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The Accuracy of Photo-Based Three-Dimensional Scanning for Collision Reconstruction Using 123D Catch

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ABSTRACT

An experiment was conducted to examine the validity of freely available photo-based 3D scanning software for generating accurate 3D geometry of a vehicle. Currently, 3D vehicle geometry is routinely captured using total station survey equipment, coordinate measuring machines (CMM), laser scanning, or traditional point-based photogrammetry. While these methods produce sufficiently accurate results for collision reconstruction, they have limitations that can affect practical implementation. For example, manual surveying with a total station, CMM or traditional photogrammetry are all limited to the production of coordinate data at discrete, pre-defined points. In addition, total stations, CMMs and laser scanning devices are also expensive and require a significant amount of time in the field with the vehicle. In contrast, photo-based 3D scanning allows a 3D mesh to be created of a vehicle simply from a series of photographs using a consumer-grade digital camera.

In this experiment, a vehicle was marked with point targets and photographed. The coordinates of the targets were then measured using: 1) A total station; 2) Traditional photogrammetry software; and 3) Photo-based 3D scanning software. The coordinates of the targets on the vehicle model produced through the photo-based scanning process were compared with the target positions measured via total station and traditional photogrammetry. The mean deviation between corresponding points on the photo-based scanning model and the traditional photogrammetric model was 3.2 ± 1.8 mm. The mean coordinate deviation between the photo-based scanning model and the total station data ranged between 3.4 ± 1.4 mm and 6.3 ± 3.1 mm.

INTRODUCTION

Documenting vehicle geometry is a crucial component in reconstructing a collision. A detailed representation of post-crash vehicle geometry is useful for determining general crash parameters, such as impact configuration and post impact vehicle kinematics. Moreover, various mathematical models, including the classic work of Campbell [5,25] require residual crush damage measurements as input to calculate damage energy and corresponding change-in-velocity (delta-V) values. Mapping the change in vehicle geometry as a result of a collision is also used to assess occupant compartment intrusion and the associated influences on the occupant dynamic response and injury biomechanics. To obtain the detailed vehicle geometry data necessary for these analyses, numerous measurement methods have been employed, each having a distinct set of advantages and limitations.

Crush Jigs

“Crush jigs” have been used to measure zones of localized crush damage. Such devices have limited availability commercially and are therefore often custom fabricated. The advantages of these tools lie in their simplicity, in both construction and measurement methodology. However, use of these crush jigs is limited to the documentation of localized crush (e.g., front, side or rear of vehicle) and are not easily adapted to measurement of complete vehicle geometry or unique situations where a measurement reference datum is difficult to establish (e.g., high-severity side impact inducing whole-vehicle bending distortion).

Plumb Line Tracing

Vehicle damage has also been recorded by manually tracing the profile of the vehicle. This technique usually employs the use of a plumb line to establish a vertical line from the vehicle to the ground surface where the profile is traced. This methodology is simple and involves a set of small, inexpensive tools, but also has considerable inherit limitations. These limitations include the measurement of geometry in one plane (x-y plane) and difficulties documenting localized geometric features (e.g., peak intrusion) where a direct plumb line to the ground surface does not exist to for tracing.

Total Station Survey

For instances where the documentation of three-dimensional (3D) geometry is important, total station survey measurement is routinely implemented. While this mode of data collection can deliver highly accurate position data, it is limited to discrete points. The density of the point data is a function of survey time. As such, dense point data can only be acquired at the cost of analyst time. In addition, in order to capture points encompassing a complete vehicle using a total station, the instrument must be moved several times. Movement of the total station during data collection results in subsets of vehicle point data instead of one point file containing data encompassing the entire vehicle. These subsets of point data must then be stitched together to form a single unified point cloud. While some total stations perform this stitching automatically using an optimization routine in free station mode, the task adds additional processing time to the project and can introduce error associated with misalignment of the various coordinate subsets. Practically, this can be a significant limitation in instances where time with the vehicle is limited. Finally, total stations also have cost-considerations (purchase and rental) and, given the size of the equipment, pose portability limitations.

Laser Scanning

Laser scanning has recently gained traction for dimensioning vehicle geometry [38]. Laser scanning allows the relatively quick acquisition of dense point data ("point clouds"). In addition to capturing three-dimensional point data, many scanning systems also identify and record surface color. The resulting point cloud can not only be used for measurement purposes, but is often of sufficient density and quality that it can be effectively used for visualization and/or demonstrative purposes. However, laser scanning suffers from many of the same limitations characteristic of total station survey. First, laser scanning is limited by the acquisition of data from a single-point perspective for each position of the instrument. As a result, only geometry that has a direct line-of-sight to the instrument can be recorded. When multiple perspectives are required, equipment movement is necessary, increasing the amount of time required to document the vehicle. Next, in order to create a point cloud inclusive of an entire vehicle, subsets of point data must be stitched together after the scanning process, introducing error to the point acquisition process. Finally, laser scanning equipment is expensive and suffers from portability considerations.

Coordinate Measuring Machines

Coordinate Measuring Machines (CMM) are instruments that measure coordinate data by physically touching a locator implement to the vehicle at the desired positions. CMMs used in collision reconstruction often take the form of a series of articulating linkages (e.g. FaroArm®; ROMER®). While the theoretical levels of accuracy attainable with these instruments are well within common requirements of the reconstructionist, point density is also a function of measurement time, similar to total station surveys. Further, portability, operator training, time with the vehicle and cost are all potential limitations.

Traditional Photogrammetry

The use of close-range photogrammetry has been validated for reconstructing the 3D geometry of vehicles [3,4,6,8,10,12,14,21,22,31,37,42]. While the cost of equipment is less and the equipment more portable compared to some of the aforementioned methods, traditional close-range photogrammetry requires extensive processing time, in which the analyst must manually identify and cross-reference desired point locations in multiple photographs in order to calculate points of interest. Further, expensive software is required to stitch the points identified in each photo into one complete point cloud. The density of the resulting point cloud is a function of the manual referencing time. Some photogrammetry software (Eos PhotoModeler® and DCS Inc. iWitness) allows for automated referencing through the use of coded targets placed on the vehicle before the vehicle is photographed. While significantly reducing manual processing time, automated projects possess inherent limitations. For example, point density is limited to the number of coded targets placed on the vehicle. In addition, the placement of the targets must be such that the ensuing photography captures the targets at sufficient resolution and viewing angles to allow the coded target to be detected and properly recognized. Moreover, the physical size of the targets may prohibit placement in local regions of crush (e.g., narrow grooves, etc).

Photo-Based 3D Scanning

Photo-based 3D scanning, also referred to as Structure-from-Motion (SfM) [24,41], is an extension of traditional photogrammetry and has been described as, "*...the most complete, economical, portable, flexible and widely used approach...*" to making "*...manual or automatic image measurements for precise 3D modelling...*"[34]. Photo-based 3D scanning has been used to document and archive archaeological artifacts[18] and sites[29], generate 3D models of terrain [15,19] and create 3D models of human anatomy [17,40]. Compared to traditional photogrammetric methods, photo-based 3D scanning does not require the explicit identification of target locations in each photograph. Instead, the algorithms implemented in photo-based 3D scanning automatically identify and mark distinct features appearing in multiple photographs. These features are then automatically referenced and stitched together, generating numerous (often thousands) of points in three-dimensional space. This point cloud is then fit with a surface and texture mapped, creating a three-dimensional, photo-real, mesh model of the object. There are several distinct advantages to modeling vehicle geometry with photo-based 3D scanning. These include the lack of specialized and bulky equipment and targets, ease of portability, low cost, both in equipment and time spent in the field, the ability to use any off the shelf point and shoot camera, even a camera phone, without having to calibrate the camera and the preservation of subtle details such as witness marks on a roadway or vehicle that can only captured through photographic documentation. Thus, photo-based 3D scanning allows for the complete documentation of a vehicle using an instrument (camera) that is commonly carried by a great majority of people.

Photo-Based 3D Scanning Theory

The theory behind creating 3D models from a set of photographs taken by uncalibrated cameras with unknown parameters has been published extensively and is well illustrated by a sequence presented by Pollyfeys et al. [30]. The authors describe five steps in the 3D reconstruction system: 1) Image Sequence; 2) Projective Reconstruction; 3) Metric Calibration; 4) Dense Correspondences; and 5) 3D Model Building. Briefly, "Image Sequence" refers to the acquisition of images or photographs. "Projective Reconstruction" refers to the construction of a matrix of point correspondences derived from multiple photographs. Point correspondences refer to a set of points in one photograph that are also identified in a subsequent photograph. "Metric Calibration" refers to the process of self-calibration, or generating camera projection matrices from image correspondences. Metric Calibration is performed using either linear or non-linear approaches depending on known factors (i.e. no skew in the image, fixed aspect ratio and absence of skew, known aspect ratio and absence of skew, known focal length, etc.). Once the Metric Calibration has been performed, each image pair can be remapped to standard geometry where epipolar lines coincide with image scan lines in a process known as "Dense Correspondences". The correspondence search is then reduced to a matching of the image points along each image scan line. Finally, once the dense correspondences and metric camera parameters have been estimated, depth maps are computed using depth triangulation to perform "3D Model Building".

Photo-Based 3D Scanning Software

Several companies have developed software to reconstruct 3D geometry from photographs (D-Sculptor, iModeller 3D, Photomodeler® Scanner). Recently, Autodesk® released freely available software for the purpose of photo-based 3D scanning called 123D Catch®[2]. To date, 123D Catch® has been used as a tool for generating accurate, textured 3D models of architecture and archaeological sites [18,29], changes in landscape [33], facial anatomy [40] and other objects [9] and has purportedly been validated as a measurement tool in monitoring changes in coral reef by Scripps Institution of Oceanography (http://www.youtube.com/watch?v=9AtKvvc4-bU&feature=plcp). 123D Catch® was first released on July 22, 2010, as a technology preview on "Autodesk Labs" (http://labs.autodesk.com/) under the name of "Project Photofly". Project Photofly "graduated" on November 7, 2011, as 123D Catch® Beta and has since come out of beta and been released as a stand-alone package for PC's, a web application (for use without installing software) and an application for iOS (iPhone and iPad).

Purpose

The purpose of this study was to evaluate the validity of 123D Catch® (Stand-alone PC version, Build 2.2.3.106, Autodesk®, San Rafael, CA 94903), for reconstructing the 3D geometry of a vehicle. The validation was untaken by comparing the 3D geometry of a vehicle generated using 123D Catch® to the geometry of the same vehicle generated using: 1) Total station survey; and 2) Traditional photogrammetry. Both total station survey and traditional photogrammetry are widely accepted techniques for documenting vehicle geometry [12,26-28,31,35]. The comparison to total station survey methodology was selected as it is widely-accepted in the field of collision reconstruction and it often considered the “gold standard” for three-dimensional vehicle coordinate measurement. Traditional photogrammetry was selected because it has been validated for both general data capture and specific application to vehicle/scene documentation for collision reconstruction using photographs and post-processing software[3,6,8,10,12,14,21,42]. Like photo-based 3D scanning, traditional photogrammetry can generate a single point cloud for the entire vehicle, thereby allowing direct comparison with the complete photo-based 3D scanning model of the vehicle. PhotoModeler® specifically, has been validated for use in collision reconstruction [4,22,31,37].

METHOD

Vehicle Preparation

An undamaged 1997 Subaru Impreza wagon was selected as the test vehicle. The vehicle has a length, width and height of 437 cm, 170 cm and 142 cm, respectively, according to manufacturer specifications. In an effort to evaluate photo-based 3D scanning under conditions similar to those commonly experienced in the field, vehicle documentation was performed outside in an open parking lot. Vehicle preparation was limited to the placement of targets on the exterior surfaces of the vehicle so as to allow examination of identical reference points for each of the measurement techniques. Specifically, eighty-nine adhesive paper Ringed Automatically Detected (RAD) targets were placed on the vehicle (Fig. 1) and used to mark the points to be documented with the total station survey method, as well as with traditional photogrammetry. The targets were generated with PhotoModeler® 6.0 (Build 6.3.3.794, EOS Systems, Inc., Vancouver, BC V6J 1Y6) and consisted of a sub-millimeter crosshair located at the center of a 12.5 mm black circular marker (Fig. 2). A unique coded ring used by PhotoModeler® to identify the target reference number surrounds the black circular marker. The adhesive targets were placed on the front, side and rear body panels of the vehicle, at the bumper level, lower rocker panel area, window sill level and roof line. Targets were also placed on the hood panel along approximately longitudinally-oriented lines.

Figure 1. Photograph of the 1997 Subaru Impreza wagon marked with RAD targets.

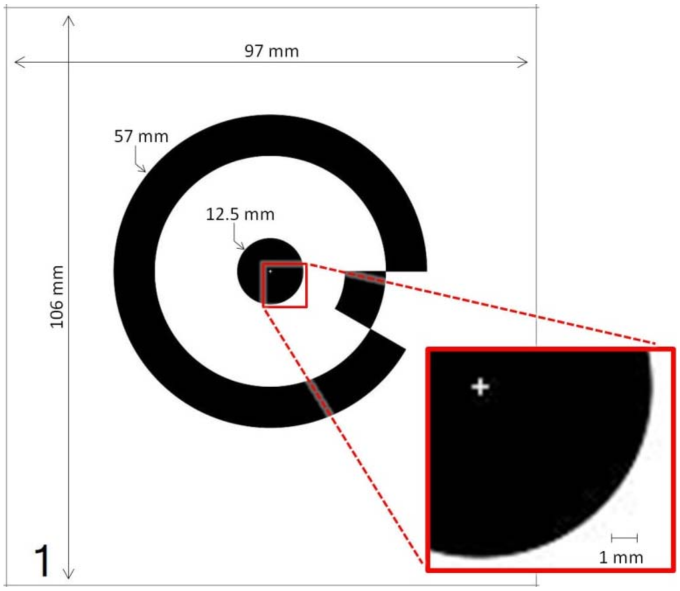

Figure 2. Example of coded target adhered to vehicle (Target ID: 1). Target crosshair visible in magnified view.

Total Station Measurements

A Topcon GPT-3205NW non-prism total station (SN: U80175, Topcon Positioning Systems, Inc., Livermore, CA 94550) was used to record the coordinates of the 89 vehicle targets. The measurement accuracy for this particular instrument, when operating in prismless mode with a Kodak gray card target, is ± (3mm+2ppm × D); where D is the measurement distance from the instrument to the target. The line-of-sight limitation intrinsically associated with total station measurement required that the instrument be moved multiple times during the vehicle documentation such that the coordinate data could be acquired for targets located on all sides of the vehicle. Specifically, the coordinates for the 89 vehicle targets were acquired from three total station instrument positions: 1) Front-right; 2) Front-left; and 3) Rear (Fig. 3). These subsets of points were acquired such that there was overlap between the adjacent regions of the vehicle. The adjacent data subsets could then have been “stitched” together (aligned) to form a continuous point cloud/data file [13]. However, due to potential measurement differences of corresponding points among the subsets of data, this stitching process can introduce error into the vehicle geometry data. To avoid this source of error for this validation, the subsets of total station coordinate data were not stitched together, but instead compared directly with corresponding subsets of the point data extracted from the photo-based 3D scanning process. That is, the comparison between the total station and photo-based scanning model was performed separately for each of the three regions of the vehicle.

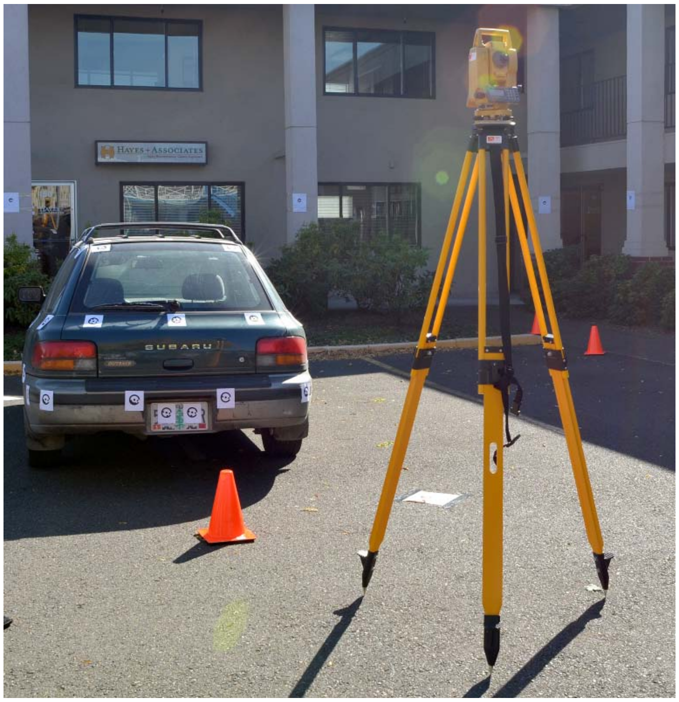

Figure 3. Topcon Total Station used to survey the positions of the targets placed on the subject test vehicle. The total station is shown in the rear position.

Traditional Photogrammetry Measurements

A Nikon D7000 DSLR (Nikon USA, Melville, NY 11747-3064) with a 20 mm Nikkor lens was used to photograph the vehicle. All photographs were taken in “auto” mode, with the flash suppressed. With respect to the photography process, the "shoebox" method [32] was employed, capturing photographs at roughly even intervals while encircling the entire vehicle. This process was repeated multiple times, with the camera positioned at varying heights above the ground surface. A total of 101 photographs were processed. The Coded Target Module within PhotoModeler® was used to identify and solve for the coordinates of the target locations on the test vehicle. While the use of the coded RAD target markers allowed for automated processing, including automatic sub-pixel point marking and point-to-point referencing, the photographic requirements related to RAD target detection required an increase in the number of photographs processed beyond that likely required for manual marking and referencing. That is, to allow the PhotoModeler® software to accurately detect the RAD targets, photographs were acquired at a shorter focal length (close-up), requiring an increased quantity of photographs to document the entire vehicle.

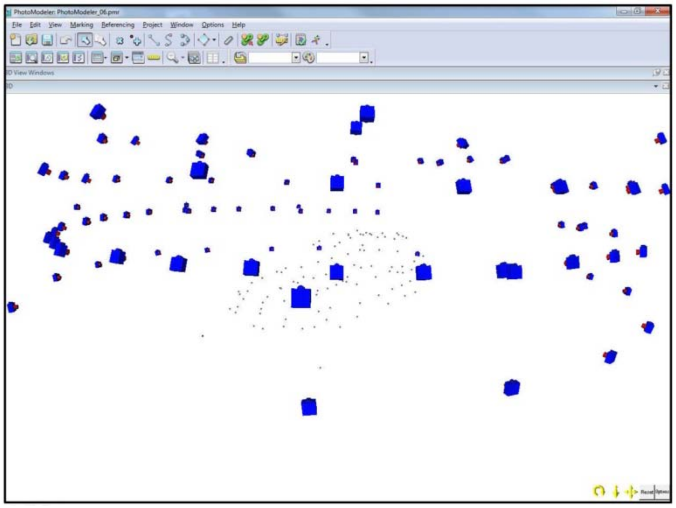

Figure 4. Screen capture from PhotoModeler® demonstrating the discrete point data and approximate locations of the camera during data collection .

Photo-Based 3D Scanning

The vehicle was also photographed for processing with the photo-based 3D scanning software, 123D Catch®. Similar to the photographs taken for use in the traditional photogrammetric analysis, the photographs captured for use with 123D Catch® were acquired using the shoebox method. However, unlike an automated photogrammetric method where there exist requirements with respect to the detection of coded targets, photo-based scanning has no such limitations. As such, the photographs taken for the photo-based 3D scanning project were acquired when standing further away from the vehicle, such that the entire vehicle was captured in each photograph. This inherent advantage of the photo-based 3D scanning process reduced the number of required photographs, compared to automated traditional photogrammetry. For this project, 35 photographs were acquired with the camera positioned at a constant height of approximately 170 cm. As with traditional photogrammetry, all photographs were captured using a Nikon D7000 in auto/flash suppressed mode with 20 mm Nikkor lens. After capturing the photographs, the resulting images were reviewed. Photographs that were out-of-focus or that contained lens flare, motion blur or other undesirable artifacts were removed.

Upon processing the photographs, 123D Catch® produced a three-dimensional textured mesh surface model of not only the vehicle, but much of the adjacent surrounding environment as well (Fig. 5). The vehicle model was isolated by cropping all extraneous environmental features from within the software (Fig. 6). "Reference points" corresponding to the center of the target locations were then added to the mesh. This process was accomplished on a point-by-point basis by zooming in on any of the project photographs and then manually selecting the center of the circular marker. Once the point was marked, it appeared within the 123D Catch® GUI as a yellow sphere (Fig. 6). The reference points were then automatically mapped to the three-dimensional surface of the vehicle mesh. Unlike traditional photogrammetric marking, in which a given point needs to be identified and cross-referenced between multiple photographs, marking reference points using 123D Catch® requires that a point be identified in only one photograph.

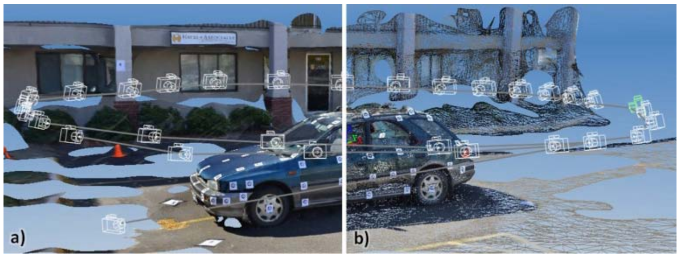

Figure 5. Photo-based 3D scanning model output demonstrating: a) Textured mesh of the subject test vehicle and surrounding environment as well as camera locations corresponding to photographs used in the analysis; and b) Textured wireframe mesh of the subject test vehicle and surrounding environment.

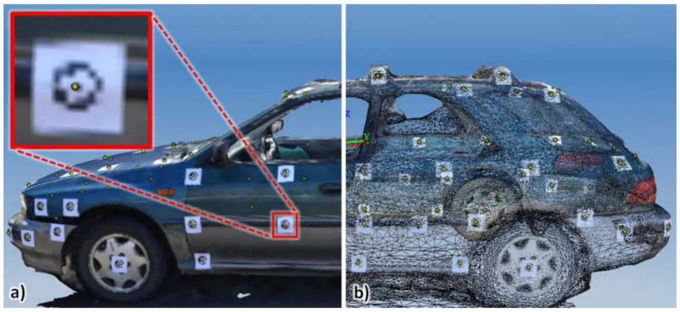

Figure 6. Photo-based scanning model output demonstrating: a) Textured mesh of the subject test vehicle with manually-placed reference points visible (yellow spheres); and b) Textured wireframe mesh model.

Data Analysis

The target coordinate data obtained through the photo-based 3D scanning process were compared with the total station measurements and point data generated with traditional photogrammetry. Comparison between sets of three-dimensional coordinate data is non-trivial. Others [4,11] have approached such comparisons by assigning three or more corresponding points for each data set as a baseline. However, small measurement differences between the data sets prevent the baseline coordinate points from being truly coincident. As such, the technique is dependent on the subjective alignment of the baseline points and therefore does not ensure that the best possible fit is achieved. To eliminate this subjective influence, the point cloud comparisons in this study were performed using an Iterative Closest Point (ICP) algorithm in which the six-degree of freedom position and orientation of the point clouds relative to each other are parametrically varied until a mean square cost function of the point-to-point distance error is minimized. The parametric comparison is continued until the difference in calculated error between iterative steps converges to a user defined threshold. This process was performed numerically using freely available software called CloudCompare (v. 2.4.Qt/MSVC - 09/22/2012)[1]. CloudCompare has been used by others for matching three-dimensional point data acquired from multiple sources (i.e. laser scanners, total stations) [16,20,23,39]. Following the ICP calculation, the required transformation matrix, along with the statistical differences between the corresponding data were reported within the software.

RESULTS

Comparison Between Total Station And Photo-Based 3D Scanning

The total station point data were compared with corresponding points from 123D Catch® using CloudCompare. The ICP process was executed iteratively until the difference in point position error converged to within 1 x10^{-6}. The mean point-to-point position error between the total station data and the 123D Catch® data ranged from 3.4 ±1.4 mm (Mean ± SD) for data subset #3 (rear of vehicle) to 6.3 ± 3.1 mm for data subset #1 (front-right region of vehicle) (Table 1).

Table 1: Error associated with comparison between total station and 123D Catch®.

Total Station Data Subset	Mean Error (mm)	Standard Deviation (mm)	Minimum Error (mm)	Maximum Error (mm)
#1	6.3	3.1	1.0	15.1
#2	4.1	1.8	1.8	8.2
#3	3.4	1.4	1.1	6.6

Comparison Between Traditional Photogrammetry And Photo-Based 3D Scanning

The point data acquired through traditional photogrammetry was compared with the corresponding points obtained with 123D Catch®. For this comparison, all of the data points, reflecting the geometry of the complete vehicle, were compared. The CloudCompare ICP process was again executed until the iterative difference in point position error converged to within 1 x10^{-6}. The resulting comparison revealed a mean position error between the PhotoModeler® coordinate data and the 123D Catch® model of 3.2 ± 1.8 mm (range = 0.7 mm to 8.5 mm).

DISCUSSION

Measurement Deviation

The target coordinates generated using the photo-based 3D scanning model of the vehicle generated using 123D Catch® agreed strongly with the point data from both the total station survey and traditional photogrammetric analysis. In fact, the mean differences in target coordinates found in this study between the coordinates generated in 123D Catch® and both total station survey and traditional photogrammetry would correspond to equivalent barrier impact speed deviations of between 0.5 and 1.2 percent from the nominal 30 mph impact speed for a class III passenger car 30 mph barrier impact involving an average frontal crush depth of approximately 46 cm (18 inches). In addition, the deviations in coordinate measurement locations in this study were consistent with, or had less deviation than those reported in previously published studies [12,31,37]. Thus, photo-based 3D scanning, and 123D Catch® in particular, has been demonstrated to be a valid tool for characterizing vehicle geometry for the purpose of collision reconstruction.

The photo-based 3D scanning model of the vehicle was found to most closely match the point data acquired through traditional photogrammetry, with an overall mean point position error of 3.2 mm. While still found to be in close agreement, the largest errors were associated with the comparison between the photo-based 3D scanning model and the total station data from instrument position #1 (front-right region of vehicle; mean error of 6.3 mm). These results are somewhat counter-intuitive, as the lowest error was noted for the point clouds with the largest number of points (whole vehicle) while the greatest error was associated with the comparison between two point clouds with fewer points (front-right region of the vehicle). With all things being equal, one would generally expect a better fit for the latter (total station) comparison, in which just a localized subset of the data is being compared. However, given the reduced error between photo-based 3D scanning data and the data generated using traditional photogrammetry, the coordinate position deviations associated with the total station comparison cannot be attributed to errors associated with the photo-based 3D scanning method or the 123D Catch® software. Instead, potential errors associated with the total station documentation must also be considered. In particular, it is suspected that attempts to capture coordinate data in prismless mode for targets positioned at shallow angles relative to the total station laser, may have induced error.

Strengths of Photo-Based 3D Scanning

Documenting geometry using photographs in general has distinct advantages over other modes. These advantages include: 1) Photographs required for model processing can be maintained indefinitely for future reassessment, whereas the physical vehicle, object or scene may be repaired, disposed of or otherwise altered and therefore not available for further physical measurement [31]; and 2) The time spent collecting data and generating a 3D model is reduced compared to other methods such as total station survey [22] and laser scanning [7]. Photo-based 3D scanning has several advantages over other measurement techniques, including traditional photogrammetry. One of the most obvious advantages is the generation of a dense surface model of the entire vehicle, rather than discrete point data or dense reconstructions of only part of a vehicle. A textured surface mesh not only allows for better visualization of the vehicle, but also allows for measurement of vehicle features that may not have been explicitly marked or targeted during the data capture/documentation phase so long as those features are visible in photographs taken during inspection of the vehicle. It should be noted that in this study, the accuracy of discrete point locations were compared between the various measurement methods. While the 3D scanning method produces a continuous mesh, analysis of the model between the point locations was not possible, given that the benchmark data collection methods (traditional photogrammetry using PhotoModeler and total station survey) are both limited to marked target locations and corresponding discrete point data. That said, the density of the target placement, along with the demonstrated accuracy at all of these locations, lends high confidence to the fidelity of the model overall.

While photo-based 3D scanning involves the automatic referencing of features among multiple photographs, it does not require specialized coded targets and the inherent photography requirements required to ensure code detection/recognition. Next, the only equipment required is an uncalibrated digital camera, a tape measure to document a scale factor somewhere in the scene and freely available software. Thus, the costs associated with the resources required to perform photo-based 3D scanning are much lower compared to the cost of purchasing or even renting total station survey instruments, laser scanners and CMM devices or purchasing expensive photogrammetry software. The ease of marking reference points in post processing accomplished by point identification of the reference point on only a single photograph within 123D Catch® is a distinct advantage in that it decreases the processing time when compared to cross-referencing a point in multiple photographs as is required with traditional photogrammetry software. Finally, in addition to capturing the 3D geometry of a vehicle, the surrounding environment is also captured to the extent that it has corresponding points in multiple photographs. While the accuracy of these representations were not assessed in this study, future work should investigate the fidelity of the model in these areas, as there exists the potential to provide a record of the surrounding scene, including evidence such as skidmarks, debris, roadway geometry, and features on the side of the road such as ditches, trees and signs. Also, while a relatively undamaged vehicle was used in this study to examine the accuracy of the photo-based 3D scanning method for documenting vehicle geometry, there do not appear to be any significant limitations to extending this process to vehicles exhibiting crush-type deformation. That said, further validation for some special cases, such as deep narrow intrusion profiles that limit the line-of-sight from camera positions may be appropriate.

Limitations of Photo-Based 3D Scanning

Given that photo-based 3D scanning involves automatic referencing of features among a series of photographs, objects that lack a sufficient quantity of unique detectable features, such as objects that are transparent (i.e. windows), reflective (i.e. windows, mirrors, glossy paint) or have uniform surfaces with little variation, can be problematic. When objects with these types of problematic areas are processed using a photo-based 3D scanning application, the resulting model may contain holes in the mesh where a sufficient quantity of features were not available for referencing. While the coded targets used in this study are not a requirement for photo-based 3D scanning, the presence of these high contrast features, distributed roughly evenly over the surface of the vehicle, likely improved the mesh results for surfaces of the vehicle, such as large body panels, that exhibited less surface variation. It should be noted that research is currently being conducted to address the limitations associated with reflective surfaces [36]. However, to date, such research has not been explicitly applied to commercially or freely available photo-based 3D scanning software. Next, while there was excellent agreement between the photo-based 3D scanning model of the vehicle and the data generated using the total station and traditional photogrammetry at all target locations, some areas of the vehicle model demonstrated visible anomalies. Most notable were regions of the vehicle that exhibited low light levels during the photography process. Those areas included the wheel well between the tire and inner fender liner, the front and rear under surface of the tires, the recessed grille area and portions of the vehicle interior. Given that these areas of the vehicle were not well illuminated, they appeared dark and featureless in the photographs, hindering the mesh creation process. It is likely that the model accuracy could be improved in these areas with the addition of auxiliary, constant lighting (non-flash) during the photography process, or by changing camera settings to increase the exposure.

SUMMARY/CONCLUSIONS

1. Photo-based 3D scanning using 123D Catch® is a valid mode of reconstructing the geometry of a vehicle for the purposes of collision reconstruction.

2. When compared with other measurement methodologies, including total station, laser scanning, CCM and crush jigs, photo-based 3D scanning requires less time to collect and process three-dimensional geometry of a vehicle [22]. Moreover, data collection using photo-based 3D scanning can be performed by anyone with a digital camera and a computer.

3. The production of a textured vehicle model allows superficial surface damage on the vehicle, including paint transfer and abrasion evidence, to be visualized in the context of the overall vehicle geometry. In addition, the production of a textured model of the environment surrounding the vehicle allows roadway evidence, such as skid marks and debris, to be visualized in the context of the overall incident.

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