

L^AT_EX Author Guidelines for 3DIMPVT Proceedings

Anonymous 3DIMPVT submission

Paper ID ****

Abstract

Automated 3D modeling of building interiors is used in applications such as virtual reality and environment mapping. Texture mapping these models accurately is vital towards visualizing the data gathered by modeling systems and increases overall usability. The localization of cameras in 3D scenes often suffers from inaccuracies, resulting in visible discontinuities when different images are projected onto a texture. Previous approaches at minimizing these discontinuities suffer from error accumulation when stitching together multiple images and do not robustly handle wide ranges of camera locations and angles. We propose two approaches for reducing discontinuities during texture mapping, tailored towards a backpack-mounted data acquisition system.

1. Introduction

Three-dimensional modeling of indoor environments has a variety of applications such as training and simulation for disaster management, virtual heritage conservation, and mapping of hazardous sites. Manual construction of these digital models can be time consuming, and as such, automated 3D site modeling has garnered much interest in recent years.

The first step in automated 3d modeling is the physical scanning of the environment's geometry. An indoor modeling system must be able to calculate camera locations within an environment while simultaneously reconstructing the 3D structure of the environment itself. This problem is studied by the robotics and computer vision communities as the simultaneous localization and mapping (SLAM) problem, and is generally solved using a combination of laser range scanners, cameras, and inertial measurement units (IMUs).

The aim of this paper is to present a solution for texture mapping the 3D models generated by indoor modeling systems, with specific attention given to a human-operated system with higher localization errors and greater variance in camera locations. The paper is organized as follows. Section 2 provides an overview of the backpack modeling system

from which data and examples used throughout this paper are from. Section 3 describes the general problem of 3D texture mapping and reviews existing approaches. Section 4 describes challenges posed by the backpack modeling system and presents our two approaches tailored for walls and floors/ceilings respectively. Section 5 compares results and presents conclusions.

2. Backpack Modeling System

Human-operated data acquisition systems provide unique advantages in terms of agility and portability over vehicular-mounted systems. Unfortunately, human-operated systems suffer from a lack of automation and stability, resulting in higher localization variance and leading to the problems discussed in Section 4.

2.1. Data Acquisition Hardware

The backpack modeling system from which our data was collected contains five 2D laser range scanners, two cameras, an orientation sensor, and an IMU (Should I even mention the IMU at all?). The laser scanners are 40Hz Hokuyo UTM-30LX 2D laser scanners with a 30-meter range and a 270° field of view. These scanners are mounted orthogonally to one another. The two cameras are Point Grey Grasshopper GRAS-50S5C units equipped with fish-eye lenses, resulting in a 180° field of view. The IMU, a Honeywell HG9900, is a strap-down navigation-grade sensor which combines three ring laser gyros with bias stability of less than 0.003°/hour and three precision accelerometers with bias of less than 0.245mm/sec². The HG9900 provides highly accurate measurements of all 6 DOF at 200Hz and thus serves as our ground truth for the experiments in this paper. The orientation sensor (OS), an InterSense InertiaCube3, provides orientation parameters at a rate of 180Hz.

2.2. Environment Reconstruction

Using a combination of these sensors and multiple localization and loop-closure algorithms, the backpack is localized over its data collection period, and a 3D point cloud of our environment is constructed. Approximate normal vectors for each point in the point cloud are then calculated

using Principal Component Analysis. These normal vectors allow for the classification and grouping of points into structures such as walls, ceilings, and staircases. RANSAC is then employed to fit polygonal planes to these structures, resulting in a fully planar model, consisting of multiple 2D polygonal planes in 3D space. This planar model, along with the set of images captured by the backpack's camera, can be considered the input data on which our approach runs.

2.3. Image Subsampling

Before beginning the texture mapping process, it is prudent to reduce the amount of images being considered as each plane is textured. The backpack modeling system takes 5 pictures/second, resulting in each plane being present in (and capable of being textured mapped by) thousands of images. For the sake of efficiency, it makes sense to associate each plane with a much smaller sample of images. When creating this subset of images for each plane, there are three criteria we keep in mind. First, we want such a subset of images to be capable of texturing the entirety of a plane, so as to ensure there are no holes in our final texture. Second, we want all our images to be taken from a relatively close distance to the plane, and at as much of a direct, head-on angle as possible. This ensures that the image projects squarely onto our desired plane, with minimal inclusion of other planes, and we get a texture with high resolution. Third, we desire an amount of overlap between the images chosen. This overlap helps us with preprocessing as well as postprocessing techniques discussed in Sections x and y.

To meet these three criteria, we tessellate each plane into [X] triangles of [Y] size. For each triangle, we find all images that can be projected upon the entirety of the triangle, accounting for occlusion with other planes as well, using standard ray-polygon intersection tests. Of these images, we then select the best one according to the heuristic in equation X, favoring closer distances and more head-on viewing angles. We also enforce that no two images are chosen such that they were taken within 0.5 meters of each other. This results in a greatly-reduced set of images such that each one is objectively the "best" location-wise for some number of areas on the plane, addressing the first two criteria. Furthermore, since cameras are only at good angles to triangles near their center of projection, images will be chosen such that there is high overlap between them. This process reduces the amount of candidate images for each plane from many thousands to around 50, at fairly even spacing. With this completed, each of our planes is associated with a sufficiently sized list of candidate images, and we are ready to begin texture mapping.

3. Introduction

Please follow the steps outlined below when submitting your manuscript to the IEEE Computer Society Press. This style guide now has several important modifications (for example, you are no longer warned against the use of sticky tape to attach your artwork to the paper), so all authors should read this new version.

3.1. Language

All manuscripts must be in English.

3.2. Dual submission

By submitting a manuscript to 3DIMPVT, the authors assert that it has not been previously published in substantially similar form. Furthermore, no paper which contains significant overlap with the contributions of this paper either has been or will be submitted during the 3DIMPVT 2012 review period to **either a journal** or any conference or any workshop. **Papers violating this condition will be rejected.**

If there are papers that may appear to the reviewers to violate this condition, then it is your responsibility to: (1) cite these papers (preserving anonymity as described in Section 1.6 below), (2) argue in the body of your paper why your 3DIMPVT paper is non-trivially different from these concurrent submissions, and (3) include anonymized versions of those papers in the supplemental material.

3.3. Paper length

3DIMPVT papers may be between 6 pages and 8 pages. Overlength papers will simply not be reviewed. This includes papers where the margins and formatting are deemed to have been significantly altered from those laid down by this style guide. Note that this L^AT_EX guide already sets figure captions and references in a smaller font. The reason such papers will not be reviewed is that there is no provision for supervised revisions of manuscripts. The reviewing process cannot determine the suitability of the paper for presentation in eight pages if it is reviewed in eleven.

3.4. The ruler

The L^AT_EX style defines a printed ruler which should be present in the version submitted for review. The ruler is provided in order that reviewers may comment on particular lines in the paper without circumlocution. If you are preparing a document using a non-L^AT_EX document preparation system, please arrange for an equivalent ruler to appear on the final output pages. The presence or absence of the ruler should not change the appearance of any other content on the page. The camera ready copy should not contain a ruler. (L^AT_EX users may uncomment

the `\cvprfinalcopy` command in the document preamble.) Reviewers: note that the ruler measurements do not align well with lines in the paper — this turns out to be very difficult to do well when the paper contains many figures and equations, and, when done, looks ugly. Just use fractional references (e.g. this line is 097.15), although in most cases one would expect that the approximate location will be adequate.

3.5. Mathematics

Please number all of your sections and displayed equations. It is important for readers to be able to refer to any particular equation. Just because you didn't refer to it in the text doesn't mean some future reader might not need to refer to it. It is cumbersome to have to use circumlocutions like "the equation second from the top of page 3 column 1". (Note that the ruler will not be present in the final copy, so is not an alternative to equation numbers). All authors will benefit from reading Mermin's description of how to write mathematics: <http://www.cvpr.org/doc/mermin.pdf>.

3.6. Blind review

Many authors misunderstand the concept of anonymizing for blind review. Blind review does not mean that one must remove citations to one's own work—in fact it is often impossible to review a paper unless the previous citations are known and available.

Blind review means that you do not use the words "my" or "our" when citing previous work. That is all. (But see below for techreports)

Saying "this builds on the work of Lucy Smith [1]" does not say that you are Lucy Smith, it says that you are building on her work. If you are Smith and Jones, do not say "as we show in [7]", say "as Smith and Jones show in [7]" and at the end of the paper, include reference 7 as you would any other cited work.

An example of a bad paper just asking to be rejected:

An analysis of the frobnicatable foo filter.

In this paper we present a performance analysis of our previous paper [1], and show it to be inferior to all previously known methods. Why the previous paper was accepted without this analysis is beyond me.

[1] Removed for blind review

An example of an acceptable paper:

An analysis of the frobnicatable foo filter.

In this paper we present a performance analysis of the paper of Smith *et al.* [1], and show it to be inferior to all previously known methods. Why the

previous paper was accepted without this analysis is beyond me.

[1] Smith, L and Jones, C. "The frobnicatable foo filter, a fundamental contribution to human knowledge". Nature 381(12), 1-213.

If you are making a submission to another conference at the same time, which covers similar or overlapping material, you may need to refer to that submission in order to explain the differences, just as you would if you had previously published related work. In such cases, include the anonymized parallel submission [?] as additional material and cite it as

[1] Authors. "The frobnicatable foo filter", F&G 2012 Submission ID 324, Supplied as additional material `fg324.pdf`.

Finally, you may feel you need to tell the reader that more details can be found elsewhere, and refer them to a technical report. For conference submissions, the paper must stand on its own, and not *require* the reviewer to go to a techreport for further details. Thus, you may say in the body of the paper "further details may be found in [?]" . Then submit the techreport as additional material. Again, you may not assume the reviewers will read this material.

Sometimes your paper is about a problem which you tested using a tool which is widely known to be restricted to a single institution. For example, let's say it's 1969, you have solved a key problem on the Apollo lander, and you believe that the CVPR70 audience would like to hear about your solution. The work is a development of your celebrated 1968 paper entitled "Zero-g frobnication: How being the only people in the world with access to the Apollo lander source code makes us a wow at parties", by Zeus *et al.*

You can handle this paper like any other. Don't write "We show how to improve our previous work [Anonymous, 1968]. This time we tested the algorithm on a lunar lander [name of lander removed for blind review]". That would be silly, and would immediately identify the authors. Instead write the following:

We describe a system for zero-g frobnication. This system is new because it handles the following cases: A, B. Previous systems [Zeus *et al.* 1968] didn't handle case B properly. Ours handles it by including a foo term in the bar integral.

...

The proposed system was integrated with the Apollo lunar lander, and went all the way to the moon, don't you know. It displayed the following behaviours which show how well we solved cases A and B: ...

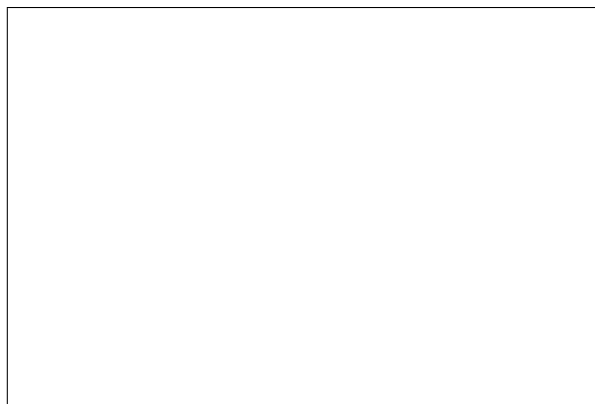


Figure 1. Example of caption. It is set in Roman so that mathematics (always set in Roman: $B \sin A = A \sin B$) may be included without an ugly clash.

As you can see, the above text follows standard scientific convention, reads better than the first version, and does not explicitly name you as the authors. A reviewer might think it likely that the new paper was written by Zeus *et al.*, but cannot make any decision based on that guess. He or she would have to be sure that no other authors could have been contracted to solve problem B.

FAQ: Are acknowledgements OK? No. Leave them for the final copy.

3.7. Miscellaneous

Compare the following:

$\$conf_a\$$ $conf_a$
 $\$\mathit{conf}_a\$$ $conf_a$

See The T_EXbook, p165.

The space after *e.g.*, meaning “for example”, should not be a sentence-ending space. So *e.g.* is correct, *e.g.* is not. The provided `\eg` macro takes care of this.

When citing a multi-author paper, you may save space by using “et alia”, shortened to “*et al.*” (not “*et. al.*” as “*et*” is a complete word.) However, use it only when there are three or more authors. Thus, the following is correct: “Frobination has been trendy lately. It was introduced by Alpher [?], and subsequently developed by Alpher and Fotheringham-Smythe [?], and Alpher *et al.* [?].”

This is incorrect: “... subsequently developed by Alpher *et al.* [?] ...” because reference [?] has just two authors. If you use the `\etal` macro provided, then you need not worry about double periods when used at the end of a sentence as in Alpher *et al.*

For this citation style, keep multiple citations in numerical (not chronological) order, so prefer [?, ?, ?] to [?, ?, ?].

4. Formatting your paper

All text must be in a two-column format. The total allowable width of the text area is $6\frac{7}{8}$ inches (17.5 cm) wide by $8\frac{7}{8}$ inches (22.54 cm) high. Columns are to be $3\frac{1}{4}$ inches (8.25 cm) wide, with a $\frac{5}{16}$ inch (0.8 cm) space between them. The main title (on the first page) should begin 1.0 inch (2.54 cm) from the top edge of the page. The second and following pages should begin 1.0 inch (2.54 cm) from the top edge. On all pages, the bottom margin should be 1-1/8 inches (2.86 cm) from the bottom edge of the page for 8.5 × 11-inch paper; for A4 paper, approximately 1-5/8 inches (4.13 cm) from the bottom edge of the page.

4.1. Margins and page numbering

All printed material, including text, illustrations, and charts, must be kept within a print area 6-7/8 inches (17.5 cm) wide by 8-7/8 inches (22.54 cm) high.

4.2. Type-style and fonts

Wherever Times is specified, Times Roman may also be used. If neither is available on your word processor, please use the font closest in appearance to Times to which you have access.

MAIN TITLE. Center the title 1-3/8 inches (3.49 cm) from the top edge of the first page. The title should be in Times 14-point, boldface type. Capitalize the first letter of nouns, pronouns, verbs, adjectives, and adverbs; do not capitalize articles, coordinate conjunctions, or prepositions (unless the title begins with such a word). Leave two blank lines after the title.

AUTHOR NAME(s) and AFFILIATION(s) are to be centered beneath the title and printed in Times 12-point, non-boldface type. This information is to be followed by two blank lines.

The ABSTRACT and MAIN TEXT are to be in a two-column format.

MAIN TEXT. Type main text in 10-point Times, single-spaced. Do NOT use double-spacing. All paragraphs should be indented 1 pica (approx. 1/6 inch or 0.422 cm). Make sure your text is fully justified—that is, flush left and flush right. Please do not place any additional blank lines between paragraphs.

Figure and table captions should be 9-point Roman type as in Figures 1 and 2. Short captions should be centred. Callouts should be 9-point Helvetica, non-boldface type. Initially capitalize only the first word of section titles and first-, second-, and third-order headings.

FIRST-ORDER HEADINGS. (For example, **1. Introduction**) should be Times 12-point boldface, initially capitalized, flush left, with one blank line before, and one blank line after.

SECOND-ORDER HEADINGS. (For example, **1.1. Database elements**) should be Times 11-point boldface,

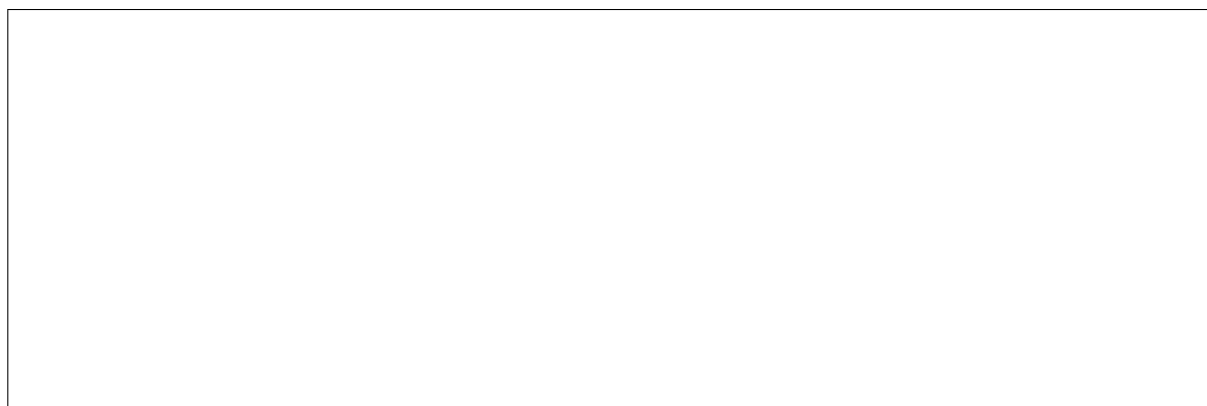


Figure 2. Example of a short caption, which should be centered.

| Method | Frobnability |
|--------|------------------------|
| Theirs | Frumpy |
| Yours | Frobbly |
| Ours | Makes one's heart Frob |

Table 1. Results. Ours is better.

initially capitalized, flush left, with one blank line before, and one after. If you require a third-order heading (we discourage it), use 10-point Times, boldface, initially capitalized, flush left, preceded by one blank line, followed by a period and your text on the same line.

4.3. Footnotes

Please use footnotes¹ sparingly. Indeed, try to avoid footnotes altogether and include necessary peripheral observations in the text (within parentheses, if you prefer, as in this sentence). If you wish to use a footnote, place it at the bottom of the column on the page on which it is referenced. Use Times 8-point type, single-spaced.

4.4. References

List and number all bibliographical references in 9-point Times, single-spaced, at the end of your paper. When referenced in the text, enclose the citation number in square brackets, for example [?]. Where appropriate, include the name(s) of editors of referenced books.

4.5. Illustrations, graphs, and photographs

All graphics should be centered. Please ensure that any point you wish to make is resolvable in a printed copy of the paper. Resize fonts in figures to match the font in the body text, and choose line widths which render effectively in print. Many readers (and reviewers), even of an electronic

¹This is what a footnote looks like. It often distracts the reader from the main flow of the argument.

copy, will choose to print your paper in order to read it. You cannot insist that they do otherwise, and therefore must not assume that they can zoom in to see tiny details on a graphic.

When placing figures in L^AT_EX, it's almost always best to use `\includegraphics`, and to specify the figure width as a multiple of the line width as in the example below

```
\usepackage[dvips]{graphicx} ...  
\includegraphics[width=0.8\linewidth]  
    {myfile.eps}
```

4.6. Color

Color is valuable, and will be visible to readers of the electronic copy. However ensure that, when printed on a monochrome printer, no important information is lost by the conversion to grayscale.

5. Final copy

You must include your signed IEEE copyright release form when you submit your finished paper. We MUST have this form before your paper can be published in the proceedings.