Vít Zýka

Článek ConTeXtem: tutoriál

Zpravodaj Československého sdružení uživatelů TeXu, Vol. 18 (2008), No. 4, 200–208

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Článek ConTEXtem: tutoriál

Vít Zýka

V tomto tutoriálu si krok za krokem ukážeme, jak vytvořit článek pomocí ConTEXtu [3, 1, 2]. Výsledný text, viz obrázek 1, bude zkrácenou verzí skutečného odborného článku a bude tak obsahovat většinu prvků takového typu dokumentu.

Zdrojový text tutoriálu

Strukturně značkovaný text torza článku:

```
\startproduct tutorial-paper-vzor

\environment paper-style-vzor

% --------------------------------------------------------------- Title
\startTitle
\Title{%
  Graph-based Range Image Registration\\
  Combining Geometric and Photometric Features}
\Author{%
  Ikuko Shimizu\Inst{1},
  Akihiro Sugimoto\Inst{2},
  Midar Asar\Inst{3}}
\Institute{%
  \Inst{1}~Tokyo University of Agriculture and Technology, Japan\\
  \Inst{2}~National Institute of Informatics, Japan\\
  \Inst{3}~Czech Technical University, Czech Republic\\
  \Email{ikuko@tt.tuat.ac.jp},
  \Email{sugimoto@nee.ac.jp},
  \Email{asar@ftr.cvut.cz}}
\stopTitle

% ------------------------------------------------------------ Abstract
\startAbstract
We propose a coarse registration method of range images using both
geometric and photometric features.  The framework of existing methods
using multiple features first defines a single similarity distance
summing up each feature based evaluations, and then minimizes the
distance between range images for registration.  In contrast, we
formulate registration as a graph-based optimization problem, where we
independently evaluate geometric feature and photometric feature and
consider only the order of point-to-point matching quality.  We then
find as large consistent matching as possible in the sense of the
matching-quality order.  This is solved as one global combinatorial
optimization problem.  Our method thus does not require any good
initial estimation and, at the same time, guarantees that the global
solution is achieved.
\stopAbstract
```

1

Graph-based Range Image Registration Combining Geometric and Photometric Features

Ikuko Shimizu[1], Akihiro Sugimoto[2], Midar Asar[3]

[1] Tokyo University of Agriculture and Technology, Japan
[2] National Institute of Informatics, Japan
[3] Czech Technical University, Czech Republic
ikuko@tt.tuat.ac.jp, sugimoto@nee.ac.jp, asar@ftr.cvut.cz

Abstract. We propose a coarse registration method of range images using both geometric and photometric features. The framework of existing methods using multiple features first defines a single similarity distance summing up each feature based evaluations, and then minimizes the distance between range images for registration. In contrast, we formulate registration as a graph-based optimization problem, where we independently evaluate geometric feature and photometric feature and consider only the order of point-to-point matching quality. We then find as large consistent matching as possible in the sense of the matching-quality order. This is solved as one global combinatorial optimization problem. Our method thus does not require any good initial estimation and, at the same time, guarantees that the global solution is achieved.

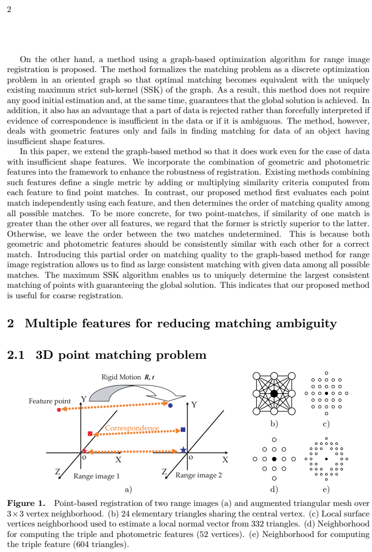
1 Introduction

Automatic 3D model acquisition of the real-world object is important for many applications such as CAD/CAM or CG. A range sensor, which is a sensing device directly measuring 3D information of an object surface, is a useful tool in modeling 3D objects. An image of an object captured by a range sensor is called a range image and it provides a partial shape of the object in terms of the 3D coordinates of surface points in which the coordinate system is defined by the position and orientation of the range sensor. To obtain the full shape of an object, therefore, we have to align range images captured from different viewpoints. This alignment, i.e., finding the rigid transformation between coordinate systems that aligns given range images, is called range image registration.

Widely used methods for range image registration are the iterative closest point (ICP) method proposed by [1] and its extensions [2]. These methods iterate two steps: Each point in one range image is transformed by a given transformation to find the closest point in the other range image. These point correspondences are then used to estimate the transformation minimizing matching errors. In order to robustly[1] realize range image registration, some features reducing matching ambiguity are proposed in addition to simply computed geometric features. They are, for example, color attributes, chromaticity, normal vectors, curvatures themselves and their features, and attributes representing overlapping areas of planes. Combining different kinds of features enhances robustness for registration; nevertheless, defining one common meaningful metric for similarity using different kinds of features is still even difficult.

[1] The terminology "robust" in this paper means that the possibility of successful registration is enhanced; registration is more successful.

(a) Strana 1



2

On the other hand, a method using a graph-based optimization algorithm for range image registration is proposed. The method formalizes the matching problem as a discrete optimization problem in an oriented graph so that optimal matching becomes equivalent with the uniquely existing maximum strict sub-kernel (SSK) of the graph. As a result, this method does not require any good initial estimation and, at the same time, guarantees that the global solution is achieved. In addition, it also has an advantage that a part of data is rejected rather than forcefully interpreted if evidence of correspondence is insufficient in the data or if it is ambiguous. The method, however, deals with geometric features only and fails in finding matching for data of an object having insufficient shape features.

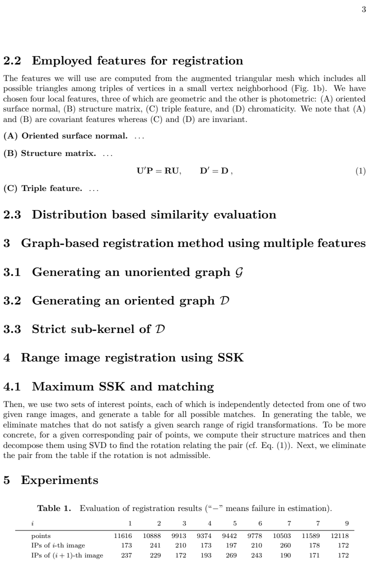
In this paper, we extend the graph-based method so that it does work even for the case of data with insufficient shape features. We incorporate the combination of geometric and photometric features into the framework to enhance the robustness of registration. Existing methods combining such features define a single metric by adding or multiplying similarity criteria computed from each feature to find point matches. In contrast, our proposed method first evaluates each point match independently using each feature, and then determines the order of matching quality among all possible matches. To be more concrete, for two point-matches, if similarity of one match is greater than the other over all features, we regard that the former is strictly superior to the latter. Otherwise, we leave the order between the two matches undetermined. This is because both geometric and photometric features should be consistently similar with each other for a correct match. Introducing this partial order on matching quality to the graph-based method for range image registration allows us to find as large consistent matching with given data among all possible matches. The maximum SSK algorithm enables us to uniquely determine the largest consistent matching of points with guaranteeing the global solution. This indicates that our proposed method is useful for coarse registration.

2 Multiple features for reducing matching ambiguity

2.1 3D point matching problem

Figure 1. Point-based registration of two range images (a) and augmented triangular mesh over 3×3 vertex neighborhood. (b) 24 elementary triangles sharing the central vertex. (c) Local surface vertices neighborhood used to estimate a local normal vector from 332 triangles. (d) Neighborhood for computing the triple and photometric features (52 vertices). (e) Neighborhood for computing the triple feature (604 triangles).

(b) Strana 2



3

2.2 Employed features for registration

The features we will use are computed from the augmented triangular mesh which includes all possible triangles among triples of vertices in a small vertex neighborhood (Fig. 1b). We have chosen four local features, three of which are geometric and the other is photometric: (A) oriented surface normal, (B) structure matrix, (C) triple feature, and (D) chromaticity. We note that (A) and (B) are covariant features whereas (C) and (D) are invariant.

(A) Oriented surface normal. ...

(B) Structure matrix. ...

$$\mathbf{U}'\mathbf{P} = \mathbf{R}\mathbf{U}, \qquad \mathbf{D}' = \mathbf{D}\,, \tag{1}$$

(C) Triple feature. ...

2.3 Distribution based similarity evaluation

3 Graph-based registration method using multiple features

3.1 Generating an unoriented graph $\mathcal{G}$

3.2 Generating an oriented graph $\mathcal{D}$

3.3 Strict sub-kernel of $\mathcal{D}$

4 Range image registration using SSK

4.1 Maximum SSK and matching

Then, we use two sets of interest points, each of which is independently detected from one of two given range images, and generate a table for all possible matches. In generating the table, we eliminate matches that do not satisfy a given search range of rigid transformations. To be more concrete, for a given corresponding pair of points, we compute their structure matrices and then decompose them using SVD to find the rotation relating the pair (cf. Eq. (1)). Next, we eliminate the pair from the table if the rotation is not admissible.

5 Experiments

Table 1. Evaluation of registration results ("−" means failure in estimation).

i	1	2	3	4	5	6	7	7	9
points	11616	10888	9913	9374	9442	9778	10503	11589	12118
IPs of i-th image	173	241	210	173	197	210	260	178	172
IPs of $(i+1)$-th image	237	229	172	193	269	243	190	171	172

(c) Strana 3

4

Table 1 shows that over all the cases, the registration accuracy of our method is not only significantly higher but also numerically more stable, compared with the method using geometric features alone.

6 Conclusion

We extended a graph-based range image registration method so that it can handle both geometric and photometric features simultaneously. Namely, we formulated registration as a graph-based optimization problem where we independently evaluate geometric feature and photometric feature and then consider only the order of point-to-point matching quality. We then find as large consistent matching as possible in the sense of the matching-quality order. This is solved as one global combinatorial optimization problem of polynomial complexity. The advantage of our method is that each match is independently evaluated by each employed feature and the order of matching quality is only concerned. Differently from existing methods, our proposed method need not define any single metric of similarity for evaluating matching. Our experimental results demonstrate the effectiveness of our method for coarse registration.

The proposed method will reduce the possibility of finding an incorrect matching but cannot be expected to increase the number of matches significantly. This follows from the fact that both the two similarity criteria have to be consistent. In principle, it is also possible to combine the two criteria in such a way that when one of them strictly favors the match of q to p and the other is at least indifferent between p and q, the edge joining p and q becomes unidirectional. Such definition requires using a different matching algorithm from the one used in this paper. This research direction is our ongoing work.

Acknowledgments. A part of this work was done under the framework of MOU between the Czech Technical University and National Institute of Informatics. This work is in part supported by the Czech Academy of Sciences under project 1ET101210406 and by the EC project MRTN-CT-2004-005439.

References

[1] P. J. Besl and N. D. McKay. A method for registration of 3-D shapes. *IEEE Trans. on PAMI*, 14(2):239–256, 1992.

[2] Y. Chen and G. Medioni. Object modeling by registration of multiple range images. *IVC*, 10(3):145–155, 1992.

(d) Strana 4

Obrázek 1: Tutoriál je vybudován na fragmentu skutečného odborného textu.

```latex
% ---------------------------------------------------------- Introduction
\section{Introduction}
Automatic 3D model acquisition of the real-world object is important
for many applications such as CAD/CAM or CG.  A range sensor, which is
a sensing device directly measuring 3D information of an object
surface, is a useful tool in modeling 3D objects.  An image of an
object captured by a range sensor is called a range image and it
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position and orientation of the range sensor.  To obtain the full
shape of an object, therefore, we have to align range images captured
from different viewpoints.  This alignment, i.e., finding the rigid
transformation between coordinate systems that aligns given range
images, is called range image registration.

Widely used methods for range image registration are the iterative
closest point (ICP) method proposed by \cite{Besl92} and its
extensions \cite{Chen92}. These
methods iterate two steps: Each point in one range image is
transformed by a given transformation to find the closest point in the
other range image.  These point correspondences are then used to
estimate the transformation minimizing matching errors.  In order to
robustly\footnote{The terminology \quotation{robust} in this paper
means that the possibility of successful registration is enhanced;
registration is more successful.} realize range image registration,
some features reducing matching ambiguity are proposed in addition to
simply computed geometric features.
They are, for example, color attributes,
chromaticity, normal vectors,
curvatures themselves and their features, and
attributes representing overlapping areas of planes.
Combining different kinds of features enhances robustness for
registration; nevertheless, defining one common meaningful metric for
similarity using different kinds of features is still even difficult.

On the other hand, a method using a graph-based optimization algorithm
for range image registration is proposed. The method
formalizes the matching problem as a discrete optimization problem in
an oriented graph so that optimal matching becomes equivalent with the
uniquely existing maximum strict sub-kernel (SSK) of the graph.  As a
result, this method does not require any good initial estimation and,
at the same time, guarantees that the global solution is achieved.  In
addition, it also has an advantage that a part of data is rejected
rather than forcefully interpreted if evidence of correspondence is
insufficient in the data or if it is ambiguous.  The method, however,
deals with geometric features only and fails in finding matching for
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In this paper, we extend the graph-based method so
that it does work even for the case of data with insufficient shape
features.  We incorporate the combination of geometric and photometric
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Existing methods combining
such features define a single metric by adding or multiplying
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In contrast, our proposed method first evaluates each point match
independently using each feature, and then determines the order of
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two point-matches, if similarity of one match is greater than the
other over all features, we regard that the former is strictly
```

superior to the latter. Otherwise, we leave the order between the two
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match. Introducing this partial order on matching quality to the
graph-based method for range image registration allows us to find as
large consistent matching with given data among all possible matches.
The maximum SSK algorithm enables us to uniquely determine the largest
consistent matching of points with guaranteeing the global
solution. This indicates that our proposed method is useful for coarse
registration.

```
% ------------------------------------------------------- ...
\section{Multiple features for reducing matching ambiguity}

\subsection{3D point matching problem}
\placefigure
  [here,top]
  [fig:p-to-p]
  {Point-based registration of two range images
   (a)~and augmented triangular mesh over $3 \times 3$ vertex
      neighborhood.
   (b)~24 elementary triangles sharing the central vertex.
   (c)~Local surface vertices neighborhood used to estimate a
      local normal vector from 332 triangles.
   (d)~Neighborhood for computing the triple and photometric features
      (52 vertices).
   (e)~Neighborhood for computing the triple feature (604 triangles).}
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       {\externalfigure[7x7ngh][width=\tmpD]}{c)}
       {\externalfigure[5x5ngh][width=\tmpD]}{d)}
       {\externalfigure[7x7onion2][width=\tmpD]}{e)}
     \stopcombination
  }}

\subsection{Employed features for registration}
The features we will use are computed from the augmented triangular
mesh which includes all possible triangles among
triples of vertices in a small vertex neighborhood
(\in{Fig.}{b}[fig:p-to-p]). We have chosen four local features, three
of which are geometric and the other is photometric: (A) oriented
surface normal, (B) structure matrix, (C) triple feature, and (D)
chromaticity. We note that (A) and (B) are covariant features whereas
(C) and (D) are invariant.

%\noindent{\bf (A) Oriented surface normal.}
\subject{(A) Oriented surface normal}\dots

\subject{(B) Structure matrix}\dots

\placeformula[eq:covariant-f]
$$
  \mat{U}'\mat{P} = \mat{R}\mat{U}, \qquad
  \mat{D'} = \mat{D} \:,
$$
```

```
\subject{(C) Triple feature}\dots

\subsection{Distribution based similarity evaluation}

% ------------------------------------------------------- ...
\section{Graph-based registration method using multiple features}
\subsection{Generating an unoriented graph ${\cal G}$}
\subsection{Generating an oriented graph ${\cal D}$}
\subsection{Strict sub-kernel of ${\cal D}$}
% ------------------------------------------------------- ...
\section{Range image registration using SSK}
\subsection{Maximum SSK and matching}
Then, we use two sets of interest points, each of which is
independently detected from one of two given range images, and
generate a table for all possible matches. In generating the table, we
eliminate matches that do not satisfy a given search range of rigid
transformations. To be more concrete, for a given corresponding pair
of points, we compute their structure matrices and then decompose them
using SVD to find the rotation relating the pair
(cf. \inM[eq:covariant-f]). Next, we eliminate the pair from
the table if the rotation is not admissible.

% ------------------------------------------------------- ...
\section{Experiments}

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   \NC \NC $i$ \NC 1 \NC 2 \NC 3 \NC 4 \NC 5 \NC 6 \NC 7 \NC 7 \NC 9 \NC\SR
   \HL
   \NC \NC points \NC
     11616 \NC 10888 \NC 9913 \NC 9374 \NC 9442 \NC 9778 \NC
     10503 \NC 11589 \NC 12118 \NC\FR
   \NC \NC IPs of $i$-th image \NC
     173 \NC 241 \NC 210 \NC 173 \NC 197 \NC 210 \NC 260 \NC 178 \NC 172 \NC\MR
   \NC \NC IPs of $(i+1)$-th image \NC
     237 \NC 229 \NC 172 \NC 193 \NC 269 \NC 243 \NC 190 \NC 171 \NC 172 \NC\LR
   %\HL
   \stoptable}
\stop

\in{Table}{}[tab:s-match-tab] shows that over all the cases,
the registration accuracy of our method is not only significantly
higher but also numerically more stable, compared with the method
using geometric features alone.

% ------------------------------------------------------- Conclusion
\section{Conclusion}
We extended a graph-based range image registration method so that it
can handle both geometric and photometric features simultaneously.
Namely, we formulated registration as a graph-based optimization
problem where we independently evaluate geometric feature and
photometric feature and then consider only the order of point-to-point
matching quality.  We then find as large consistent matching as
```

```
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matching-quality is only concerned.  Differently from existing
methods, our proposed method need not define any single metric of
similarity for evaluating matching.  Our experimental results
demonstrate the effectiveness of our method for coarse registration.

The proposed method will reduce the possibility of finding an
incorrect matching but cannot be expected to increase the number of
matches significantly.  This follows from the fact that both the two
similarity criteria have to be consistent.  In principle, it is also
possible to combine the two criteria in such a way that when one of
them strictly favors the match of $q$ to $p$ and the other is at least
indifferent between $p$ and $q$, the edge joining $p$ and $q$ becomes
unidirectional.  Such definition requires using a different matching
algorithm from the one used in this paper.  This research direction is
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Czech Technical University and National Institute of Informatics.
This work is in part supported by the Czech Academy of Sciences under
project 1ET101210406 and by the EC project MRTN-CT-2004-005439.

% --------------------------------------------------------- Bibliography
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  [k=Besl92,t=article,a=Besl,y=1992,s=,n=,u=]
  \artauthor[]{P.~J.}[]{}{Besl}
  \artauthor[]{N.~D.}[]{}{McKay}
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  \journal{IEEE Trans. on PAMI}
  \pubyear{1992}
  \volume{14}
  \issue{2}
  \pages{239--256}
\stoppublication

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  \artauthor{G.}{}{Medioni}
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  \pubyear{1992}
  \volume{10}
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  \pages{145--155}
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\fi

\completepublications

\stopproduct
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Definice strukturních značek, vzhledu a formátování:

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\setupindenting[medium,yes]

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% --- Links

% --- Misc
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BibTEX databáze citované literatury:

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  author =       {Besl, P. J. and McKay, N. D.},
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  journal =      {IEEE Trans. on PAMI},
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  number =       {3},
  pages =        {145--155},
}

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  edition =      {2},
}
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Zdrojové kódy tutoriálu jsou ke stažení na adrese `http://zyka.net`.

Reference

[1] Hans Hagen. *ConTEXt the manual*. `http://www.pragma-ade.com/general/manuals/cont-eni.pdf`, November 2001.

[2] Taco Hoekwater. *ConTEXt module: Bibliographies*, 2006. `http://dl.contextgarden.net/modules/t-bib/doc/context/bib/bibmod-doc.pdf`.

[3] Ton Otten and Hans Hagen. Exkurze do ConTEXtu. *Zpravodaj Československého sdružení uživatelů TEXu*, 16(2–4):59–224, 2006. Český překlad manuálu ConTeXt on Excursion, `https://foundry.supelec.fr/docman/view.php/22/14/ma-cb-cz-screen.pdf`.

Summary: Article by ConTEXt: Tutorial

In this tutorial we show how to create a technical article using ConTEXt [3, 1, 2]. The resulting text will be a shortened version of the real article, see Figure 1, and so it will contain most of the elements of this kind of document.

Vít Zýka `vit.zyka@seznam.cz`