Chassis Geometry Optimization based on 3D-scans of the Ergonomic Driving Position

Paweł Żur, Andrzej Baier, and Alicja Kołodziej
Department of Mechanical Engineering, Silesian University of Technology, Gliwice, Poland
Email: pawel.zur@gmail.com, andrzej.baier@polsl.pl, alickol96@gmail.com

***Abstract*— The paper presents the process of modifying the chassis of an electric vehicle of the Silesian Greenpower team based on 3D scanning technology. Principles of 3D scanning technology using Kinect 3D have been described, as well as preparation of the scans of the driver to optimize the geometry of the chassis. The driver has been scanned in various driving positions in order to establish the most ergonomic one. The geometry of the chassis has been modified according to the scanned convenient driving position and the newest technical regulations. The research allowed to improve the vehicle's behavior on the corners, to reduce the frontal cross-section analyze the mass center of the driver.**

***Index Terms*—3D-scanning, chassis design, electric vehicle, ergonomics, human body scanning, Kinect 3D,**

I. Introduction

A. Principles of 3D-scanning

Nowadays many designs, graphics, animations. and applications require realistic models of the human body. Such models can be obtained by adopting 3D scanning technologies. Scanning devices using structured light or laser scan often are very expensive and require expert knowledge of the device operation [1][2].

There are other ways of obtaining a 3D-scan of an object such as photogrammetry, whereby combining many pictures taken from different angles of an object. However, this method causes problems, when the texture of the objects is not rough enough for the computer program to distinguish characteristic points [3].

3D scanning is based on a triangulation mechanism. Triangulation works on the basic trigonometric principle - three triangle measurements are made, which are then used to calculate the remaining dimensions needed. If we take a photo of the object from two perspectives, we will receive two angular measurements (based on the position of the object in the camera photos). Also knowing the distance between two cameras - two angles and one side is known. This allows calculating the distance to the item.

New kind of devices are becoming more popular and accessible – Kinect 3D scanners for Xbox 360 (Fig. 1). The device registers RGB images with depth-information needed to create a 3D model [1]. The device has a variety of advantages over existing 3D scanning technologies: It can measure depth and color simultaneously, which makes it very suitable for fast object scanning. The depth sensor does not interfere with the scene in the visual spectrum.

Finally, its usage is not different from a video camera; end-users intuitively deal with it and are able to collect data with only a few explanations [4]. However, the Kinect has a low resolution, so it may be difficult to register small image details, it is advised to use it for the general shape of the human body scanning.

Figure 1. Kinect 3D scanner [5]

In contrast to Time of Flight (ToF) cameras, the Kinect provides rather clean data of relatively low random noise and systematic error. With such data, local rigid alignment techniques, such as Iterative Closest Points (ICP) and its variants or global rigid alignment techniques, can be used to register the scans against each other. Then, a merging procedure can be applied to build a single 3D mesh [4].

To scan a full human shape, Kinect should be put around 3 meters away from the body. The scanned object should not be rotating. Instead, the scanner should move around the object. The Kinect 3D will get the best results when worked with the speed of 10-20 mm/s.[6]

So far, Kinect cameras have not been used as sensors for 3D object scanning, even though they have a variety of advantages over the above technologies. This is mainly due to the high noise level which makes direct application of established filtering and alignment techniques infeasible [4].

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B. Greenpower Electric Vehicles

Silesian Greenpower is a students' project of which aim is to design and build an electric race car. There are two main components of the car which are designed in Siemens NX software: the aluminum chassis and the carbon-fiber bodywork. Shape and dimensions of some elements of the chassis (shown in Fig. 2) such as roll bar are specified by the regulations of Greenpower formula races [7]. The shape of the body is unrestricted and each of the teams designs it on their own. In this particular case, aerodynamic drag represents 70 percent of all the frictions that are the consequences of car motion [7][8].

Each of the electric cars taking part in Greenpower races is equipped with the same electric motor. The motor is powered by two 12 V batteries with a capacity of 36 Ah each. The main goal is to drive as many laps as possible in a certain amount of time [9][10].

Based on the results obtained in the analysis of new solutions, constructions, and parts are being applied in the vehicle. Each year adjustments have to been made in order to make a car compliant with new regulations [11].

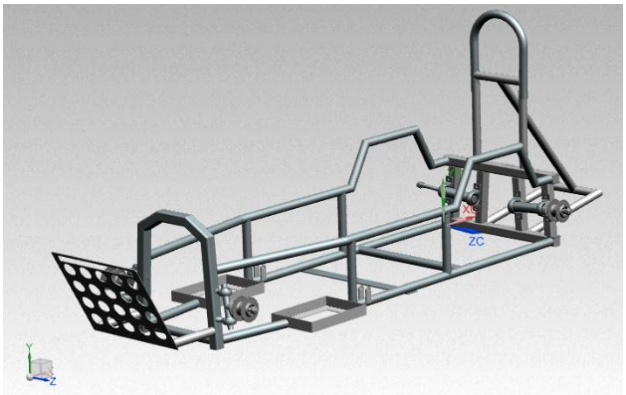

Figure 2. Chassis of Silesian Greenpower's vehicle

This year's new technical regulations require the chassis to have a height above the driver's elbow. Previous chassis allowed the driver to rest the elbows on the bars, so anew chassis had to be designed. This modification allowed to change also other aspects of the car, which have been further described in the paper.

II. Preparation of the Scans

3D scanning technology was used to improve the geometry of the new frame. In this case, Kinect for Xbox 360 was used.

The device has two cameras, and the depth sensor which consists of an infrared laser projector combined with a monochrome CMOS sensor, which captures video data in 3D under any ambient light conditions, The first of the cameras is a standard RGB video camera with a resolution of 640x480, used for processing video image (including face recognition) and applying colors and textures to virtual objects.

The other is part of the sensor subsystem that returns depth information. This subsystem works by measuring the distance with structured light. An infrared sensor displays in front of the camera a cloud of points, the positions of which are registered by the camera with an infrared filter.

The obtained resolution of depth information from the camera is 300x200 and further, it is interpolated to the resolution of the video camera (640x480). The range of operation of the distance sensor is 0.4-6.5 m. Information about the distance in all points gives the possibility to programmatically read e.g. a human figure and detect his gestures.

The use of the structured light method allows flawless operation of the sensor only in indoor spaces - the sensor is sensitive to excessive sunlight.

The software used to process the information from the camera was the ReconstructMe program (Fig. 3), which allows creating 3D scans in real-time. The software allows to control such parameters as volume size of the performed scan and its position – whether it is centered around the sensor or always in front of the sensor. The program also allowed to adjust the offset position of the sensor in front of the scanned object. Other parameters adjusted in software were start delay and scan duration. The scan delay option allowed the scan operator to properly set the scanner in position before scanning began.

When the scanning speed was incorrect, the software would stop the scanning process and allow to move the camera back to the last scanned point. Then the scan could be continued without starting over each time the scanning speed changes.

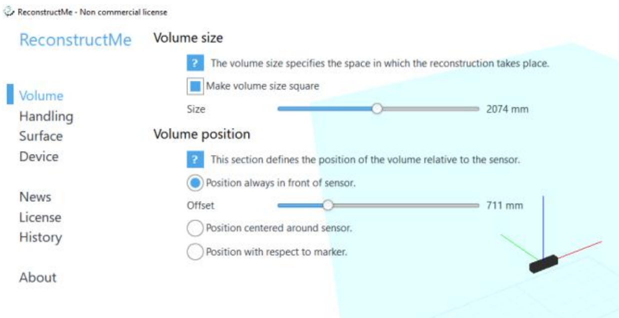

Figure 3. Program view

Some of the obtained scans have been presented below (Fig. 4), which have been further processed to remove unnecessary elements (Fig. 5). The driver has been scanned in three different environments. The first scan was the scan only of the driver in ergonomic driving position. The second scan was a driver in ergonomic driving position in bear chassis. The third scan was the scan of the driver in the actual car without the bodywork on. The last scan shows the position, which is now prohibited by the regulations – with the elbows resting on the chassis.

Scans have been obtained as .STL files. The .STL format only approximates the geometry (outer surface) using triangles. Each of them is described by three points and normal to the surface defining the direction of the existence of the solid (so the triangle has internal and external surfaces). The structure of the file itself is a list of triangles, described by means of the spatial orientation of points, i.e. locations in three axes (x, y, z) of each of them and the direction of the previously mentioned vector. Each triangle has its "normal", i.e. a vector set at right angles to the surface with a turn according to the right-hand rule; these are concepts from mechanics, implying two sides of the triangle as surfaces - one of the surfaces is thus positive and the other negative.

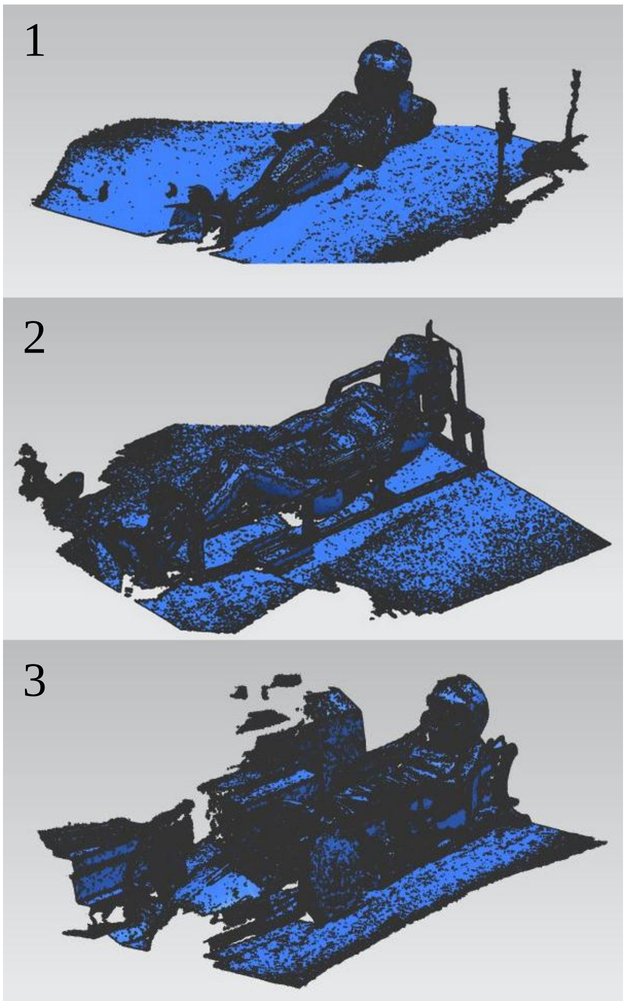

Figure 4. Raw 3D-scans (from the top: 1, 2 3) – before processing

It can be seen, that raw scans have a lot of noise and some elements of the background, which are unnecessary for further analysis. The obtained .STL scans have been processed in Siemens NX software with reverse engineering module. The reverse engineering module enables the user to process .STL files i.e. allow trimming unnecessary background. It also allows smoothing the surface of the scan which is composed of the triangular mesh. Another application of the module was to fill in holes in the obtained model, holes have formed in places the scanner could not reach.

In the processed images the driver's position is better visible (Fig. 5). Although scans 2 and 3 show the driver's actual position in a current car and current chassis, scan 1 allows to design and build new chassis, which will not only comply with new regulations but will also be more ergonomic, because the optimal driving position has been established.

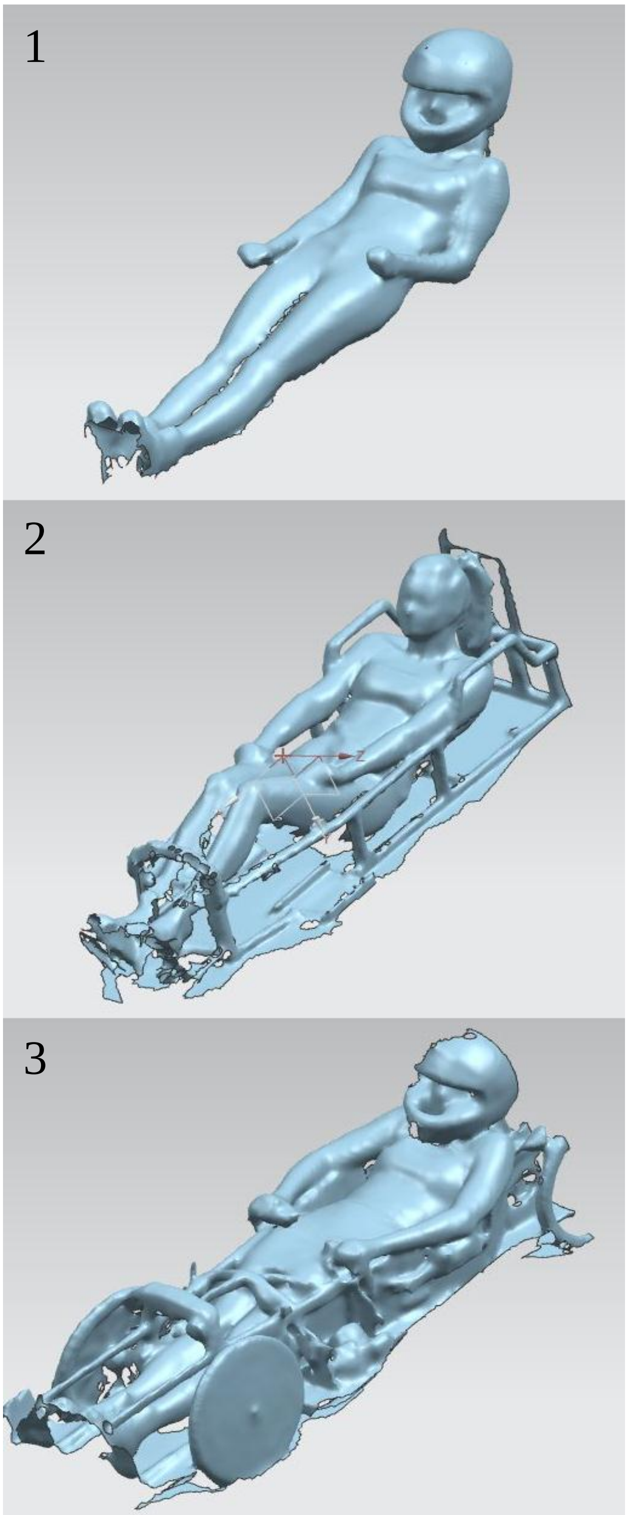

Figure 5. Processed 3D-scans (from the top: 1, 2, 3)

In the 3rd scan, the driver was placed in the current chassis. The scan has revealed the fact that the current design does not meet the requirements introduced in the latest competition regulations of the Greenpower league (Fig. 6). The driver must have placed elbows on the chassis (highlighted with red circle in the picture below), due to lack of additional space inside it and because of the position of the steering arms.

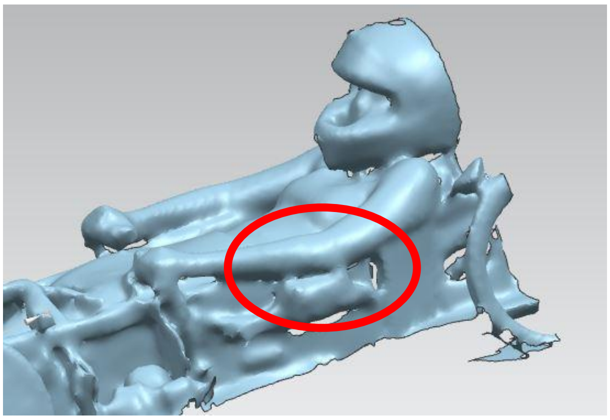

Figure 6. Scan of the driver in chassis before optimization

Scan number 1 was chosen for further work because the driver's position was the most ergonomic, which is important during the one hour race. The driver should be in a convenient position to stay focused on driving the car throughout the entire race. Also, the fact, that the scan represents only the driver argues for designing a new chassis around this scan. New chassis design would also allow optimizing the currently applied steering system and position of batteries, which was expected to result in improving the bodywork, therefore achieving enhanced aerodynamic properties of the car.

III. Modification of the Chassis

The structure has undergone a number of modifications. The first stage was changing the axle base. Tests not covered in this article have shown, that shorter axle base reduces the centrifugal force generated in a curve during a race. In order to make such a modification, it was necessary to change the mounting place of the batteries. They were moved in front of the front axle of the vehicle. This gave the opportunity to reduce the axle base by more than 130 mm. With the previously presented analysis of a 3D scan, the transverse spacing of the batteries was also reduced, so that the vehicle's beak could have the smallest frontal cross-section.

The modifications introduced into the design compared with the chassis before optimization are shown in Fig. 7. It can be seen that front wheels have switched places with battery mounting.

In the next design phase, the aluminium chassis was replaced with a chassis made of plywood. It was decided to take this step due to the fact that it is easier to connect individual parts, the ability to independently modify parts of the chassis, as well as greater elasticity of the material itself. Also, further modifications of the chassis will be easier due to the fact, that they can be done in a workshop with widely available tools, on contrary to welding aluminium parts which require an expert technician and professional equipment.

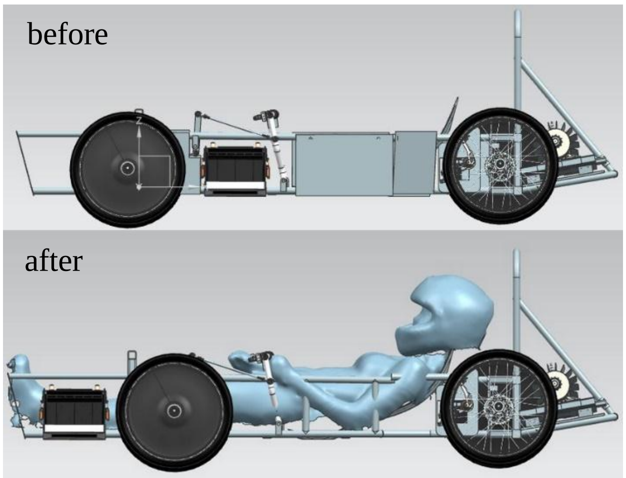

Figure 7. The chassis before (top) and after (bottom) axle base shift

An important assumption during design was to use the maximum of available space under the bodywork. The chassis before modification is shown in the Fig. 8 below. With red arrows have been marked critical spots where additional space inside the chassis was needed.

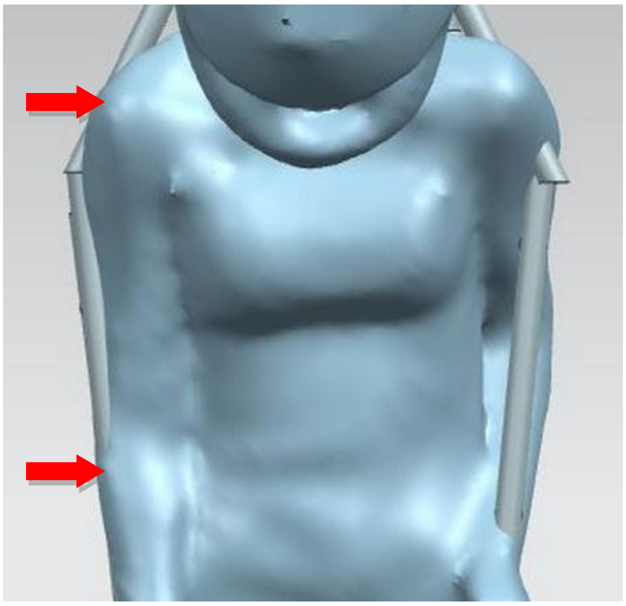

Figure 8. The problematic chassis' points before modification

The chassis' critical points after optimization have been shown in Fig. 9 below. With green are marked points where additional space for the driver has been achieved. This modification allowed to make the chassis wider for a convenient driving position without widening the bodywork. The additional space inside the driver's cell allowed to fit the arms and shoulders of the driver inside the chassis, and not as before – on the chassis. This change improves the safety of the driver too.

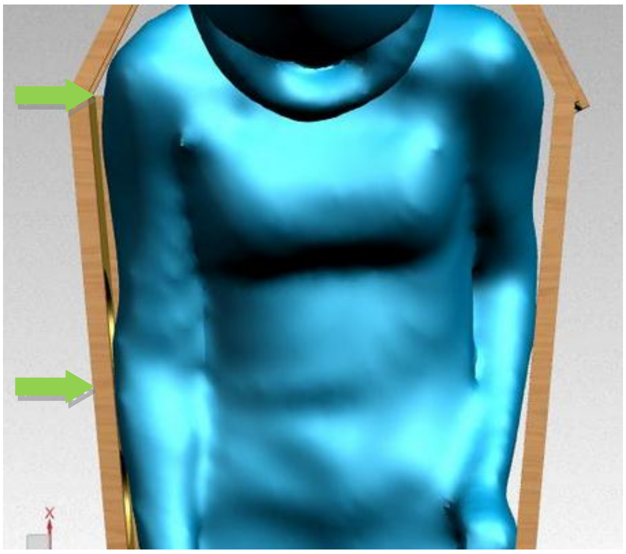

Figure 9. The chassis after modification

At the time of writing, the bodywork is still in the design phase, but a 10% reduction in the frontal cross-section is assumed due to modifying the geometry of the chassis after design optimization using 3D scanning techniques. In this case, the aerodynamic plays a major role, so even a slight reduction in the frontal cross-section may significantly affect the C_d drag coefficient. The complete chassis has been presented in Fig. 10. Holes in the panels were applied in order to reduce the mass of the whole structure. Thanks to applying the newest manufacturing technologies of the plywood chassis, the new structure will weight approximately the same as the aluminum model. The durability of the chassis will not worse when applying plywood material.

In the new chassis a newly designed driver's seat will be applied. Its weight has been reduced thanks to applying innovative 3D printing of ABS optimization techniques. The weight of the seat has been reduced by 50% and printing time by 33% [12].

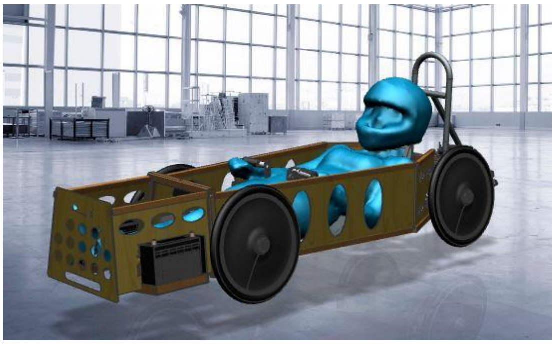

Figure 10. The chassis after applied modifications

IV. Center of Mass Analysis

The last part of the research was the analysis of the mass center of the driver in the ergonomic driving position in the Silesian Greenpower's electric vehicle.

The driver's center of gravity was determined on the basis of an analysis of the percentage of individual body parts. Given the driver's weight, the weight of single body parts could be calculated. The next step was the calculation of the distance between the ends of the joints and the selected reference point. In this way, the centers of gravity of individual body parts were determined, followed by the center of gravity for the whole body of the driver in a given position (Fig 11). Joints have been marked with blue dots, the mass center of the individual body parts with green dots, and with a red dot the mass center of the whole body.

The above analysis has revealed the fact, that the mass center point is slightly moved towards the front axle of the car. In further design phase, it will be taken into account in a way, which will result in moving the mass center point back towards the rear axle of the vehicle. This operation will result in better overall weight distribution – moving the driver a bit backward will balance the weight of batteries, which is approximately 11 kg each.

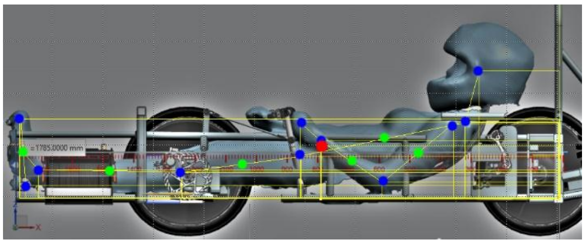

Figure 11. Analysis of mass center of the driver

V. Conclusions

Obtained 3D-model of the driver in the ergonomic the driving position allowed to improve the geometry of the chassis. The driver will be able to take a comfortable position throughout the race, which will result in a better focus on the track situation.

Modifications allowed reducing the frontal cross-section by 10% compared to previous cars while gaining space for the driver inside of the car. This will significantly improve the car's aerodynamics. Given the fact that aerodynamics play a significant role in drag force during the race in this class of cars, this will significantly improve the performance of the car.

Also, the axle base has been shortened, which is supposed to improve the vehicle's behaviour on the corners during the race. It is expected that the forces adversely affecting the vehicle will be reduced, and thus lower electricity consumption during the race.

The 3D scans allowed to define the mass centre of the driver. This revealed a shift in the center of mass towards the front axle, which is not expected.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Paweł Żur conducted the research and analyzed the data; Alicja Kołodziej analyzed the data and wrote the paper; Andrzej Baier supervised the research and edited the paper; all authors had approved the final version.

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Paweł Żur, B.Eng., student, member of Silesian Greenpower team since 2015. He has been working as main project manager since 2017. His research topics are focused on mechanical engineering, specifically 3D printing, modelling and control systems. Studied at Silesian University of Technology in Gliwice, Poland. Currently working as Young Project Manager at Airtificial Intelligent Robots Poland. Co-author of publications: Studies on optimization of 3D-printed elements applied in Silesian Greenpower vehicle, Telemetric System for Silesian Greenpower's Vehicle, Finite Elements Analysis of PLA 3D-printed Elements and Shape Optimization and others.