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Automated control of the laser welding process of heart valve scaffolds

DOI 10.1515/cdbme-2016-0067

Abstract: Using the electrospinning process the geometry of a heart valve is not replicable by just one manufacturing process. To produce heart valve scaffolds the heart valve leaflets and the vessel have to be produced in separated spinning processes. For the final product of a heart valve they have to be mated afterwards. In this work an already existing three-axes laser was enhanced to laser weld those scaffolds. The automation control software is based on the robot operating system (ROS). The mechatronically control is done by an Arduino Mega. A graphical user interface (GUI) is written with Python and Kivy.

Keywords: automation; electrospinning; heart valve; Kivy; laser; ROS; scaffold.

1 Introduction

Tissue engineering became a growing field of research over the past years. The older the humans get the higher is the need for replacement of damaged tissue. It is not possible to cover the demand by donated tissue or organs with transplantation [1]. This leads to the idea of growing artificial tissue, e.g. heart valves or bone tissue, *in vitro* and implant them into the patient [2]. Therefore a scaffold is necessary to mimicry the extra cellular matrix (ECM) and support the cells during growth [1]. Electrospinning is a very suitable method to produce highly porous scaffolds for tissue engineering that resemble the ECM (Figure 1). It utilizes high voltages to form fibers of nanometer scaled diameters from a melt or a polymer solution (Figure 2) [4]. The fibers are as a scaffold deposited on a collector and can then be used for tissue engineering [3].

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The aortic and pulmonary heart valves, which suffer the most diseases, have a quite complex geometry (Figure 3) [6]. Using the electrospinning process this geometry is not replicable by just one manufacturing process. Therefore the heart valve leaflets and the vessel have to be produced in separated spinning processes. For the final product of a heart valve they have to be mated afterwards. Possible joining technologies could be glueing, sewing or laser welding. An existing 3-axis CO_2-laser at the Institute of Multiphase Processes (IMP) was enhanced, both mechanical and electrical, to be able to laser weld the heart valves.

2 The IMP lasercutter

The workspace has enough room for work pieces of 680 mm – 280 mm – 150 mm. The work piece can be placed on a height-adjustable table. The laser jet is placed on the so called laser wagon, which can be moved in two axes. The third axis is the height-adjustable table. The laser beam will be deflected by three mirrors and afterwords focused by the laser jet (Figure 4). The laser specifications are listed in Table 1. The design of the lasercutter allows to laser two-dimensional contours. For the laser welding of the heart valves another (rotational) axis is needed.

3 The rotation-device

3.1 Mechanical design

To implement the necessary rotation of the collector the so called rotation-device is designed. It provides the possibility to mount the IMP collectors. Two stepper motors allow both a rotational and a translational movement by a threaded spindle. A home position is generated via two light barriers (Figure 5). This is fundamental for a automated welding process. The rotation-device and the three additional axes of the lasercutter allow a three-dimensional laser welding of the heart valves.

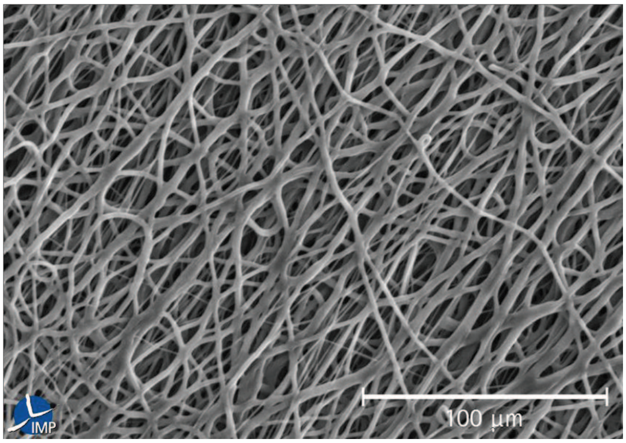

Figure 1: Highly porous fibrous scaffold electrospun at the institute of multiphase processes.

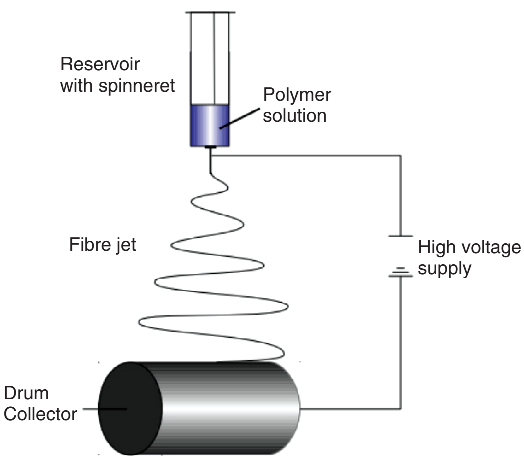

Figure 2: Electrospinning setup with reservoir, spinneret, drum collector, and high voltage supply [3].

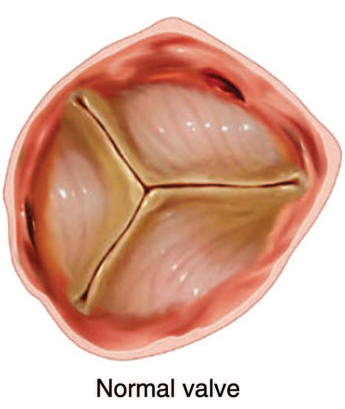

Figure 3: The geometry of a aortic heart valve [5].

3.2 Hardware

The rotation devices is controlled by an Arduino Mega which is responsible for driving the stepper motors, culling the light barriers and firing the laser. Two self-etched boards allow a user friendly assembly and replacement of the hardware components. To keep up the original way of working with the lasercutter one of them is designed to carry relays which cut of all connections of the lasercutter board when the Arduino gets connected to a USB-port (Figure 6). Instead all connections are transmitted to the Arduino and the two self-etched boards.

3.3 Software

The robot operating system (ROS) is the basis of the control software. It allows a modular program structure and is responsible for the communication between the sub-programs. As mentioned above the mechatronically control is done by the Arduino Mega. A graphical user interface (GUI) is written with Python and Kivy. The user can load the welding-track into the program and set all the necessary laser settings. The GUI transmits all those information via the ROS Network to the Arduino which controls the laser process afterwards.

4 Computer control for the laser and the rotation-device

The whole computer control is based on the ROS which is designed to control robots on the first hand. It's ability to build a really modular software structure is the reason why it is used for this application. Unique processes are outsourced in so called nodes (sub-programs) to increase the programs modularity. The nodes can communicate with each other using a topic based messaging system. Thereupon a graphical user interface is build.

The first tab called “Homing” is used to move the lasercutter and the rotation device back into their home-positions. The user can correct the home-position of all axes stepwise in case a new or slightly different collector is used. In addition a laser test beam can be triggered. If a user needs help he can access a help section in this first tab. After setting the home-position the user can switch into the next tab called path planning. He has to upload the welding track now. This is done by using a basic csv-file which lists all the trackpoints. A trackpoint is defined by its height (translational) and its angle (rotational movement) (Table 2).

After uploading the csv-file a preview graphic is calculated and displayed. The user can now decide between a continuous and spot-welding. The program will switch

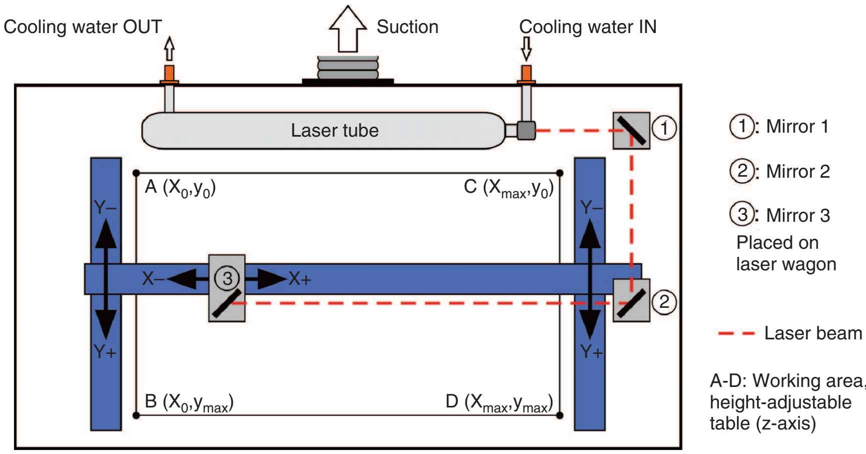

Figure 4: Schematic of the lasercutter, view from above [7].

Table 1: Laser specifications.

Specifications	**40 W Laser**
Wavelength (nm)	10,600
Laser beam diameter (nm)	1,95
Power (W)	40
Firing voltage (kV)	22
Operating voltage (kV)	15
Nominal current (mA)	18
Tube diameter (mm)	55
Tube length (mm)	700
Power stability (%)	±5

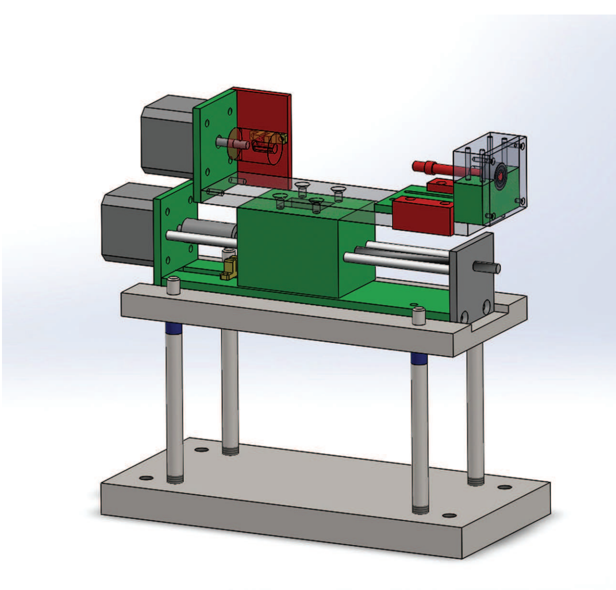

Figure 5: The rotation-device. Design drawing of the rotation device, green parts have been modified, red parts are new.

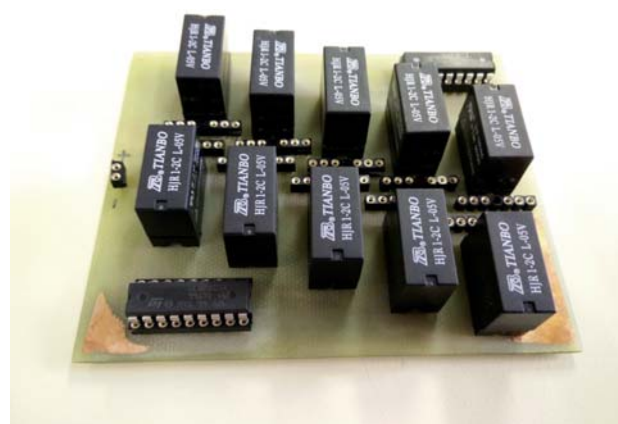

Figure 6: The relays board keeps up the original way of working with the lasercutter.

Table 2: A sample csv-file for laser welding a heart valve leaflet.

0	,	0
1.53	,	0.174
3.61	,	0.349
5.57	,	0.523
7.16	,	0.698
8.14	,	0.872
8.46	,	1.047
8.14	,	1.221
7.16	,	1.396
5.57	,	1.570
3.61	,	1.745
1.53	,	1.919
0	,	2.094

automatically to the corresponding tab. In each of them the user has to specify the laser settings such as laser-power, exposure time (spot-welding) or velocity (continuous welding). Subsequently the user can transmit these

Table 3: Test parameters for spot welding heart valve scaffolds. Laser defocus of 10 mm.

Laser power (W)	Exposure time (ms)
3.0	200–1600
3.2	200–1600
3.3	100–700
3.5	75–300
3.7	50–400
3.8	100–350
4.0	50–275

Figure 7: The laser welded heart valve scaffold, view from above.

information to the Arduino Mega which is done by different ROS messages. The program switches into the last tab where the welding process can be launched. A check list makes the user aware of common handling mistakes.

5 Experiments

The laser settings in Table 3 have been tested for spot welding the heart valve scaffolds. Every scaffold was checked visually and manual mechanically. The best test results were achieved by a laser power of 3.5 W and an exposure time of 200–300 ms. Figure 7 and 8 show a final laser welded heart valve scaffold. The first mechanical tests indicate that the weld spots connect the heart valve components permanently. The fibre mats are torn apart way before the weld spots.

6 Conclusion

By means of the design, the hardware and the software of the newly designed rotation device and the lasercutter

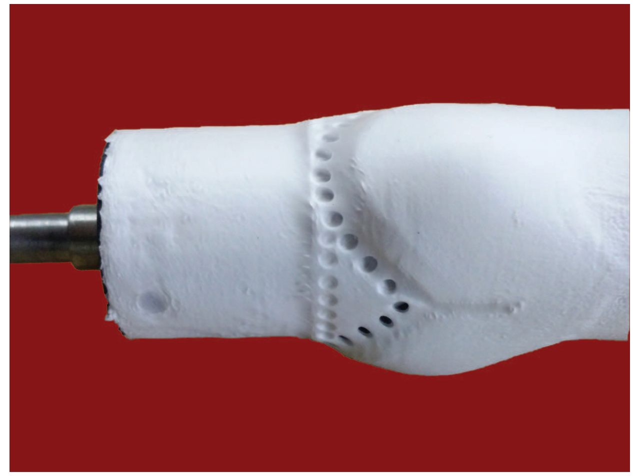

Figure 8: The laser welded heart valve scaffold, view from side.

it is possible to laser weld heart valve scaffolds. Within this thesis expedient development regarding the construction of the lasercutter and the rotation device could be achieved. The laser welding process was integrated into the whole production process of a heart valve scaffold by electrical hardware and a specifically designed and evaluated software. As part of a test series the components were approved for suitability for use. Process parameters were evaluated for different applications.

Acknowledgment: I would like to thank my mentors Anna Lena Hoheisel, Marc Müller and Holger Zernetsch for their support over the years and Prof. B. Glasmacher for making this study possible. Furthermore I want to give a shout-out to Andre Papke and his workshop crew for manufacturing all the mechanical components.

Author's Statement
Research funding: The author state no funding involved. Conflict of interest: Authors state no conflict of interest. Material and Methods: Informed consent: Informed consent has been obtained from all individuals included in this study. Ethical approval: The conducted research is not related to either human or animal use.

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