

A WWW-Accessible Database for 3D Vision Research*

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Abstract

Reproducibility and thorough experimental evaluation are essential elements of the dissemination of systems, including the systems developed for object recognition by computer vision researchers. Systems tested on widely used image databases are more directly comparable than systems which are tested on customized data. This paper describes the components of an evolving database of 3D object models, 3D (range) images, and code to support research in and evaluation of model-based object recognition and range image analysis systems. Images and models are available in a variety of geometric formats (*e.g.*, VRML, GIF as well as documented neutral formats) and the entire database can be browsed and retrieved through the World Wide Web.

1 Introduction

Model-based three-dimensional object recognition continues to be a popular and productive area of research in the computer vision community. The different assumptions inherent in designing a complete system have spawned many original systems and the subsequent development of variants and improvements [3, 2]. Object recognizers employing dense range maps have been particularly popular systems for experimental computer vision researchers to construct. Recent drops in the prices of range sensors and dramatic improvements in the processing power and memory capacity of research workstations have combined to make experimentation with real (as well as synthetic) range data and historically-slow recognition strategies approachable, even in research labs with significantly limited resources.

At the 1991 NSF-sponsored workshop entitled “Future Directions in Computer Vision Research” [8], computer vision methodology (or lack of same) received focused attention, and a series of articles in *CVGIP: Image Understanding* [10] has hopefully prompted researchers to standardize those parts of their experiments, systems, and data where such standardization is warranted. While improvement of the situation requires activity on many fronts, one theme that has been sounded repeatedly in recent years is the value of comparisons against standard data sets. Such comparisons allow the strengths and weaknesses of competing techniques to be highlighted, as well as demonstrating the domain of applicability of the methods under study (promoting the ‘where does it break?’ question asked of researchers describing implementations and algorithms by reviewers and conference presentation attendees). There are signs that this need is beginning to be addressed by researchers, as evidenced by the use of standardized databases in applications as diverse as stereo matching [9], character recognition [7], and (most relevant to this work) range image segmentation [1].

In this article, we describe a database of range images and 3D objects constructed over an nine-year period at two institutions, which was designed to facilitate research in model-based 3D object recognition. Almost

*Support for the construction of the databases described in this article was provided by the National Science Foundation under grants CDA-8806599 (to Michigan State University), CDA-9121675, CDA-9422044, IRI-9209212, and IRI-9506414 (to Washington State University), by the Washington State University Research Grant-In-Aid program, by the Washington Technology Center, and by the Northrop Corporation.

by accident, this database (freely available over the Internet) has become a popular source of imagery for evaluation of range image segmentation algorithms. Dissemination and use of this database will allow for realistic comparative studies as well as a source of test data for development of new techniques for range image analysis and understanding.

The remainder of this paper is organized as follows. Section 2 describes the overall organization of the database, along with some commentary about the history of its construction. Section 4 describes two techniques for accessing the database and suggests a standard scheme for crediting the authors in publications employing the database. Section 5 presents some final comments.

2 Database Contents and Organization

At present, the database has two main components: an archive of over 250 3D object models, and an archive of over 400 real and synthetic range images. New items are added to the database regularly and documented on its home page. Access statistics for the database are incomplete but the available data indicates a minimum of 100 downloads of one or more items from the database each month.

2.1 Object Model Database

The object model database contains descriptions of 3D objects in a variety of formats. Different descriptions of the same object are employed for different purposes in our model-based object recognition system. For example, each object in the database is described as a polyhedron, which for objects with curved surfaces is merely an approximation to the true object shape. This polyhedral description is useful for synthesizing images of the object, both to provide data sets for system testing and to provide images of hypotheses for verification [5]. Many objects are described in terms of the types and parameters of their constituent surfaces; this description is useful during recognition as a source of surface primitives to correspond to surfaces extracted from range image segmentations. Each file format is described via example below.

There are presently three sub-archives in the model database:

1. The **MSU-Ideas** database contains descriptions of twenty 3D objects used in testing of the BONSAI and IFI object recognition systems developed by Flynn and Jain [5, 6]. These objects were originally designed in 1989 and 1990 with the I-deas solid modeler sold by Structural Dynamics Research Corporation. A subsequent redesign phase employed the IRIT public-domain solid modeler¹ written by Gershon Elber (of the University of Utah and Technion). Object shapes are generally simple and piecewise-planar, cylindrical, spherical, or conical. Objects in this database are described in four formats:
 - (a) IRIT solid modeler input.
 - (b) IGES 3.0 formatted data.
 - (c) An ASCII polyhedral approximation.
 - (d) An ASCII file of surface types and parameters.
2. The **USF** database contains descriptions of 81 polyhedral objects designed by students and faculty at the University of South Florida. A custom solid modeler developed at USF was used to fabricate these models. Each object is presented in two formats:
 - (a) An ASCII polyhedral description.
 - (b) An ASCII file of surface types and parameters (in this database, all object surfaces are planar).
3. The **NETLIB** database contains descriptions of 119 polyhedral objects obtained from the NETLIB scientific data repository. Each object is presented in two formats:
 - (a) An ASCII polyhedral description.
 - (b) An ASCII file of surface types and parameters (in this database, all object surfaces are planar).

¹<http://www.cs.technion.ac.il/~gershon/irit/home/irit.home.html>

4. The **WSU-PRO/E** database contains descriptions of seven objects constructed from drawings in mechanical design texts. The models were designed using the Pro/Engineer CAD package sold by Parametric Technologies, Inc. and are currently presented only as polyhedral approximations. We are currently designing more models and making surface descriptions available.

Figure 1 shows a synthetic range image of an object from each of the four databases. Figure 2 shows excerpts from the four files used to describe the ‘curvblock’ object in the MSU-Ideas database. As mentioned above, the file formats most useful to our object recognizers are the polyhedral approximation (*i.e.*, the `.poly` format, Figure 2(c)) and the neutral surface description (*i.e.*, the `.neutral` format, Figure 2(d)).

2.2 Range Image Database

The range image archive consists of several sub-archives.

- The **Synthetic** sub-archive contains five synthetic range images of each of the models in the MSU-Ideas database described above (for a total of one hundred images). These images were generated from the polyhedral approximations (`.poly` files) accompanying each of the MSU-Ideas models. Software to generate these synthetic range images is also available in the archive and is described below.
- The **Isolated** sub-archive contains five real range images (taken with a Technical Arts 100x range sensor) of each of the twenty objects whose models are in the MSU-Ideas model database (for a total of 100 images).
- The **Cluttered** sub-archive contains ten real range images (taken with the 100x range sensor), each of a scene containing two of the objects in the WSU-Ideas object database.
- The **Miscellaneous** sub-archive contains 47 images taken with the 100x range sensor, containing one or more miscellaneous objects.
- The **seg-comp** sub-archive contains 80 images used in the segmentation comparison project conducted at the University of South Florida, Washington State University, the University of Bern, and the University of Edinburgh since 1993 [1]. Forty of the images were taken at Bern with a structured light scanner built by ABW GmbH and forty images were taken at Oak Ridge National Laboratory with an Odetics Perceptron laser scanner.
- The **USF** sub-archive contains 19 range/reflectance image pairs taken with the Odetics Perceptron laser range finder at Oak Ridge.

2.3 Range Image Rendering Software

The archive also contains the source code and supporting libraries for a program that synthesizes range images from the polyhedral approximations (`.poly` files) mentioned above. The program currently available is somewhat limited in that it centers the object in the synthetic aperture, scales the coordinates appropriately to fill the image with the object, and specifies the object orientation by an index between 0 and 319. The index identifies one of 320 viewpoints which are drawn from the centers of the triangles comprising a 16-frequency subdivision of the icosahedron. The program requires the Mesa software library (which is a freely available implementation of most of the OpenGL graphics library) and a pointer to the home site for Mesa is provided in the database description.

3 Impact and Lessons Learned

The primary impact of a database such as the one described here on its research community is demonstrated by its frequency of appearance in the literature. A brief examination of recent issues of *IEEE Trans. on PAMI* revealed several uses of database images, including these two uses.

- Dickinson *et al.* [4] used Technical Arts 100X images as input to a system to derive part models for the objects in the images.

- Sun and Sherrah [11] used images as input to a procedure that identifies symmetries in objects.

Images in the database have also been used in the literature to evaluate range image segmenters. The object models in the database have not been used to any great extent (this is perhaps due to the proliferation of free and inexpensive databases of CAD models developed for use in computer graphics and animation applications). Therefore, the record of success of this database is mixed. It is reasonably well-known and well-regarded as a source of range imagery, but has had little impact at a level above segmentation.

In retrospect, the design, updating and ‘marketing’ of the database might have been done differently to enhance its value to the community. Inexpensive CD-ROM writers and media as well as inexpensive high-capacity rewritable disks have impacted and are continuing to impact the for-free and for-profit approaches to selling data. More publicity about databases such as the 3D database also raises their profile in the community and the recent and continuing activities to improve the experimental rigor of computer vision research will help reinforce their value.

4 Access and Citation

The ‘top’ of the 3D model/image database is available at the following URL:

<http://www.eecs.wsu.edu/~flynn/3DDB/>.

The archive is organized as a tree; at the top level the visitor can elect to browse the object models, the range images, or the rendering software. Each leaf directory’s contents (*e.g.* a group of related object models or images, or the entire rendering program source code) is available as a compressed UNIX `tar` file, and every individual file may also be browsed or downloaded separately. The several WWW pages associated with this database will be instrumented with programs to keep track of the database’s usage; this will help to guide future development of the archive.

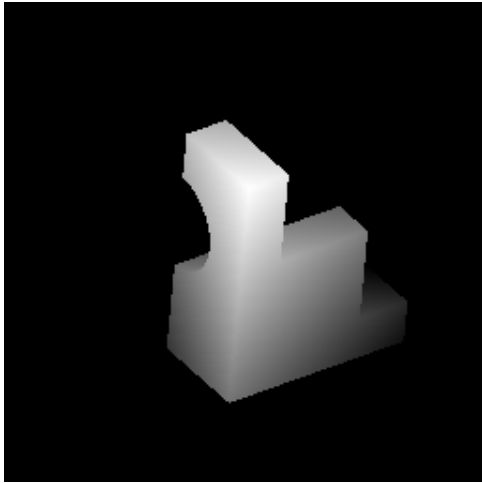
5 Conclusions

In this short article, we have described a nine-year-old archive of data used in model-based 3D object recognition. As the archive matures, additional items are begin added and its value to the computer vision research community should continue to increase. Ultimately, the success of this archive depends on the willingness of researchers to use it; this was the basis of our decision to make the data freely available over the Internet and World Wide Web.

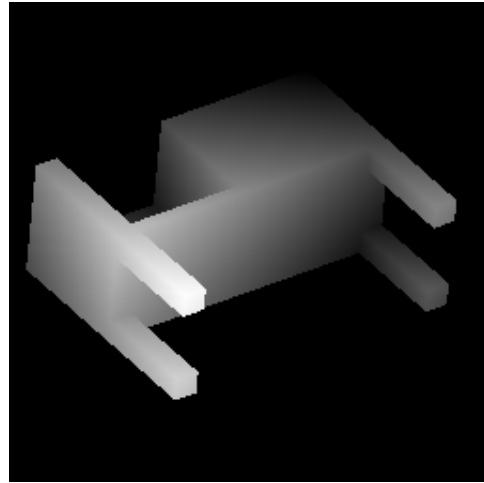
References

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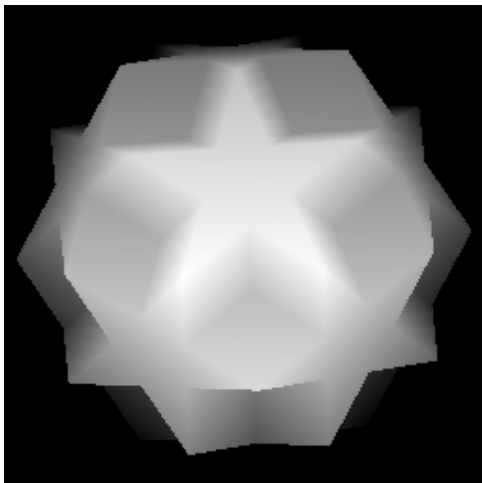
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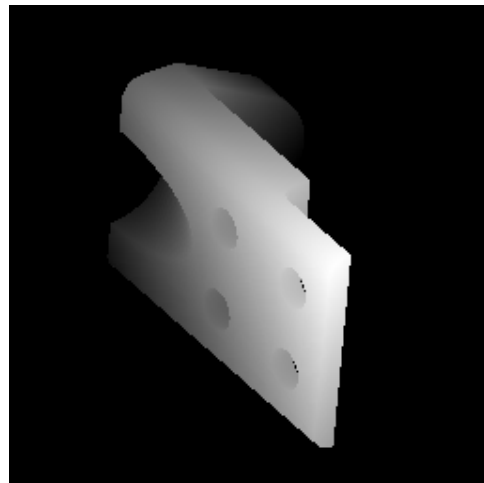
(a)



(b)



(c)



(d)

Figure 1. Synthetic range images of objects from the four databases in the object model database. (a): MSU-Ideas database. (b): USF database. (c): NETLIB database. (d): WSU-PRO/E database.

```

# the curvblock object
# 7/95 pat flynn

# x=0 polygon
i1 = poly(list(vector(0,0,0),vector(0,5.5,0),
               vector(0,5.5,2.75),vector(0,0,2.75)),FALSE);

# y=0 polygon
i2 = poly(list(vector(0,0,0),vector(6.75,0,0),
               vector(6.75,0,2.75), vector(0,0,2.75)),
           FALSE);

16 lines omitted

# z = 2.75 polygon (L-shaped. Note cylinder isn't
subtracted yet.)
i11 = poly(list(vector(0,0,2.75),vector(6.75,0,2.75),
               vector(6.75,1.25,2.75),
               vector(1.25,1.25,2.75),
               vector(1.25,5.5,2.75),
               vector(0,5.5,2.75)),
           FALSE);

# Note: negation needed because irit seems to create an
# inside-out object.
a = - mergepoly(list(i1,i2,i3,i4,i5,i6,i7,i8,i9,i10,i11));

# resolution=128;

c = cylin(vector(4,-1,2.75),vector(0,5,0),1.375);
b=a-c;

save("curvblock",convex(b));

```

(a)

```

GEOMETRY CREATED BY SURC GBOMOD 1.0
,,9HCURVBLOCK,9HCURVBLOCK,36HSRDC GBOMOD;V4.0 ,SUN ,TYPE-IGES30,,32, G 1
8,24,8,56,9HCURVBLOCK,1,0,1,ZHIN,,13H900108.085616,1.0E-05,6.8E+00,, G 2
110 0 5 2 0 0 0 000000000D 1
110 1 1 1 0 0 0 000000000D 2
110 3 1 1 0 0 0 000000000D 3
110 0 5 2 0 0 0 000000000D 4
110 5 1 1 0 0 0 000000000D 5
110 0 5 2 0 0 0 000000000D 6
110 7 1 1 0 0 0 000000000D 7
110 0 5 2 0 0 0 000000000D 8

244 lines deleted
108 268 1 1 0 0 0 000000001D 253
108 0 2 3 1 0 0 0D 254
110, 0.1250000E+01, 0.5500000E+01, 0.2750000E+01, 1P 1
0.1250000E+01, 0.5500000E+01, 0.0000000E+00, 0, 0, 1P 2

261 lines deleted
110, 0.0000000E+00, 0.5500000E+01, 0.0000000E+00, 249P 264
0.0000000E+00, 0.5500000E+01, 0.2750000E+01, 0, 0, 249P 265
102, 4, 243, 245, 247, 249, 251P 266
0, 0, 251P 267
108, 0.0000000E+00, 0.1000000E+01, 0.0000000E+00, 0.5500000E+01, 253P 268
251, 0.0000000E+00, 0.0000000E+00, 0.0000000E+00, 253P 269
0.0000000E+00, 0, 0, 253P 270
S 1G 2D 254P 270
T 1

```

(b)

```

pnt 0: 4.000000 1.250000 1.250000
pnt 1: 4.000000 1.250000 0.000000
pnt 2: 6.750000 1.250000 0.000000
pnt 3: 6.750000 1.250000 1.250000
pnt 4: 1.250000 0.000000 0.000000

57 lines deleted

pnt 62: 2.692300 0.000000 2.325100
poly 0: [4] 25 26 44 45
poly 1: [4] 45 44 42 48

40 lines deleted

poly 42: [3] 62 61 59
poly 43: [4] 24 13 5 61
poly 44: [4] 14 15 7 6
surf 0: [10] 0
surf 1: [11] 10
surf 2: [2] 21
surf 3: [1] 23
surf 4: [1] 24
surf 5: [1] 25
surf 6: [2] 26
surf 7: [1] 28
surf 8: [3] 29
surf 9: [1] 32
surf 10: [1] 33
surf 11: [10] 34
surf 12: [1] 44

```

(c)

```

igesID: 1
type: cylinder axis: 0 1 0 point: 4 0 2.75
length: 2.0 radius: 1.375000

igesID: 2
type: plane coefficients: 0.000000 1.000000 0.000000 1.250000

igesID: 3
type: plane coefficients: 1.000000 0.000000 0.000000 1.250000

igesID: 4
type: plane coefficients: 0.000000 0.000000 1.000000 1.250000

igesID: 5
type: plane coefficients: 0.000000 1.000000 0.000000 4.000000

igesID: 6
type: plane coefficients: 1.0 0.0 0.0 4.0

igesID: 7
type: plane coefficients: 0.000000 0.000000 1.000000 2.75

igesID: 8
type: plane coefficients: 0.000000 0.000000 1.000000 2.75

igesID: 9
type: plane coefficients: 0.000000 0.000000 -1.000000 0.000000

igesID: 10
type: plane coefficients: -1.000000 0.000000 0.000000 0.000000

igesID: 11
type: plane coefficients: 1.000000 0.000000 0.000000 6.750000

igesID: 12
type: plane coefficients: 0 -1 0 0

igesID: 13
type: plane coefficients: 0.000000 1.000000 0.000000 5.500000

```

(d)

Figure 2. Four descriptions of the MSU-Ideas curvblock object. (a): IRT (.irt) file. (b): IGES file (excerpts). (c): Polyhedral approximation (.poly file, excerpts). (d): surface descriptions (.neutral file).