Conversion of a Lada 2106 car into a rally racing car

Ferenc Zombori, Sándor Forrai, István Péter Szabó
University of Szeged Faculty of Engineering
Moszkvai körút 9. HU6729 Szeged, Hungary

pszi@mk.u-szeged.hu

Abstract. The subject of this publication is a rally car designed as a diploma thesis and later produced. G-Sport Ltd. designs and manufactures racing car bodies, chassis components and all other motorsport related components for both the domestic and international markets. The aim was to design the Lada 2106 race car to accept a Ford Mk2 suspension, a Toyota 4A-GE engine and other parts that would enable it to compete in official FIA rally events. The work was done using a 3D scanner. The first phase involved creating 3D models of the body, engine, gearbox and other components, while checking their dimensional accuracy. Then, the custom parts of the car, including the roll cage, had to be designed to meet FIA specifications. This article describes the steps of the 3D scanning method, how the scans are processed, oriented, assembled correctly, and how the deformations of the body frame were detected. In addition, the typical problems encountered during 3D scanning of large objects and their generally applicable solutions are shown. The components of the drivetrain and components of own custom design are also described.

1. History

G-Sport Ltd. designs and manufactures racing car bodies, chassis parts and all other parts related to motorsports for both domestic and international markets. The design and manufacture of a prototype car in 3D was under preparation. The plan was to redesign a 2101 Lada body to adopt a Ford Mk2 chassis, a Toyota 4A-GE engine and other parts, which would enable it to compete in an official FIA rally race.

3D scanning is used in the automotive industry in many areas, especially for modifying vehicles, e.g., in the manufacture of sightseeing buses or racing cars [1]. Improving aerodynamics can be one of the goals when making racing cars. 3D scanning is an important tool for the IndyCar field to create a digital model of previous racing cars [2]. The method is also used successfully in Formula 3 racing cars. An Artec Leo scanner was used to scan the DallaraF399/01 race car [3]. These scanned models can be used to verify the original CAD models; an important starting point for further development.

Scanning a car can run into several difficulties. This can be caused, for example, by shiny, smooth surfaces. Glass surfaces should be covered or temporarily painted, glossy surfaces should be patterned [4], or other methods detailed in this publication should be used to assist the process. Among Artec's scanners are those that are specifically designed to scan large objects, yet are accurate enough for the job [5] [6]. They are very effective tools when rebuilding cars, significantly speeding up the design
process. This is true not only for body modifications but also for engine, driveline, or chassis modifications [7] [8].

2. Requirements for the racing car
The set of prototype cars is called the group P. This may include cars that combine the features of numerous cars. In Hungary, the MNASZ (Hungarian National Motorsport Association) has issued a regulation for the existing FIA (International Automobile Federation) regulations, entitled “Specific National Rules for Group P Vehicles”. In this document, it defines 3 subcategories for prototype cars: P - rally, PH - Rally Hobby-car, PT - Terrain Rally [9]. Article 253 of the FIA Appendix is a set of rules issued by the FIA that contains rules for safety equipment for cars in groups N, A, R-GT. The appendix deals in detail with the roll cage and its design. In accordance with the rules, roll cages could receive ASN (National Automobile Association) homologation and must be marked with an identification plate, which must include the manufacturer's name and a unique serial number.

The roll cage is a tubular structure inside the passenger compartment, that is installed close to the chassis and is intended to reduce the deformation of the body in the event of an impact.

3D scanning is an opportunity for reverse modeling of 3D elements and components, in which information about more complex components that are difficult to model, such as an engine block, steering knuckle, etc. is obtained.

During the work, several such recordings had to be made about the different parts, which can be basically divided into two groups. The first group includes the chassis itself, which does not have to move, its position can be considered fixed. The second group includes parts that can be considered more general, such as the steering gear.

3. 3D scanning of the 2101 chassis
An Artec EVA 3D scanner was used for the work [10]. The design of the car required the entire chassis (Figure 1) in order to design the fitting parts, for example: the roll bar, the shock towers, and to visualize the relative position of the individual parts, such as the engine position in chassis.

![Figure 1. A 2101 chassis on a rotisserie](image)

The chassis was sandblasted so that the surfaces were non-reflective, which was essential since bright surfaces could not be scanned.
An internal shot was taken that included the chassis viewed from the passenger compartment, to which the engine compartment also belongs viewed from above, as well as the luggage compartment also viewed from above.

This interior room was divided into 1 meter x 1 meter sections. Such large areas were scanned simultaneously so that there was always an overlap between the shots.

The device is able to scan much larger areas in one piece, however, in this case the accuracy of the images drastically reduces. This 1 meter x 1 meter raster is an experimental value with an accuracy of ± 0.2 mm at this size.

After the recordings have been made, the magnitude of the error number gives a preliminary indication of the quality of each scan.

The roof, pillars A and B were more difficult to scan. The roof was only scanned from the inside, as it only encountered matching parts from the inner side. EVA loses its orientation in space on large flat surfaces, as a result, the recording becomes unusable. For this reason, magnets were placed on the flat plate of the roof, which served as reference points for EVA. The roof was a big challenge, even with the magnets shown in Figure 10; the shots weren’t always good, so a piece of clothing was placed on both sides of the scanned areas (Figure 2). Its irregular geometry ensured that EVA did not lose its orientation.

Scanning pillars A and B was a problem, as the scanned parts were extremely narrow, thus EVA lost its orientation. To eliminate this, the chassis was turned to its side and extra objects were placed next to pillars A and B, therefore increasing the size of the scanned surfaces.

Before scanning the lower part of the chassis, it had to be considered which points would be the ones that would be used in the future. Such points are, for example, the front cradle points and the rear trailing arm connection points. Screws were tightened to these points. That is how they were visible on the shots. Images of their axis lines were taken later (Figure 2). Scanning was performed in this case too as it was described above.

4. Processing and compilation of the recordings of the 2101 chassis

The scan was followed by the processing of the recordings, which was done in Artec Studio. 3. Different algorithms had to be run on each recording to get the mesh files with the final size and resolution. In the first step, algorithms had to be run, which fine-tuned the size and position of the recordings (Rought serial registration, Fine registration, Global registration).

The software is able to correct 5-7 mm slips, but unable to correct larger ones, such shots are useless (Figure 3).
In the second step, the algorithm that cleans the edges and contours of the recordings and eliminates the disturbances on the surface of the recordings (Outlier removal) was run. The last step was to run the “Fusion” algorithm. This finalizes the recording, which “fuses” the images into one layer. The first algorithm, based on the orientation data, arranges these images in the right place, the second algorithm cleans the surfaces, removes disturbances, and the third one averages these images into one “image”.

After cleaning, 1m x 1m processed shots were created. The next step was to make a final scan out of these shots. 2 recordings can be composed at the same time. The origin of the first recording, to which other recordings are joined, will be the reference origin. While joining the recordings, reference points are being looked for on the images (Fig. 5). Having joined all the recordings together, the “Registration” and “Fusion” algorithms had to be run again, which re-arranged and averaged the individual recordings. The last step was to examine the dimensional accuracy of the whole recording in relation to reality.
At this point, point pairs were also being looked for that were well measurable from each other. Special attention was paid to critical locations during the work, such as the distance between the front spars, and the distance between the inner sill edge and the roof (Figure 6).

The mesh recording of the 2101 chassis has been completed, which consists of 2 main parts as described above. They are “Internal Recording” and “External Recording.” In order to perform substantive technical work with any mesh, orientation needs to be executed on them.

In each case, the orientation was performed in SolidWorks, in a module called SolidWorks for Geomagic. If possible, adjustments must be done to those points on the chassis, whose position is clear and well recognizable. Examples of such points on the chassis are the front cradle points, rear cradle points, trailing arm connection points, etc.

By arrangement, the origin had to be placed in the middle of the back points of the first cradle. During the scanning, screws were tightened into the first cradle points. Screws were put into the trailing arm
connection points as well. With the module called Geomagic, a plane was recorded on the bearing surface of the points of the first cradle. Subsequently, the axis lines of the screws, which were screwed into these points, were recorded too in such a way that in the recording it was specified, that these axis lines had to be perpendicular to the previously recorded bearing plane. The same process was done at the trailing arm connection points on the rear of the chassis. As a result, 4 points were obtained on the chassis. In a 3D sketch, the first two points and the back two points were connected. The centers of these lines defined the center plane of the car.

Before scanning the chassis, it was found out that the right front of the car could have been damaged in the past because there were traces of repair work there. The spars were examined in the mesh, and it became clear that they were significantly twisted.

5. Engine scan

The Artec EVA 3D scanner was also used to scan the engine. The engine was scanned together with the gearbox housing. With the help of colleagues, the gearbox housing and the structure of the clutch was removed from the engine. Pictures about it were taken in this form. This was necessary because it made the flywheel visible; the significance of which will be explained during the orientation. The engine will be adjusted into the chassis model along with the axis line of the crankshaft. One of the most important aspects was to be able to capture this axis line as accurately as possible. This is why the flywheel was needed, because the axis line of the crankshaft could be defined by using its cylindrical surface (Figure 7). From the polygons marked in red, the system calculates the axis line which was specified to be perpendicular to Plane1 recorded in the rear plane of the flywheel.

![Figure 7. Recording of the axis line of the Toyota engine main shaft based on mesh](image)

The placement of the engine and transmission unit was emphasized in terms of positioning the largest mass in the car, which was very important for the final center of gravity. It had to be placed as low and as far back as possible. In a suspended position, it was examined what the lowest position of the car would be to the ground and then its height was adjusted by leaving a safety distance. The other essential matter was to keep the engine, transmission, and its environment repairable with enough space to access individual parts even in competitive conditions.
6. Rear axle orientation
The orientation of the rear axle was relatively simple due to the nice regular surfaces. The orientation started by recording the axis line of the output shafts by using Geomagic, so that essentially axis X was defined (Figure 9). Subsequently, the bearing plane of the hubs, the bearing plane of the output shafts and its axis line were recorded.

7. Floor Tunnel
The floor tunnel is also subject to the rules laid down by the FIA (International Automobile Federation). The entire tunnel is made of high-tensile Docol 800DP plane.
While drawing the floor tunnel, the plate was overhung everywhere on the chassis. The part was cut to the correct size with the connecting surfaces of the scanned chassis. The 3D scanning thus allowed the laser-cut and the bent plane metal parts to fit precisely, without further alignment.

The location of the seat had to be considered, while designing the floor tunnel. As far as the seating position was concerned, it was relevant that the passengers of the car sit as far back as possible in order for the center of gravity to be optimal. Another important aspect was that they could look out of the car and be able to position themselves comfortably. The seat and seat holder are also regulated by the FIA. The seat position had to be determined in such a way that the seat belts approach the seat at the angles specified in the rule [11].

The seat position was followed by the steering pillar and pedal position. To maintain the center of gravity, the steering wheel and pedals are adjustable, not the seat. The pedal was attached to a sliding rail.

8. Design of the roll cage

The roll cage in the car is a safety unit, therefore it is a highly regulated area by the FIA [3]. In relation to the weight and performance of the car, the size and tensile strength of each pipe are given. Among others, it is also given how much each node can be displaced due forces on the roll bar.

By mutual agreement, a roll cage with a rear main hoop was designed into the car. In accordance with the regulations, the recording of the specified load forces is shown in Figure 11.
Figure 11. Analysis of the vertical static load of the roll cage at the main hoop

Under vertical load, the displacement of the node of the main hoop under a force of 78.75 kN was 8.1 mm. The maximum allowable displacement here, can only be up to 50 mm. (FIA, 2017)

In the second analysis, the largest displacement according to the study was 2.5 mm under a force of 36.75 kN (Figure 12). Here, in this case, the maximum allowable displacement is 100 mm. (FIA, 2017)

Figure 12. Analysis of the horizontal static load of the roll cage at the main hoop

Test 3 was performed at the lateral half-roll bar. At this time, the magnitude of the load force and the dimensions of the pressure prism did not change compared to the previous test (Figure 13).
Figure 13. Static load test of the roll cage at the lateral half-roll bar

In this case, the maximum displacement was 2.49 mm under a force of 36.75 kN. As in the previous test, the maximum displacement could have been up to 100 mm. The results of the three tests produced a relatively low value, which can be best explained by the small weight of the car and the magnitude of the load force.

The designed roll cage passed the load test, did not prove to be too rigid, and complied with the values specified in the rule. This roll bar was made of 25CrMo4. The weight of the completed roll bar was 40.5 kg. While designing the roll bar, the material quality, and sizes of it were different to the parameters given in the FIA regulation. The primary reason for this was to lose weight. In order to prove our design, a version of the roll cage was made using the mechanical properties, bar sizes and node displacements specified in the rules. It is important that a minimum tensile strength of 350 \( \frac{N}{mm^2} \) is given in Appendix J. An ST35 (ANSI 1020) bar was used for this roll cage version with a tensile strength of 420 \( \frac{N}{mm^2} \).

9. Summary

Plans for a race car based on the Lada body have been completed. We used modern methods for the design. 3D scanning significantly facilitated the production of some parts, so no subsequent modifications were required. According to our plans, the build of the racing car is in progress. The custom body kit for the race car is currently being developed.
Figure 14. Interior of the racing car under construction

The results can be used when designing additional racing cars. A roll cage with sufficient strength but reduced weight is an advantage in competitions. The reverse engineering method, which uses a scanned body model, greatly simplifies the design and manufacturing process. It can be used to accurately detect previous body defects and the deformations they cause. Scanning the body in 3D is an unusual task, given that the large part contains relatively small, plate-thick dimensions, so the accuracy of the final result is determined by the accuracy of assembling each scanned part. The methods used for this purpose are also presented in the publication.

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