AUTOMATED SURFACE PROFILING OF DRYWALL SURFACE FOR SANDING

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ABSTRACT: The growing interest in the industrialization of construction process; promotes opportunities for automation. Automation brings improvement in quality and productivity, while reducing worker's exposure to hazardous work environments. The integration of robotics in interior finishing works, such as sanding and painting of drywalls is a relatively new concept. Progressing to a stage where fully autonomous robots are used for interior finishing works requires intermediate steps; namely surface profiling. This paper describes a theoretical concept of shadow profilometery to profile the surface of an installed drywall. A shadow was cast over the area under consideration, and the shadow profile was captured as a 2D image by a camera. Digital image processing techniques were utilized for identifying regions that deviate from a flat surface. The methodology discussed in this paper, was tested on a virtual system, and the results were found to be encouraging.

Keywords: *Smoothness Evaluation, Shadow, Light Sectioning, Sanding, Drywall Surface Evaluation*

1. INTRODUCTION

Research in construction automation and robotics has been gaining interest in the past two decades. The growth of interest in construction automation and robotics is mainly due to the solutions that its implementation provides to the problems that have been identified in the construction industry. Bock classified current problems of the construction industry as declining productivity, shortage of skilled workers, and working conditions [2].The implementation of automated and robotic systems has become more common in the automobile and other manufacturing industries, bringing about significant improvements in the productivity of these industries. The productivity in the construction industry, however, continues to remain constant, as discussed by Balaguer [1]. The implementation of an automated system would enable a greater degree of flexibility in the construction industry, while reducing labor requirements, improving safety, and increasing productivity [4]. Until recently, the construction of buildings has primarily been an onsite process. The unstructured nature of the construction environment has brought many challenges to the suggested implementation of automated systems and robotics. The main difference between other industries which employ automated solutions and the construction industry is the lack of a controllable environment in an onsite construction location. Implementing an environment similar to the manufacturing industry solves the challenges of an unstructured and uncontrollable work environment. The growing interest in modular construction makes industrialization of construction processes prospective. The use of modular techniques for construction is often motivated by the need to meet strict deadlines and high quality requirements [12]. Basic surface operations can be categorized into three categories namely, *Cleaning and Shaping, Coating and Spraying* and *Covering* [14]. Sanding of drywalls is an interior finishing process that is categorized under cleaning and shaping. Cleaning and shaping processes are often repetitive and hazardous tasks, which require protective equipment, continuous control, and high accuracy [14].

Currently, the sanding process of dry walls is a manual process that exposes workers to ergonomic and respiratory health hazards. A report that was published by National Institute of Occupational Safety and Health indicates that drywall sanders were exposed to at least 10 times the Permissible Exposure Limits (PEL) of total dust [11]. Automating this process would reduce exposure to hazardous environments, improve productivity, and improve the quality of sanding. The integration of robotics in interior finishing works, such as sanding and painting is a relatively new concept [8]. The understanding of the surface geometry becomes an important step in the development of a fully autonomous system for performing surface operations. This process of understanding the surface geometry is known as surface profiling. Surface profiling ensures proper identification of areas that require processing, and can also be used for the assessment of quality of the conducted operation. Manual assessment is a highly subjective way of assessing quality and it is often prone to errors resulting from human fatigue and judgment [7]. From the characteristics of these surface-finishing tasks it is possible to replace these manual tasks by robotic control strategies [14]. Knowledge of the surface is valuable in determining the parameters, such as force, location, speed etc. that influences the performance of an automated operation.

Physically, surface-profiling methods can be broadly classified into two main categories: “contact based” and “non-contact based”. In principle, however, they span across a wide range of methods, including *stylus*, *optical*, *ultrasonic*, *capacitive* and *inductive* techniques [5].Among the various principles discussed, the generally preferred methods for measurement are non-contact-based. A number of non-contact-based sensors have been developed and tested; however, almost no research has been conducted on evaluating the surface of drywalls. Computer vision, which incorporates the use of image processing and morphological techniques, is used to assess quality in the ceramic industry where the process of quality assessment is a difficult and labor intensive process [3] Machine vision is also utilized in the textile industry, where a combination of computer vision and neural networks is employed to identify and classify textile defects [6]. Extensive research on different surface profiling techniques have been previously conducted by Whitehouse [15].The goal of the paper is to present an accurate scanning system that is capable of producing a three dimensional profile of a drywall surface.

2. METHODOLOGY

This study makes use of the principle of Shadow profilometry to profile the surface of a drywall. Shadow profilometry is the technique of tracing a surface profile, by the use of shadows. When an object blocks the path of a light source a shadow is formed. Shadow regions have a lower luminous intensity than the remaining regions, which are illuminated by light. It is this difference in intensity that is used for detecting edges. The cross section of a shadow is a 2D profile. The principle behind shadow profilometry is that, when a plane of light is made to intersect with an irregular surface at an angle, the resultant intersection line follows the topography of the surface [10]. Shadow profilometry is considered to be one of the most efficient and scale independent methods for 3D characterization of a surface [9]. Sandak and Tanaka described the use of a shadow scanner for surface profiling in the timber industry to assess the quality of machine cutting [13]. This study uses the principle of Shadow profilometery to capture the three dimensional profile of a drywall surface through the methodology illustrated in Figure 1.

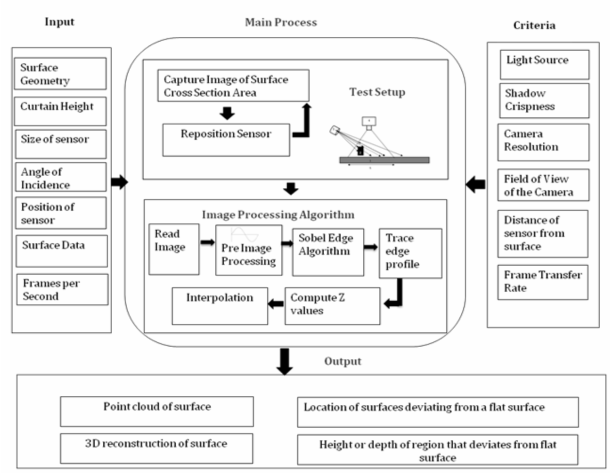


Fig. 1: Proposed Methodology

The methodology illustrated in Fig 1 incorporates input factors such as the drywall surface geometry, the angle of incidence of the light, and various parameters of the sensor. Information regarding the type of the light source used, the camera resolution, and the crispness of the shadows formed are taken into consideration in the pre-image processing phase of the computational logic. The outputs provide valuable information on the surface profile and its deviation from a flat surface. The main process is comprised of two phases, namely, test setup and the image processing algorithm.

Test Setup

In this study, the drywall surface is evaluated as collection of cross section areas. The Test setup refers to the process of capturing information corresponding to a cross section area of the surface being evaluated. The shadow profile over the surface cross section is captured as an image and the location of the sensor at the time of taking the image is also known. Multiple images of the shadow profile are then used to reconstruct the surface profile of the drywall. For this study, a virtual instance of the test setup was created using the 3D modeling tool as illustrated in Fig 2.

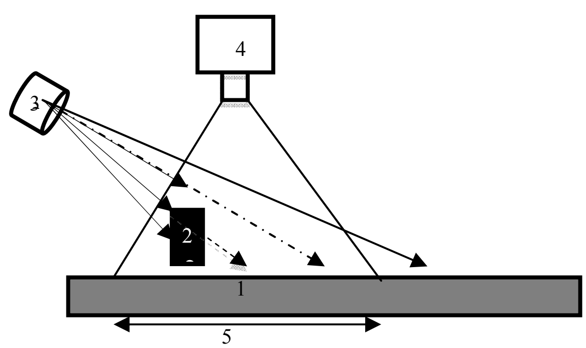


Fig. 2: General Schematic of proposed method.

The setup comprises of a light source (3), curtain (2), drywall surface (1) and an overhead camera (4). The field of view of the camera is represented by region 5. The light is incident on the surface at an angle α. A straight edge shadow is cast upon the surface by a curtain, which is modeled as a rectangular slab. The drywall surface is modeled as a rectangular slab. Surface irregularities such as elevated bumps and depressions are also modeled into the surface. A distance of 2 cm was maintained between the surface and the curtain. In practice, this is done so as to assure that the curtain does not come in contact with the surface, thereby preventing any damage. The shadow cast by the curtain was captured as a frame through the overhead camera, which was aligned perpendicular to the surface and the curtain. Each frame represents one cross section of the surface. In order to capture all sections of the surface, the setup comprising of the light source, curtain, and camera is moved, and images of the other cross sections of the surface are taken. The image processing algorithm is an integral part of the proposed methodology. Based on the images captured by the overhead camera, the image processing algorithm is capable of creating a three dimensional surface map of the drywall surface. The image processing algorithm is shown in Fig 3.

Image Processing Algorithm

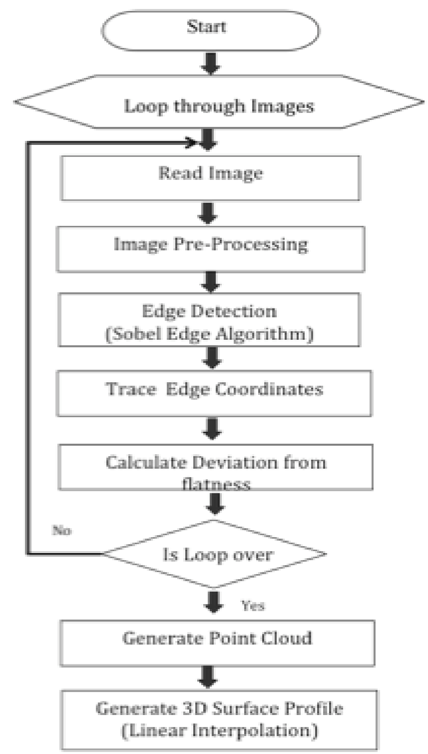
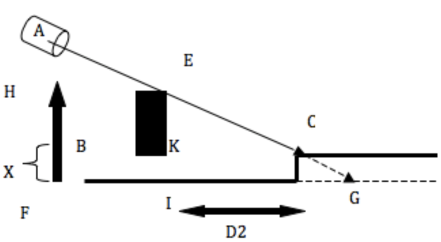


Fig. 3: Image Processing Algorithm

The first step of the algorithm involves reading the first sample image into the program workspace. The image matrix then undergoes a set of preprocessing algorithms.

The first preprocessing operation carried out on it was the grayscale conversion. The grayscale image is then converted into a binary image using a threshold method. The end result of the binary operation results in an image matrix comprising of the binary values of 0 and 1. The edge of the shadow profile is the border between the illuminated region and the shadow. After the binary image has been processed with an edge algorithm, a matrix of binary values is obtained.. Through this matrix, the numerical coordinate value of the shadow edge profile can be obtained. The process of determining the extent to which the surface deviates from flatness involves a set of trigonometric functions which is explained in this paper using the example of a surface with an elevated deviation as illustrated in Fig 4a and its geometrical representation in Fig 4b

a)



b)

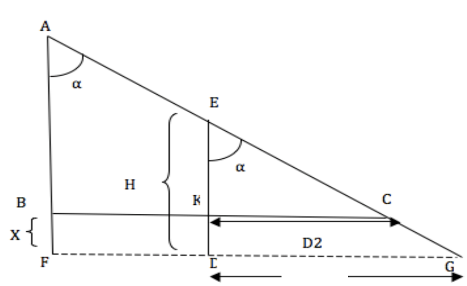


Fig. 4: a) Setup of surface elevation. B) Geometrical representation of Fig 4a.

Surfaces that have been filled with a joint compound tend to generally exhibit an elevation in their surface profile. In Fig 4b, the deviation of the surface is denoted by *X*, which corresponds to *FB*. The line *AC* represents the direction of the light ray. *AF* represents the height of the light source from the surface, and *ED* represents the height of the curtain from the surface. This height is inclusive of the region of separation between the surface and the curtain. The region where the shadow is formed is denoted by the line of *KC*. *DG* represents the area where the shadow edge would have been formed, had the surface been flat. The light source is incident at an angle of α, which is denoted by $\angle BAC$. Since the curtain is placed perpendicular to the surface, *AB* and *ED* are in parallel.

Let *ED* be denoted as *H*. The distance at which the shadow edge is formed, *KC*, is denoted as D_2. D_1 is the region at which the shadow would have been formed had the surface been flat. The height of the elevation *BF* is taken as *X*.

Hence,

$$ED = H + X \qquad (1)$$

In Δ EKC

$$Tan\ \alpha = \frac{D2}{H - X} \qquad (2)$$

From Equation 2,

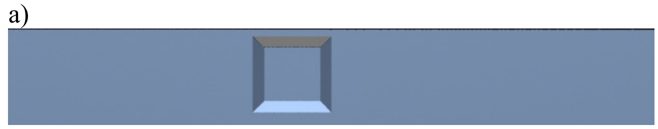
$$\boxed{X = \frac{(H * \tan\alpha) - D2}{\tan\alpha}} \qquad (3)$$

The value obtained for *X* in Equation 3, quantifies the deviation of the surface from flatness.

3. RESULTS

The study evaluated the methodology across different surface profiles. The surface profiles were modeled in the virtual setup to closely resemble surfaces that are usually encountered during the sanding process. Fig 5a gives an example of how an electric-socket like feature in a drywall is modeled in the virtual system. As the system progresses over the surface, the shadow profile is captured as images shown in Fig 5b. Using the methodology described in this paper, three dimensional maps of the surface is generated as shown in Fig 5c.

a)



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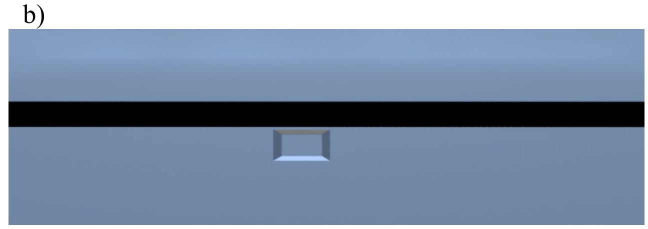


c)

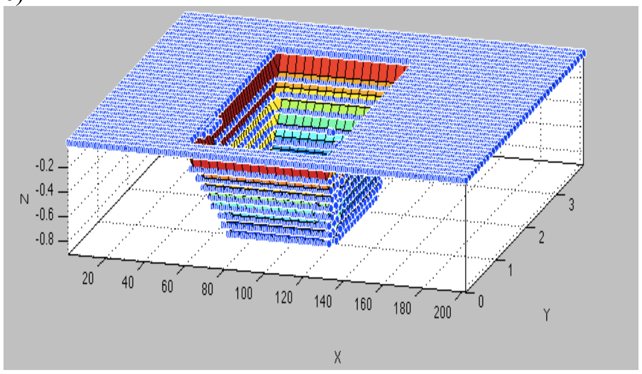
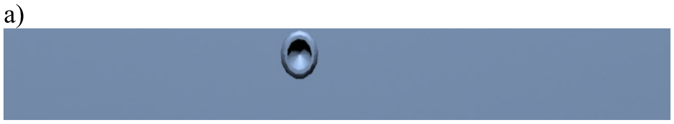


Fig. 5: a) Surface modeled with an electric-socket like depression. b) Sample images of shadow profile over surface with electric-socket like depression. b) 3D reconstruction of surface.

The output was validated against the original model. Points corresponding to the point cloud are compared against the original points of the particular section in the base model. By comparing the results of different sections of the surface with the original data, the maximum error was determined to be in the order of 0.05 cm from the original model with an average error of 0.005 cm and a standard deviation of 0.015. Similarly, case studies were run on surfaces which were modeled with a nail hole as shown in Fig 6a.

a)



b)

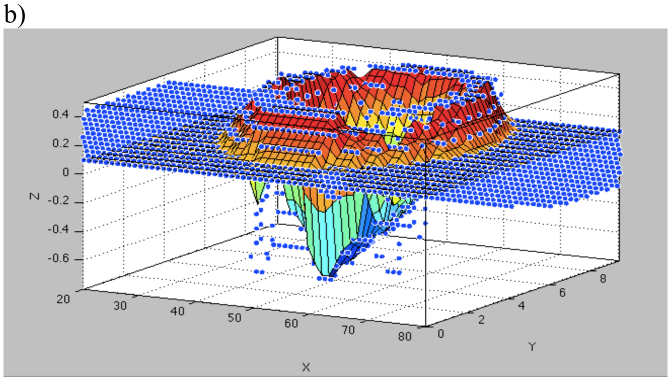


Fig. 6: a) Surface modeled with a nail hole. b) 3D reconstruction of nail hole.

The maximum error in the case of the surface with the nail hole was determined to be 0.05 cm with an average error of 0.009cm and a standard deviation of 0.035.

The next case study that is presented in this paper is of a deep narrow crack in the surface of the drywall. A representation of this case is shown in Fig 7.

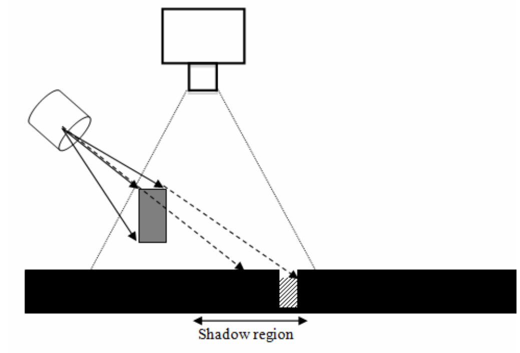


Fig. 7: Base model of a surface with a deep narrow crack.

As can be seen from Fig 7, light cannot reach the bottom of the crack surface and therefore, the shadow border will not be formed as it did in the previous cases. As a result, the crack remains totally dark and therefore the crack edge is presumed by the camera as the shadow border. It is clear that in such case, the distance at which the presumed shadow edge is formed does not correspond to the bottom of the crack. The three dimensional reconstruction of the crack is shown in Fig 8.

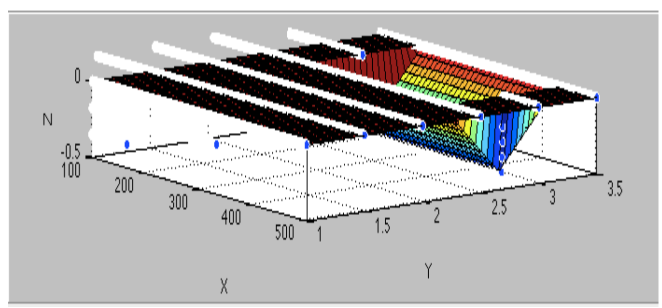


Fig. 8: 3D model of a surface with a deep narrow crack.

The maximum error was found to be of the order of 0.55cm and the average error was 0.36 cm with a standard deviation of 0.452. Though the depth calculated would differ from the actual depth of the crack, the information is not irrelevant in the scope of the application, as it does indicate the presence of a depression in the surface and thus identify the need to treat the surface. In practice, depressions such as those represented by the crack in this case, are treated by the application of mud. Owing to the difference between the calculated value and the actual depth of the crack, the amount of mud required would not be accurate. However, this is not very critical because, the applied mud would settle into the depths of the crack. As the mud has not covered the entire depth of the crack, a depression would still be present and would turn up in subsequent evaluation of the surface. Subsequent layers of mud can be applied until the region is found to be free from any depression.

4. CONCLUSION

The main contribution of this research is the development of an algorithm for the purpose of identifying and quantifying surface deviations in a drywall. The algorithm proposed in this study was tested across different case scenarios and the results were found to be encouraging. The algorithm utilizes existing methods and integrates them for the use of profiling the surface of a drywall for the purpose of sanding. Using a 3D modeling environment, the algorithm was tested across various cases such as an surface with an electric-socket like depression(average error: 0.005 cm), a surface with a nail hole(average error: 0.009 cm) and a surface with a deep crack (average error: 0.36 cm). The results of this study were found to be encouraging.

REFERENCES

[1] Balaguer, C. and Abderrahim, M. (2008). "Trends in Robotics and Automation in Construction, Robotics and Automation in Construction." IN-TECH, 1-20

[2] Bock, T. (2004). "Construction robotics and automation past-present-future." World Automation Congress, Proceedings June 28 2004-July 1, 2004.

[3] Elbehiery, H. , Hefnawy, A. , and Elewa, M. (2005). "Surface Defects Detection for Ceramic Tiles Using Image Processing and Morphological Techniques", 3World Enformatika Society Conference on Computer, Electrical, and Systems Science, and Engineering, Istanbul, Turkey , 158–162.

[4] Haas, C., Skibviewski, M., and Budny, E. (1995). "Robotics in civil engineering." Microcomputers in Civil Engineering, Vol.10, No. 5, pp. 371–381.

[5] Huynh, V. M. and Fan , Y. (1992). "Surface-texture measurement and characterization with applications to machine-tool monitoring." The International Journal of Advanced Manufacturing Technology Volume 7, Number 1, 2-10

[6] Islam, A., Akhter, S., Mursalin, T. E. (2006). "Automated Textile Defect Recognition System using Computer Vision and Artificial Neural Networks." Proceedings World Academy of Science, Engineering and Technology, Volume 13, , ISSN:1307-688.

[7] Islam, N., Parkin, R., Jackson, M.,Mueller, P. (2007). "A Novel Surface Profile Measurement System", AU J.T. 10(0):203-209

[8] Kahane, B. and Rosenfeld, Y. (2004). "Balancing human and robot integration in building tasks." Computer-Aided Civil and Infrastructure Engineering, 19(6):393-410.

[9] Maerz, N. H. Franklin, J. A. and Bennett, C. P. (1990). "Joint roughness measurement using shadow profilometry", International Journal of Rock Mechanics and Mining Science and Geomechanics, Abstract 27, pp. 329–343.

[10] Maerz, N. H., and Hilgers, M. C. (2010). "A method for matching fractured surfaces using shadow profilometry." Third International Conference on Tribology and Design 2010, Algarve, Portugal, pp. 237-248.

[11] Miller, A. K., Esswein, E. J. and Allen, J. (1997). "Health hazard evaluation report 94-0078-2660", NIOSH HETA 94-0078-2660 [cited 2010 Dec 16] Accessible online at http://www.cdc.gov/niosh/hhe/reports/pdfs/1994-0078-2660.pdf.

[12] Mohsen, O.M., Al-Hussein, M., Olearczyk, J., Abdulaal, B., Knytl, P.J.(2008). "Simulation of Modular Building Construction," Proceedings of the 2008 Winter Simulation Conference, pp. 2471-2478, Miami, FL, 2008.

[13]Sandak, J., and Tanaka, C. (2005). "Evaluation of surface smoothness using a light-sectioning shadow scanner." Journal of Wood Science 51(3): 270-310

[14] Skibniewski, M., and Hendrickson, C. (1988). "Analysis of robotic surface finishing work on construction site." Journal of Construction Engineering and Management, ASCE, 1141, 53–68.

[15] Whitehouse, D.J. (1987). "Surface Metrology Instrumentation", Journal of Physics, p. 1145.