Linear solution for oneshot active 3D reconstruction using two projectors

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Abstract

Development of active 3D scanning system that can capture fast-moving dynamic objects is an important research topic for many applications. To capture fast-moving objects, a oneshot scanning method that uses a single static image is preferable than those that uses multiple patterns. Recently, oneshot scanning methods that use intersection points of grid patterns have been proposed. In those methods, solutions only from intersection points have ambiguity, and thus, additional information, such as variation of grid intervals, were used to solve this. However, the variation of grid intervals makes it difficult to increase the density of the pattern. In this work, we propose a system that consists of a camera and two projectors and each of the projectors projects parallel line patterns instead of grid patterns. Shape is reconstructed from the intersection points between those two sets of parallel lines. It is shown that a unique linear solution is possible for such a system, thus, dense grid patterns with uniform intervals can be used to increase density of the pattern. Furthermore, by using two projectors, blind areas caused by occlusion and self-occlusion are drastically reduced. In the experiment, we built a system which consists of two projectors and a single camera, and successfully captured a dense shape of fast moving objects with video rate.

1. Introduction

Dense shape acquisition of dynamically moving object with high frame-rate is strongly required in wide fields. For example, for capturing dynamic motion of muscle through exercise or a body structure analysis of a object at the moment of explosion, dense shape acquisition with high frame-rate is critical.

For such purposes, active 3D scanning methods are considered to be a practical solution because of its accuracy and fidelity. Especially, for capturing dynamic objects, a structured light system that consists of a projector and a camera is suitable, because it can capture a wide range of view with a short period of time. However, there remain several essential problems to use the system to capture a dense shape of the object with high frame-rate. A structured light system can be categorized into two types, i.e. a temporal and spatial encoding technique. Since a system based on a temporal encoding technique requires a set of images in which the object is captured with different projected patterns, it is basically difficult to capture a moving object and also a synchronization of multiple set of them is technically unsound. In contrast, a system based on a spatial encoding technique requires just a single input with static pattern and it is preferable to capture fast-moving object. However, since the pattern used for the system is usually complicated, pattern is easily affected by texture and depth discontinuities.

If a shape reconstruction using a small number of colors with parallel line pattern is realized, aforementioned problems can be solved. Recently, the methods that can reconstruct the shape from a single image using a static grid pattern with two colors are proposed for scanning fast moving objects[7, 10, 12]. In those methods, solutions only from intersection points have ambiguity, and additional information, such as variation of grid intervals, were used to solve this. Because of using varying grid intervals, it is not easy to make both vertical and horizontal lines to be dense; this results in not only sparse reconstruction, but also failure in reconstruction of small objects.

In this work, to solve the problem, a shape reconstruction method using intersection points between two sets of parallel lines projected by two projectors is presented. In such a system, it is shown that a unique linear solution can be realized only from intersection points, and thus, both the vertical and horizontal lines can be dense as long as tractable and it results in successful reconstruction of small objects. Another advantage of the proposed system is that, by using two projectors, blind areas caused by occlusion and self-occlusion are significantly reduced.

Although a unique linear solution is obtained with the proposed method, the solution may be affected by detection noises of the intersection points. To further improve the accuracy of the solution, we propose to use two types of additional information. One is adjacency information between detected lines and the other is de Bruijn based line IDs. Although the line IDs are not globally unique, they are sufficient to determine the unique positions for each detected lines in the presence of noises. We developed an actual system based on the proposed method, and show several experiments conducted by the system followed by detailed analyses and evaluations.

The main contributions of the paper are as follows: (1) oneshot dense shape reconstruction by using two projectors and cameras, (2) linear solution for shape from grid pattern, and (3) an actual system which can capture a moving object with high-frame rate is constructed to show the strength of the method.

This paper is organized as follows. Section 2 discusses related works and Section 3 presents the overview of the system. Section 4 describes theory and algorithm for the 3D reconstruction technique, and Section 5 presents the experimental results and evaluations. A discussion of the results concludes the paper.

2. Related work

So far, for practical 3D acquisition purposes, an active sensor has been widely used and a number of projector camera based system are intensively researched because of its efficiency and simple installation [15, 1]. In terms of projector camera based 3D reconstruction techniques, the techniques can be categorized into two types: temporal encoding and spatial encoding techniques. Although temporal encoding technique can achieve dense and accurate reconstruction, it is basically difficult to capture a moving object since the technique requires a set of images captured while different pattens are projected to the object.

Recently, several methods for high-speed scan were proposed by using a DLP projector and a high-speed camera. Weise et al. [14] proposed a stereo system with active illumination based on phase-shift. Narasimhan et al. [9] proposed a method to recognize high-speed temporal codes produced by a DLP projector. Several research reducing the required number of patterns using both temporal and spatial changes were presented [5, 15]. Though these methods can capture depth information at high frame rate, the motion of objects must be slow in the image sequence to recognize the temporal codes. In addition, synchronization of multiple sets of them is not easy.

On the other hand, techniques using only spatial encoding of a pattern allow scanning with only a single-frame image [6, 13, 16, 8, 3] and are suitable for capturing dynamic

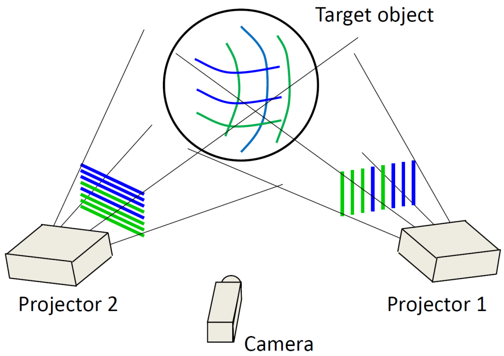


Figure 1. The setup of the proposed approach consist of two projectors and a camera. The two projectors project vertical and horizontal lines patterns, respectively, and the camera observes the intersection points of the lines.

objects. However, they typically use complex patterns or colors for decoding process and may be easily affected by texture or depth boundaries and lead to erroneous results. In addition, if multiple patterns are projected on the same object to capture a wider area, those patterns interfere each other and it is difficult to decompose them.

Recently, the solution for the complex pattern by using a simple grid pattern which embeds information in relation of connection of parallel lines is published [7, 10, 12]. However, since the system still projects dense vertical and horizontal grid patterns, it is difficult to decompose them after multiplication on the same surface. If the pattern is composed of only one directional parallel lines with one or two colors, such problems can be drastically reduced. Also, those methods theoretically have 1-DOF indeterminacy and it should be eliminated by other information, such as irregularity of intervals between lines or de Bruijn sequence; sometimes it is an unstable process.

3. Overview

3.1. System configuration

In the proposed 3D measurement system, two projectors are used to reconstruct wide area of the scene. The projectors and a camera are placed so that the camera can observe the intersection points of line patterns projected by the projectors. The projected pattern is fixed and does not change, so no synchronization is required. The minimum setup consists of two projectors and a camera as shown in Fig. 1. The camera and the projectors are assumed to be calibrated (i.e., the intrinsic parameters of the devices and their relative positions and orientations are known).

The two projectors project vertical and horizontal line patterns, respectively, and the system reconstructs the shape of a target object by observing the intersection points of the lines. Since discrimination of the vertical and horizontal patterns are required for reconstruction, efficient technique using a belief propagation and de Bruijn sequence are used.

3.2. Color pattern and efficient line detection

For robust image processing, a smaller number of color is more preferable. To the contrast, a large number of color is suitable to achieve accurate reconstruction. In this paper, to fulfill both requirements at the same time, the belief propagation based method [10] and the de Bruijn sequence [6, 11, 16] are used. The belief propagation method is used to distinguish vertical and horizontal lines effectively even if a single color is projected.

The de Bruijn sequence is used to determine each line ID. A q-ary de Bruijn sequence of order n is a sequence of length q^n consisting of an alphabet of size q in which every possible subsequence of length n is present exactly once. If a projected pattern is encoded by two or more symbols distinguished in a camera image, the correspondence between an element in the projected pattern and the observed pattern is uniquely determined by matching subsequences of length n in a de Bruijn pattern. Instead of using large q and n as [6, 16], we used periodic patterns generated with small q and n as [10]. In this paper, we used the number of colors $q = 2$ and the length of codes $n = 3$. Namely, each cycle of the pattern consists of eight lines, and the line IDs are from 0 to 7.

The position of intersection points of vertical and horizontal lines are computed in sub-pixel accuracy. Since the adjacent intersection points can be determined by using the connectivity of a detected line, grid graphs that consist of connected intersection points are obtained as a result of the line detection. In the case that two intersection points that belong to different lines are wrongly connected in the image, the wrong connection can be cut by using the color pattern [10].

4. Algorithms for 3D reconstruction

4.1. Shape from two pencils of planes

We describe our reconstruction method for the configuration of two projectors and a single camera. The assumed inputs are 2D curves lit by line patterns detected from an image and their intersection points. Each curve is labeled as vertical or horizontal. De Brujin IDs of the curves are also known. The 3D points lit by a line pattern are on a single 3D plane. Our objective is deciding the 3D plane for each curve.

All the patterns of parallel lines projected from a projector form planes that share a single line. These planes are elements of a pencil of planes and the shared line is the axis of the pencil of planes. This fact can be effectively used for representation of the planes.

Kawasaki et al. used a single projector that projects both vertical and horizontal lines (e.g. a grid pattern). In this configuration, axes of the two pencils of planes (vertical and horizontal) intersect at the optical center of the projector. This enables elimination of all the constant terms of the linear equations obtained from the grid points. Thus, the linear equations have 1-DOF indeterminacies. Kawasaki et al. determined a unique solution by using a modulated grid pattern in which the intervals between lines are varied randomly.

In contrast to the above work, projectors are configured so that the axes of the pencil of planes are skew in this work. The linear equations constructed from this configuration have constant terms and generally have a unique solution.

In our method, a pattern plane p is represented by an equation

$$p_1 x + p_2 y + p_3 z + 1 = \mathbf{p}^\top \mathbf{x} + 1 = 0, \tag{1}$$

where 3D vector $\mathbf{p} = (p_1, p_2, p_3)^\top$ is a parameter vector of the plane.

When we regard the parameter vector $\mathbf{p}$ as a point in 3D parameter space, the point is called the dual of the plane, and the 3D parameter space is called the dual space. In contrast to the dual space, the normal 3D space with the coordinates $\mathbf{x} = (x, y, z)$ is called the primal space.

The dual of a plane in the primal space is a point in the dual space, and the dual of a pencil of planes in the primal space is a line in the dual space. By using this fact, as the same way in which points on a line can be represented by a single parameter (i.e., Points $\mathbf{x}$ on a line can be represented as $\mathbf{x} = \mathbf{x}_0 + s\mathbf{x}_d$, where $\mathbf{x}_0$ is an arbitrary point on the line, $\mathbf{x}_d$ is a directional vector of the line, and s is a parameter.), parameter vectors of planes from a pencil of planes can be represented by a single parameter. In this representation, arbitrary vertical planes $\mathbf{v}$ that share an axis l_v (thus, planes in a pencil of planes) can be expressed as

$$\mathbf{v} = \mathbf{v}_0 + \mu \mathbf{v}_d \tag{2}$$

where $\mathbf{v}_0$ is an arbitrary point of the line in dual space (i.e., the dual of the pencil of planes), $\mathbf{v}_d$ is a directional vector of the line, and μ is a parameter. Vector $\mathbf{v}_0$ can be obtained as the dual of arbitrary vertical plane, and $\mathbf{v}_d$ can be calculated by $\mathbf{v}_d = \mathbf{l}_{\mathbf{v}0} \times \mathbf{l}_{\mathbf{v}d}$, where $\mathbf{l}_{\mathbf{v}0}$ is a positional vector of an arbitrary point of the axis l_v, and $\mathbf{l}_{\mathbf{v}d}$ is a directional vector of the axis l_v. The proof is omitted because of the limits of the pages.

The set of the horizontal planes are represented by a similar equation as follows.

$$\mathbf{h} = \mathbf{h}_0 + \rho \mathbf{h}_d. \tag{3}$$

Suppose that an intersection between vertical pattern v and horizontal pattern h is detected at $\mathbf{u} = (u, v)$ in the coordinates of a normalized camera. Let $\mathbf{v}$ and $\mathbf{h}$ be dual vectors of v and h. Then, from the formulation of [4],

$$\mathbf{u}^\top (\mathbf{v} - \mathbf{h}) = 0. \tag{4}$$

By using equations (2) and (3), we obtain

$$\begin{aligned} & \mathbf{u}^\top(\mathbf{v}_0 + \mu\mathbf{v}_d - \mathbf{h}_0 - \rho\mathbf{h}_d) \\ = \; & (\mathbf{u}^\top\mathbf{v}_d)\mu - (\mathbf{u}^\top\mathbf{h}_d)\rho + \mathbf{u}^\top(\mathbf{v}_0 - \mathbf{h}_0) = 0. \end{aligned} \tag{5}$$

Since equation (5) can be obtained for each intersection point, a system of simultaneous linear equation can be obtained from the detected image. Let μ_i be the parameter μ in equation (2) of the plane that corresponds to the i-th detected vertical pattern. Similarly, let ρ_j be the parameter ρ (equation (3)) of the j-th detected horizontal pattern. Suppose that K intersections are detected. We also define functions $\alpha(k)$ and $\beta(k)$, such that the k-th intersection point ($\mathbf{u}_k = (u_k, v_k, -1)$) is an intersection between the $\alpha(k)$-th detected vertical pattern and the $\beta(k)$-th detected horizontal pattern. Then, by substituting $i = \alpha(k)$ and $j = \beta(k)$, we obtain

$$\begin{aligned} A_k \equiv \mathbf{u}_k^\top\mathbf{v}_d,\; B_k \equiv \mathbf{u}_k^\top\mathbf{v}_d, C_k \equiv \mathbf{u}^\top(\mathbf{v}_0 - \mathbf{h}_0), \\ A_k\mu_{\alpha(k)} - B_k\rho_{\beta(k)} = -C_k, \end{aligned} \tag{6}$$

for $k = 1, \cdots, K$.

Let the system of simultaneous equations (6) obtained from all the intersection points be represented in matrix form $\mathbf{Ax} = \mathbf{b}$, where $\mathbf{x}$ is the vector of μ_i and ρ_j, $\mathbf{A}$ is a $K \times M$ matrix that includes A_k and B_k where M is the number of detected lines, and $\mathbf{b}$ includes C_k. Normally, the equation is over-constrained ($K > M$) and regular. Thus, it can be solved by using a pseudo-inverse matrix.

Then, since μ_i and ρ_j becomes known, the plane for each detected pattern is obtained. Using triangulation of light sectioning method, 3D positions of the detected patterns can be calculated.

4.2. Using adjacency information

Generally, the system of equations (6) can be solved without ambiguity. However, for real problems, the solution is often unstable because the minimum singular value of $\mathbf{A}$ becomes close to zero. To deal with this problem, we can also use information of adjacency between detected patterns obtained from image processing. The information can be represented as linear equations of μ_i or ρ_j, which can be used as additional equations to increase stability.

As already described, the duals of vertical planes are aligned on a line in the dual space. Suppose the case in which those duals (points in the dual space) of the vertical planes are arranged in uniform intervals between adjacent planes. Generally, this case does not happen, unless the positions of the vertical lines are specially arranged in the projected image. However, if the positions of the projector and the camera fulfills a certain condition, this case is realized by projecting an image of parallel lines of uniform intervals. The condition is placing the optical center of the camera on the focal plane of the projector [1]. The proof is omitted because of page limits. Briefly, this case happens because the point at infinity of the line in the dual space becomes included by the pattern plane generated by the line at infinity of the image plane of the projector.

Suppose that L pairs of adjacent patterns are detected, and the l-th pair is a pair of $\gamma(l)$-th detected vertical pattern and the $\delta(l)$-th detected vertical pattern. Then, we obtain

$$\mu_{\gamma(l)} - \mu_{\delta(l)} = D_j, \tag{7}$$

where D_j is a constant that can be determined from $\mathbf{v}_0$, $\mathbf{v}_d$, and position order between the $\gamma(l)$-th pattern and the $\delta(l)$-th pattern. If the vertical planes are uniformly arranged in the dual space as described, equation (7) is rigorously true. The solution of the $K + L$ simultaneous equations (6) and (7) is more stably calculated than those of equations (6).

4.3. Improvement of accuracy using de Bruijn sequence

In the previous section, the method for estimating the planes that corresponds to the detected patterns using simultaneous linear equations is described. However, if erroneous intersection points (which are caused by noise disturbances or falsely detected lines) are detected, the solution of the liner equations becomes unstable. Thus, we use periodic IDs of de Bruijn sequence given for each line to correct the solutions with error.

In our method, the projectors and the cameras are assumed to be calibrated. This means that the pattern planes projected from the projector, and their IDs of de Bruijn sequence are known. Thus, for the correct correspondence between a pattern plane of a detected pattern and a plane projected from the projector, the planes should match for both the positions and the de Bruijn IDs. The solution is corrected by using this property.

The method is as follows. The known planes around the solution of the linear equations that have the same de Bruijn IDs are searched. Then, the constraints of the intersections (i.e., equation (4)) are checked. The meaning of these constraints is that distance between the detected intersection point and the projected line of the intersection line of two pattern planes (in this case, the selected known pattern planes) is zero. Thus, these distances are calculated for all the intersection points, and the solution with the minimum sum of squares of these distances is selected.

The above search method does not work effectively if the intrinsic and extrinsic parameters of the projectors and the camera are not correct. However, for real systems, the parameters obtained by calibrations include errors. In the

[1] Note that the projector is regarded in the same way as a camera. In this paper, the definition of a focal plane of a camera follows that of book of Faugeras[2], where the focal plane is defined as the plane that includes the optical center of the camera and is parallel to the image plane.

Figure 2. Experimental system with a camera and two projectors.

proposed method, such errors often cause gaps between the results from the vertical and the horizontal patterns. These gaps are harmful for using the reconstruction results as a unified surface model. Thus, the calibration accuracy is important.

To achieve accurate calibration, we use gray-codes for both of the projector-camera pairs to obtain correct correspondences between the camera and each of the projectors. Then bundle adjustment is applied to correct the extrinsic parameters of the projectors and the camera using the obtained correspondences.

4.4. Improving linear solutions

3D reconstruction by only solving linear equations is possible using the proposed method, which is achieved by using two projectors. In conventional works (Kawasaki et.al[7] and Sagawa et.al[10]), solution from only linear equations was not possible.

If we use one projector and do not use adjacency information between detected patterns, the linear equation becomes degenerated and the 3D reconstruction fails. We generated a simulated data for such cases and calculated the eigenvalues of the coefficient matrix of the linear equations (i.e., eigenvalues of $\mathbf{A}^\top\mathbf{A}$). The minimum eigenvalue became small compared to other eigenvalues, and the 3D reconstruction was practically impossible.

Here, we discuss cases of one projector where adjacency information is used. If two sets of parallel lines, each of which has uniform intervals, are projected, the optical center of the projector should be on the focal plane of the projector so that each set of the duals of the pattern planes becomes a set of points with uniform intervals on a line. This case can be proved to be a degenerate case even if adjacency information is used. If we do not restrict the case to the configuration where two sets of parallel lines with uniform intervals are projected, linear solution with one projector is possible. However, to achieve this, the projected pattern should be changed depending on the extrinsic parameters between the projector and the camera. Thus, practicality of the system is compromised.

If two projectors are used, 3D reconstruction using only linear solution is possible by configuring the projectors so that the two axes of the two pencils of planes of the projectors become skew. We conducted 3D reconstruction from a data generated by a simulation, and confirmed that, if the distance between the two axes of the pencils of planes is small, which we call a small axes distance condition, reconstruction only by using information of intersection points fails, and that, if adjacent information is used, reconstruction is possible even if in the small axes distance condition.

5. Experiments

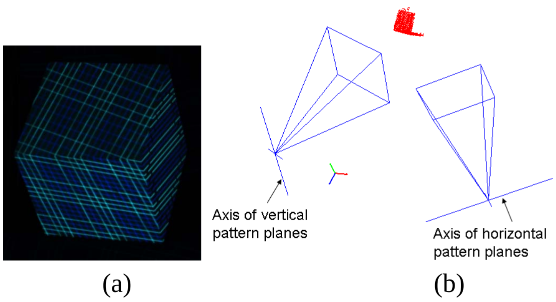
In the experiments, we used an experimental system with a camera and two projectors shown in Fig. 2. The relative position between a camera and projectors depends on the target to be captured. When a person was captured, the distance between a camera and a projector was about 1m, and the relative orientation was about 25 degrees. The resolution of the camera is 1280×960 pixels and the frame rate is 15 frame/second. The resolution of the projectors is 1024×768 pixels.

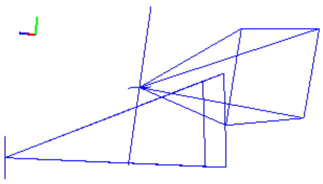
5.1. Improving accuracy by using adjacency information and de Bruijn sequence

To show effectiveness of using adjacency information and de Bruijn sequence, experiments of 3D reconstruction with and without using this information were conducted. The conditions are using only information of intersection points (method A), using information of intersection points and adjacency between curves (method B), and using de Bruijn sequence in addition to information of method B (method C). To evaluate the results, a cube-shaped object was measured, and the measured point sets on the two faces of the shape were fit to two planes, and the angles of the two planes were measured. Roots of mean squared error (RMSE) of the points from the fit planes were also calculated. The distance from the camera to the cube-shaped object was 1.6m.

The source image and the positions of the projectors are shown in figure 3, the reconstruction results are shown in Fig. 4 and the plane angles and the RMSE are shown in table 1. The results show that the shape accuracy (angles between two planes) is improved by using adjacency information (method B), and further improved by using de Bruijn sequence(method C). The position of the result of method C becomes the same as the gray code measurement, which is the correct solution whose error is caused only by the line detection errors and the calibration errors.

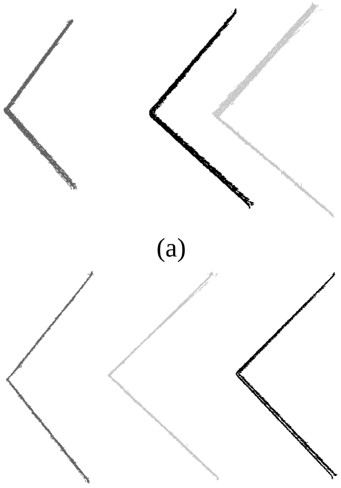
The RMSE of the reconstructed points from the fit planes became larger when additional information was used. This is natural, because, if no additional information is used, the gaps between the vertical and horizontal reconstruction are minimized without other constraints. However, when other constraints such as adjacency or de Bruijn sequence





(c)

Figure 3. Configuration of experiments for evaluation of accuracy improvement: (a) the source image, (b),(c) positions of the projectors. (c) is viewed in the direction of the axis of the horizontal pattern planes



(b) (c) (d)

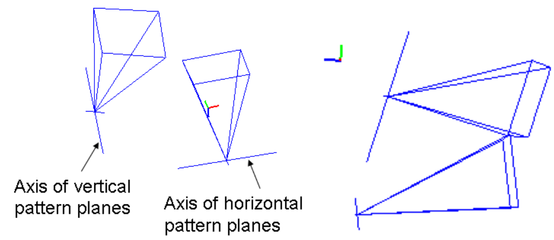
Figure 4. Evaluation of accuracy improvement by using adjacency information and de Bruijn sequence: (a) positions of the reconstruction results, (b) the result of method A using only information of intersection points viewed from direction of the edge between the faces, (c) the result of method B using adjacency information, and (d) the result of method C using de Bruijn sequence seen in the same way. The result of method A is shown by dark gray points, the result of method B is shown by light gray points, and the result of method C is shown by black points. In the result of method C, the position becomes the same as the gray code measurement, which is the correct up to the calibration accuracy.

are added, these gaps generally become larger.

We also conducted experiments for a small axes distance condition (the condition where the distance between the axes of the two pencils of planes is small). The positions

Table 1. Evaluation of accuracy improvement by using adjacency information and de Bruijn sequence.

Evaluation values	Methods		
	A	B	C
Angle between 2 faces(degrees)	102.6	87.5	89.2
Deviation from gray-code measurement(mm)	225.8	96.5	the same
RMSE of points from fit planes(mm)	0.46	0.75	2.46



(a) (b)

Figure 5. Configuration of experiments for a small axes distance condition: (a),(b) positions of the projectors. (b) is viewed in the direction of the axis of the horizontal pattern planes.

Table 2. Evaluation of accuracy improvement by using adjacency information and de Bruijn sequence.

Evaluation values	Methods		
	A	B	C
Angle between 2 faces(degrees)	fail	89.9	89.0
Deviation from gray-code measurement(mm)	fail	70.1	the same
RMSE of points from fit planes(mm)	fail	1.46	2.47

of the projectors are shown in figure 5, and the plane angles and the RMSE of the reconstruction results are shown in table 2. The distance from the camera to the target object(a cube) was 3.7m. The results show that method A failed in the small axes distance condition. However, methods B and C succeeded in this condition, which means that, by using adjacency information, 3D reconstruction in a small axes distance condition was possible in this case.

5.2. Small shape reconstruction

Next, the proposed method is compared with one-shot scanning method with one projector [10]. The proposed method can use more dense pattern than that in [10] because the 1D search for shape reconstruction is not necessary with our method. The advantage is that reconstruction of small object like thin fingers is more stable with the

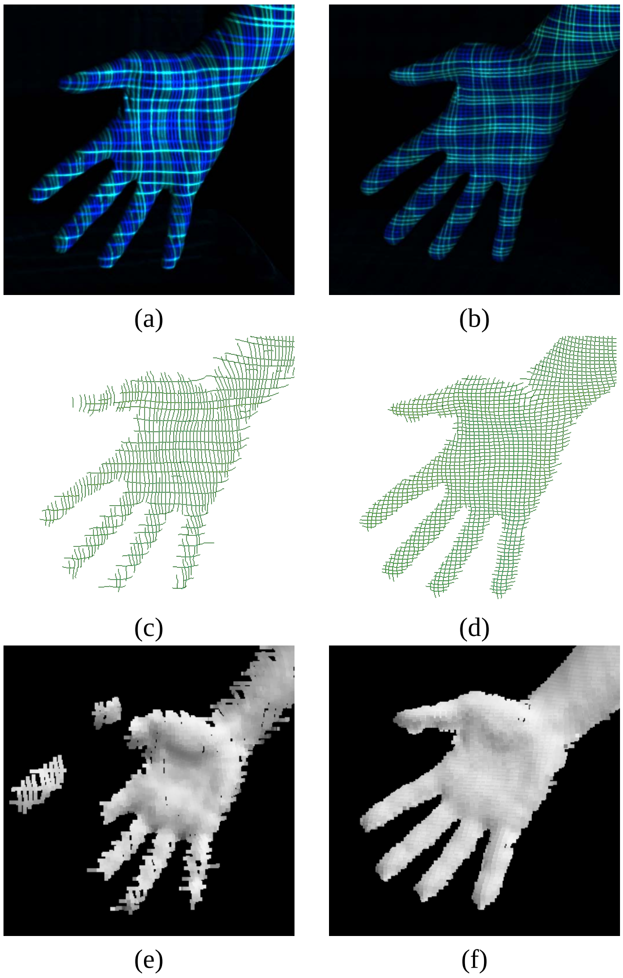


Figure 6. A hand is reconstructed by [10] (left) and the proposed method (right). The top row is the input images, the middle row is the grid graph by line detection, and the bottom row is the reconstructed shape.

proposed method than that of [10]. Fig. 6 shows the result of reconstructing a hand by the both methods. The top row is the input images, the middle row is the grid graph by line detection, and the bottom row is the reconstructed shape (point cloud), which is rendered by a point shading method. The result of the proposed method (right column) succeeded in reconstructing all the fingers, while the result by [10] (left column) failed some fingers due to insufficient density of the grid graph.

5.3. Dense human body shape acquisition

Finally, we measured moving upper bodies of a human. Fig. 7 shows the results of 3D reconstruction for different poses of two subjects. The column (a) represents input images, and the column (b) shows the results of line detection and the estimated de Bruijn IDs for each line, which are indicated by their colors. The column (c) shows the results of 3D reconstruction with point shading. Since some parts of the bodies, for example, flank and shoulder are occluded from one of the two projectors, only vertical or horizontal pattern is projected on those parts. Even though, the shape can be reconstructed successfully by connecting the areas to the parts that are not occluded as shown in the results. Note that this is one of the important advantages to use multiple projectors.

6. Conclusion

In this paper, a reconstruction method for oneshot scanning system that consists of two projectors and a camera for capturing dense shapes of dynamic objects is presented. To solve the problem, we proposed a new method with which each projector project just one directional parallel lines with two colors. Reconstruction is achieved by solving linear equation derived from intersection points between lines, and it was shown that obtaining a unique linear solution from intersection points is possible. To further improvement of accuracies, information of adjacency between detected lines and de Bruijn based line IDs were used. In our experiment, we constructed a system that consists of two projectors and a single camera. We captured static objects for evaluation and confirmed that correct IDs for each detected lines were obtained. We also successfully demonstrated capturing moving human body. In the future, an entire shape acquisition by increasing the number of a projector and a camera is promising.

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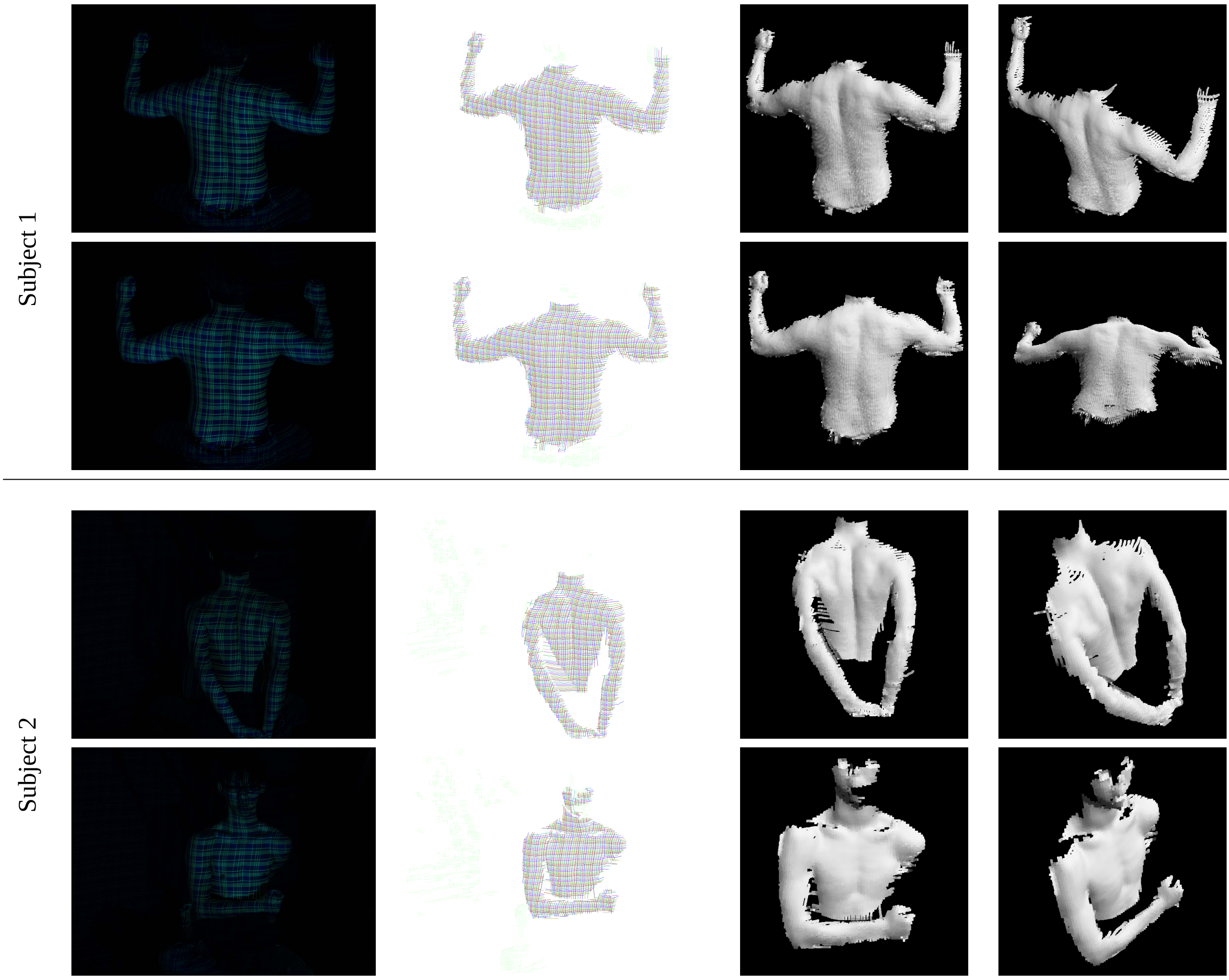

Figure 7. Reconstruction of moving human bodies: (a) input images of different poses, (b) detected grid patterns, and (c) reconstructed shapes for poses.

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