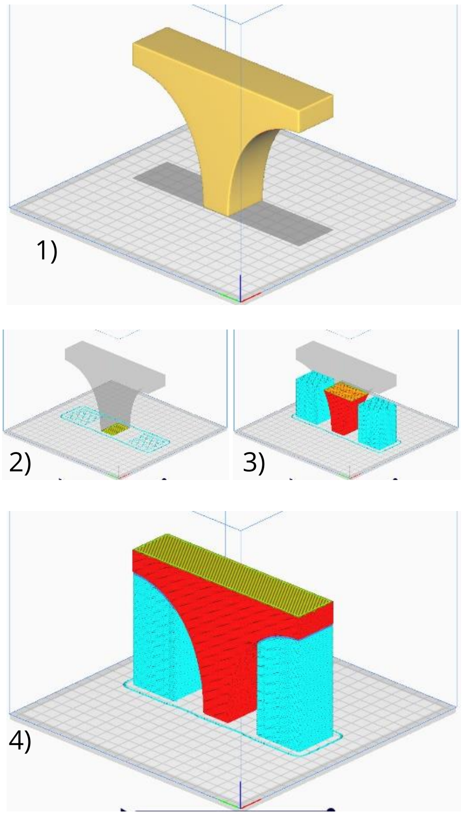


Fig. 13: Slicer for an FDM-based print. © PFI 1) placed part; 2) preview of first layer; 3) mid-print with infill visible (orange); 4) finished part

After preparing all the settings the program calculates the cross sections of each layer and, depending on the used printer, the instructions for the machine. In a 3D-Viewport you can preview the printing process and estimate if the procedure will be effective, and the result fits your purposes.

4.3 Problems and difficulties

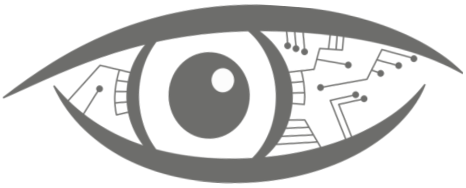
Although 3D printing opens up a lot of new possibilities and gives designers a lot of freedom, it is still a very new technology. This is particularly evident in material development, where there are constant improvements and new developments in the market. These developments are also necessary, since the physical properties of printed parts are decisive as to whether and how they can be used in end-user-products.

4.4 Overview

	SLA/DLP	FDM	SLS/SLM	MJT	BJT
surface quality	high	Low to medium	sandy	high	medium
Tolerances	Mid	Bad	Good	Good	Mid
durability	mid to high	mid	high	low	low to mid
colour possible	single colour	1 to 4 colours	single colour	multi colour	multi colour
support structures	yes	yes	no	no	no
hardware cost	low	low	high	high	mid
material costs	mid	low	mid	high	mid
user experience	safety instructions	experience needed	safety instructions	only maintenance	only maintenance

5 Machine Vision

5.1 What is Machine Vision?



Machine Vision describes the process of capturing and processing image data, to gather various types of information, which can be used for process control and / or validation.

5.2 What is an image?

From the point of view of computers, an image is just a matrix of arbitrary values that express the colour intensities for red, green, and blue. Those three colours are the base from which all visible colours are mixed. This is similar to how our eyes are working. They also have three different receptor cells which are sensitive to either the red, green or blue spectrum of light. If, for example, you see yellow light, this means your red and green receptors are triggered equally, and your brain interprets this as yellow.

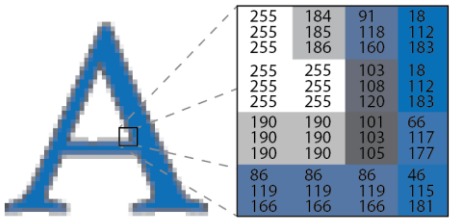


Fig. 14: RGB-colour values of the different pixels © PFI

For typical images each value for each channel has a range between 0 and 255 (8 bit). 0 means no and 255 means max intensity in this channel. Figure 9 on the right shows the additive mixing of those values (colours).

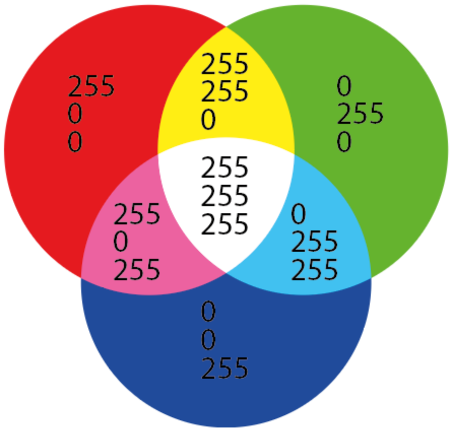


Fig. 15: Additive mixing of colours © PFI

5.3 Key components

The following components are required for image processing:

Light

Artificial light is generally used for industrial image processing. Although it is also possible to work with natural light, fluctuating lighting conditions can significantly interfere with the further processing of the image data. Therefore, light sources specially tailored to the task are usually used to create a shadow-free and consistent lighting situation.

Lens

Before the light reflected from the object reaches the camera sensor, it is bundled and focused by a lens in order to achieve a sharp image. A lens usually consists of an arrangement of different lenses to minimize aberrations and distortions. A typical aberration is, for example, the so-called chromatic aberration in which different colours are refracted to different degrees when they pass through the lens. This results in blurred edges and colour fringes, which make image processing much more difficult. Although some errors can also be compensated by appropriate algorithms, it is always advantageous to use high-quality optics. However, since the costs of such lenses are not insignificant, it should always be weighed up which quality is really required.

Camera sensor

A suitable sensor is required to convert the light into digital data. Depending on the task, a decision can already be made here whether a colour or black-and-white sensor is used. A black-and-white sensor is not necessarily cheaper than a colour sensor, but a colour sensor should not always be used for this reason. With the same resolution, a black-and-white sensor has better edge accuracy than a colour sensor, especially when it comes to coloured edges. In order to understand this, it is briefly explained here how a camera sensor works.

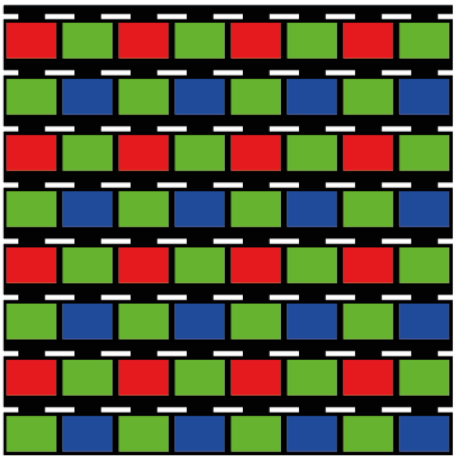


Fig. 16: Schematic of a colour sensor with a bayer-filter; black parts symbolize the non- sensitive chip areas required for read-out-electronics. © PFI

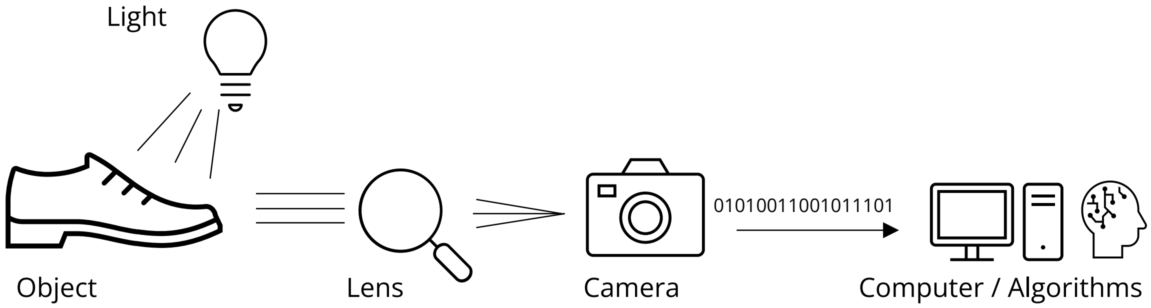
A camera sensor consists of a matrix of light-sensitive semiconductor elements (pixels). These are charged during an exposure process, and when reading out, the amount of charge that each individual pixel has absorbed is measured. A high charge means a high light intensity and thus a bright pixel in the later picture. With black-and-white sensors, measurements are made regardless of the colour of the incident light. In the case of colour sensors, a colour filter is added in front of the sensor fields, which limits the spectral range of the incident light. Since in the later picture the colour components are divided into red, green and blue, precisely these colour components are also distributed to the pixels. The adjacent figure shows 8x8 sensor fields of which 50% are only sensitive to green, 25% only to red and 25% only to blue light. The higher proportion of green light sensors does justice to the fact that our eyes also have the highest sensitivity in the green spectral range. This filter structure is called a Bayer-filter. However, in order to obtain a full-colour image, the respective remaining colour components of each pixel must now be interpolated afterwards.

There are many different algorithms which can be used for this purpose, but they will not be discussed in detail in this document. The keyword to find more information about this is "Demosaicing".

But with this knowledge it is now understandable which advantages a black and white sensor has over a colour sensor. The light sensitivity is higher because no light is lost due to colour filters, and the subsequent interpolation process is also eliminated. Therefore, these sensors can resolve strong colour contrasts more accurately even in weaker light.

Another important property of image sensors is the available resolution, and again, more is not always better. The more pixels there are on the same area, the smaller the individual sensor becomes and the less light it can absorb. The electronic circuit required in addition to the light-sensitive areas, which are used to read out the pixels, also reduce the actually usable area, and thus the sensitivity of the entire sensor. And last but not least, the higher the resolution, the higher the data volume and thus the computing power required for its processing increases. When selecting the resolution, you should always proceed according to the principle: "As much as necessary, as little as possible."

The actual size of the sensor has a major impact on the amount of light it can absorb and thus the general sensitivity. Larger sensors deliver noise-free images with a high dynamic range. However, these are more expensive per se and also require more expensive optics that are matched to the large sensor area. A higher sensitivity means shorter exposure times with less light, which is usually more important for photographers. In industrial environments, however, it is usually easier and cheaper to increase the lighting in order to make the sensors' work easier. In certain cases, such as vehicle crash tests, this can mean that extreme illuminance levels are used to ensure clean imaging.



5.4 Image Processing

After the images are captured and converted into digital data the computer needs to understand what it sees. For this purpose, many different algorithms have been invented which accomplish tasks from simple colour recognising to area calculations of incoming stock leather, up to complex augmented reality applications. It's not possible to address all the options in this document, so only some examples will be shown below.

Barcode and QR-code detection

An application of image recognition that has been used for a long time is barcodes or QR codes. Special patterns are recognized by a software and the information contained therein is made available to the user. Depending on the scope of the code, these can be simple serial numbers but also complex data sets such as business cards or a vaccination certificate. The formatting of the individual codes can be different, but current cell phones with the appropriate app recognize them very reliably. In the industrial sector, scanners specially designed for this task are often found, be it at the supermarket checkout, at the airport or in storage systems.

Colour control

This is one of the simple tasks a digital algorithm is capable of. The colour of a sample is compared to a reference value from a database. Normally this only means a slight averaging of the image in an area of the sample to get a representative colour value. If this value is inside the specified tolerances the object passes the test. Although this is simple on the digital side a good controllable lightning situation is key to get reliable results.

Area measurement

For the area measurement of an incoming leather stock, it's important to accomplish a good contrast between the object and the background. Furthermore, it is important to correctly include the geometric situation of the camera and measuring area in the software so that there are no incorrect measurements due to perspective distortions. An algorithm now recognizes the area of the sample in pixels and accordingly calculates the area in the desired units.

Defect identification

This task is a bit more demanding for image recognition and it is often helpful if several measurements (images) are made under different lighting situations. Under the right light, even small dents and scars in the material can cast shadows, which make the respective defect stand out much more clearly. The software can now examine the image data for irregularities and compare any possible defects with samples from a database. In this way, incoming raw material can be automatically checked and categorized into different quality classes.

Position detection

Recognizing the orientation and position of a part is a common task of image recognition, especially in connection with robots. If the position of a component is correctly identified, an appropriately programmed robot can reliably grasp it and then in turn feed it to a machine in a defined position. This is nowadays very common for rigid components, but gripping pliable parts is still a tricky undertaking for robots.

Augmented reality

The goal of augmented reality applications in the industry is to support the worker with important information directly in his / her view. For example, part numbers and processing instructions could be displayed according to the part being held in the hand, thus making work easier for the worker and reducing sources of error. In combination with other intelligent links, for example, appropriate programs could be automatically set on the machines used when picking up a part.

6 Anatomy and biomechanics

6.1 Locomotor system

The locomotor system is also called the musculoskeletal system. It consists of:

- the skeleton,
- skeletal muscles,
- tendons,
- ligaments,
- joints,
- cartilage
- other connective tissue.

The nervous system (brain and nerves) sends signals to activate the muscles and allows for voluntary movements.

The study of the structure, function and motion of the mechanical aspects of organisms is called biomechanics. Biomechanical studies are used to gain a comprehensive understanding of movements and the forces generated by and acting on the body. Key areas of biomechanics are: dynamics, kinematics, kinetics and statics.

6.2 Foot anatomy

The foot is part of the locomotor system and bears the load when standing and moving. It is a complex structure with 28 bones, 33 joints and many muscles, tendons and ligaments, which is able to adapt to unevenness and at the same time has sufficient rigidity to propel the body forward. Foot anthropometry is influenced by many factors such as age, gender, region, mobility, and health. Shoes should be designed that the support the natural foot movement and do not restrict and confine the foot significantly. Foot deformities are often rooted in unsuitable footwear during the early development stages. Problems such as flat, skewed feet often manifest in adults due to wrong footwear, insufficient exercise and unhealthy lifestyles.

6.3 Gait Cycles

Walking and running are dynamic, periodic movements during which forces are generated that have to be supported by the musculoskeletal system. During the different phases in the gat cycle the load and function of the foot varies. During initial contact the impact needs to be dampened, the load needs to be supported over the stance time and during push off the body needs to be propelled forward. The load exceeds the body weight and can reach up to 2.8 times of the body weight during running.

6.4 Measurement methods

There are a number of static and dynamic measurement methods to investigate movement, pressure distribution and forces generated over the course of the gait cycle. Variables that are measured may be temporal, kinematic (position, displacement, velocity, acceleration), kinetic (force, energy, work, power) or related to muscle activity, metabolic measurements.

Measurement equipment includes force plates, high speed cameras, pressure sensor mats, pressure sensor insoles, EMG-Sensors, IMU-Sensors, GPS- Sensors, gas analysers.

7 Sensors

7.1 What can be measured?

Every physical property that can be experienced by a human is also measurable by some kind of a sensor. In addition, the information given by electronic sensors is unbiased and objective. In addition, there are tons of other physical properties a human has no sense for, like for example radio waves. Real world properties you want to measure can be:

- Distance
- Velocity
- Acceleration
- Time
- Pressure
- Temperature
- Magnetic fields
- Brightness
- Force
- Etc.

7.2 How can sensors measure?

Distance

A distance can be measured in several ways. A common design for rather precise distance sensors bases on the principle of triangulation. A laser projects a dot onto the object and a “camera” with an offset to the laser observes the location of that point, as seen in Figure 16. Another method are "time-of-flight" sensors, which measure the time for an echo of a previously transmitted signal of acoustic or electromagnetic nature.

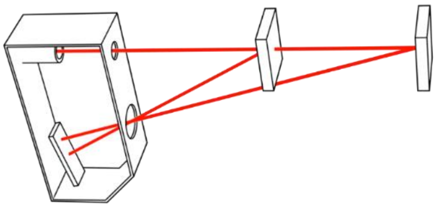


Fig. 17: Triangulation-based distance sensor © PFI

Velocity

Speed is the distance over time and can therefore be measured using the time required for a known distance. In cars for example the circumference of the wheel is the known distance and the time it needs for one rotation is the other value to calculate the speed of the car. A velocity is always measured relative to a reference frame.

Acceleration

This can be measured either in terms of the time it takes for an object to accelerate from one speed to another, or in terms of the force a known mass counteracts a change in speed. The second method in particular is beneficial because a sensor does not need any external reference to measure an acceleration. Acceleration sensors are built into cell phones, for example, and are often used to determine the orientation of the device via gravity. A freely oscillating mass is clamped in a frame by several spring elements. When the outer frame is accelerated, the springs are deformed due to the inertia of the center mass. This deformation is detected and converted into an acceleration via a corresponding evaluation electronics. Current micro-construction acceleration sensors are no bigger than a pin head

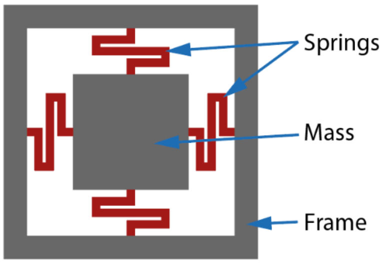


Fig. 18: Schematic of an acceleration sensor © PFI

Gyroscope

Similar to acceleration sensors, gyroscopes can detect changes in the rate of rotation. They also do not require an external reference and are offered in designs comparable to acceleration sensors.

Temperature

There are many ways to measure a temperature. An inexpensive and reliable type in electronic design largely uses the temperature-dependent resistance of various materials to draw conclusions about the ambient temperature.

Magnetic fields

Magnetic sensors are mostly used to record the geomagnetic field and to deduce the orientation from it. Since an electric current that flows through a conductor in connection with a magnetic field exerts a force on this conductor, it is also possible here to design highly integrated, low cost electronic components.

Pressure / Force

Pressure or force detection is a basic instrument in biomechanical studies. There are different physical properties that can be measured, but most of the sensors have a deformable layer between two conductive layers. For example: If the layer is insulating, the other two result in a capacitor, the capacitance of which depends on the distance between the two outer layers. This capacitance is measured and converted into the applied pressure; therefore, this sensor type is called a capacitive sensor.

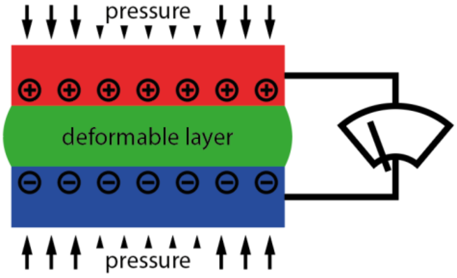


Fig. 19: Principle of a capacitive senso
© PFI

7.3 Inertial measurement unit (IMU)

An IMU is not a single sensor, but a combination of an accelerometer, gyroscope and magnetic sensor in one. The evaluation unit and digital interfaces are often also combined into a single package so that the component can be easily integrated into existing circuits. This unit can now determine its orientation in space and also recognize changes in its position. The alignment is very reliable because the rotation can be compared again and again with the magnetic alignment in the earth's magnetic field and the direction of gravity. The position, however, can only be estimated on the basis of the accelerations, from which a speed is calculated and from this, in turn, the spatial deviation is determined. Since a sensor always has a certain deviation and tolerance, this gradually leads to an ever-increasing error, which cannot be compensated for without absolute positioning. Example: a sensor lies still on a table. Actually, it should not show any movement apart from the acceleration due to gravity (gravitation). However, the slightest errors due to manufacturing tolerances lead to a minimal acceleration value. This means that the evaluation unit assumes an ever-increasing speed, which results in an ever faster position shift. At some point the unit thinks it is moving through space at the speed of sound or faster, even though it has not even moved. To compensate for this, some form of position reference is necessary, such as a GPS signal or maybe the strength of nearby Wi-Fi-signals.

7.4 Local sensors

Fixed sensors are linked to a non-mobile measuring station, such as a treadmill. These have the advantage that they are usually immediately ready for use and calibration only needs to be carried out if there are problems with the measurement.

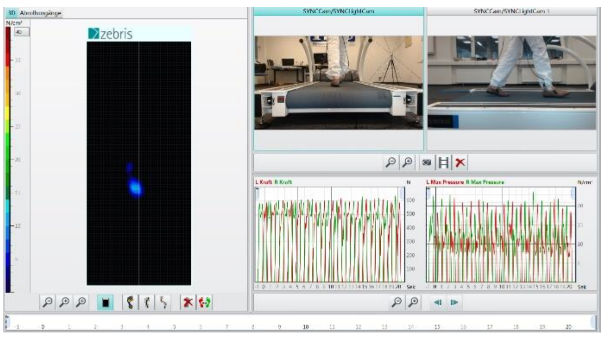


Fig. 20: Software interface of a sensor equipped treadmill; left: overview of treadmill surface; top right: camera view; lower right: visualisation of captured data.
© PFI

7.5 Mobile sensors

Mobile sensors are carried with the user and record the data for later investigation onto a SD- card or transmit the information via a radio-connection like Wi-Fi or Bluetooth. These sensors need to be attached directly to the user and usually require some sort of calibration process. Those sensors are for example:

- Inertial measurement units (IMU)
- Electromyography sensors (EMG)
- Pressure or force sensors

7.6 Use of sensors in shoes

The use of sensors in shoes offers a wide range of possibilities, from simple pedometers in everyday life to biometric gait analysis in science and research. Medicine can also benefit from data on the walking and running behavior of patients and better adapt treatment methods to the respective situation. With all this, however, the disposal and recycling of the electronic components in shoes and clothing must not be neglected.

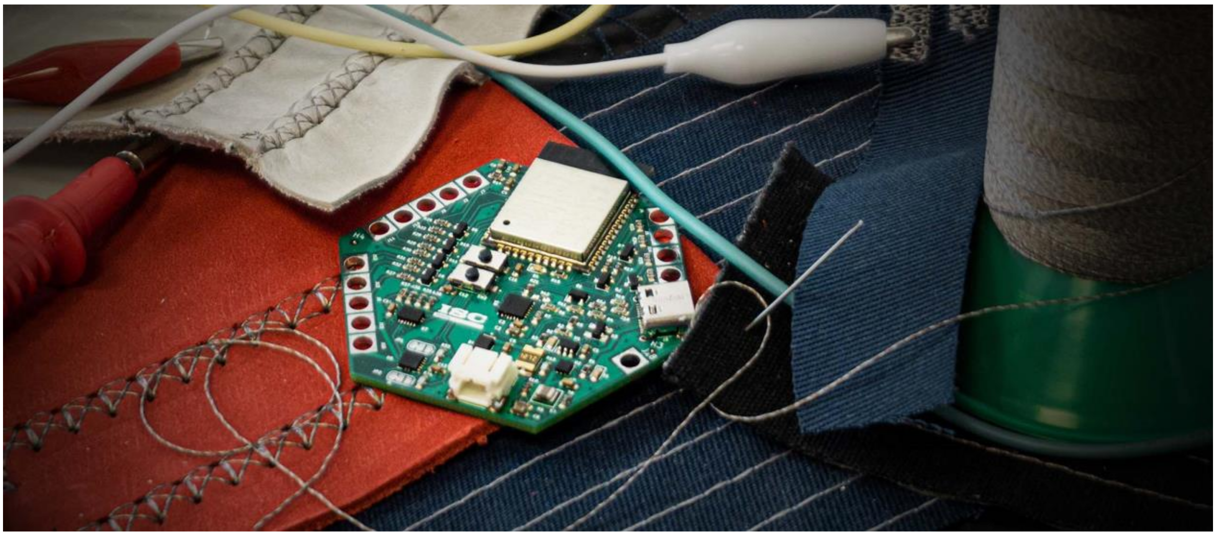


Fig. 21: Basic platine for smart textiles © PFI

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