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Mass-produced Parts Traceability System Based on Automated Scanning of "*Fingerprint of Things*"

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Abstract

This paper presents a prototype of parts traceability system which employs the "Fingerprint of Things"-based individual identification technique. Traceability of mass-produced tiny parts such as bolts and nuts are required to ensure quality and safety of big machines. However conventional systems using ID tags or serial marking are not applicable because of quantity and tiny size. To overcome this problem, we propose a tag-less traceability system which uses their appearance images as "fingerprints" to identify each of them. Our traceability system consists of three components; (i) automated fingerprints scanning machine for enrollment, (ii) mobile device for query and (iii) cloud server for identification from database. The key to success of our traceability system is enabling us to capture repeatable image features from the same parts in both of (i) enrollment and (ii) query. To this end, we designed the two lighting mechanisms; one for fast scanning of numerous bolts by automatic feeding, and another for a mobile device to capture one parts by hand. In our experiments, we achieve that 1,000 metal bolts produced with the same mold are perfectly identified by matching their surface images captured with our automatic scanning machine and a smart phone.

1. Introduction

Traceability of individual parts is essential to realize high-quality, reliability and safety products. Recently, counterfeits are increased significantly not only for luxury goods but also for mass-produced tiny parts. The critical damage occurred by misuse of invalid-spec parts has been increasingly reported, so there is demand for an identification technique that enables us to identify numerous tiny parts. The traditional way of tracing products is using ID tags such as barcodes, RFID, etc. These identification techniques improve identification process accurately and conveniently. However, attaching these tags causes additional costs to manufacture the products. Especially in case of tiny parts which produced on a large scale, adding tags would require explosive costs in proportion to its amount.

Emerging identification techniques that use a unique pattern as a "fingerprint" of the object have been proposed [1]-[4]. These techniques take advantage of patterns formed in nature during the manufacturing process. Bunchanan et al. [1] proposed a document and package identification technique that uses laser speckle patterns. Beekhof et al. [2] proposed a basic framework to identify papers by random microstructures of fibers. Matsumoto et al. [3] proposed a nano-artifact metrics based on the random collapse of resist pillars. Furthermore, as a target material that is widely used in industrial products, fingerprint-based identification method of metal parts has been proposed [4].

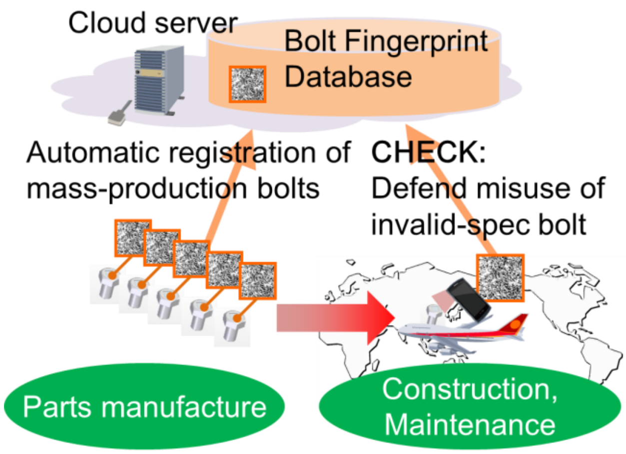


Figure 1. Concept of our traceability system using the "*Fingerprint of Things*"-based identification technique. First, all tiny parts are registered their surface patterns as fingerprint on a cloud server by parts manufacturer. Then a worker in the construction or maintenance process checks the parts with a mobile device before embedding them into products.

To employ these "*Fingerprint of Things*"-based identification approaches in the practical use, automation of fingerprint scanning process is mandatory especially for mass-produced parts traceability applications. In the previous literature, the identification and enrollment process is manually operated one-by-one with the same device. This framework is convenient for ensuring repeatable observation of the unique patterns. However it is impractical for large-scale industrial applications.

In this paper, we present a prototype of tiny metal parts traceability system which is able to scan numerous fingerprint images automatically. The system realizes individual identification of the metal bolts based on matching their fingerprint. No costly ID tag or serial marking is used; the target bolts are manufactured as the same ones with the identical mold, but the fingerprints are naturally differed and unique for each individual.

Figure 1 shows the concept of our traceability system. First, fingerprint images of numerous metal bolts are automatically captured in the manufacturing process. Then the images are uploaded to the cloud server and the fingerprint image database is created. It enables users around the world to check the individual bolts with a mobile device by sending their fingerprint images to the cloud server.

Through our experiments, we demonstrate that 1,000 metal bolts, which are produced with the same production mold, with identical appearance are perfectly identified by using our prototype of parts traceability system.

2. Design of Automated Scanning Machine for "*Fingerprint*" of Metal Bolts

To realize the individual identification of metal parts using their fingerprints with high accuracy, an imaging method which enables us to capture their unique features robustly against environmental changes is needed. Our approach ensures a quality of the captured image which has plenty of unique features by lighting design. Consequently it does not require neither special tune of feature extraction technique to the target metal bolts, nor huge image data are required for machine learning in order to achieve individual identification of the metal parts. We can identify each of the metal bolts perfectly using only standard image matching techniques in computer vision such as local features. This is mandatory to enlarge the application of the system to a huge variation of parts.

In this paper, we use the metal bolts as shown in Fig. 2 (a). Each of the metal bolts has the identical logo and pear-skin finish on their head. They were manufactured to be the same parts through the same process using the identical mold shown in Fig. 2 (b). The pear-skin finish is a kind of industrial metal finishing, which creates the glittery and rough texture like a pear skin on the surface. This metal finishing adds some functionality such as scratch hiding, anti-slipping, etc., to the products. This finishing is not designed to add information to identify individuals, but it gives plenty of unique features.

FIBAR imaging method which described in [4] enables us to capture the unique but microscopic features from metal surface. The point is that we enhance the unique micro bumps on the metal surface which are commonly considered as noise in the factory automation applications. The original design of FIBAR described in [4] is a smart phone attachment. It captures a bolt one-by-one by hand, thus it is impractical for automation of numerous bolts to be enrolled. In this paper, we propose a new design of FIBAR imaging method that employs a ring LED light in order to realize contactless fingerprints scanning with automated exchange of bolts by linear sliding. Figure 3 shows concept lighting idea of FIBAR imaging method and the proposed design of FIBAR imaging method for automation.

Figure 4 shows our prototype of automatic scanning machine for fingerprint of metal bolts. We use a monochrome camera whose resolution is 1,280 x 1,024 pixels In addition, we employ a macro lens and a ring LED light to realize FIBAR imaging method. The prototype scanning machine delivers the metal bolts just below the camera then captures the "fingerprint" images individually. Our prototype can capture one fingerprint image within 1.7 seconds, which enables us to scan more than 50,000 bolts per a day.

The unique pattern that can be used as fingerprint is the pear-skin finish area around the logo. Therefore, we

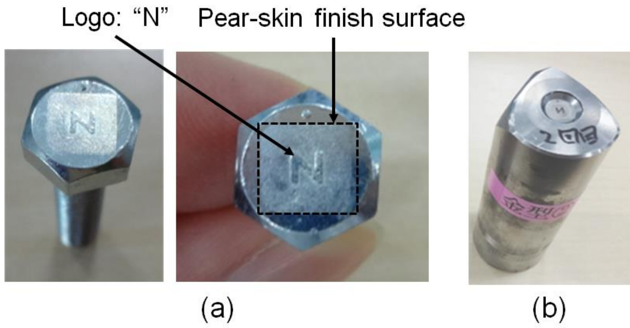


Figure 2. Target of our traceability system: (a) metal bolt with logo and pear-skin finish head, (b) production mold of the metal bolt.

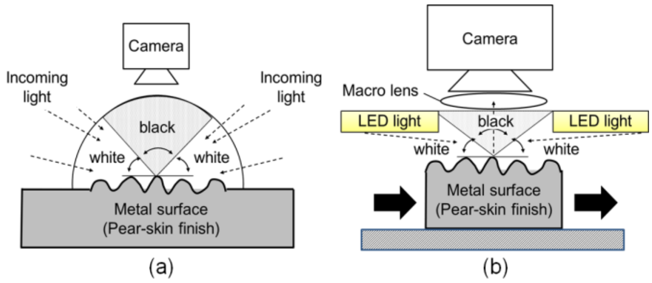


Figure 3. FIBAR imaging method for individual identification of metal parts: (a) basic idea of FIBAR, (b) proposed design of FIBAR imaging method that realizes contactless scanning in factory automation line.

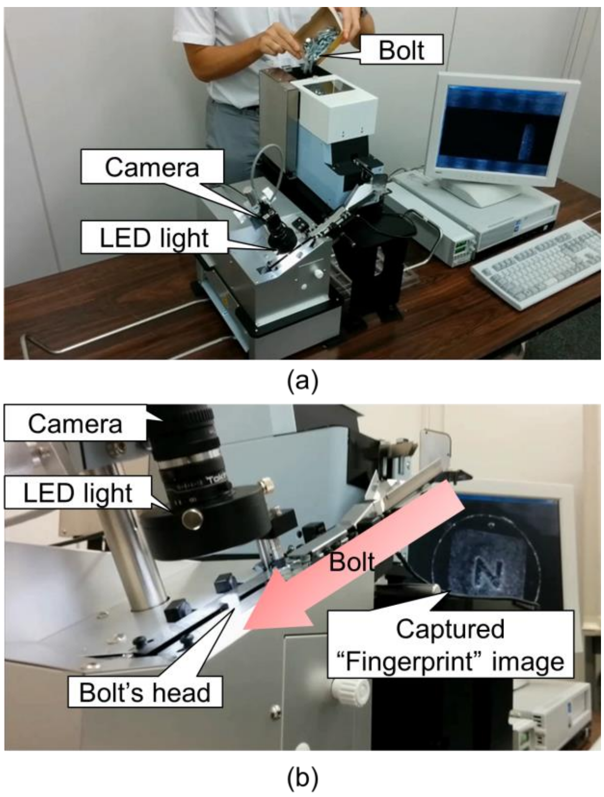


Figure 4. Automatic fingerprint scanning machine for the metal bolts: (a) fingerprint scanning machine, (b) bolts scanning process. The bolts are delivered just below a USB camera with a ring LED light. Then, their fingerprints are captured automatically with the camera.

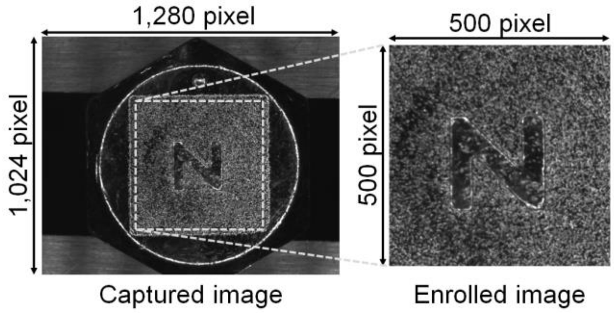


Figure 5. Enrolled fingerprint image. All of the captured images are trimmed in order to enroll the patterns of pear-skin finish surface area.

trimmed the captured image in order to enroll the patterns available for identification only as shown in Fig. 5. In this study, we set that the size of trimmed area is 500 x 500 pixels and the position of the area is fixed. Our prototype scanning machine collects the patterns of pear-skin finish area automatically and enrolls the patterns with unique serial number to the database.

After fingerprint scanning process, each bolt is sorted into the bulk tray as shown in Fig. 6. The bulk tray holds up to 50 metal bolts and each bulk tray has unique number. Figure 6 shows the correspondence between each metal bolt and its serial number issued in the fingerprint enrollment process. In this way, every bolt scanned by our prototype scanning machine is identified with unique serial number automatically.

3. Individual Identification Technique

Our traceability system identifies individual metal bolts with a mobile device such as a mobile phone or a mechanic tool [5]. This is because we assume the practical situation; for example, checking metal bolts before fastening products in order to prevent such mistakes as misuse of different bolts and applying improper torque. As shown in Fig. 1, such identification task is conducted at many places all over the world, where the bolts are shipped to. Although the bolts are manufactured in one supplier, the users are distributed in many places. Therefore, the identification must be available with an inexpensive and mobile device.

In this paper, we use a smart phone with FIBAR tool [4] as shown in Fig. 7 (a) to obtain a unique pattern of metal bolts robustly. FIBAR tool consists inexpensive components; a diffuser produced by the 3D printer with translucent PLA filaments, a toy macro lens, and a black ring absorber. We attached the FIBAR tool to a Google Nexus 5, so that we can easily capture the images, shown in Fig. 7 (b), that have the same features to be robustly matched with those captured by the automatic scanning machine described in Chapter 2.

Since FIBAR imaging method provides unique patterns robustly, the fingerprint images are successfully matched by the standard image matching techniques. The enrolled and query fingerprint images include some geometric transformation such as 2D rotation and some scale change. We employ the image matching technique based on local features to identify individual bolts in the same way described in [4].

Figure 6. Bolts serialization with our fingerprint scanning machine (above). Each bolt is assigned unique serial number according to its position on the bulk tray (below).

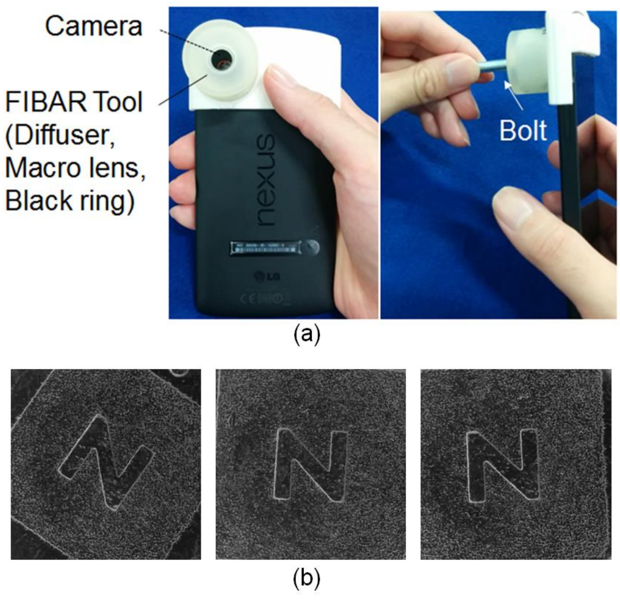


Figure 7. Mobile device design for identifying metal bolts: (a) smart phone (Google Nexus 5) with FIBAR tool, (b) example of captured images from the device.

First, we use Oriented FAST and Rotated BRIEF (ORB) [6] to obtain the corresponding point pairs between the query image and the enrolled image. Second, the corresponding point pairs are verified with the geometric consistency between the enrolled image and the query image. In this geometric verification step, we employ RANSAC [7] to obtain correct correspondence as inliers. Finally, we calculate the matching score on the basis of the number of inliers as following equation.

$$s = n_{inliers} / N_{total}, \qquad (1)$$

where, $n_{inliers}$ is the number of inliers, and N_{total} is the number of corresponding point pairs obtained by using ORB local feature matching. The score means the similarity between the enrolled image and the query image. If the score is higher than the fixed threshold, the enrolled and query images are identified as the same individual.

4. Experiment

In order to evaluate the performance of our traceability system, we used 1,000 metal bolts produced from the same production mold. Using the production mold shown in Fig. 2 (b), we produced over 10,000 metal bolts that have identical appearance of their surfaces with pear-skin finish. Then, we randomly chose 1,000 metal bolts in order to evaluate the performance of individual identification with our system.

In the experiment, we checked the matching scores between the images captured from our scanning machine and query images captured using the smart phone with FIBAR tool. We use a Google Nexus 5 which has 8 mega pixel CMOS sensor inside with FIBAR tool. The resolution of captured image was set 1,280 x 720 pixels. In addition, the captured images are trimmed around the pear-skin finish area in a similar way as automated scanning process (see Fig. 7). The size of trimmed images was 626 x 626 pixels. Then the trimmed images were resized to 323 x 323 pixels and used as query images.

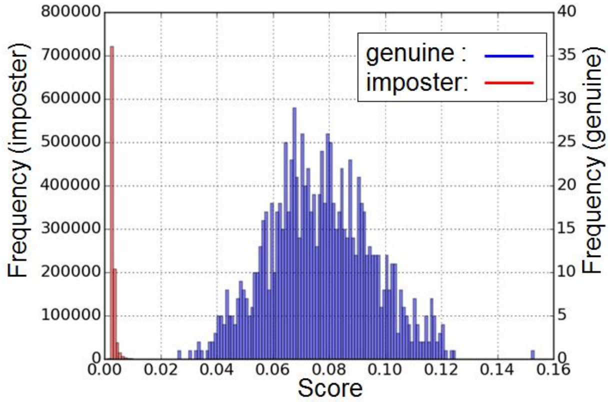
We use 2,000 captured images of 1,000 metal bolts. One query image of an individual metal bolt was matched with one enrolled image of the identical bolts and 999 enrolled images of the other individual bolts. Consequently, 1,000 genuine pairs and 999 x 1,000 = 99,900 imposter pairs were matched in our experiments. The accuracy of identification is evaluated by the False Acceptance Rate (FAR) and False Rejection Rate (FRR). The parameters of the image matching technique we set in the experiment are shown in Table 1.

Figure 8 shows the histogram and cumulative distribution of image matching scores between images of the same individual (genuine pairs) and different individuals (imposter pairs). FAR and FRR are separated, which means identification was successful with no error by setting the fixed threshold around 0.025. Figure 9 shows an example of image matching results using ORB local feature matching and geometric verification with RANSAC. In case of the same individuals (genuine pairs), plenty of local feature points are extracted from pear-skin finish area (around logo “N”) and matched correctly. On the other hand, in case of the different individuals (imposter pairs), less local feature points are matched. Especially, local feature points that extracted from pear-skin finish area hardly matched. Thus we can identify the score based on the number of inlier pairs thanks to the FIBAR imaging method implemented our prototype of automatic fingerprint scanning machine and the smart phone with FIBAR tool.

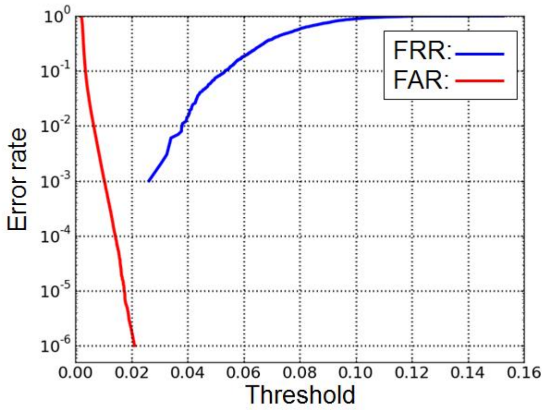
Table 2 shows the average processing time of the image matching on the desktop computer (CPU: Core i7-4790 3.6GHz, MEM: 32GB, OS: Windows 7 Professional SP1 64bit) for one enrolled image versus one query image. Because of a plenty of extracted keypoints, keypoints matching and RANSAC process need a lot of time. In this paper, in order to verify only the accuracy of individual identification of the bolts using their images captured with our automated scanning machine, we extracted as many keypoints as possible. In addition, we

Table 1: Parameters of ORB local feature matching and RANSAC in the experiment

ORB local feature matching	
Maximum number of keypoints	10,000
Matching method	Brute force matching with cross check
RANSAC	
Geometric model	Similarity transformation
Maximum number of iterations	50,000
Distance threshold	5 pixels



(a)



(b)

Figure 8. Experimental result of individual identification: (a) histogram of image matching scores between images of the same individual (genuine pairs) and different individuals (imposter pairs), (b) Cumulative distribution of genuine scores and imposter scores. The distributions of both scores were separated, which means identification was successful with no error by setting the fixed threshold around 0.025.

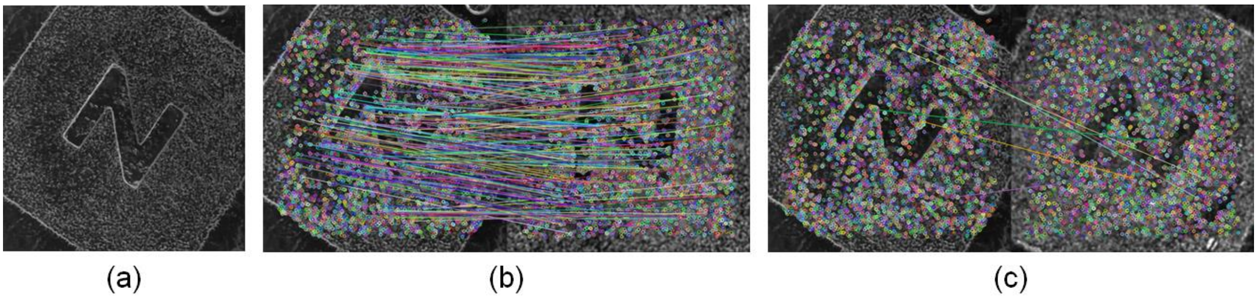


Figure 9. Example of image matching result using ORB local feature and geometric verification with RANSAC: (a) query image, (b) matching result of genuine pairs (the same individual), (c) matching result of imposter pairs (different individuals).

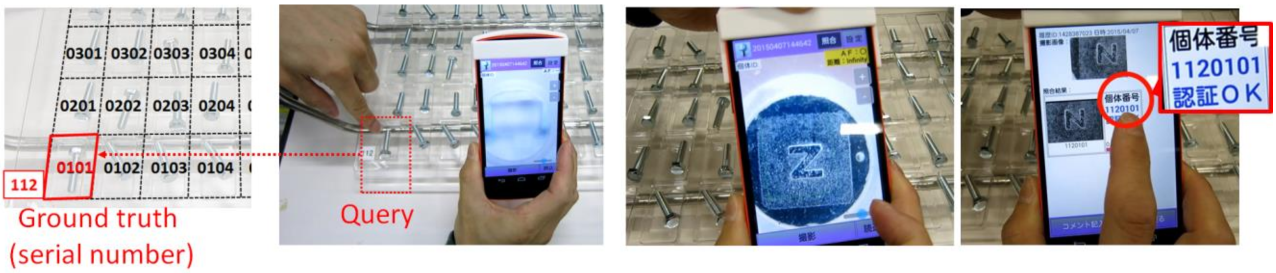


Figure 10. Demonstration of individual identification of the metal bolts using a smart phone with FIBAR tool. First, a user picked up the metal bolt enrolled with our automatic fingerprint scanning machine. Using the smart phone with FIBAR tool, fingerprint of the bolt is captured easily. Then the captured image is sent to a server and image matching is done on the server. Finally, the user gets information about the bolt such as serial number (1120101).

Table 2. Computational time of the image matching (CPU: Core i7-4790, 3.6GHz, OS: Windows 7 64bit)

Computational time of image matching (1 vs 1) [s]	
Keypoint detection	0.022
Desctriptor extraction	0.029
Keypoint matching	0.208
RANSAC	0.568
Total	0.827

employed brute-force matching with cross-check and geometric verification with RANSAC. The computational time can be reduced by using more efficient matching techniques such as voting method described in [8] instead of computationally expensive RANSAC process.

Figure 10 shows the demonstration of individual identification of the metal bolt with the smart phone and the FIBAR tool. The metal bolts scanned with our automated scanning machine can be identified easily using the smart phone so that a mechanic is able to check the bolt in hand on site before screwing it into products.

5. Conclusion

In this paper, we have presented a traceability system for metal bolts using "*Fingerprint of Things*"-based individual identification. The new design of lighting method is proposed for contactless scanning of numerous fingerprints images of metal bolts, which opens the practical applications with mass-production. The images captured with the proposed method are compatible with the images which captured with a smart phone, attached with the low-cost and portable version of FIBAR. In our experiments, we succeeded to identify 1,000 individual metal bolts perfectly. In future, we reduce processing time of the image matching for individual identification on a large scale image database.

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