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Image Segmentation and View Factor Calculations in predicting Urban Microclimates

Abstract

This poster presents the creation of a semi-automated process for calculating view factors from various enveloping structural and natural surfaces onto a central point. This process nests in a larger research initiative to quantify the relationship between building facades and thermal comfort in a manner that can easily be used as a planning tool. The surfaces are categorized as follows: sky, concrete, vegetation, and glass, and whether they are directly lit by sunlight. The code used for these segmentations and following calculations is written in MATLAB.

Introduction

With the rapid growth of today's urban quarters, thermal comfort considerations are becoming crucial in the urban planning process. As many cities build up, expand, or remodel their urban centers, opportunities arise to mitigate urban heat island effects intrinsic to traditional concrete-heavy and dense construction.

A way of quantifying thermal comfort is the mean radiant temperature, T_{mrt} , which is the uniform temperature of an area in which the radiant heat transfer from the human body and that of the actual non-uniform enclosure are equal. The overall goal of our research is to derive an equation that predicts the effect of building facades on the T_{mrt} of the public spaces that they enclose.

This presentation is focused on a theoretical derivation of view factors, one of the components needed for predicting T_{mrt} . View factors, along with surface properties, are what connects mean radiant temperatures with architecture, through their effect on radiative heat transfer between surfaces and the centers of their environments. An algebraic expression of this phenomena can be seen below:

$$t_{mrt} = \sqrt[4]{\left(\frac{S_{STR}}{\epsilon_p \sigma}\right) - 273.15} \quad (1)$$

S_{STR} = mean radiant flux of the human body
 K_i = short-wave radiation fluxes ($i = 1-6$)
 L_i = long-wave radiation fluxes ($i = 1-6$)
 F_i = view factor between a person and the surrounding surfaces
 α_s = absorptivity for short-wave (standard 0.7)
 ϵ_p = emissivity for long-wave of human body, which is equal to absorptivity by Kirchhoff's laws (standard value 0.97)

$$S_{STR} = \alpha_k \sum_{i=1}^6 K_i F_i + \epsilon_p \sum_{i=1}^6 L_i F_i \quad (2)$$

By definition, the view factor, F_{12} , is "the fraction of energy exiting an isothermal, opaque, and diffuse surface 1 (by emission or reflection), that directly impinges on surface 2 (to be absorbed, reflected, or transmitted)."

$$F_{12} = \frac{1}{2r_o} \int_{\gamma_1}^{\gamma_2} \int_{\omega_1}^{\omega_2} \sin\left(\frac{\pi r}{2r_o}\right) \cos\left(\frac{\pi r}{2r_o}\right) dr d\alpha. \quad (3)$$

F_{12} : view factor of a "wall"
 α : the angle between the next classified pixel and the previous one
 r : distance center to pixel
 r_o : radius of fisheye image

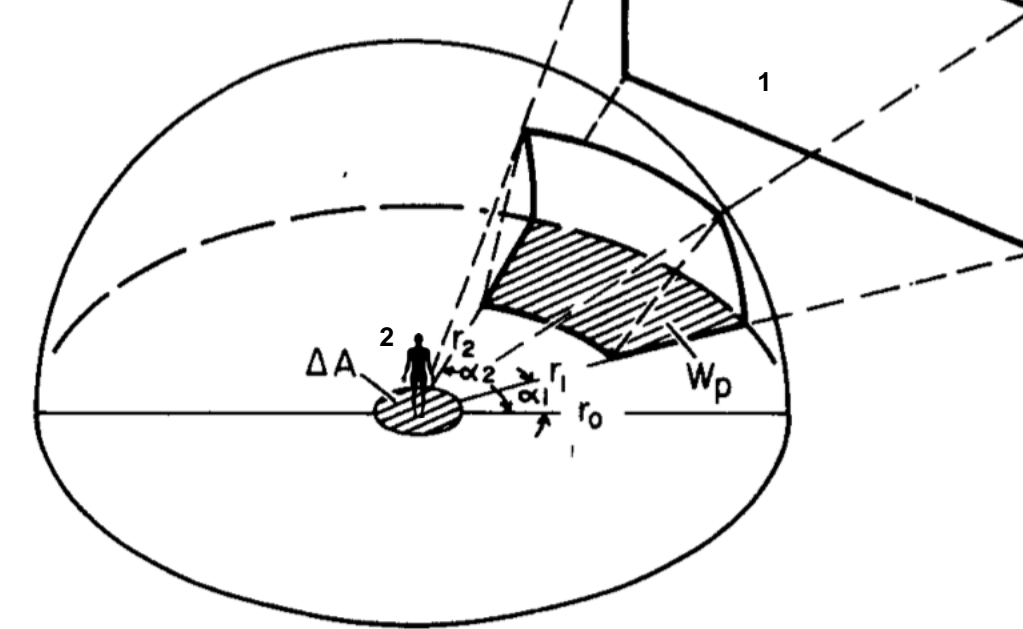
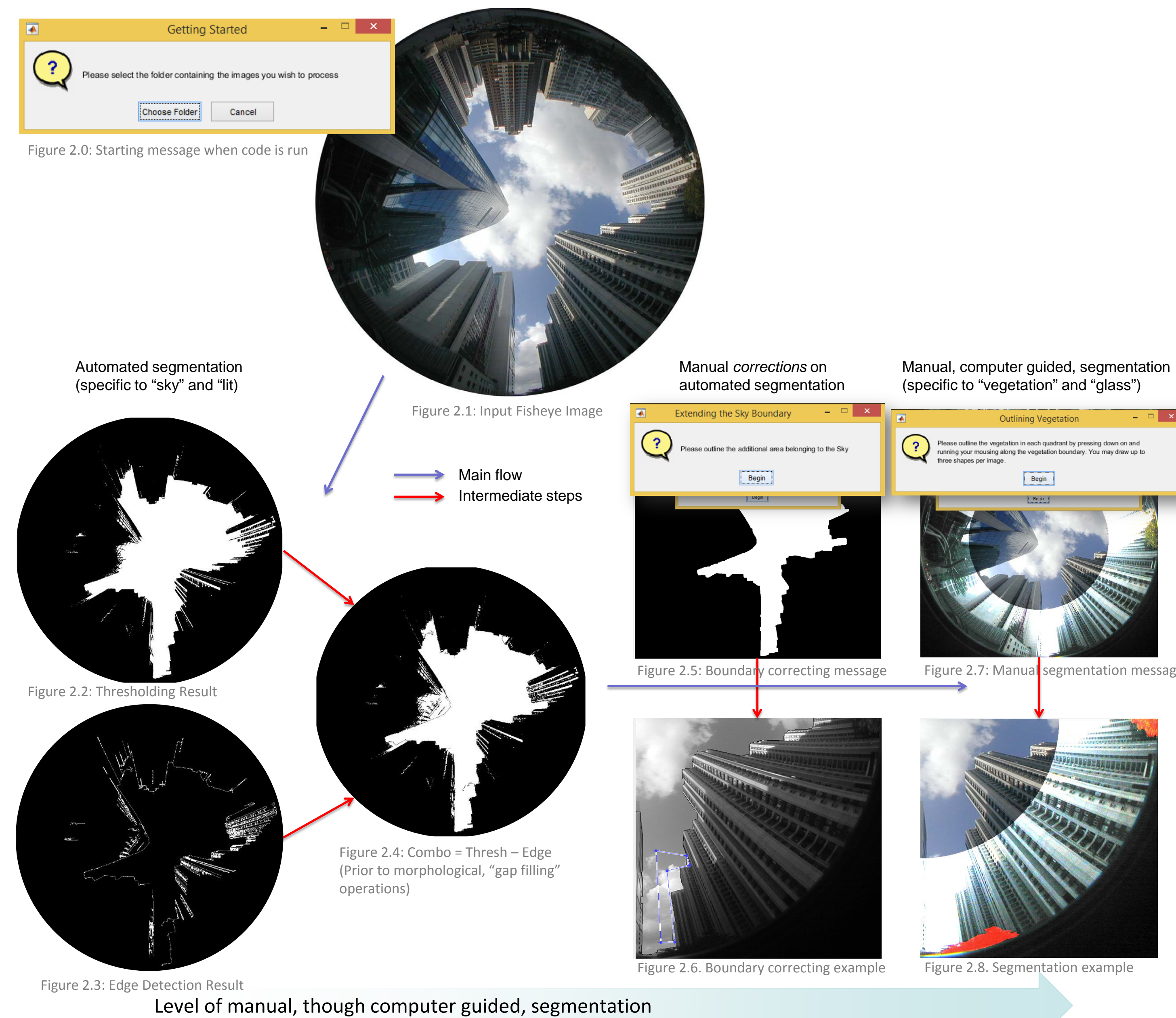


Figure 1.0: a visual representation of F_{12}

References

- Liang Tan, et al. "Outdoor urban mean radiant temperature estimation in the tropical urban environment". 2013.
- Martinez. *Radiative View Factors*. 1995-2015, <http://webserver.dmt.upm.es>.
- Johnson, et al. "The Determination of View-Factors in Urban Canyons". 1983.
- Shin. "Image Processing and Pattern Recognition: Fundamentals and Techniques" 2010.

User Experience



Resulting Segmentations

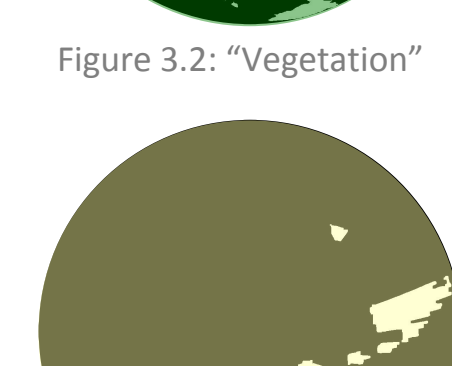
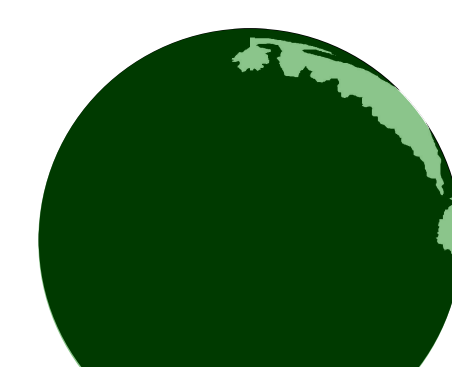
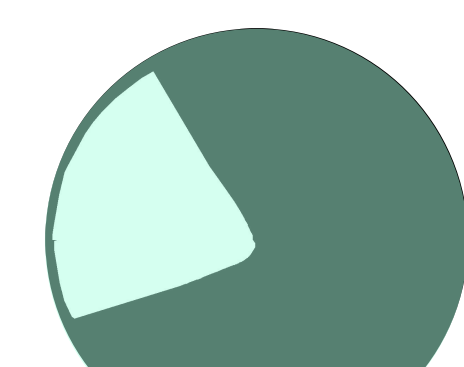


Figure 3.4: Overlay of resulting segmentations

* Resulting images usually in binary format. For presentation purposes, images were overlaid and color was added. This example also only contains "lit" concrete- usually "lit glass" and " lit vegetation" are derived through logic operations using the total "lit" region.

Methods

Image Segmentation

Given that the project focuses on a building facades effects on urban microclimates, the elements of our fisheye images that were segmented were chose based on prevalence in urban environments: concrete, vegetation, glass, and sky.

There are typically four primary techniques used in image segmentation:

- Thresholding:** using clusters in image histograms to distinguish objects within the picture
- Boundary-based:** isolating objects via pixel discontinuity
- Region-based:** isolating objects via pixel similarity
- Hybrid:** a combination of the above.

The initial steps in creating the code were to test each technique individually, under the assumption that some may work better for isolating certain elements in the pictures than others. It was soon realize though that a combination of the techniques is needed for most elements for proper segmentation. This is partially due to the complexity of the images. While thresholding may separate unlit, darker buildings from the sky, as soon as clouds are present next to well lit buildings, isolating one from the other is not feasible. To resolve these type of problems, edge detection (a boundary based solution), and morphological operations (a region-based solution) are used.

View Factor Calculation

The view factor calculations are derived through automating the process described in equation (3) and shown by figure 1.0. This automated process, utilizing the freshly segmented fish eye pieces, does however slightly deviate from the suggested methods α calculation. Given that images are processed in the form of matrices, instead of having a circular path in which alpha travels, diagonals were used.

Moving Forward

The image segmentation and view factor calculation codes are currently in the process of being tested on larger sets of images to see if further improvement is needed. The parameters for testing the accuracy of the image segmentation are still under debate though and at this point the segmentation code is simply subject to a qualitative analysis.

In terms of the calculated view factors from the code, an additional script needs to be written to estimate T_{mrt} , using the view factors calculated from this program, which can then be compared to measured T_{mrt} values.

T_{mrt} values are measured at each fisheye image site via CNR 4s and a flat gray globe thermometer as shown in the figure to the right, using the equation below.

$$t_{mrt} = \left[(t_g + 273.15)^4 + \frac{1.1 \times 10^8 V_a^{0.6}}{\epsilon D^{0.4}} \times (t_g - t_a)^{0.25} - 273.15 \right]^{0.25} \quad (4)$$

T_g = globe temperature (C)
 V_a = air speed (m/s)
 T_a = air temperature (C)
 D = globe diameter (mm)
 ϵ = globe emissivity



Figure 4.0: CNR 4 and globe thermometer setup