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Recognition of Multi-Stage Pallets in Docking Station for A Self-Driving Forklift

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Abstract

This paper has presented a new multi- stage pallet surface recognition technique by surface segmentation and verification procedure. Surface segmentation is accomplished by two-pass algorith. verification procedure is executed by three step: first step is surface MER verification of surface. It accomplish by whether label MER and vertex MER are matched or not. Second step is surface vertex verification and it is accomplished by clockwise array verification to 4 vertices. Final step is surface edge verification. Used pallets consist of edge, blank and pattern region. It is accomplished by checking crossing region of vertex diagonal and boundary between edge and blank. Also presentation scheme which can be used for efficiently recognizing polyhedral objects is proposed. It considers a polyhedral object as a combination of primitive surfaces and represents it in a hierarchical way of two levels: In the lower level, the geometrical features of each primitive surface are represented by its signature which is a distance trajectory of the surface boundary measured from the mass center of the image in a counter-clock wise manner. In the higher level, the topological relationship between the primitive surfaces of an object is represented in the inter-surface relation table (ISRT).

***Keywords**: 2-D image, multi-stage pallet recognition, self-driving forklift*

1. Introduction

Despite the easiness in extracting 3-D features, the use of depth information for recognizing 3-D shape has several disadvantages: a relatively long time spent in acquiring 3-D images and a high sensitivity to the distance of a target object. Accordingly, many researchers[1-4] are involved in the analysis of 2D images. Current approaches for recognizing 3-D objects based on a single image are well summarized in [5,6]. Some of them are unique. For examples, Horaud[1] proposed the new approach of using a model-based interpretation of a single perspective image. In the approach, image linear features and linear feature sets are back-projected onto the 3-D space and geometric models are then used for selecting possible solutions. Huttenlocher and Ullman[2] proposed a computational method which calculates a closed-form transformation from a 3-D model coordinate frame to the 2-D image coordinate frame, using three pairs of model and image points. This method determines a possible alignment of a model with an image based on just three corresponding model and image points (or two corresponding points and unit orientation vectors). Lowe[3] recognized models by detecting the perceptual group that has the same geometric relationships such as collinearity, parallelism, connectivity in the repetitive patterns or in the randomly distributed

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set of image elements. Dhome *et al.*, [4] proposed the analytical solutions for the determination of the 3-D object's attitude in the 3-D space from a single perspective image. Its principle is based on the interpretation of a triplet of any image lines as the perspective projection of triplet of linear ridges of the object model, and on the search of the model attitude consistent with these projections. Those approaches aforementioned have used in common the simple 2-D primitives such as edge segment, corner, inflections and 2-D perceptual structures. Although these primitives are attractive because of their invariance from viewpoints, the representation of a 3D object requires a large number of primitives and a large database resulting in a waste of a lot of time recognizing and localizing a test object. Also some of the approaches are not appropriately providing a solution for the problem of the pose determination. To solve those problems mentioned above, this paper proposes a new representation scheme for recognizing 3-D polyhedral objects using a single 2-D image. The proposed representation scheme based on the signature technique allows us to solve the recognition and localization problems at the same time. Section 2 describes the concept of the signature representation scheme, and Section 3 illustrates how to recognize the objects in a 2-D single image based on the proposed representation scheme.

2. The Hierarchical Representation Scheme

2.1. Lower Level Representation

An object is defined here as the combination of primitive surfaces, each of which is different from each other and only one surface is considered as a primitive if there exist multiple surfaces having the same geometrical shape. To obtain the vertex of a polygon, it is located in the (X, Y) plane such that the centroid ($\bar{x}, \bar{y}$) of the polygon may coincide with the origin of the plane as shown in Figure 1a. Then the vertex of a primitive surface contain two kind of vertex, reflection vertex and refraction vertex. Figure 1 presents reflection and refraction vertex and position of each vertex is represented as Formula (1).

$$(\bar{x},\bar{y}) = (M_{10}(s)/M_{00}(s), M_{01}(s)/M_{00}(s))$$
$$where\ M_{jk}(s) = \sum_{(x,y)\in s} x^j y^k \quad (1)$$

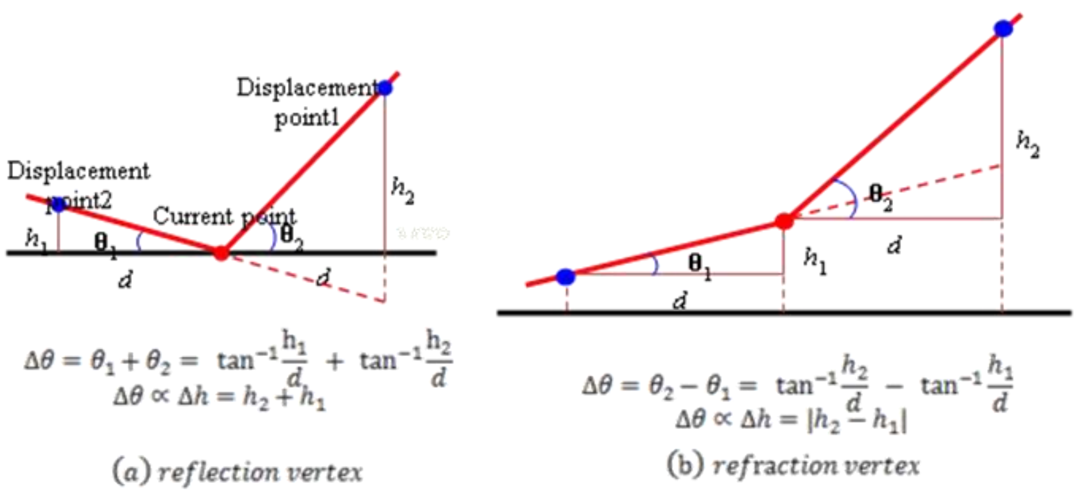


Figure 1. Vertex of Polygon

Now the primitive surface is represented by two types of parameters of its signature: the geometric features and the rotational features. The parameters of the signature shown in Figure 1b are given as an example in the following:

2.1.1. Geometric Features

· Number of peaks (vertices): $vtx = 4$

· Number of edge: $edg = 4$

· Angel between peaks: $\{\Psi_{ij},\ i, j=1,vtx\}=\{\Phi_{12}=71,\ \Phi_{23}=97,\ \Phi_{34}=45,\ \Phi_{41}=147\}$

· Curvature of edge: $\{\kappa_i,\ i=1,vtx\}=\{\kappa_1=3,\ \kappa_2=-7,\ \kappa_3=0,\ \kappa_4=-6\}$

Symmetry: $sym=1$ (1 means that the surface has at least one pair of parallel edges and 0 means that there is no parallel edge pair.)

2.1.2. Rotation Features

· Angle difference between peaks:
$\{dp_{ij},\ i, j=1,\ ,vtx\}=\{dp_{12}=71,\ dp_{23}=97,\ dp_{34}=45,\ dp_{41}=147\}$

· Magnitude of the signature at peaks:

$\{dist_i : i=1,,vtx\}=\{dist_1=68,\ dist_2=56,\ dist_3=47,\ dist_4=74\}$

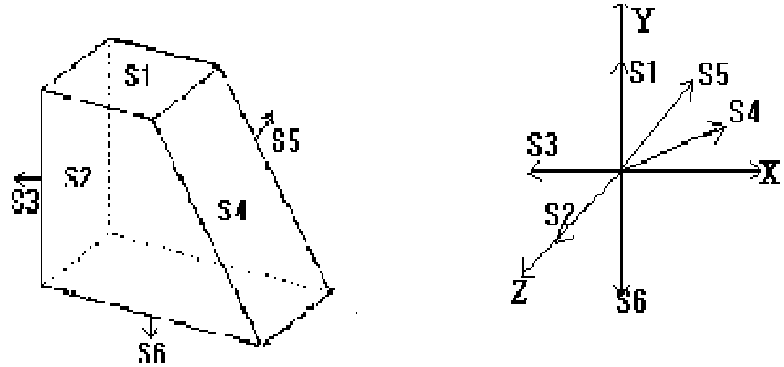
2.2. Higher Level Representation

The object model in the proposed representation scheme is interpreted as a combination of primitive surfaces. Let's assume that n surfaces consists of a primitive surface set $Ps=\{Ps_1, Ps_2, \ldots, Ps_n\}$, and l surfaces of which constructs an object model OM^i. Then OM^i can be represented as a union of l primitive surfaces which are transformed and represented by $OMs^i=\{OMs^i_1, OMs^i_2, \ldots, OMs^i_l\}$ as follows;

$$OM^i = \bigcup_k OMs^i_k$$
$$OMs^i_k = A^i_k Ps^i_k \qquad (2)$$

In (2), A^i_k is a transformation for Ps^i_k to make OMs^i_k and Ps^i_k is the kth primitive surfaces among the l primitive surfaces selected to form OM^i. Based on the above interpretation of an object, the structure of OM^i is represented by the inter-surface relation table(ISRT) in the higher level. The diagonal terms of the ISRT are filled with the surface features represented by a 4-tuple vector: [Ps^i_k, A^i_k, SFVk, Dk], where Ps^i_k is the primitive surface, A^i_k is the transformation of the primitive surface (translation and rotation), SFVk is the surface feature vector describing the orientation of surface k, and Dk is the distance from the origin of the object reference frame to SFVk. The SFV of a plane is its normal vector [7].

As shown in Figure 2b, the SFV distribution graph of an object contains the structural features between surfaces such as the crossing angle, concavity, *etc*.



(a) (b)

Figure 2. Example of a Surface Feature Vector Distribution Representing a 3-D Object: (a) Sample Polyhedron, (b) The SFV Distribution of the Object in (a)

The upper diagonal elements of the ISRT are filled with a relation vector between corresponding surfaces represented by the following 3 tuples: [Relation Type, Relation Value, Number of Sharing Edges], where the relation type is one of adjacency, convexity and parallelism between surfaces. For simplicity of description, the relation type is classified as follows: adjacent and convex(I), adjacent and concave(N), adjacent and parallel(P), non-adjacent and non-parallel(E), non- adjacent and parallel(D). The relation value is an angle between an SFV pair if the relation type is I, N, or E. Otherwise it is a distance between surfaces. The ISRT of OM_5 of Figure 4 is given in Table 1 as an example.

3. Recognition and Localization

The notations used in this section are summarized in the following.

· Ps_i : the i _th primitive surface
· OM^j : the j_th object model
· OT^j : the j_th test object
· OMs^j_k :the k _th surface of the j _th object model
· OTs^j_k :the k _th surface of the j _th test object
· NM^j_k : SFV of OMs^j_k, NO^j_k : SFV of OTs^j_k

The recognition of a test object is to find the object model having the super set of those primitive surfaces of the test object and the localization is to determine the transformations between the corresponding primitive surface pairs. The recognition and localization algorithm based on the signature representation is given in the following. The algorithm deals with the target image transformed into the skeletal edge image.

3.1. Recognition Algorithm

Step 1: Search the primitive surface set to find the possible primitive surfaces $\{Ps_i\}^j_k$ matching with OTs^j_k using the signature parameters of OTs^j_k, { vtx , edg , sym }.

Step 2: Generate vertex of each surface OTs^j_k of the test object OT^j in the scene.

Step 3: Extract candidate of surface R_i^j between OTs_k^j and each of $\{Ps_i\}_k^j$ using the equation $Ps_i = R_i^j$ x OTs_k^j ; select the primitive surface Ps_i^j having the feature set { Ψ_ϕ ,κ} most similar with that of OTs_k^j, based on $OTs_k^j = (R_i^j)^{-1}$ x Ps_i .

Step 4: Search the diagonal terms of the ISRTs of individual object models to find a model object OM^i containing the primitive surfaces of the test object OT^j, using the diagonal terms of the ISRT of OT^j.

Step 5: If found, compare the upper diagonal terms of the ISRT of OM^i with the diagonal terms of the ISRT of OT^j. If all terms match, then OT^j is recognized as OM^i. In a case when multiple matches are found in step 4, repeat step 5 for all object models found.

Step 6: Determine the pose of OT^j by calculating the transformation between the SFVs of OM^i and OT^j.

In Step 3, to obtain candidate primitive surface, region partition technique by projection and two-pass labeling are used. Figure 3 represents two pass algorithm .For each OTs_k^j, there may exist more than one possible primitive surfaces and, if so, they are gathered in the set $\{Ps_i\}_k^j$. In the Step 3, the transformation between each of $\{Ps_i\}_k^j$ and OTs_k^j is represented by three rotation angles (Θ ,ф ,ψ) respectively about the X, Y, Z axis of the model object's coordinate system. However, since a 2-D image does not provide the information on the Z-axis, it has been considered impossible to obtain three rotation angles (Θ , ф , ψ) using a single 2-D image. To solve this problem, this paper proposes a new method to recover the Z-axis information from a single 2-D image which uses a rotation map representing the variation of the rotation features (dp_i and $dist_i$ described in a low level representation) of the signature as the functions of three rotation angles (Θ , ф , ψ): $dp_i = f_{dp}$(Θ , ф , ψ), $dist_i = f_{dist}$(Θ , ф , ψ). Figure 3 is an example of a rotation map of the primitive surface Ps_8 of Figure 5. It consists of 8 3-D graphs since the signature of Ps_8 has four peaks, four for dp_i, $i = 1,..,4$ and four for $dist_i$, $i = 1,..,4$. Therefore, if a set of dp_i and $dist_i$ of a test surface is given to find the rotation angles { Θ ,ф ,ψ } against Ps_8, eight sets of the possible rotation angles are obtained from eight 3-D graphs. If they are all within a certain error boundary, their average is finally determined as the rotation angle set. The rotation angle set (Θ , ф , ψ) satisfying this condition can be calculated by Eq. (3) below.

$$R_{\theta\phi\psi} = \begin{bmatrix} dp_1 \\ dp_2 \\ dp_3 \end{bmatrix}_{Ps_i} \begin{bmatrix} dp_1 \\ dp_2 \\ dp_3 \end{bmatrix}_{OMs_i}^{-1} = \begin{bmatrix} dist_1 \\ dist_2 \\ dist_3 \end{bmatrix}_{Ps_i} \begin{bmatrix} dist_1 \\ dist_2 \\ dist_3 \end{bmatrix}_{OMs_i}^{-1} \quad (3)$$

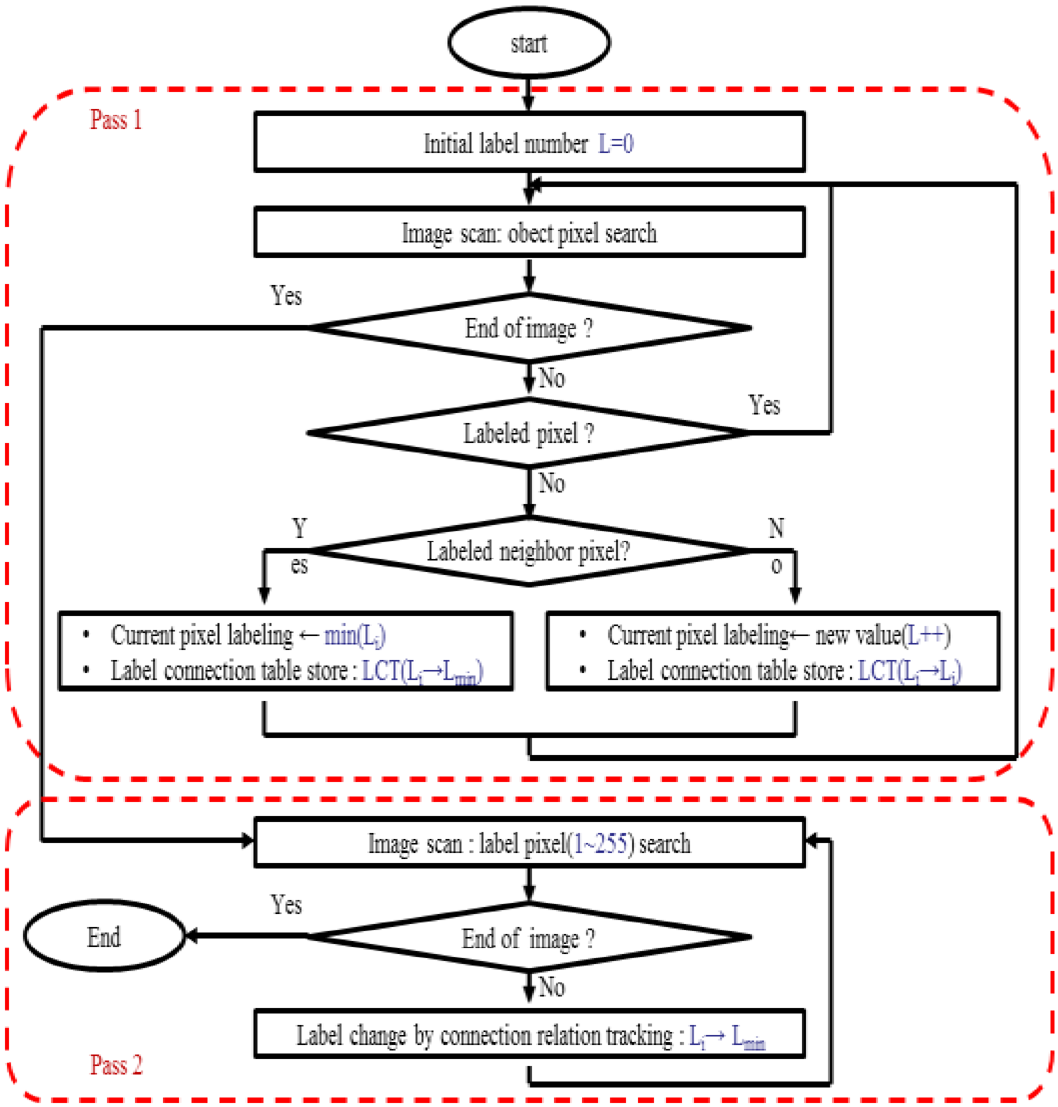


Figure 3. Two Pass Algorithm

Among possible primitive surfaces $\{Ps_i\}_i^j$, only the most similar one with OTs_i^j is left after applying step 3. By repeating step 2 and 3 for each of all *m* surfaces of OT^j, OT^j can be represented by a union of the primitive surfaces, $OT^j = \bigcup_i A_i Ps_i$, transformed by corresponding $A = R_{\theta\Phi}$.

In step 4, the ISRT of OT^j is constructed first based on the information on OT^j obtained in step 3. Then it is compared with those of all the object models. The SFV in the diagonal terms of the ISRT of OT^j is determined by rotating the SFV of the corresponding primitive surface by $A = R_{\theta\Phi}$. The type of relationship between two surfaces is determined by using their SFVs. Convexity between two surfaces is defined if the angle between their SFVs is between 90° and 180°, the concavity being defined if it is between 0° and 90°. The relation value is determined as described in Section 2 after the type of relation is determined. Since the ISRT of OT^j contains only partial information on OT^j, there may exist many possible matching object models, even having multiple matching in one ISRT. To simplify the matching process, the diagonal terms are compared first to see whether the object model being searched has the same primitive surfaces with OT^j. If they match, the upper diagonal terms are compared in step 5. Otherwise, a match fails and another ISRT is compared. If even upper-diagonal terms match, then the object model being searched is selected as the model object of OT^j. Verification of surface procedure consists of three step. First step is surface MER verification of surface. It accomplish by whether label MER and vertex MER are matched or not. Figure 4 is the example of MER verification.

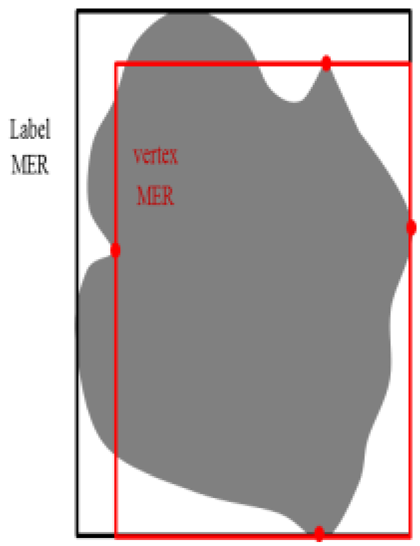


Figure 4. Example of MER Verification

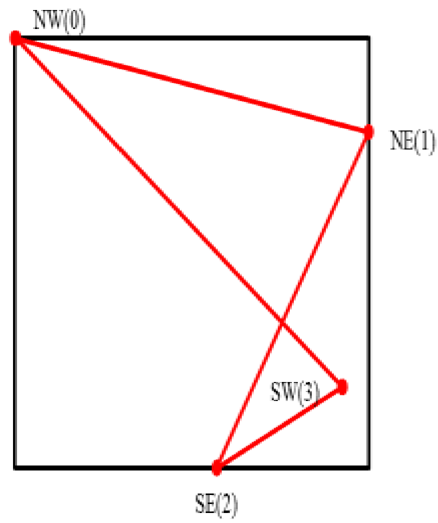


Figure 5. Surface Vertex Verification

Second step is surface vertex verification and it is accomplished by clockwise array verification to 4 vertex, that is NW.x<NE.x, NE.y<SE.y, SE.x>SW.x, SW.y>NW.y. Figure 5 represents example of surface vertex verification

Third step is surface edge verification. A used pallet consist of edge, blank and pattern region. Test region is crossing region and ratio of test region is (2 ± δ) / 9, (7 ± δ) / 9 0.0 <δ< 0.5.

In step 6, the pose of the test object is determined by calculating the transformation based on the correspondences between the SFVs of the test object and its corresponding object model. If the match between the test object and the selected object model is successful in step 5, the transformation *T* between the two objects which is the result of the localization, can be extracted from the following equations:

$$NM_j^k = T\,NO_i^l,\; NM_j^m = T\,NO_i^n \quad (k = l,\ m = n)$$
$$T = QQ^{-1}$$
$$Q = [NM_j^k, NM_j^m, NM_j^k \times NM_j^m],\; Q^{-1} = [NO_i^l, NO_i^n, NO_i^l \times NO_i^n]$$

3.2. Definition of Ten Object Models and their Primitives

The ten object models ($OM^j, j = 1..10$) are polyhedrons containing concave or convex shapes as shown in Figure 6. These object models were constructed by differently selecting and combining the primitive surfaces given in Figure 6. Using the geometrical and topological information of the object models, their database was constructed first. To obtain the test image, one of the object models was selected and located at the center of the image after rotating it arbitrarily.

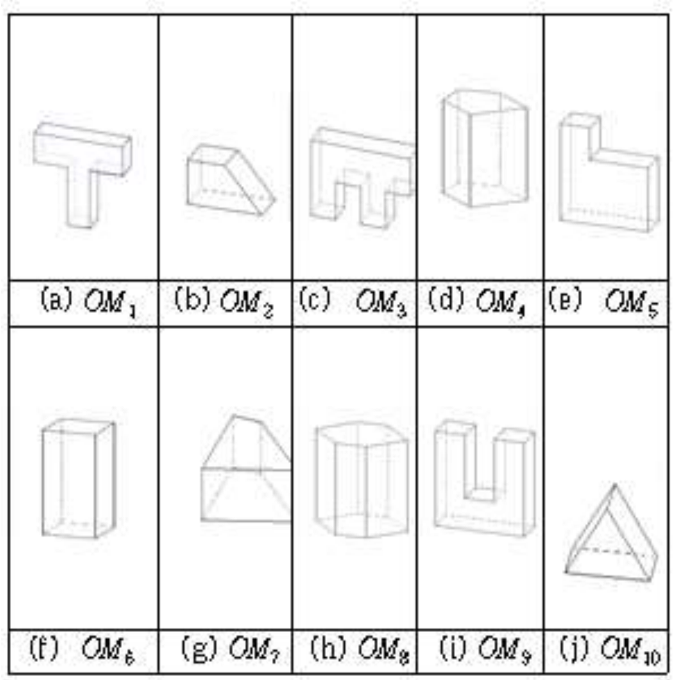


Figure 6. Ten Object Models

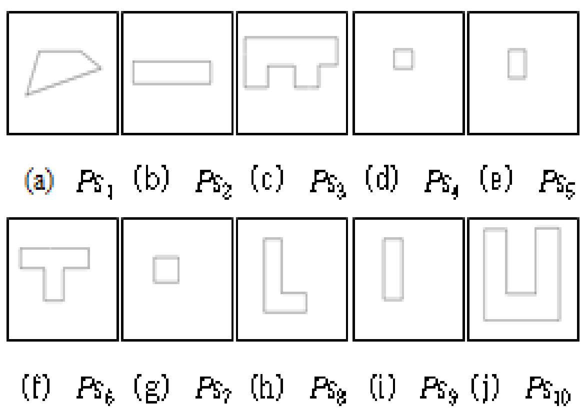


Figure 7. The Primitive Surfaces Used to Construct of the Object Models Given in Figure 6

Figure 7 is the primitive surfaces used for constructing the object models given in Figure 6. For the individual surfaces of each test object, the proposed algorithm searched the database with their signatures to find the corresponding primitive surfaces.

4. Experimental Results

The proposed algorithm has been applied to multi- stage pallet. The algorithm was implemented using open CV. Structure of Pallet is defined as Figure 8. In order to apply the algorithm, the surfaces given in the multi –stage pallet object's image were separated in advance by using the algorithm proposed in [8]. Figure 8 presents structure of pallets. The used pallet consist of edge, blank and pattern region. Test region is crossing region and ratio of test region is $(2 \pm \delta) / 9$, $(7 \pm \delta) / 9$ $0.0 < \delta < 0.5$. Figure 9 presents multi stage pallet used in this paper and Figure 10 is the binary image and result of surface detection of Figure 8.

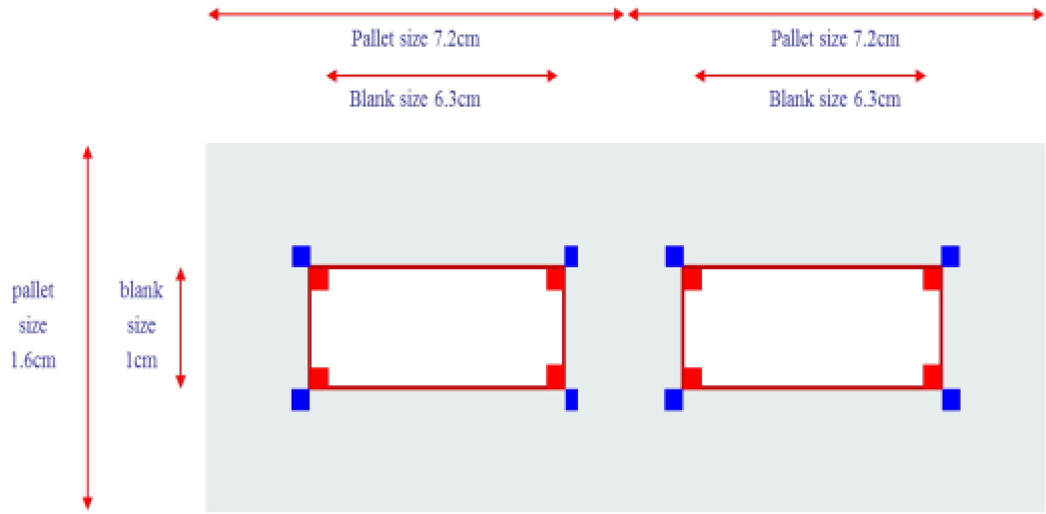


Figure 8. Structure of Multi-Stage Pallet

Figure 9. Multi Stage Pallet

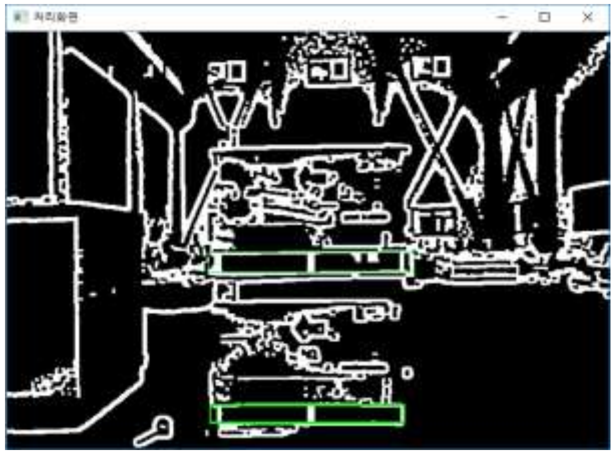


Figure 10. Detected Two –Stage Pallet

5. Conclusion

This paper has presented a new multi- stage pallet surface recognition technique by surface segmentation and verification procedure. Surface segmentation is accomplished by two-pass algorithm. Verification procedure is executed by three step: first step is surface MER verification of surface. It accomplish by whether label MER and vertex MER are matched or not. Second step is surface vertex verification and it is accomplished by clockwise array verification to 4 vertices. Final step is surface edge verification. Used pallets consist of edge, blank and pattern region. It is accomplished by checking crossing region of vertex diagonal and boundary between edge and blank

Also presentation scheme which can be used for efficiently recognizing polyhedral objects is proposed. It consists of two levels: the lower level where the geometrical features of the primitive surfaces of an object are represented by their signatures and the rotation maps, and the higher level where the topological features among the surfaces of an object are represented by its ISRT. The signature representation allowed the comparison process to be done in the surface level not in the feature level. The rotation maps made the transformation between the test surfaces and the primitive surfaces be derived at the same time with the determination of the match. The ISRT has the structure where the search process may be performed in a hierarchical way, the surface features first and then the relationships between the surfaces next. As shown in the experiment, the signature representation made it easy to recover the disconnected edges in the 2-D image. Further research is in progress to apply the proposed signature representation to natural quadric objects.

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