Journal of Sports Science 4 (2016) 279-286
doi: 10.17265/2332-7839/2016.05.004

A Method to Evaluate Abrasion of Shoe-Sole Using 3D Scanning Technique

Glen Lim Chun Yee[1], Yeo Joon Hock[1], Tsuyoshi Nishiwaki[2], Kenta Moriyasu[2] and Kenichi Harano[2]

1. Nanyang Technological University/School of Mechanical & Aerospace Engineering, 50 Nanyang Avenue, Singapore 639798, Singapore

2. ASICS Institute of Sport Science, ASICS Corporation, 2-1, Takatsukadai 6-chome, Nishi-ku, Kobe 651-2271, Japan

Abstract: A study was carried out to evaluate abrasion of shoe-sole for subjects with different running gait. A 3 dimensional (3D) scanning approach together with a commercial software, CloudCompare Mesh Cloud Comparison was utilized for this study. In CloudCompare, a grid system and colored scale was applied to identify the region and extend of abrasion of the shoe-sole. This study clearly showed the extent of abrasion on regions of shoe-sole identified from the colored scale. This paper was done with kind support from Asics Institute for Sports Science, Kobe, Japan and Institute for Sport Research (ISR-NTU).

Key words: Shoe wear pattern, cloud comparison, 3D Wear analysis.

1. Introduction

There is significant research on various shoe technologies that enhances the running experience either upon impact with the running surface, or the general running comfort. However, the pertinent question still lies insufficiently answered—when is it the right time to replace the shoe? This question branches out to various areas, specifically to how worn out the shoe is, how much the body realigns and compensates due to the altered shoe pattern and finally, what is the limit where the body's natural adaptation to the worn out shoe results in harm and hurt to the body.

National Academy of Sport Medicine [1] quoted running distances of 300-500 miles (480 km to 800 km) that indicates the shoe reaching the tail-end of its lifespan while others merely quote 300 km as being the key number. The large variance of uncertainty as well as the vagueness of this mileage range has brought other researchers and athletes to derive alternative methods of observing the wear patterns of the shoe. Cary Zinkin [2] proposed that runners should visually check the shoe alignment on a flat surface, feel for any creasing in the midsole and try on a new pair of shoes of the same model to compare the difference in bounce and support.

Evidently, these observable methods are tangible indicators of determining whether a shoe is worn out. However, these physical examinations are still subjective and not fully reliable as people might still over or under-estimate the level of shoe degradation.

1.1 Objective

The paper attempts to develop an objective methodology to evaluated abrasion of shoe-sole by applying 3D scanning of the shoe-sole before and after abrasion and to extract the difference and derive the abrasion. A grid system will be implemented to ensure consistency in analyzing the same region before and after abrasion.

2. Methodology

Asics Gel Noosa Tri 9 was used in this experiment. 15 volunteers who have competitive experiences in mid to long running distances were recruited to participate in this study. Written and informed consent

Corresponding Author: Yeo Joon Hock, Dr., assoc professor, research field: artificial heart valve, cardiovascular engineering, innovation in medical devices.

Table 1 Descriptive Characteristics of Participants (Standard Deviations denoted in brackets).

	Males	Females	Total Sample
Number of Participants	11	4	15
Average Height (cm)	173.82 cm (5.40 cm)	163.62 cm (6.12 cm)	173.33 cm (7.11 cm)
Average Weight (kg)	67.09 kg (8.00 kg)	49.42 kg (5.13 kg)	66.16 kg (10.80 kg)
Age (Years)	22.82 yrs (1.40 yrs)	22.75 yrs (1.25 yrs)	22.83 yrs (1.32 yrs)
Average 2.4km time	9 min 22.54 s (1 min 25.82 s)	9 min 53.75 s (48.88 s)	9 min 28.16 s (1 min 17.31 s)
Average Mileage (km)	370.40 km (19.60 km)	357.00 km (10.45 km)	368.61 km (18.31 km)

was sought from each test subject and detailed running experience as well as prior injuries were documented before starting experiment. A pair of Asics Gel Noosa TRI™ 9 T485N was issued individually. Table 1 details a summary of the descriptive characteristics of the participants while the Appendix records the mileage breakdown.

2.1 Experimental Scope and Assumptions

The experiment spanned over a 10-month duration with each participant running distances of 350 km to 400 km (either on road or track). The experiment was not confined to a closed and consistent environment hence various initial assumptions have been made in terms of the shoe usage. These assumptions include the consistent shoe care (or the lack of it) across all participants, and that the speed and distances covered per participant will vary but is normalized across the board over the 10-month duration. Running conditions like the shoe-to-ground temperature difference, wet or dry conditions and other exogenous variables can be assumed to have constant impact on the rate and quantity of under sole degradation given the consistent climate and humidity throughout the experiment.

2.2 Selection of Participant's Shoe for Study

In order to ascertain a consistent measure of abrasion pattern changes of the shoes selected for analysis, Participants G, H, I and J were identified since all are Normal Pronation. All these participants also wore the same US size 9.5. In addition, these participants also exhibited the same fitness level that is on the upper spectrum of average according to the 2.4 km fitness test score adopted by MINDEF [3]. Hence the shoes of these participants were selected for 3D scanning and analysis.

2.3 3D Scanning and Comparison

Using a David Laser Scanner SLS-2, the 3D images of the new and worn left shoes were categorically documented. It is assumed that abrasion on the both feet is symmetrical and hence only the left foot shoe was scanned. The next step is to "superimpose" the 3D scanned images of the new and worn shoe. CloudCompare was used to extract the difference in the 3D scan images of the new and worn shoe. CloudCompare is a free open software that manages and compares 3D point clouds, developed externally by Salma [4].

By importing the 3D scan image into CloudCompare, it is able to extract sampled points as dictated by the user through the <Sample Point on A Mesh> function [5]. 2 million points[1] were sampled from the 3D scan image and subsequently, triangular meshes were exported for comparison.

As it is a comparison of meshes of a used and unused shoe of identical size, there is a need to align the 2

[1] There does not seem to be an apparent physical upper limit to the number of sampled points, but at 9 million points, there was a significant drop in clarity of the mesh cloud to depict the details in spite of having the smallest possible point size. As such, it appears that there is a certain upper limit for the number of sample points that compromises the image clarity.

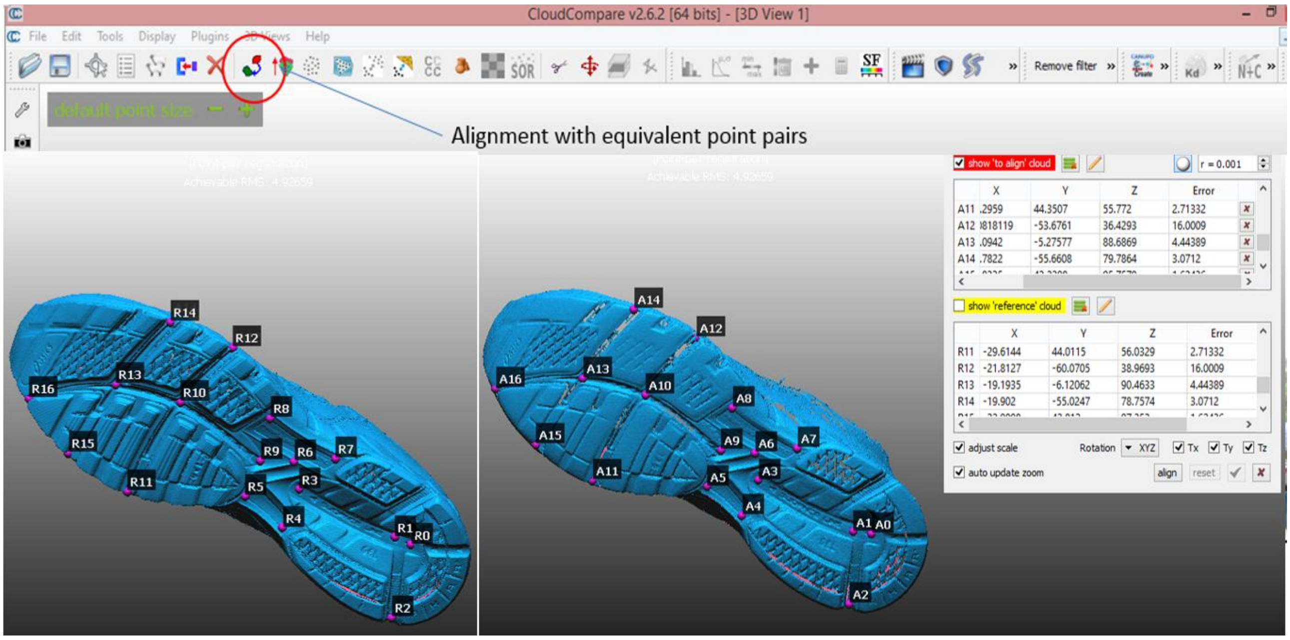

Fig. 1 Ordered points for alignment of 3D image.

Fig. 2 Gap between shoe sole and the ground.

separate 3D images through the <Alignment with Equivalent Point Pairs> function. In Fig. 1, 16 ordered points were extracted from the used and unused mesh clouds and their data sets were calibrated to match. After the approximate manual alignment, a fine alignment was carried out in CloudCompare via the "Iterative Closest Point (ICP)" algorithm through the <Fine Registration using ICP> function. The "Iterative Closest Point" (ICP) algorithm [6] from Paul Besl and Neil McKay [7] obtained the closest approximate on a geometric image to a given point by iteratively converging ordered points to the nearest local minimum of a mean-square distance metric, and thus minimizing the global mean square distance matrix over 6 degrees of freedom. The ordered points were manually picked as that they lied in between the sole material and do not come into direct contact with the ground throughout the use of the shoe.

One of the fixed points was physically sought along mid region of the shoe itself. Based on the fact that the midpoint of the shoe does not touch the ground as seen in Fig. 2, it is a reasonably good estimate that the midpoint of the shoe will undergo negligible change over the lifecycle of the shoe. Thus it is reasonable to assume that these are consistent points on both the used and unused mesh.

Selected points were scattered along the length and width of the mesh to ensure that there is complete alignment in all 6 degrees of freedom of the shoe. The assumption that the midpoint of the shoe faced negligible wear was visually inspected and validated. All the specimen shoes that underwent more than 350 km of running wear experienced no visible wear and tear in that region.

By launching the <Compute Cloud to Cloud distance> function, CloudCompare measured the approximate differences in mesh clouds based on a predetermined

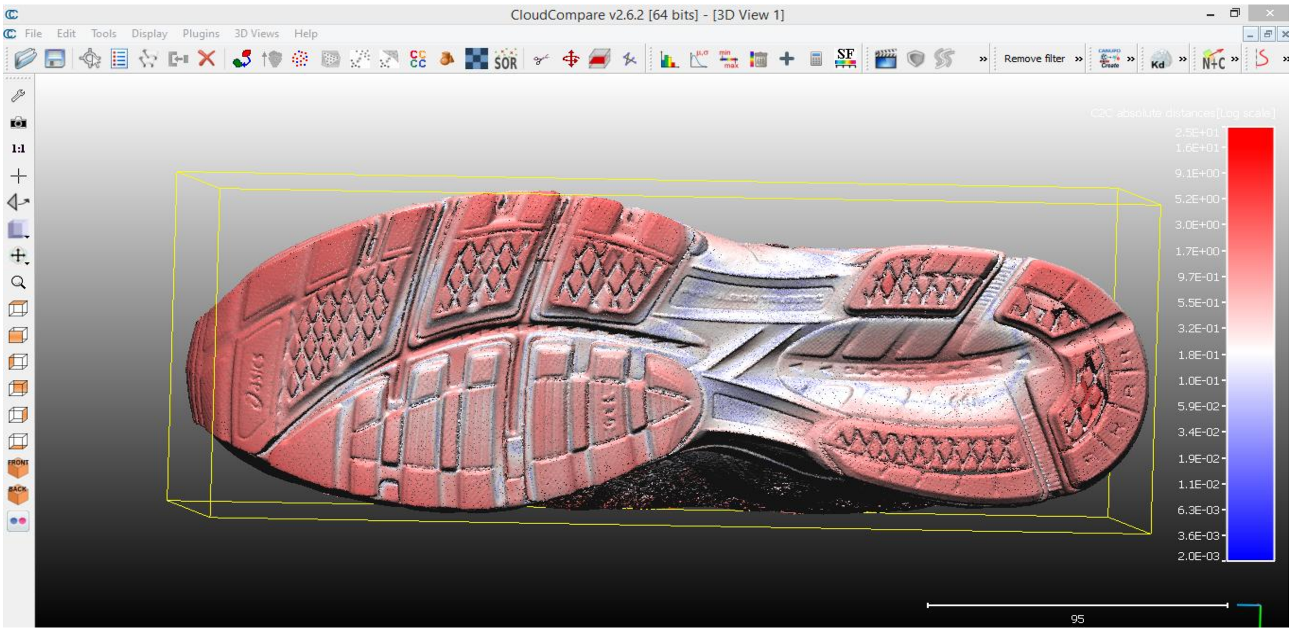

Fig. 3 Red>White>Blue Mesh comparison results.

Fig. 4 Manually determination of unchanging reference point.

octree level[2]. Using the concept of "Nearest Neighbor Distance", CloudCompare takes a triangulated data set on the nearest point and its neighbors in the reference cloud to compute an absolute distance value. Subsequently, the reference cloud can be hidden whilst the compared cloud is colored with the approximate cloud distances based on a log scale as seen in Fig. 3.

Finally, a 2D shoe print of the comparison image can be extracted by saving the comparison cloud as a jpeg file or via a screenshot. Thereafter, a grid system is manually added for consistent analysis of regions before and after abrasion. By drawing 2 intersecting lines from the 4 fixed corners of the pattern at the bridge area of the shoe, a reference point can be located as depicted in Fig. 4.

Next, the frame of the image is added by extending 2 parallel lines along the vertical length of the shoe, one intersecting the outermost width of the shoe on its inner side, the other cutting through the origin previously created. With a horizontal line stretching across the width of the shoe and cutting through the origin, divide the length into 10 each portions, each of γ (mm). A grid is eventually derived by dividing the entire image with vertical and horizontal lines that are spaced γ (mm) apart as referenced from the origin.

This step-by-step description is illustrated in Fig. 5.

The described quantitative derivation of the grid can be consistently repeated and hence it was used as a consistent method of obtaining a visual reference point.

[2] The Octree level is one of the main parameters for the mesh to mesh distance computation besides the maximum distance and normal distance. Critically, the higher the subdivision level of Octree is, the smaller the octree cells accommodating fewer points within each cell. This results in fewer computations done to locate the nearest points. However, the smaller cells size means a greater number of cells are iterated of which requires significant amount of computer RAM.

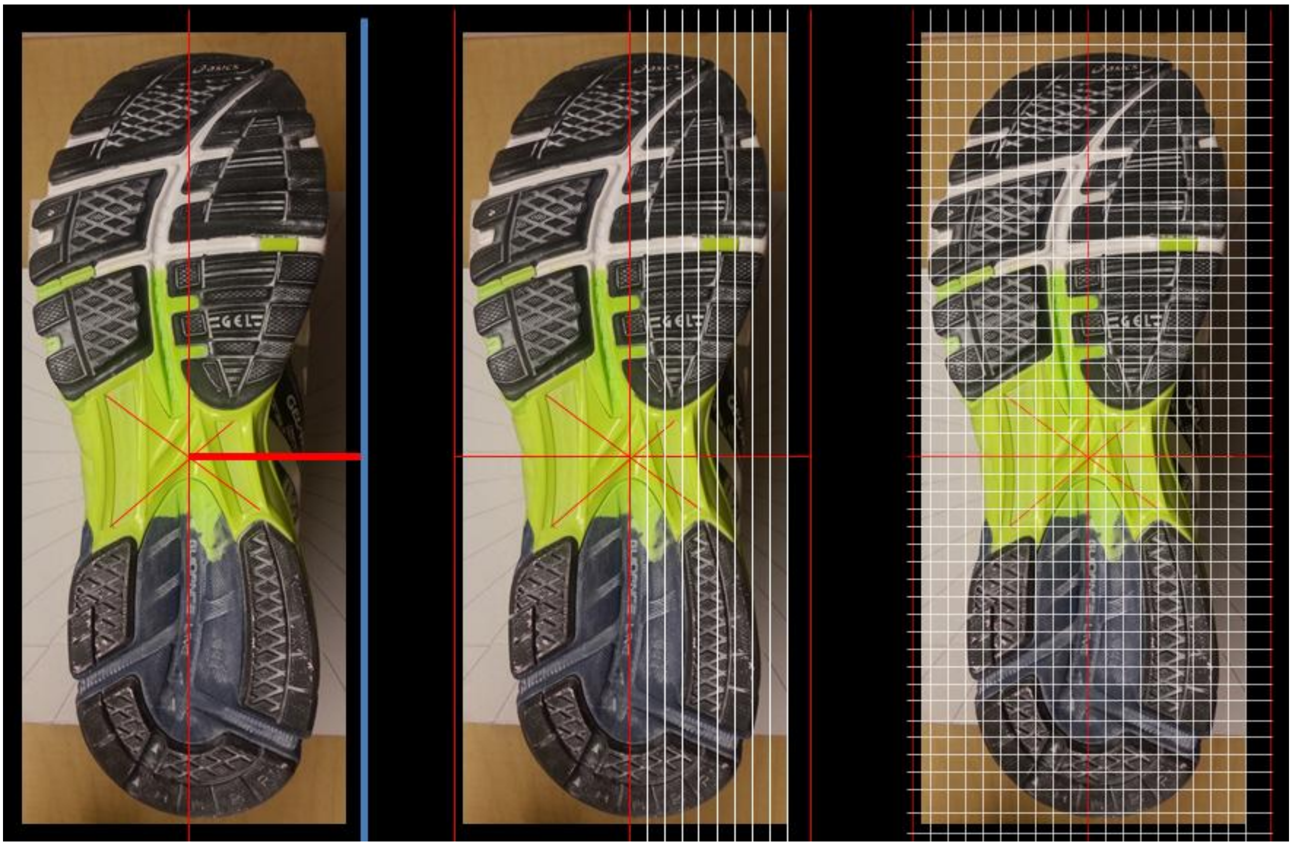

Fig. 5 Development of grid system for measurements.

At this junction, it is notable to point out that each size has differing width for both Men and Women. This means each grid is specific to a particular size and width and the grid square size γ (mm) will vary according to the existing length and width. Similar approach by Gao and Allison [8] using a 2-dimensional shoe print reported a systemic accuracy of 88%.

3. Results and Discussion

Sample results from the 3D scan and measurement of the wear patterns in the grid system is presented in Fig. 6. This result was derived from the left shoe comparison of Participant I.

The color code varies across the sole of the shoe, illustrating uneven abrasion. Evidently those grid cells containing colors nearing the red end of the spectrum exhibit a higher degree of wear. It is notable that the wear on the left shoe is focused around the edges of the forefoot. At the rear end (heel and left) similar red end of the spectrum can also be seen, indicating higher wear.

At the midpoint region where visual inspection of the sole showed not physical wear and tear, the color code is white/light blue. This color code is consistent across the midpoint region as in Fig. 6. It is also noted that some of the larger and deeper "grooves" are color coded lightly indicating minimum of no wear. This result is also consistent with visual inspection. On the other hand, there are 2 large "grooves" around the heel region that exhibits red color indicating noticeable abrasion. This is also consistent with visual inspection. Abrasion around these "grooved" regions is likely due to striking force (upon land of the shoe) followed by compression of the sole and "squeezing and rubbing". The "groove" around these worn regions is noticeably smaller compared to that of a new shoe.

With a grid system, it is possible to make comparison across different subjects. For comparing

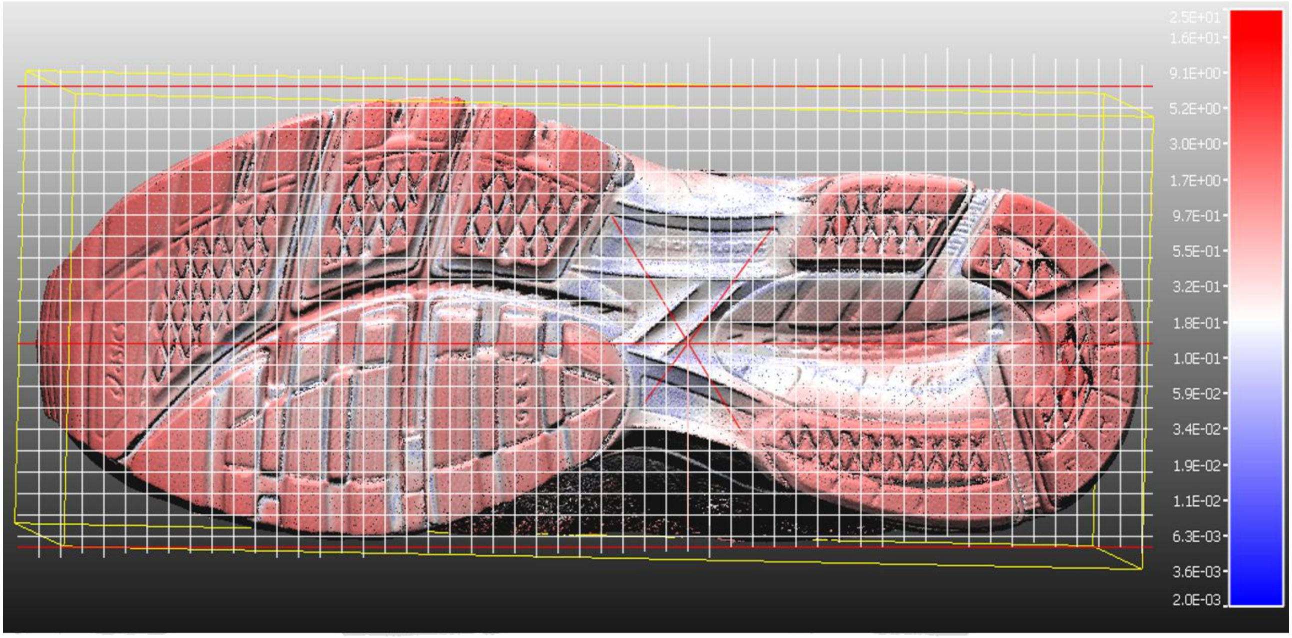

Fig. 6 Grid on scan results for CloudCompare of unused vs used shoe sole.

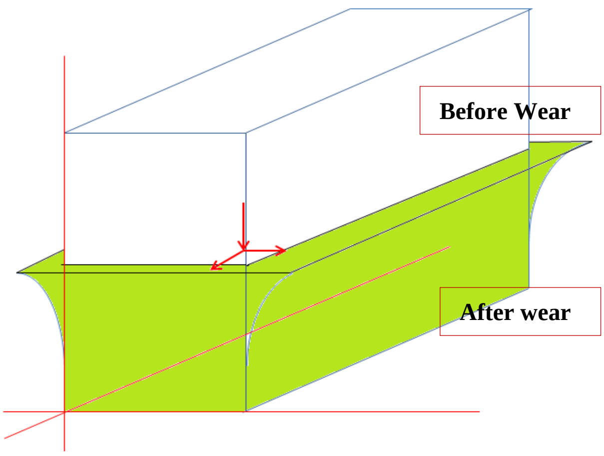

Fig. 7 Deformation of the bottom sole in 3 different axis.

shoe of different sizes, a normalized grid system can be introduced. In comparison to the grid system used in Fingerprint Biometric [9] and Forensic analysis [10], the analysis using the grid system is directed within the cell draw up by the grid and not the grid node itself. Although there are certain data that can be derived at the grid nodes, it is more meaningful to ascertain the overall color (and thus sole changes) based on the cell in entirety as the general change is distributed in a continuous manner and not in a discrete form.

The physical point derivation in this method also avoided the issue of an inconsistent reference point allocation seen in the principal component vector line system used by Sheets [11]. Wear at the bottom sole occurs in 3 dimensions instead of 2 as described in Fig. 7. The worn out width of the shoe is assumed unchanged and there might be error arising in terms of the grid size which result in an inaccurate positioning of the grid points. With this, there will be a significant statistical error as the comparative measurements will be done between 2 different points due to the shift in the original position.

Wear measurements of shoe sole described previously by Cappaert [12] was a destructive analytical approach focused on selected region of study by placing thickness gauge to monitor wear depth.

In the open literature, there is a lack of a quantification methodology on shoe wear. In this study, abrasion of the shoe-sole can be seen through color code variation. Abrasion of the shoe sole develops over time and usage. If scanning of the shoe is planned in stages, this method described can provide a progressive analysis of abrasion over time on selected grid region accordingly.

Although the extent of abrasion is evident from the colored scale, there is a lack of physical dimension at the moment. At the midpoint region where abrasion is reasonably assumed to be negligible, the corresponding scale of 5.9E-2 (approximately) can be calibrated as zero wear. On the red end of the spectrum, the scale is 2.3E01 and this should correspond to physical point around the forefoot region. A physical dimension at this point would be required for calibration. Progressively, this technique can be expanded so that the surface of each cell can be integrated to determine the volume change.

By combining this knowledge against the participant's particular gait change, it is possible to map a correlation between the development of abrasion of shoe-sole and the gait pattern. These correlations, along with a normal health and safety implications could provide an individualized measurement of how much a person can use a worn shoe before it can have a negative effect.

4. Conclusion

This study described a 3D scanning approach together with a commercial software to evaluate the extent of abrasion of shoe-sole of subjects with different running gait. Open-source software CloudCompare derived a colored scale illustrating the difference between the used (worn) and unused (new) shoe-sole in 3D space. A 2D grid system was implemented manually to ensure consistent analysis before and after abrasion.

The color scale and grid system of the shoe-sole indicated the region and abrasion. Likewise this method of evaluating abrasion can be investigated over time or running distance; that is, progressive abrasive with respect to time and usage. This study can be extended to include striking force of the shoe with respect to weight of subject and running speed. Hence, an extensive experimental knowledge base can be developed for verification of a numerical model for shoe-sole abrasion. This will be a useful tool for the shoe designer/manufacturer.

Acknowledgements

This research was carried out with kind support from Asics Institute for Sports Science, Kobe, Japan and Institute for Sport Research (ISR-NTU).

References

[1] National Academy of Sports Medicine. 2011. "How Often Should I Change My Athletic Shoes?" Accessed September 29, 2015. http://www.sharecare.com/health/fitness-footwear/how-often-change-my-shoes.

[2] Zinkin, D. C. 2001. "4 Signs It's Time for New Shoes." Accessed September 29, 2015. http://www.footlocker.com/striperpedia/articleDetailsWriter?content_id=5001686&mode=PDF.

[3] Mindef Singapore, Cyberpioneer. 2015. "New IPPT Motivates SAF Servicemen to Do Well and Keep Fit." Assessed September 29, 2015. https://www.mindef.gov.sg/imindef/press_room/official_releases/nr/2015/feb/27feb15_nr.html#.V9NcdSh97IV.

[4] CloudCompare. 2015. "CloudCompare 3D Point Cloud and Mesh Processing Software Open Source Project." Accessed Janruary 9, 2016.http://www.danielgm.net/cc/doc/qCC/Documentation_CloudCompare_version_2_1_eng.pdf.

[5] CloudCompareWiki. 2015. "Mesh\Sample Points." Accessed Janruary 9, 2016. http://www.cloudcompare.org/doc/wiki/index.php?title=Mesh%5CSample_points.

[6] Wild, M. 2010. *Recent Development of the Iterative Closest Point (ICP) Algorithm: An Overwiew of the Years 2002 to 2007*. Autonomous systems lab report. Assessed Janruary 9, 2016. http://students.asl.ethz.ch/upl_pdf/314-report.pdf.

[7] Besl, P. J., and McKay, N. D. 1992. "A Method for Registration of 3D Shapes." *IEEE Transactions on Pattern Analysis and Machine Intelligence* 14 (2): 239-56.

[8] Gao, B., and Allinson, N. 2010. "A Novel Multiresolution-Based Hybrid Approach for 3D Footwear." Presented at 2010 18th European Signal Processing Conference, Aalborg, Denmark.

[9] Easy Clocking. 2015. "What Is Biometrics?" Accessed December 19, 2015. http://www.bioelectronix.com/what_is_biometrics.html.

[10] Woodford, C. 2014. "Biometric Fingerprint Scanners." Accessed December 19, 2015. http://www.explainthatstuff.com/fingerprintscanners.html

[11] Sheets, H. D., Gross, S. Langenburg, G., Bush, P., and Bush, M. A. 2013. "Shape Measurement Tools in Footwear Analysis: A Statistical Investigation of

Accidental Characteristics over Time." *Forensic Sci. Int.* 232 (1-3): 84-91.

[12] Cappaert, J. M., Ocif, J., and Rich, B. 2005. "Inter & Intra-Subject Classifications of Outsole Wear in Running Shoes." In *International Society of Biomechanics Footwear Symposium Proceedings*.

Appendix

Tag	MILEAGE	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
A	367	35	36	40	40	36	45	40	20	45	30
B	347	39	36	35	25	40	40	30	35	40	27
C	365	25	36	34	40	50	50	30	40	30	30
D	349	35	30	45	45	35	25	46	15	33	40
F	358	40	35	35	45	38	29	37	29	40	30
E	367	50	31	38	28	50	24	31	45	30	40
G	354	12	50	48	36	44	50	18	41	35	20
H	385	38	30	25	39	20	40	50	88	55	
I	398	24	40	74	70	40	-	15	60	75	
J	362	24	15	30	90	50	33	10	10	100	
K	394	24	40	30	50	40	60	50	50	50	
L	352.4	80	40	2.4	30	35	20	40	30	35	40
M	370	120	150	100							
N	394	60	55	51	36	51	98	27	16		
O	340	40	40	40	40	40	20	20	30	70	