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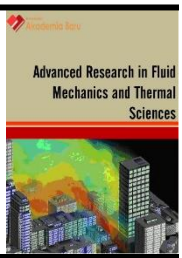

Reconstruction of 3D Models in Automotive Engineering Applications Using Close-Range Photogrammetry Approach

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ABSTRACT

The use of digital close-range photogrammetry techniques is becoming an interesting area in 3D modeling and design. The present study focuses on developing 3D measurement system method for measuring complex shapes by means of quality control assessment and surface inspection, and simulation studies for hard-to-define parts geometries. The idea is to introduce an alternative solution to conventional method of geometry generation, which for use in CAE simulations. Therefore, the main objective of this research is to propose the photogrammetric measurement system on a car model (sedan) using a smartphone camera for the data acquisition procedure. Attempts are made to evaluate the precision and accuracy of the constructed 3D computer model of the car using Autodesk ReCap photogrammetry software. These attempts include the modification of photogrammetric data acquisition procedure and the car exterior geometry. Their photogrammetric products are then outlined clearly by each digital model due to the surface body panel differences. The different model visualizations are shown, where before the car modification is made the produced digital model is imprecise and poorly reconstructed, while after modification the model is more precise and accurate. The photogrammetric 3D car model is used for preliminary thermal behavior analyses. The results highlight the engine hood panel without the polyurethane (PU) foam has the highest surface temperature distribution of 347.65 K (74.65 °C) and panel with PU foam covered show the highest temperature distribution of 294.03 K (21.03°C).

Keywords:
Digital close-range photogrammetry; 3D modeling design; photogrammetric measurement system

1. Introduction

Recently, the visualization and three-dimensional reconstruction methods have become an important and powerful technique for applications in the areas of digital close-range photogrammetry [1]. Moreover, the emerging of computer technologies of those enabling the

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storing of metadata and data exchange between software have created several new digital platforms for monitoring and visual quality assessment [2-4]. In the modern smart manufacturing industry, increasing demands for Class-A surfaces of body panels in the automotive production are seen as a driving factor [5]. With this in mind, the car body panels are the most crucial components in the vehicles production line, where it comprise all inner and outer parts covering the vehicle frame (chassis), engine blocks, steering cab and the entire closed system of a vehicle's body [6]. The surface quality specification of the standard body panels for any regular size vehicles must not be built with a thickness of more than 3 mm [7, 8]. Therefore, with large structure sizes, huge number of components, complex shapes, higher accuracies and smaller relative thickness ratio requirements, the manufacturing processes poses a significant impact on the quality of the automotive components [9]. Meantime, the current developing of the computer-aided manufacturing (CAM) technologies have fostered in the measurement procedure by introducing 3D measurement approaches [10].

Conventional techniques, for instance, the contact measurement machine method (CMM) has better precision in measurements, but the major drawbacks are difficulties in acquiring surface information and the surfaces are more prone to scratches during the measurement phases [11]. Additionally, the equipment is very expensive and due to the large machine size, handling the machine during measurements becomes very challenging. On the other hand, non-contact optical measuring methods, in particular, Moore projection and laser triangulate methods have higher accuracy and faster processing period [12]. However, the working principles of these approaches may influence the relatively low specificity, whereby potential measurement ratios and precision errors could result to overvaluation of true cases [13]. Therefore, to overcome the existing measurement defects, new and modern techniques of photogrammetry 3D measurement methods have been described extensively. The proposed photogrammetric measurement system is able to achieve a large-scale of accurate measurements and potential cost solution, is user-friendly and anyone including non-experts can easily adapts the method [1, 14]. In addition, one of the major benefits of the photogrammetric method is the shorter measurement process period compared to other methods [15-17].

In order to evaluate the potentials of the photogrammetric system by means of close range, the 3D photogrammetry modeling of a car is investigated. Therefore, the reconstructed car model, specifically all of its body panels are studied to determine the factors those effect the consistency during the photogrammetric procedures [5]. This preliminary study provides the required elements for the photogrammetric data acquisition initially before pursuing further analyses such as measurement and quality control assessments, shape reconstruction for automotive components and CAE simulation purposes. In this study, the surface data of the car is obtained through images captured by a smartphone camera. The practicability of the smartphone camera for close-range photogrammetry is discussed and a method for the image acquisition of the car is presented. Last, the outcomes and consistency of the reconstructed 3D geometric model on the used method are outlined. Consequently, giving a glance on how the photogrammetric product can be used in the thermal behavior investigation. Moreover, the future works for the digital modeling on cars are proposed.

2. Methodology

This section discusses the photogrammetric method for a case study of a 3D car (sedan) model reconstruction, which is used for post-processing of thermal simulation purposes in this research. Most importantly, emphasized will be given on this sample study to outline the essential conditions and provide better insight for the applied photogrammetric technique on the car modelling before pursuing the further investigation. Therefore, Figure 1 illustrates the overall flow chart of this research study.

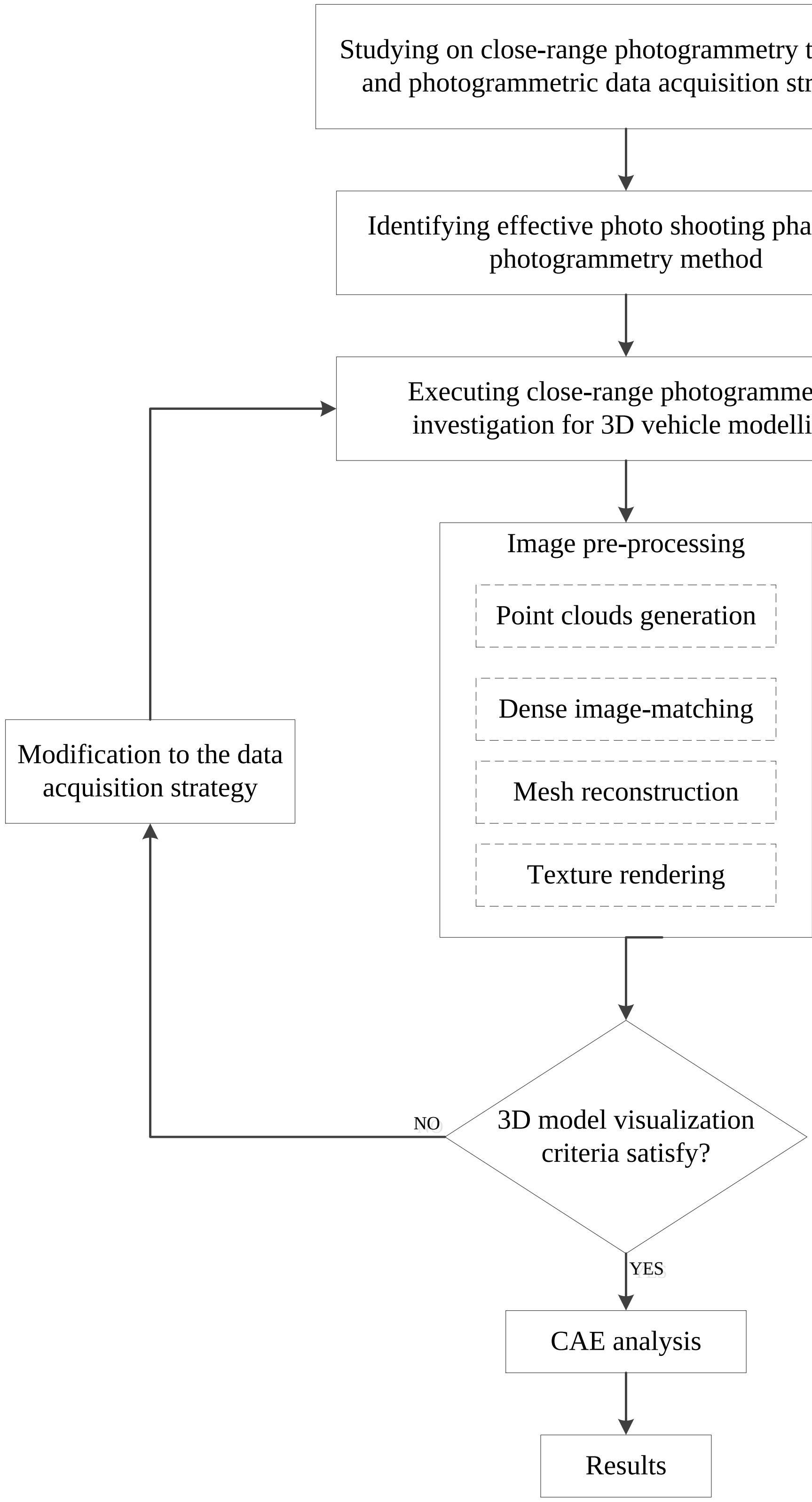


Fig. 1. The overall research's methodology for investigation

2.1 Camera Configuration

A 12Mpixels digital camera of an iPhone 7 Plus smartphone model is used to acquire surface information of the car model. The smartphone camera has to be configured initially to ensure proper 3D digital modeling is achieved by means of precision [27]. The camera configuration settings and calibrations (Figure 2) are one the major importance in the context of photogrammetric data acquisition phase as follows.

i. The captured set of photographic images has to be persistently sharp during the photography session of the sample car model. Enabling the Auto Exposure (AE) and Auto Focus (AF) lock modes (AE/AF Lock) does this, which it activates the tone by locking onto an impeccable focus and consistency of exposure magnitudes in the photographic images. Thus, the AE/AF Lock ensures that the captured photographs are highlighted with every details displayed and exposure remains balanced throughout the data acquisition period.
ii. Enabling High dynamic range (*HDR*) imaging mode is another essential element to aid quality surface texture acquisition in generating higher dynamic range detailed images [18].
iii. Ensure the car model is placed at the center of the camera frame (photo mode), which sates relatively about 70% of the sample within the full-frame. This prior percentage requirement is achieved via utilizing grid mode feature on the camera for better target acquisition purposes. Thus, the 70% is estimated to comprise all the nine square grids on the camera with the 5th grid being the most filled and the rest are filled marginally of the examined subject.
iv. Image editing features such as cropping, masking and filtering are switched off before reconstruction phase. The editing process may affect the photogrammetry process afterwards.
v. Camera flash is deactivated during the photo session.

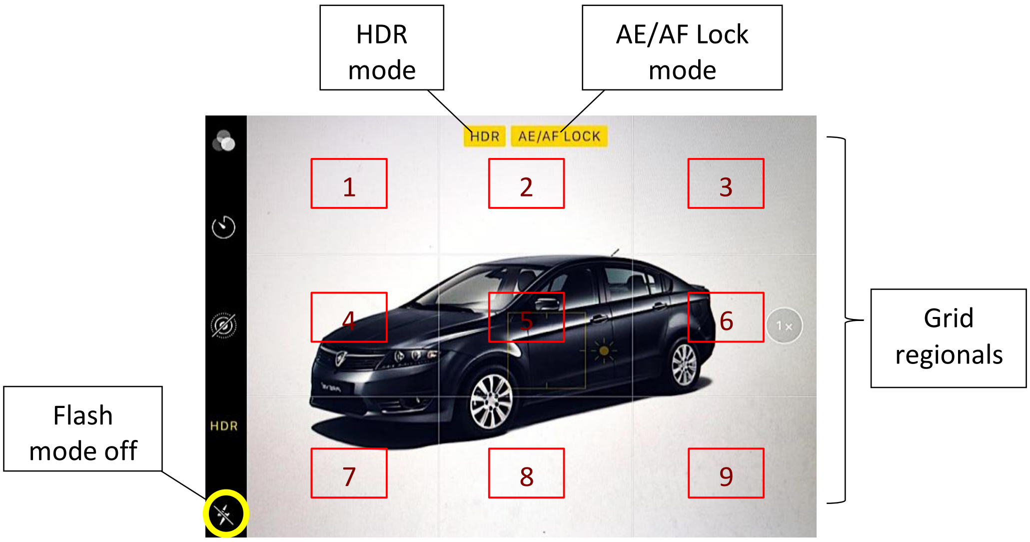


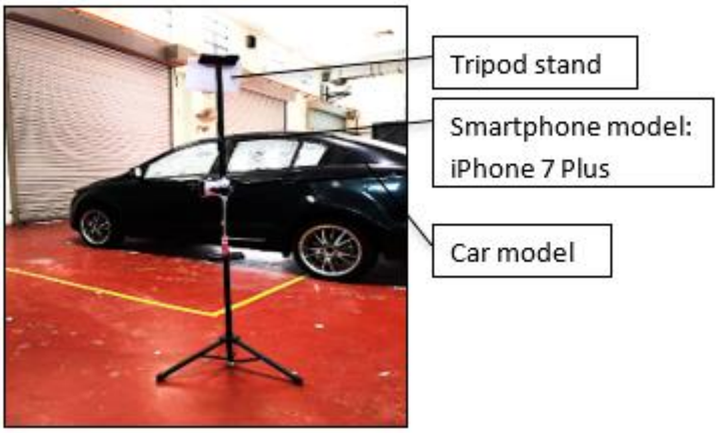
Fig. 2. Essential camera settings for quality image acquisition

2.1 Photogrammetric Data Acquisitions

This case study focuses on collecting the surface data of the car model using close-range photogrammetric technique for reconstructing a three-dimensional digital car model. The car mirrors are covered with lime shoes (Figure 3(a)) to avoid any present of transparent materials as the photogrammetric procedure may fail during the processing period. The dimension of the sedan car model is acquired in the standard specification from the supplier, where the car dimensions are 4544 mm × 1786 mm × 1524 mm (LxWxH). With this in mind, the mid length and width are measured to be 2272 mm and 893 mm respectively. After determining those mid-lengths, the center point of the sample car model is located. Subsequently, contours projection of 5° are equally extended in a circumference and marked from the center of the car as shown in Figure 3(b). Moreover, the smartphone is mounted and stabilized on a tripod stand as shown in Figure 3(c) during the photographing phase. Any shaking movements during photography may result in noisy images and consequently poor image recognition or failure during the digitizing stage in the photogrammetry software [19].

(a)

(b)



(c)

Fig. 3. Photogrammetric data acquisition procedures: (a) smeared mirrors, (b) shooting phase boundary and (c) equipment and simplified car model Proton Preve (sedan)

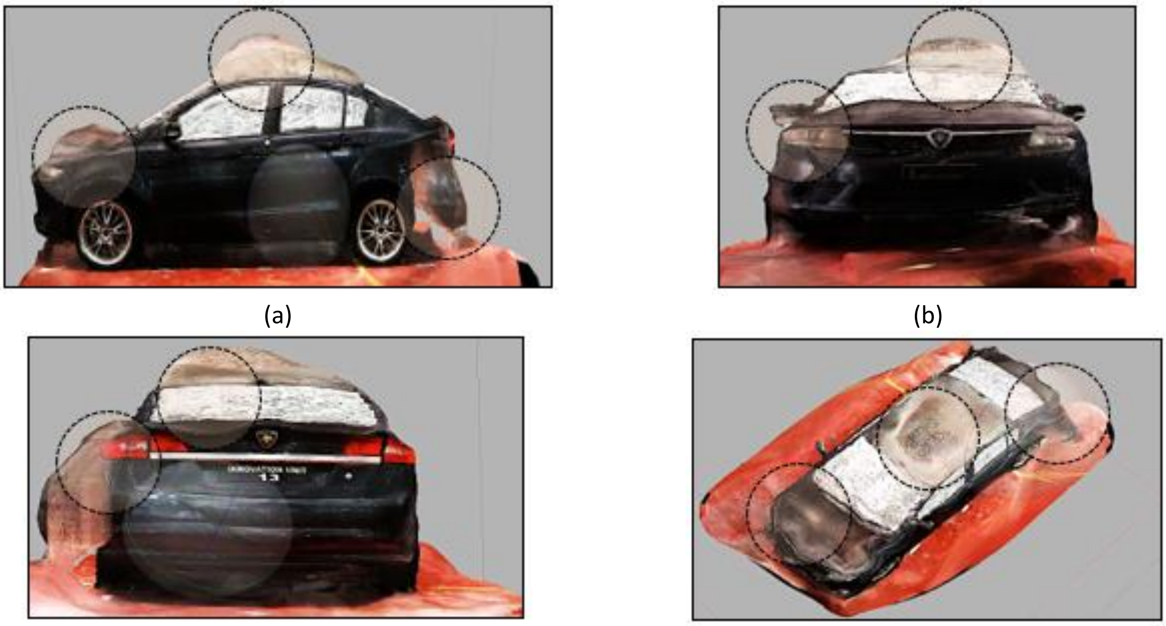
The image acquisitions of the car model from every 5° angles are performed in full loops. Therefore, a total set of 72 images of the car model is obtained in a single loop. Additionally, this study has proposed the surface acquisition of the sample to be collected in three various heights, which are from the top, middle and bottom rows as shown in Figure 4. This aids to improve the overlapping between images for better and quality recognition of 3D spatial data in the context of photogrammetric technique.

Fig. 4. Image acquisition from three various rows of the car

3. Results

3.1 Post-processing Analysis

The processing time for the 3D car model reconstruction was approximately 20 minutes on a i3-4005U/1.70GHz processor. Albeit the photogrammetric reconstruction took a shorter processing time, the 3D digital modelling of the car showed very poor visualisation and model reconstruction, and very low consistency. This is because the photogrammetric product failed to derive most of the collected data from the imageries [20]. The reason to this is that the shiny and reflective surfaces of the car body panels and the surroundings that causes geometric distortion in the digitizing phase [21, 22]. This results in poor quality and incomplete meshes generated for the digital reconstruction. Figure 5 shows the post-processing analysis of the digital workflow of the defected 3D car model.



(a) (b) (c) (d)

Fig. 5. 3D car model visualisation: (a) side view (b) frontal view (c) back view and (d) top view

3.2 Enhancement of 3D Photogrammetric Product

The dash-circles in the figures above portray the region of the deformities of the reconstructed 3D model. In regard to this matter, to overcome these defects the body panels of the sample car are modified as shown in Figure 6 to reduce the reflective panels surfaces. The car panels except its roof are sprayed with polyurethane (PU) foam initially before proceeding into multiple sanding and cementing processes. The final subsequent step is made by covering the panels with a red coloured vehicle vinyl wrap. Therefore, these modifications have greatly reduced the reflection on the car body, which are the major issues while capturing images for the photogrammetry technique.

(a) (b) (c) (d)

Fig. 6. Car body panels modifications: (a) polyurethane (PU) foam spraying process, (b) sanding process (c) cementing process and (d) vinyl wrapping process

3.3 Final Modeling

The physical information of the new modified sample car for photogrammetry are collected using the similar photogrammetric data acquisition as described earlier. The new 3D car model is then processed in the same photogrammetry software (Autodesk ReCap) and the photogrammetric product has shown a huge improvement in terms of model reconstruction and visualisation. The new reconstructed 3D model of the modified sample car has higher geometrically consistencies, improved rendering performances and sharper visualisation, and better efficiencies in terms of surface recognition. Figure 7 shows the new developed 3D car model of the modified sample sedan car.

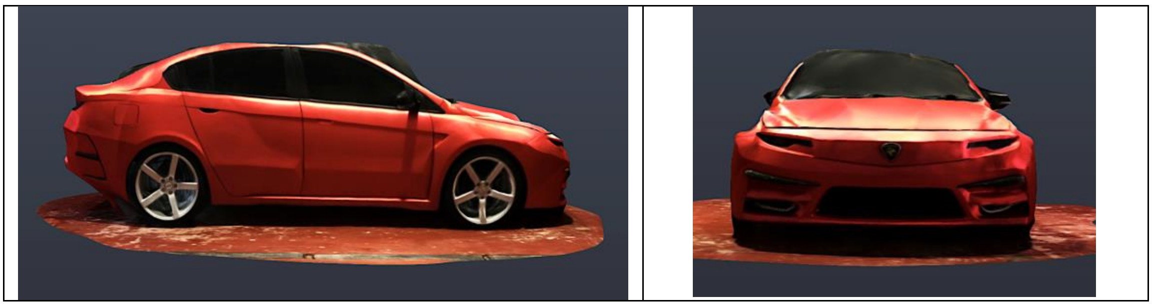


Fig. 7. Improved 3D car model visualization: (a) side view (b) frontal view (c) back view and (d) rear view

3.4 Photogrammetry Methods in Automotive Field Studies

The photogrammetry techniques have provided many benefits to most area of applications. These can be said in terms of small investments, faster execution time and not inheriting a complicated procedure, and process compared to the existing equipment and workstation for 3D modelling [15].

In general, the 3D modelling using these old methods are very costly. The expensive equipment and workstation needed in certain investigation of study cases have cause them to postpone the experiment and possibly certain are not carried out [16]. Moreover, these methods required many complicated and complex steps to be followed for the succession of the 3D model development. For this reason, the implementation time is very consuming. On top of that, the image-processing period is lengthy as well. Furthermore, most of these traditional methods are tactile and thus the major disadvantages are the targeted objects are highly prone to scratches and dents during the tests [17].

On the other side, the photogrammetry techniques have generated greater value to overcome these conventional methods weaknesses. Specifically in the automotive field, the use of this modern method has become increasingly popular among the areas of thermo-fluid studies, wind tunnel tests, surface quality assessments and measurements, and redesigning of parts [18]. For instance, in the wind tunnel investigation the laser interferometer and accelerometer are the two most important instruments used to measure the wind-induced in response of the models. However, due to limitation of some cases, both of these two instruments are inapplicable or at least unreliable. Therefore, the photogrammetry technique is used to provide the movement information of measured object through digital video recording as a series of continuous frames and determining the accurate positions in world coordinate [19, 20]. The stored information of the wind tunnel tests can also be used for future analysis. Thus, the photogrammetry techniques do not only provide similar or higher accuracy of 3D geometric models as the previous methods but they also create metadata for future prospects [20]. Besides, the photogrammetry methods are the cheapest approach comparatively for producing 3D models, which can also be used as thermal and computational models [21]. Besides, physical touch with the selected objects is not needed for the surface information extraction. Also, digitizing period is a lot shorter and no additional equipment is required to develop the 3D models in photogrammetry.

Although the precision and accuracy in photogrammetry are alike to the previous methods but these parameters largely depend on the effectiveness of camera calibration [22]. In brief, good calibrated and quality camera can produce efficient and precise 3D models. Furthermore, the methods may not work well under poor weather conditions unlike those conventional methods.

Above all, the photogrammetry techniques are still more preferable and productive considering all of its beneficial over conventional methods. In fact, good camera calibration for image acquisitions in photogrammetry can be done easily by simply setting a fixed and suited exposure, and activating the grids on the camera's monitor [13].

Apart from all its advantages over the old methods, the speciality in photogrammetry is these techniques do not need professionals and skilful operators to perform the investigation unlike the old methods they required at least an expertise for execution [23]. Secondly, there are number of photogrammetry software that have sufficient and strong optimization tools with more convenient user-interface are freely accessible on the Internet. Whereas, the software for 3D models processing for old methods come only together with its expensive workstation [24]. For these reasons, anyone can adapt very easily with the photogrammetry procedure and experience the technique on wide cases of studies using the free available software.

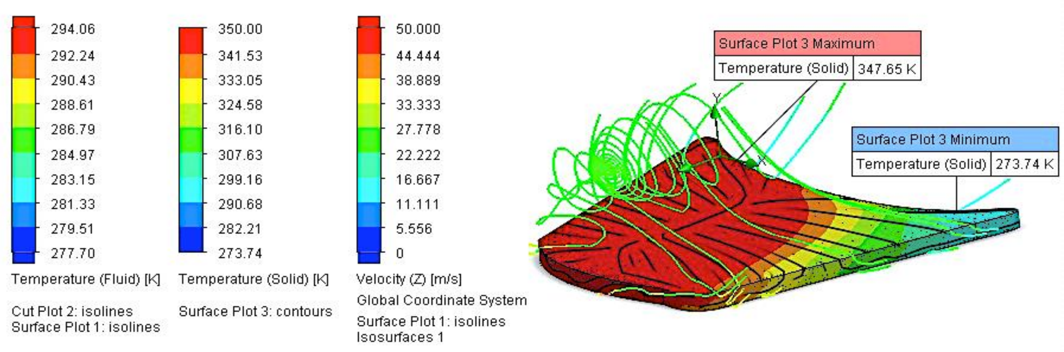
Therefore, the photogrammetry technique is implemented for the preliminary studies in this research by developing a 3D model of the sedan car, which is used as the computational model for the following thermal analyses. Obviously, the photogrammetry method is the most preferable option for this study owing to not having an expensive contact measurement machine (CMM) in the automotive laboratory [11]. On top of that, the equipment is very large and challenging to be used, and required very skillful operator. On the other hand, the used of 3D scanning equipment is tedious. This is because moving the equipment around the car demonstrator in such a congested space in the laboratory is very time consuming. Thus, the photogrammetry method is very reliable in this study as the procedure only required a digital camera for image acquisitions.

3.5 Thermal Analysis

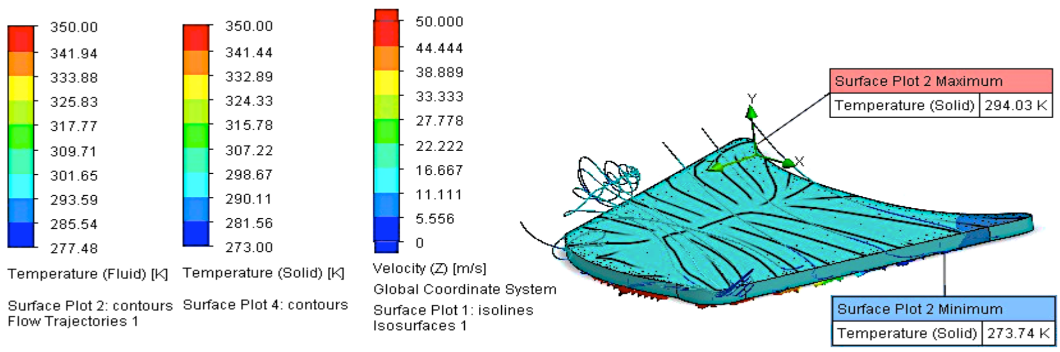
Presently, studies on thermal management to improve the heat rejection capacity of vehicles are increasing in importance [25, 26]. Moreover, recent studies have proved that the heat rejection factor can be greatly enhanced by treating the vehicle body panels as a heat exchanger to limit the requirement of finned heat exchangers. However, CAD drawings of the car body panels are initially needed in order to progress on the investigation and some intrinsic features are very difficult to create by mechanical drawings, and are time consuming. Therefore, this study focuses on how the development of the 3D car model using the photogrammetry technique can aid to provide solid geometric body (thermal model) for the following thermal study purposes as shown in Figure 8. Additionally, this preliminary study is to elucidate the operation of heat transfer of the flat panel surfaces to ambient air.

Fig. 8. Development of 3D model for thermal analysis using photogrammetry

In this study, the engine hood panel of the car is an area of keen interest as shown in figure above for the thermal properties investigation. As mentioned previously, the car panels are sprayed with polyurethane (PU) foam to reduce the surface's reflectiveness for efficient photogrammetry outcomes. Following, two types of thermal investigations are performed, which are the panel's surface without the polyurethane (PU) foam and the other with the foam covered. Therefore, both of the results in terms of temperature distribution is observed and shown in Figure 9.



(a)



(b)

Fig. 9. Temperature contour distribution on engine hood panel: (a) without polyurethane (PU) foam and (b) with polyurethane (PU) foam

In this study, heat transfer by means of radiation, conduction and convection of the engine hood panel are investigated by assuming the car is traveling at 50 ms^{-1} and the geometry, and frontal design of the car is not taken into consideration. The heat transfer by radiation occurs when heat is dissipated from the running engine to the surface below of the hood panel. Subsequently, the heat gained is then transferred through microscopic collision of particles (conduction) across the length of the panel's thickness towards the inner surface of the polyurethane (PU) foam and finally transferred by forced convection as illustrated in Figure 10.

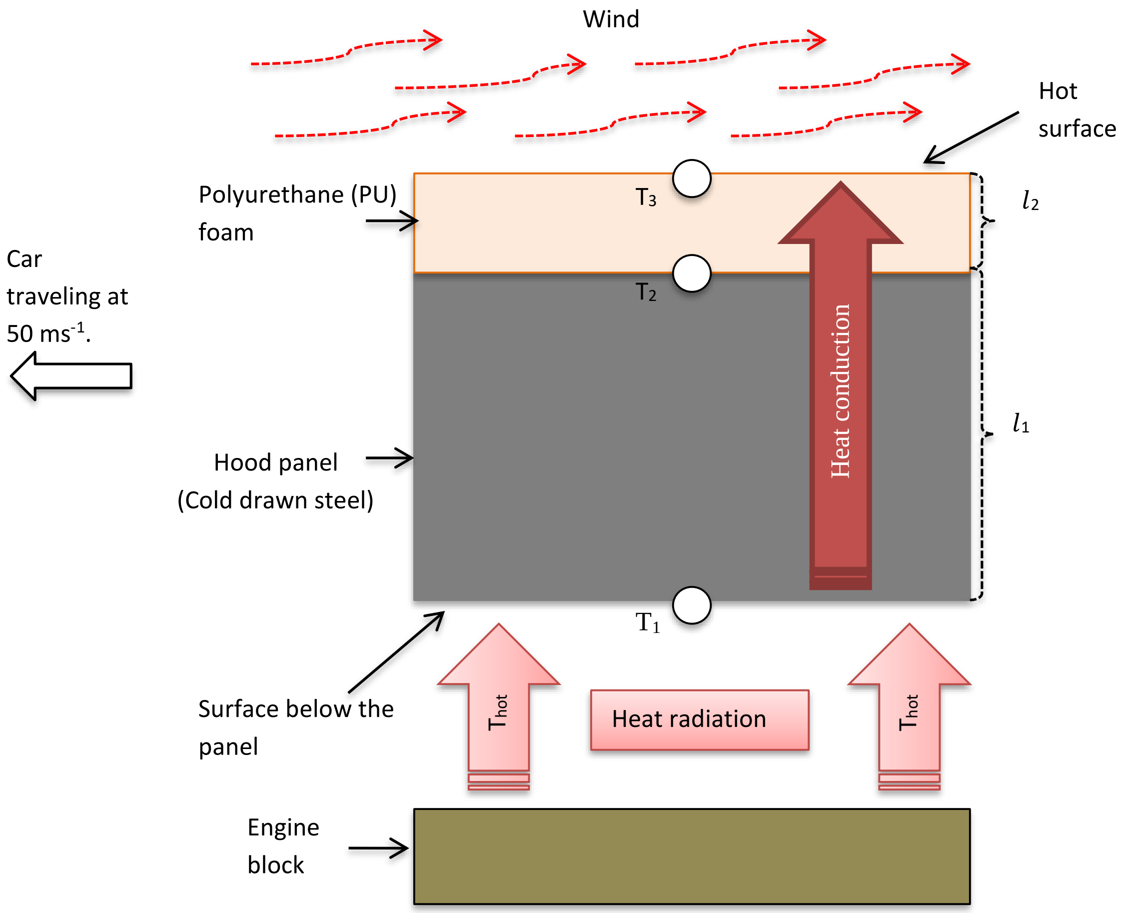


Fig. 10. Mechanisms of heat transfer between the engine and hood panel, and PU foam

Indeed, the thermal simulations have shown that the hood panel without the polyurethane (PU) foam covered has the highest temperature distribution compared with the used of (PU) foam. This is because most of the hood panels are made with cold drawn steel. Accordingly, the material has high heat conducting properties, whereas the polyurethane (PU) is a polymer-based material that has very low heat conductivity. Therefore, the rate of heat conduction in the first case for the hood panel without the (PU) foam is greatly higher. The steel panel is able to transfer most of the heat at a faster rate from T_1 to T_2. On top of that, from the Figure 3, it can be seen that all of the car body panels are initially coloured black and black has a higher degree of heat absorptivity compared to lighter colours. As a result, the heat radiated from the engine is absorbed at the greatest amount by the coloured black hood panel. Thus, transferring the high quantity of heat by conduction to the outer edge surface. For these reasons, the simulated maximum temperature distribution for the hood panel without PU foam at point T_2 is 347.65 K (74.65°C).

The following investigation is performed for the hood panel covered with PU foam. In this case, the maximum temperature shown by the software is 294.03 K (21.03°C). In depth, the PU foam contains abundant tiny and large air gaps (voids) in their structure. These air gaps reduce the heat transfer by conduction and thus resulting a lower rate of heat conductivity across the material. This has significantly influenced the temperature distribution of the interface between the two outer surfaces of the hood panel and PU foam. Therefore, the heat quantity on the surface above the panel at point T_2 is transferred slowly across the PU foam to the outer surface at point T_3. Moreover, heat transfer by means of forced convection is also considered in these simulation analyses. As previously shown in the Figure 9, the thermal car model is set to travel at the maximum velocity of 50 ms^{-1}. That is, this creates a forced convention between the hot surface of the hood panel and moving air above the surface. Emphatically, the maximum and minimum temperature distributions simulated by the software for both case conditions have included the heat convection factor.

The introduction of this new and trending integration approach between photogrammetry and automotive studies have address modern engine generations and new powertrains studies. For instance, the investigation in this research can expand to enhance the temperature control of the subsystems for an increase of the heat rejection demand and, as a consequence, of the heat exchange surfaces and of the constraints for the aerodynamics.

4. Conclusions

The interrelationships between the photogrammetry technique and automotive studies have been proven to be very advantageous in this study involving thermal elements. The used of photogrammetry technique is to create a 3D model of the sedan car beforehand being used as a thermal model to run the following thermal simulations. Moreover, the sample car is modified in this study for the purpose to reduce the reflectiveness of the body panels. Accordingly, this produces more efficient 3D model reconstruction to be used as thermal model during the thermal studies. That is, accurate 3D models can result in better learning outcomes and data qualities. As shown, the post-processing outcomes through the simulations of hood panel cases have provided incisive thermal analyses. Furthermore, these simulations illustrated by the thermal car model (photogrammetric model) in this study are satisfactory and theoretically intact. The data obtained showed that the photogrammetric technique could be used to perform several investigations in the automotive industry such as quality surface inspection, measurement assessment, simulation purposes and other more.

The current method has managed to obtain great improvement over the previous study with only a minimal adjustment to the technique. Additionally, regarding on the foregoing future work, improvements can be further made by controlling the lighting system around the object and further preparation on the vehicle surface to improve the accuracy of the model. Nonetheless, this work has proved the great potential behind photogrammetry and broaden its applications.

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