Theoretical use of SVD to Save Information on the surface of a 3D Object

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***Abstract*—The needs of information have made innovation in information storage overflowing. This ranged from traditional method, up to using unconventional physical object as a medium. This paper provides exploration in the potential of using SVD to save information on the surface of a 3D object. By utilizing color, texture, and other micro-geometry shape, information could be embedded into an object's surface. This method of data storage offers secure data storage, personalized 3D-printed figure, and many more.**

***Keywords*—3D Information Saving, Information Object, SVD Information**

I. Introduction

In this modern age, the importance of information cannot be underestimated. Even the most frivolous information could be spread worldwide within seconds. This of course requires a way to store information. Through the revolutionary inventions in storing method, now even an electronic device that is as large as an adult human's thumb could store an enormous amount of data. Not only that, Technological advancement has allowed us to store data in cloud-storage, seemingly intangible object that could store an unimaginable amount of information. However, this form of data storing is mostly intangible, thus there is a growing interest to make a more tangible, physical representation of data storage.

This paper aims to introduce the possibility of storing and accessing information on the surface of 3D object by utilizing color, texture, and other perceivable features. By using binary number system (0s and 1s), we can store data on the surface of a 3D object by emphasizing on the, for example, density of the color, or roughness of the surface's texture. This approach of data storage has usage potential as identification, where the object themselves is the key that stores the data.

Fig 1. Example of a 3D model character
Source: https://in.pinterest.com/pin/pinterest--685321268314854243/

The original idea of this paper comes from tabletop Role-Playing games, specifically *Dungeons & Dragons*, where people create their own characters. It will be much more immersing, if people were able to 3D-print their own character models, that could also store information about that character. This creates a lot of possibilities make this type of game more immersive.

II. Basic Theory

A. Eigenvectors and EigenValues

Eigenvectors and Eigenvalues are the basic concept before doing SVD or many other linear algebra techniques, especially in the context of transforming matrix.

Eigenvector is a non-zero vecctor that only changes in scale when linear transformation is applied.

$$A \cdot v = \lambda \cdot v \quad (1)$$

Mathematically, given a square matrix A, an eigenvector v that satisfies (1), where λ is the corresponding eigenvalue. This eigenvalue represents the scale of the transformation of the eigenvector.

B. Singular Value Decomposition (SVD)

Singular Value Decomposition is a powerful linear algebra technique. SVD have often been used to point out the feature of the matrix, dimensionality reduction, image compression, and many more. This is because of the characteristics of SVD that could simplify complex data while preserving important information.

$$A = U \sum V^T \quad (2)$$

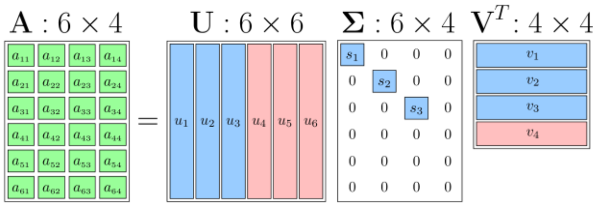

Fig 2. Illustration of SVD

Source: https://truetheta.io/concepts/linear-algebra/svd-and-the-fundamental-theorem-of-linear-algebra/

As shown in Figure 2, given a matrix A of size $m \times n$, SVD decomposes A into three matrices, where U is a $m \times m$ matrix, $\sum$ is a $m \times n$ matrix, and V^T is a $n \times n$ matrix. The columns of U are known as the left singular vectors, while the rows of V^T are knowns as right singular vectors.

To perform SVD, the principal step is to compute Matrices A^TA and AA^T. After finding those matrices, the next step is to find the eigenvectors and the eigenvalues of those matrices. The eigenvectors of A^TA will form matrix V, while the eigenvectors of AA^T will form the matrix U. The singular values, that is contained in the diagonal of $\sum$, are the square roots of the eigenvalues of either matrices (A^TA or AA^T).

$$AA^T = U \sum V^T V \sum U^T$$

$$AA^T = U \sum I \sum U^T$$

$$AA^T = U \prod U^T$$

C. 3D Printing

Fig 3. Image of a 3D printer

Source: https://images.app.goo.gl/sJTeKg6aweNhKesG9

The process of creating objects layer by layer using digital model is known as additive manufacturing, or more widely known as 3D printing. Unlike traditional manufacturing method that uses large object and then reducing its volume, 3D printing prints the object from zero, or builds it from scratch using given materials. This innovation has given a lot of opportunity in creating complex design that could be personalized depending on the usage of its user.

The process begins with designing the 3D object using computer-aided-design (CAD) software. This design would be converted into thin layers using software. These slices would then be printed layer by layer using the 3D printer, fusing each layer with the previous ones.

Materials are crucial in determining the usage of the 3D printed object. Usage of 3D printed object are vast, ranging from prototyping up to medical implants. Thermoplastics like PLA (Polylactic Acid) and ABS (Acrylonitrile Butadiene Styrene) are often used for lighter purposes as it is easier to use. Other materials like metal and resins are used for more precise and crucial use like medical implants.

III. METHODOLOGY

This section will dive deeper into the concept of storing and encoding information in form of binary into the surface of an object. Even though the methodology faces technological challenges, it still provides the potential in the future when said technological challenges has been solved.

A. Overview

Currently, one of the most common practice to store data is to use hard drives that rely on electronic components like hard disk or flash disk. However, in this paper, the medium is the 3D object itself, mainly using its surface as a method to store data. This process will need several processes to be able to be implemented, and it involves mathematical techniques to encode and decode the information, that is, Singular Value Decomposition (SVD).

The processes that needs to be done starts with data encoding, in the sense to store raw data into binary data. This data will be saved in a matrix that could later be processed. Raw data includes color, texture, or any other factors that could be used to store data.

After encoding the raw data, making the 3D object comes next. The encoded data needs to be incorporated into the 3D object, with as less originality removed as possible. This of course also needs to be decode-able. Decoding will involve a lot of processes using cameras to detect visuals and tactile sensors to know the roughness of the surface.

Lastly, maintenance is also a problem that needs to be concerned about. Objects are bound to differ the longer they are exposed to environmental factors. The problem lies on how to suppress this as much as possible, while also increasing the decoding efficiency to ensure that the object could be used for as long as possible.

B. Storing data

One of the most crucial part in this methodology is the method to store the data, and then translates the data back into its original form. This process will mainly utilize binary data because it matches the design of electronics, and thus it requires less factor to be concerned about.

Binary number system is based on 2, unlike the decimal number system that is based on 10. The only number in binary is 0s and 1s. For example, 5 in decimal number system would be 110 in binary. This binary encoding would be put into a matrix, preparing for SVD.

C. Object Design

This process involves making a 3D figure, along with encoding the binary data into its surface. The creation of the 3D figure itself uses computer-aided design tool. The model itself may vary depending on what it is used for, but it will be integrated with the encoded data.

Models should be free and not restricted because it speaks art for whoever made it. This makes it harder to incorporate the binary data. What is left to be under control is, how to process the data so that the information could be conveyed. One possible way is to divide the 3D figure into several grids, or several shapes. The separator could be from rough surface that loops around, or a slightly different color that loops around. Each grid would contain information that could be interpreted.

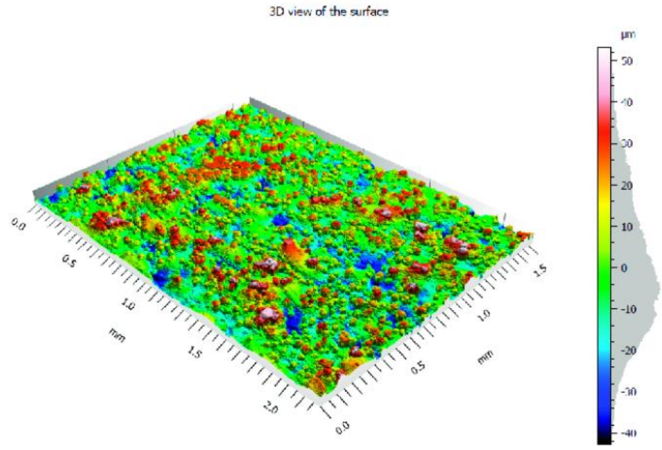

Fig 4. Example of surface roughness map sample

Source:https://www.researchgate.net/publication/352999591_Effect_of_Surface_Sandblasting_and_Turning_on_Compressive_Strength_of_Thin_316L_Stainless_Steel_Shells_Produced_by_Laser_Powder_Bed_Fusion

One method to encode data is by manipulating the surface roughness as shown in Figure 4. Using threshold as separator, encoding 0s and 1s into the surface. Ideally, this will be made using a high-precision 3D printer.

Material is also an important factor in object design. Right now, using a high-resolution 3D printer is preferable to maintain the feature in the surface of the 3D figure. In the future however, a more steady and sturdier material would be better. This especially asks for materials with distinctive texture and/or coloring method of said material, to further decrease mistakes in reading the surface, for example, misjudge in the roughness of the surface.

D. Decoding

Collecting data from the surface proves to be a challenge. Not only is it difficult to process surfaces that is hard for the camera to reach, resolution also needs to be consistent and at least up to standard, to maintain the data within. This process will consist of 2 sub-process, that is, collecting the data and processing the data.

Data collection would vary, depending on how many variables to account in the surface (color, texture, or any other micro-geometry shape). The tools that is used to capture the surface will be different, if the variable is different.

Color sampling requires camera that could capture colors that is used to take picture of every part of the figure. If the figure has hard-to-reach surface, then micro-camera that could capture colors must be used meticulously, accounting the dimension of the surface.

Texture sampling requires pressure-sensitive sensors that could detect surface's texture. This proves to be a challenge, as detecting the roughness of the surface is still very hard.

Processing the data is done by converting the raw data into binary values, then putting them inside matrix, for later to be processed. This conversion faces many challenges, such as lighting, environmental dust, noises, and a lot more.

The next step of data processing before it is usable is by extracting the features using (1). This will approximate the original data, making the data meaningful and usable. However, data corruption and misalignment could still happen due to outside factors.

IV. Challenges and Limitations

Despite the potential of this method of data storage, there is still a lot of challenges to be accounted. This includes not only technological difficulties, but also environmental-related difficulties.

One of the technological difficulties includes the difficulty to maintain precision during printing the surface. Demands of sturdy materials and precision of printing proves to be a challenge.

Another problem is of the limited space on the surface, as printing in a very small scale is not currently possible. However, this problem will naturally be solved, as soon as smaller-scale printing is made possible.

The other problem is to be precise during surface scanning. With just one error, it bounds to make the data harder to read, hindering the processing of the data. The current technological innovations also faced difficulties in scanning a very small scale of details, for example, nano-scale detection. It requires a very meticulous process that takes up a lot of time, rendering it inefficient and ineffective.

Environmental factors come with a lot of forms. One of it being degradation overtime it being used. All we can do is to maintain the quality for as long as possible. Another problem is due to lighting condition during scanning the color, or dusts or particles that could affect the data, rendering it corrupted.

V. Future Directions

In the future, where innovations are blooming, there are a lot of innovations that could help with this theoretical innovation.

Nano-scale 3D printing will directly help solve the problem of having limited space to work on, but also making it harder to maintain the data's integrity as the environmental factor-problems like scratches or dusts becomes more significant.

Materials remain a resolute problem. Once an innovation about dynamic materials that could change the surface dynamically has been made, maintenance of the 3D object would be much more doable.

VI. Applications

This methodology could be used in various aspects. One of the most general use would be identification systems, which would be harder to steal digitally because it is not directly connected to the digital world. Other application may vary depending on the usage, starting from gaming until education.

VII. Conclusion

With our current technologies, implementation would be hard. However, This theoretical framework using SVD to encode information on the surface of a 3D object provides unique information storage and retrieval method. Despite many challenges, it promises usage in various fields in the future. In short, this is invitation for researcher to explore more in the method of saving information in 3D object.

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DECLARATION

With this, I declare that this paper is my work, not a replica or translation of someone else's paper, and not plagiarized.

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