Presentation and validation of a new optical sensing concept based in a 3d-printing solution

Anthony Pimentel, Tiago Noversa, Luis Capela, João Pedro Nunes & António Brito
U. Minho, Guimarães, Portugal

Tiago Alves, Reinaldo Sousa & Ricardo Lima
Bosch Car Multimedia Portugal, Braga, Portugal

ABSTRACT: In high competitive markets, such as the automotive industry, the better quality of products, reduction of manufacturing costs and the fulfilment of all delivery deadlines can only be achieved through continuous improvement of production capabilities. One current strategy is to develop and create smarter and adaptive assembly tools.

Automation is a relevant area of development in the current industrial world and the baseline of the fourth industrial revolution (Industry 4.0). Namely, it is very important to use sensing components on jigs for assembly parts in the production line. The arrangement of sensing components on the assembly tools is very dependent of the product, making the project more complex and less flexible. This issue can penalise the productivity heavily, especially if a wide range of products and changeover operations are usual.

The use of Additive Manufacturing (AM) is growing in the industry and offers a high potential for research and development in the present stage. The AM is advantageous in many areas, especially in the rapid construction of complex tools (RP). This paper presents a new optical sensing concept based on the 3D printing of internal circuits in the assembly tools. This solution can bring many advantages and increase tools flexibility.

1 INTRODUCTION

1.1 *Background*

The discovery of new technologies and solutions has accompanied the industrial development, through early adoption of new mechanical systems to support the production process. The high level of automation present in current days in production lines aims the rapid response and adaptation to the market requirements, which are constantly changing. Under the Industry 4.0 concept, astounding growth in the advancement and adoption of information technology and social media networks has increasingly influenced consumer's perception on product innovation, quality, variety and speed of delivery (Lee et al., 2014).

Assembly devices (jigs) are commonly used to assemble electronic components in manufacturing industries. These, guarantee the product positioning in a unique, accurate and repeatable way and allow automation assembly tasks to be performed in a defined sequence and with specified control parameters.

There have also been significant efforts in finding solutions to provide a rapid response to the market, namely, focused on solutions for quick construction and changeover of assembly tools. In this context, the concept of Rapid Tooling (RT) was born, consisting in applying Rapid Prototyping principles in the production of tools (Levy et al., 2014).

Product and process quality are the final outcome of the manufacturing process. In a repetitive process, such as on an assembly line, operator mistakes are likely to occur, which may compromise product quality. Thus, it is necessary to guaranty the correct positioning and presence of all components that constitute the product. The positioning mistakes are many times resolved using error-proof design systems like Poka-Yoke (Shingo, 1986). Other types of error are detected with the use of sensors that provides information and validate each step through multiple checks along the assembly process. Therefore, the sensing elements play a paramount role in both assembly line and device.

As it is represented in Figure 1, a sensor acquires a physical parameter and converts it into a signal suitable for processing, which can be transmitted to a controller.

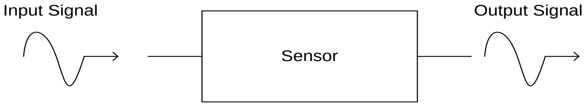


Figure 1. Basic representation of a sensor.

1.2 *Sensing Solutions*

There are many sensing solutions for application on assembly devices. The main functions of the type of sensors mounted on a jig are presented in Table 1.

Table 1. Main functions of different types of sensors

Components	Functions
Inductive sensors	-Metal parts detection; -Mask open/closed; -Pneumatic cylinder end of travel;
Optical sensors	-Parts detection;
Laser sensors	-Parts detection; -Distance control; -Part correct placement; -Laser barriers;
Optical fiber sensors	-Parts detection; -Part correct placement; -Transparent parts detection;
Vision Systems	-Parts detection; -Parts correct assembly; -Parts connection verification; -Pattern analysis (glue, thermal past, etc);

Vision systems are increasingly used because of its great flexibility. However, the image data acquisition, processing, storage and display of these systems require powerful industrial cameras with a specific hardware and software which make this solution very expensive. Therefore, significant efforts have been made to develop more cost-efficient solutions.

1.3 *About Fiber Optic Sensors*

Fiber optic sensors consist on a fiber optical cable (fiber unit) connected to a remote sensor or amplifier. The sensor emits, receives and converts a light energy into an electrical signal. These sensors are extremely sensitive, immune to electromagnetic interference and resistant to weather and shocks (Gholamzadeh & Nabovati, 2008).

The fiber optic cable consists of a glass or polymeric core surrounded by a cladding layer. The difference between the refraction index of the core and cladding allows the conduction of light without losses. The light beam travels through core with successive reflections on cladding surface. The light having passed through the fiber unit is dispersed at an angle of approximately 60° [Figure 2] (Keyence, 2014).

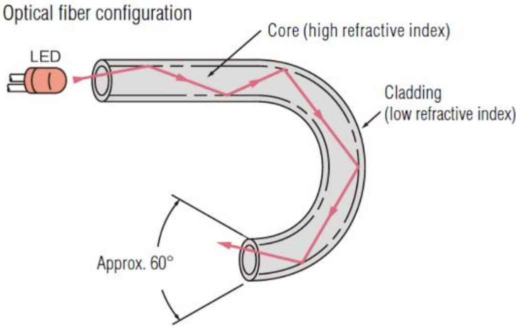
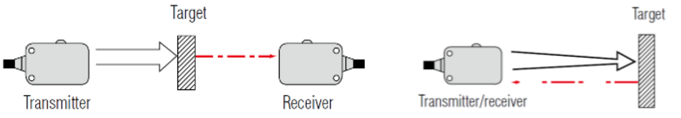


Figure 2. Fiber optic configuration.

The fiber units can be divided in two categories: through-beam and reflective. The through-beam type consists in a separate transmitter and reflector. Alternatively, the reflective type comprises only one unit that emits and receive [Figure 3] (Keyence, 2015).



(A) (B)

Figure 3. Different types of fiber units ((A) – Through-beam type; (B) – Reflective type).

1.4 *Additive Manufacturing*

One recent application of additive manufacturing is the construction of assembly devices (jigs) (StrataSYS, 2016). In an electronic components industry, it is necessary ensure that the materials used in the assembly devices have ESD (Electronic Static Discharge) properties in order to protect the product against electrostatic (Rahman & Aziz, 2010). These electrostatic charges can damage electronic components, resulting in economic losses

In terms of Additive Manufacturing techniques, the FDM (Fused Deposition Molding) brings great advantages since it allows the construction of both solid and spare parts. The construction of spare parts reduces the mass of parts, their production time, material used and consequently the final price of the part (Wong & Hernadez, 2012). In an assembly device, mass reduction facilitates the transport and handing of tools mainly in changeover operations. Therefore, FDM technique using ABS ESD 7 material is a good solution for construction of assembly devices for an electronic components industry.

1.5 *Motivation*

The challenge of this study is to design a new sensing solution based on the concept of rapid construction and change of assembly tools. Sometimes sensor components increase the time of changeover and construction of tools because they are embedded in the tool, which increases its complexity.

Rapid construction of tools through additive manufacturing technologies allows the inclusion circuits which, in turn enables the application of the metrological principle to strategic points of monitoring in the design phase. In this way, additive manufacturing provides the ability of printing circuits into the tool during its construction. These circuits allow independence between the sensing components and tools, increasing the system flexibility and facilitating changeover operations.

2 EXPRIMENTAL TESTS

2.1 *Introduction*

The use of experimental tests allows for increased knowledge and control over particular aspects of a process, through measurement of quantifiable results. So, in order to test the sensing concept and validate feasible circuits, an experimental methodology using different AM parts was adopted to study the behavior of the light beam in straight and curved circuits.

2.2 *Experimental parts*

Two parts in ABS- ESD7 were designed and produced using FDM technology for testing the behavior of the light beam in straight circuits and curved circuits. These parts are respectively presented in the Figure 4 and Figure 5.

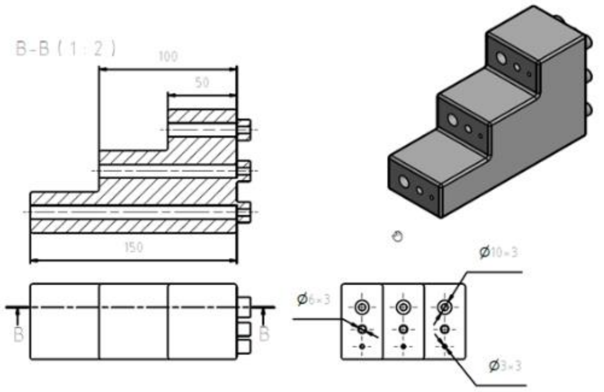


Figure 4. Part design for testing straight circuits.

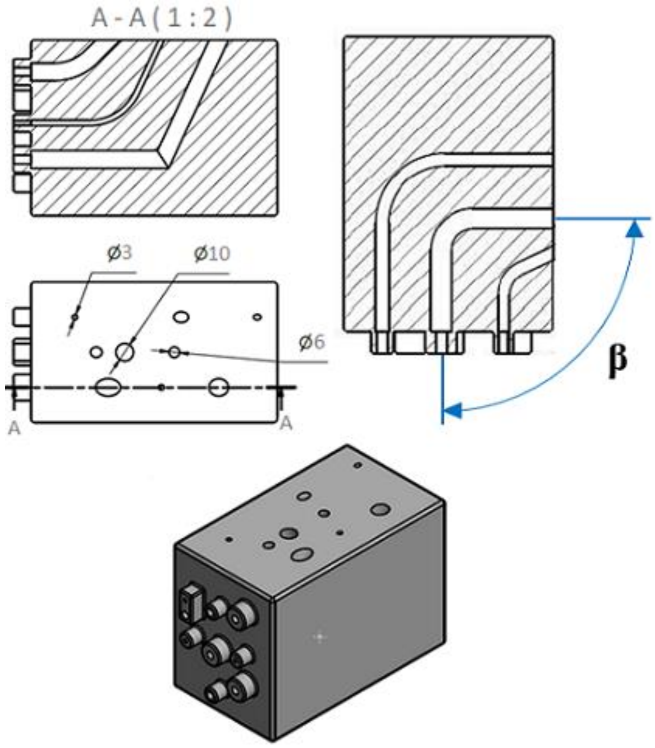


Figure 5. Part design for testing curved circuits.

The geometric parameters of the circuits present inside the parts are presented in the tables 2 and 3.

In the straight circuits, the controlled parameters in the experimental tests were the diameter and the total distance of the circuit. The geometric parameters of the circuits present inside the part are presented in the table 2.

Table 2. Control parameters of the straight circuits.

Parameter Circuit	Total distance of light path (mm)	Circuit diameter (mm)
1	50	3
2	50	6
3	50	10
4	100	3
5	100	6
6	100	10
7	150	3
8	150	6
9	150	10

In the case of the curved circuits the controlled parameters were the total diameter, the distance of the circuit and the angle (β) between the input and output channels. The parameter β must be considered in the design phase.

Table 3. Control parameters of the curved circuits.

Parameter Circuit	Total distance (mm)	Circuit diameter (mm)	Angle β (°)
1	50	3	90
2	50	6	115
3	50	10	135
4	100	3	115
5	100	6	135
6	100	10	90
7	150	3	135
8	150	6	90
9	150	10	115

2.3 *Methodology*

The following methodology was used in the experimental tests made:

1- The sensor was connected to a Rohde & Schwarz HMP4040 programmable power supply. A voltage of 12V and a maximum current of 50 mA was assigned [Figure 6];

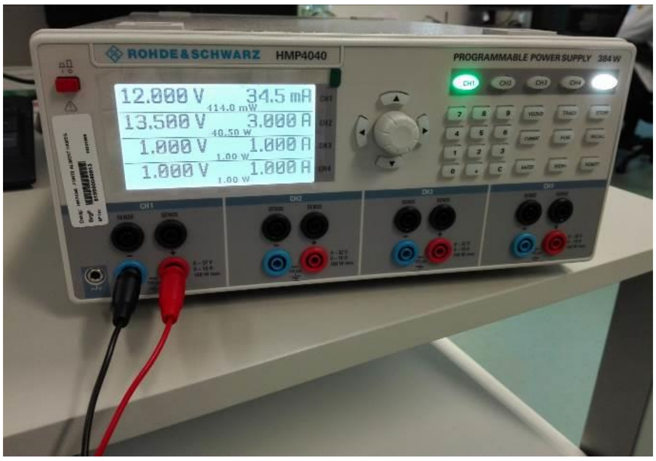


Figure 6. Programmable power supply.

2- For the experimental tests, an OMRON E3X-DA51-S fiber optic amplifier and a fiber unit with 3 mm diameter were used. The sensor was coupled to each circuit test (straight and curved);
3- The signal provided by the sensor without identification part (without target) was recorded;
4- An identification was given to the part (with target);
5- The new signal provided by the sensor after insertion of the identification part was recorded;
6- A set of 5 measurements were made;
7- The data obtained was processed.

All the components used in the experimental tests are presented in Figure 7.

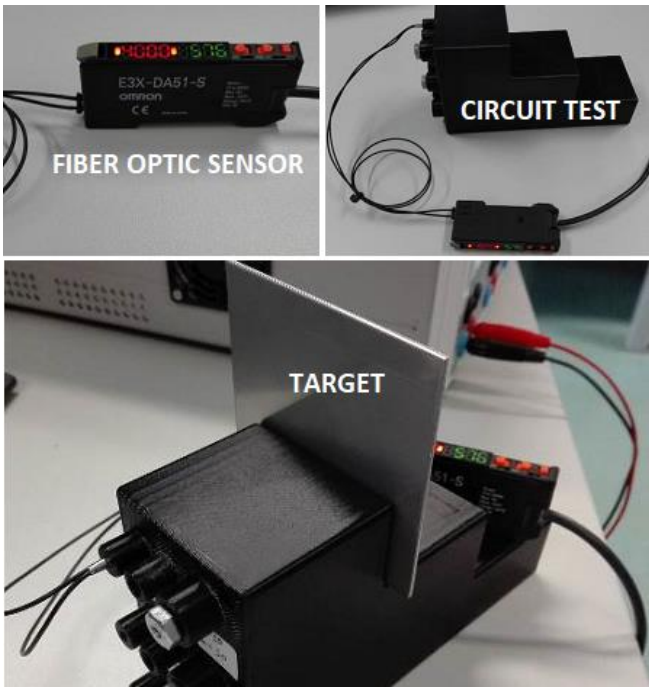


Figure 7. Components used to perform the experimental tests.

3 EXPERIMENTAL RESULTS

After data processing, results obtained in straight circuits are presented in Table 4.

Table 4. Sensor outputs for straight circuits.

Circuit	w/o Target*	w/ Target*	Δ*
1	824 ± 2.0	925 ± 6.0	**101 ± 5.0**
2	397± 0.0	645 ± 5.0	**248 ± 5.0**
3	112 ± 0.0	515± 12.0	**403± 12.0**
4	822 ± 2.0	838 ± 2.0	**16 ± 1.0**
5	334 ± 1.0	380 ± 3.0	**46 ± 3.0**
6	124 ± 0.0	210 ± 2.0	**86 ± 2.0**
7	854 ± 0.0	860 ± 1.0	**6 ± 1.0**
8	397 ± 0.0	415 ± 2.0	**18 ± 2.0**
9	126 ± 0.0	159 ± 2.0	**33 ± 2.0**

The difference Δ between values with (w/) and without (w/o) target is the most important parameter since it allows part detection. * The presented results are dimensionless and refer to the saturation of the sensor relative to received light. The absolute uncertainty of measurement is presented in the results. The value of total sensor saturation is 4000.
The higher the Δ value the easier the part detection. From the results presented in Table 4, a graph that relates the diameter and the length of the circuit with Δ can be plotted. Such graph is presented in Figure 8.

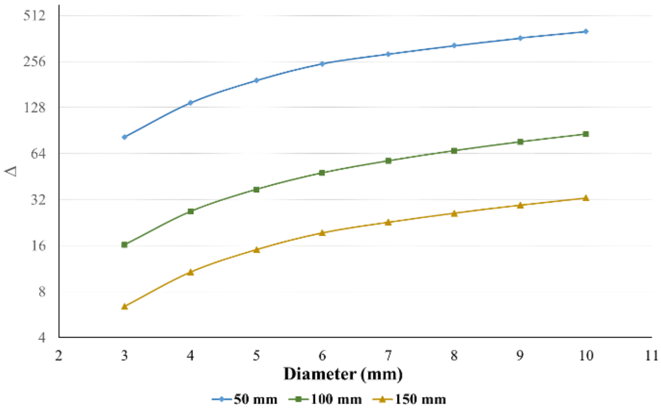


Figure 8. Graphic that expresses the obtained results.

Table 5 shows the results obtained for curved circuits.

Table 5. Sensor outputs for curved circuits.

Circuit	w/o Target*	w/ target*	Δ*
1	520 ± 0.0	520 ± 0.0	**0 ± 0.0**
2	442± 0.0	442± 0.0	**0 ± 0.0**
3	84 ± 0.0	84 ± 0.0	**0 ± 0.0**
4	489 ± 0.0	489 ± 0.0	**0 ± 0.0**
5	490 ± 0.0	490 ± 0.0	**0 ± 0.0**
6	33 ± 0.0	33 ± 0.0	**0 ± 0.0**
7	423 ± 0.0	423 ± 0.0	**0 ± 0.0**
8	428 ± 0.0	428 ± 0.0	**0 ± 0.0**
9	141 ± 0.0	141 ± 0.0	**0 ± 0.0**

As seen in Table 5, Δ values equal to zero were always obtained for the curved circuits, which means that is not possible to identify parts in these cases. Also, the geometric characteristics of the printed circuits (diameter, length and curvature) cannot be related with the Δ value.

Overall, the experimental results obtained show that:

- Larger circuit diameters achieve better results;
- Shorter circuit length present better outcomes;
- It's not possible to identify parts in curved circuits, because the Δ value obtained is always null.

In order to increase the light conductivity inside the circuits without reducing the sensing systems flexibility, fiber optic filaments were implemented, i.e., the circuits were fit with fiber-optic filament to improve the conduction of beam light. The diameters of the applied filaments are 2 mm, 2.2 mm and 5 mm. Thus, the light beam emitted by the fiber optic amplifier travels through the fiber optic filament, instead of just the printed channel, until it reaches the target point.

The fiber optic filaments present good flexibility and can be applied to all curvatures, as long as the bend radius is higher than 2mm.

The same experimental methodology was applied for the fiber optic filaments inside the circuits. The results obtained to the straight circuits are presented in Table 6.

Table 6. Sensor outputs for straight circuits with fiber filaments

Circuit	**w/o Target***	**w/ target***	**Δ***
1	1497 ± 2.0	4000 ± 0.0	**2503 ± 2.0**
2	1502 ± 3.0	4000 ± 0.0	**2498 ± 3.0**
3	1480 ± 1.0	4000 ± 0.0	**2520 ± 1.0**
4	1517 ± 2.0	4000 ± 0.0	**2483 ± 2.0**
5	1509 ± 2.0	4000 ± 0.0	**2491 ± 2.0**
6	1526 ± 2.0	4000 ± 0.0	**2447 ± 2.0**
7	1545 ± 2.0	4000 ± 0.0	**2455 ± 2.0**
8	1493 ± 2.0	4000 ± 0.0	**2507 ± 2.0**
9	1482 ± 2.0	4000 ± 0.0	**2518 ± 2.0**

The graph expressing the parameter Δ as a function of the geometric characteristics, diameter and length, of the straight circuits is presented in Figure 9.

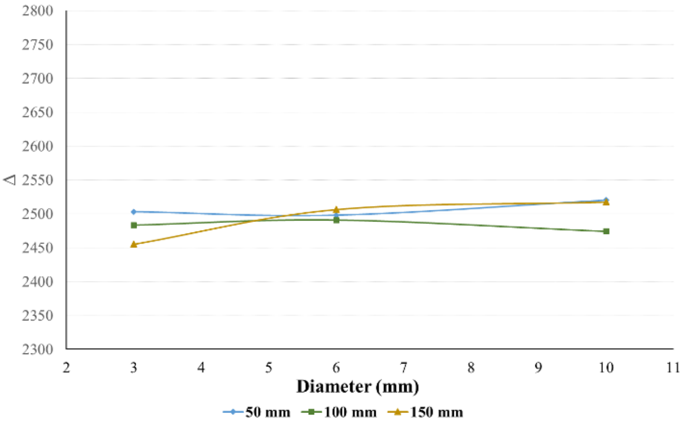


Figure 9. Graphic that expresses the obtained results with fiber optic filaments for straight circuits.

As shown in Figure 9 the results are roughly the same, which suggest that the parameter Δ is independent of the geometric characteristics.

For curved circuits the obtained results are shown in Table 7.

Table 7. Sensor outputs for curved circuits with fiber filaments

Circuit	**w/o Target***	**w/ target***	**Δ***
1	1567 ± 2.0	4000 ± 0.0	**2433 ± 2.0**
2	1602 ± 3.0	4000 ± 0.0	**2398 ± 3.0**
3	1574 ± 3.0	4000 ± 0.0	**2426 ± 3.0**
4	1631 ± 3.0	4000 ± 0.0	**2368 ± 3.0**
5	1620 ± 4.0	4000 ± 0.0	**2380 ± 4.0**
6	1536 ± 2.0	4000 ± 0.0	**2464 ± 2.0**
7	1604 ± 4.0	4000 ± 0.0	**2396 ± 4.0**
8	1589 ± 2.0	4000 ± 0.0	**2411 ± 2.0**
9	1581 ± 3.0	4000 ± 0.0	**2418 ± 3.0**

The graph expressing the parameter Δ as a function of the geometric characteristics of the straight circuits is presented in Figure 10.

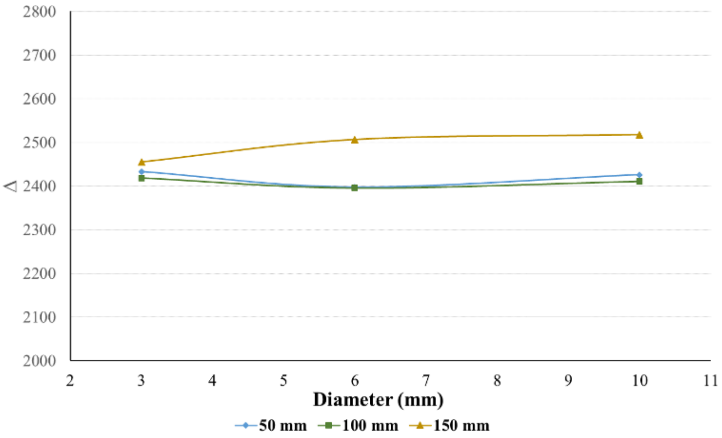


Figure 10. Graphic that expresses the obtained results with fiber optic filament for curved circuits.

As shown in Figure 10, the results follow the same trend of the straight curved circuits where the parameter Δ is independent of the geometric characteristics.

4 DISCUSSION OF RESULTS

The experimental results show that is possible detect the presence of a product using a light beam which goes through the printed channels of additive manufactured tools.

Regarding the straight circuits design, the signal emission and reception efficiency of the optic fiber system is closely related with the geometric characteristics of the printed channels. Short circuit lengths and large diameters present better results. Depending on the type and color of the material and the manufacturing quality of the process, a significant part of the light beam may be absorbed. As it is shown in

Table 4, the measured values are very low when compared with total sensor saturation value, which suggest that ABS ESD-7 parts produced by FDM process absorbs a lot of signal and, therefore, are not well-suited to this kind of applications. This becomes more evident with a look at the curved circuits results shown in Table 5. In this case, no signal is received by the optic sensor, which means that the light beam was completely absorbed by the circuit walls. Consequently, the part detection is no longer possible.

A simple, practical and cheap solution to improve significantly the results, in both straight and curved circuits, is to use optic fiber filaments inside the circuits. It is not possible to introduce an optical fiber filament inside circuits that have a bend radius less than 2 mm, which means that all circuits must be designed considering this limitation. In this work several bend radii were considered in the curved circuits and it is possible to conclude that, when optic fiber filaments are used, the radius of curvature along the circuits do not influence the feedback signal of the system.

5 CONCLUSION

This study presented a new optical sensing concept based in a 3D printing solution. The concept is based on the introduction of internal circuits in the assembly tools for transmission and routing of optical signals. The excellent results obtained in the experimental tests demonstrated that is possible to apply this concept on assembly tools by using optic fiber filaments.

The solution brings more flexibility to the sensing arrangement with clear industrial advantages. It also opens new possibilities for sensing standardization, simplify the electronic implementation and making maintenance and change-over operations much easier. In addition, this inexpensive solution exploits the potential of the additive manufacture to support the design of new assembly devices which can fulfill the requirements and expectations of the industry 4.0.

6. ACKNOWLEDGEMENTS

This work is supported by: *European Structural and Investment Funds* in the *FEDER* component, through the *Operational Competitiveness and Internationalization Programme* (COMPETE 2020) Project nº 002814; Funding Reference: POCI-01-0247-FEDER-002814” between Minho University and Bosch Braga, Portugal.

7. REFERENCES

- Gholamzadeh, B., & Nabovati, H. (2008). Fiber Optic Sensors. *International Journal of Electronics and Communication Engineering*. 6 (2), 1107-1117.
- Instrument Society of America. (1975). *Electrical Transducer Nomenclature and Terminology*.ANSI Standard MC6.1. Research Triangle Park, North Carolina: Instrument Society of America.
- KEYENCE. (2014). *Fibreoptic sensor – Selection examples and Countermeasures to avoid problems*.
- KEYENCE. (2015). *Sensor Basics – Understanding fundamental principles and features*. 8-12.
- Lee, J., Kao, H.A. & Yanh, S. (2014). Service innovation and smart analytics for Industry 4.0 and big data environment. *The 6th CIRP Conference on Industrial*. Ontario: Canada.
- Levy, G., Schindel, R., et al. (2003). Rapid Manufacturing and Rapid Tooling with Layer Manufacturing (LM) Technologies, State of the Art and Future Perspectives. *CIRP Annals—Manufacturing Technology*, 52(2), 589-609.
- McGrath, M.J., & Scanaill, C.N. (2013). *Sensor Technologies*. Spring Street, New Yotk: Apress Open.
- Rahman, M. A., & Aziz, F. A. (2010). Electrostatic discharge (ESD) improvement to reduce customer complaint. *Scientific Research and Essays*, 5 (11), 3003-3008.
- StrataSYS, D.M. (2016). *3D Printing JIGS & Fixtures for the Production Floor*. 9-11.
- Shingo, S. (1986). *Zero Quality Control: Source Inspection and the Poka-Yoke System*. Massachusetts: Productivity Press.
- Wong, K. V., & Hernadez, A. (2012). A Review of Additive Manufacturing. *ISRN Mechanical Engineering*, 2012, 1-10.