TDI2131 Digital Image Processing

Image Segmentation
Lecture 12

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Most figures from Gonzalez/Woods.
Some Announcements

• For those who have not inform me of your Assignment 3 groupings, please do so at the end of this class.

• A note about dropping this course...
Lecture Outline

• Thresholding
  – Overview
  – Basic Global Thresholding
  – Optimum Global Thresholding
  – Multiple Thresholds
  – Variable Thresholding

• Region-based Segmentation
  – Region Growing
  – Region Splitting & Merging
Thresholding

- **Thresholding:**
  - A transformation process on image pixels that results in a two-level or bilevel (binary) image.
  - Have been often mentioned in many other topics discussed earlier – by far, one of the most important tasks in image segmentation.
  - Prepares image for higher-level tasks – representation, analysis, recognition, etc.
  - Now, thresholding will be discussed more formally – study of various techniques.
Thresholding

• Previously, regions were identified by finding edge segments, then attempt to link the segments into boundaries (edge linking)

• **Thresholding** – **Partition images** directly into regions based on intensity values and/or properties of these values
Basics of Intensity Thresholding

• Suppose the intensity histogram of an image, $f(x,y)$ composed of light objects on a dark background. Assuming that the intensity values are grouped into two dominant modes in the distribution.

• Obvious method – extra the objects (light) from the background (dark) by selecting a threshold, $T$, that separates these modes.
Basics of Intensity Thresholding

- Any point \((x,y)\) in the image at which \(f(x,y) > T\) is called an object point, otherwise, it is called a background point.

- The segmented (thresholded) image, \(g(x,y)\) is:
  \[
  g(x, y) = \begin{cases} 
  1 & \text{if } f(x,y) > T \\
  0 & \text{if } f(x,y) \leq T
  \end{cases}
  \]

- \(T\) is a constant applicable over an entire image – **Global Thresholding**
Basics of Intensity Thresholding

- A histogram with three dominant modes (two light objects on a dark background) – **Multiple Thresholding** classifies a point \((x,y)\) as belonging to the background if \(f(x,y) \leq T_1\), to one object class if \(T_1 < f(x,y) \leq T_2\), and to the other object class if \(f(x,y) > T_2\).

- The segmented image is given by:
  
  \[
  g(x, y) = \begin{cases} 
  a & \text{if } f(x,y) > T_2 \\
  b & \text{if } T_1 < f(x,y) \leq T_2 \\
  c & \text{if } f(x,y) \leq T_1 
  \end{cases}
  \]
Basics of Intensity Thresholding

- Segmentation problems requiring more than two thresholds are difficult (often impossible) to solve.
- Better results usually are obtained using other methods, such as variable thresholding or adaptive thresholding, where the value of $T$ changes over an image.
Effect of Noise

With the added Gaussian noise, there is no way to differentiate between the two modes!
Effect of Illumination & Reflectance

Nonuniform illumination causes the deep valley between peaks to be corrupted to the point where separation of the modes is no longer possible.
Key Factor – The Valleys?

- Intuitively, we can say that the success of intensity thresholding is directly related to the width and depth of the valley(s) separating the histogram modes?

- Key factors affecting the properties of the valley(s):
  - Separation between peaks
  - Noise content
  - Relative size of objects and background
  - Uniformity of illumination source
  - Uniformity of reflectance properties
Determining T by Trial-and-Error?

• Can we determine the threshold value, T, by trial-and-error?

• Are there more elegant methods of finding the value of T?

• If we have many images to be processed with thresholding, how are we to determine the threshold values of these images, automatically?
Basic Global Thresholding

- Global thresholding may be sufficient when there is enough variability between images (distribution of object pixels and background pixels are sufficiently distinct).

- Even if global thresholding is a suitable approach, we need an algorithm to automatically estimate the threshold value for each image.
Algorithm: Basic Global Thresholding

• Basic Global Thresholding (iterative algorithm):

1) Select an initial estimate for the global threshold, \( T \)

2) Threshold the image using \( T \). This will produce two groups of pixels: \( G_1 \) consisting of all pixels with intensity values \( > T \), and \( G_2 \) consisting of pixels with values \( \leq T \).

3) Compute the average (mean) intensity values \( m_1 \) and \( m_2 \) for the pixels in \( G_1 \) and \( G_2 \), respectively.

4) Compute a new threshold value: \( T = \frac{1}{2}(m_1 + m_2) \)

5) Repeat Steps 2 through 4 until the difference between values of \( T \) in successive iterations is smaller than a predefined parameter \( \Delta T \).
Basic Global Thresholding

• This simple algorithm works well in situations where there is a reasonably clear valley between modes of the histogram

• Parameter $\Delta T$ is used to control the number of iterations when speed is an important issue
  - Larger $\Delta T$, fewer iterations, faster
  - Smaller $\Delta T$, more iterations, slower

• The average intensity of the image is a good initial choice for $T$. 
Basic Global Thresholding

**FIGURE 10.28**
(a) Original image. (b) Image histogram. (c) Result of global thresholding with $T$ midway between the maximum and minimum gray levels.
Basic Global Thresholding

**FIGURE 10.38** (a) Noisy fingerprint. (b) Histogram. (c) Segmented result using a global threshold (the border was added for clarity). (Original courtesy of the National Institute of Standards and Technology.)
Any Better Methods?

• Basic Global Thresholding requires successive calculation of means (for both groups of pixels) at each step.

• It is possible to develop a more efficient and accurate procedure by expressing all computations in terms of the image histogram, which has to be computed only once.
Optimum Global Thresholding

- View thresholding as a statistical-decision theory problem
- Objective: Minimize the average error incurred in assigning pixels to two or more groups (or classes)
- Solution – based on only two parameters
  - The probability density function (PDF) of intensity levels of each class
  - Probability of each class in the application
- Estimating PDFs is a common problem
- Alternative: Otsu's Method
Otsu's Method

• Maximizes the between-class variance

• Basic idea: Well-thresholded classes should be distinct with respect to the intensity values of pixels

• A threshold giving the best separation between classes in terms of intensity values will be the best (optimum) threshold

• Histogram of image – does create a PDF of intensity values

• A separability measure is used to measure the ratio of between-class variance to global variance

• Detail explanation of Otsu's Method in textbook, pp.764-769
Otsu's Method (in short)

1) Compute normalized histogram of the image
2) Compute cumulative sums for all k (intensity values)
3) Compute the cumulative means for all k
4) Compute the global intensity mean
5) Compute the global variance, and between-class variance for all k
6) Obtain the Otsu threshold, $k^*$, as the value of k for which between-class variance is maximum.
7) Obtain the separability measure, $\eta^*$
Otsu's Method

**FIGURE 10.39**
(a) Original image.
(b) Histogram (high peaks were clipped to highlight details in the lower values).
(c) Segmentation result using the basic global algorithm from Section 10.3.2.
(d) Result obtained using Otsu's method. (Original image courtesy of Professor Daniel A. Hammer, the University of Pennsylvania.)
Improvements to Global Thresholding

- **Image Smoothing** – reduces noise prior to thresholding
- **Use Edges as Mask Image** – improve relative size of objects and background regions, give more balanced reflection of image content in the histogram
Remedy: Reduce Noise By Smoothing

**FIGURE 10.40** (a) Noisy image from Fig. 10.36 and (b) its histogram. (c) Result obtained using Otsu’s method. (d) Noisy image smoothed using a $5 \times 5$ averaging mask and (e) its histogram. (f) Result of thresholding using Otsu’s method.
Remedy: Reducing Relative Size of Object & Background

FIGURE 10.42  (a) Noisy image from Fig. 10.41(a) and (b) its histogram. (c) Gradient magnitude image thresholded at the 99.7 percentile. (d) Image formed as the product of (a) and (c). (e) Histogram of the nonzero pixels in the image in (d). (f) Result of segmenting image (a) with the Otsu threshold based on the histogram in (e). The threshold was 134, which is approximately midway between the peaks in this histogram.
Multiple Thresholds

- Objective: Segment image into three regions – the dark background, illuminated area of iceberg, area in shadows
- Solve with finding two thresholds using Otsu's Method (pp.774-778)
Variable Thresholding

- In certain cases, preprocessing methods can be either impractical or simply still ineffective in improving the accuracy of thresholding.

- **Variable thresholding** (or **adaptive thresholding**) techniques can be used.

- Threshold values can be made to change or vary according to local image regions.

- One of the simplest approach – **Image Partitioning**
Image Partitioning

- Subdivide an image into nonoverlapping rectangles (areas)
  - Compensates for non-uniformities in illumination and reflectance
- Rectangles are to be chosen small enough so that illumination is approximately uniform
Example: Image Partitioning

**FIGURE 10.46** (a) Noisy, shaded image and (b) its histogram. (c) Segmentation of (a) using the iterative global algorithm from Section 10.3.2. (d) Result obtained using Otsu’s method. (e) Image subdivided into six subimages. (f) Result of applying Otsu’s method to each subimage individually.
Region-based Segmentation

- Edge segmentation (+ edge linking) – find regions using edges
- Threshold segmentation – find regions using distribution of pixel intensity values
- Segmentation methods that find regions directly
Region Growing

- Procedure that groups pixels or subregions into larger regions based on predefined criteria for growth
- Basic approach: Start with a set of “seed” points and from these, grow regions by appending to each seed those neighbouring pixels that have predefined properties similar to the seed (intensity, color, etc.)
- **Similarity criteria** depends on type of image data available
Example: Region Growing
Region Splitting and Merging

• Procedure that subdivides an image initially into a set of arbitrary disjoint regions and then merge and/or split the regions in an attempt to satisfy the conditions of segmentation

• With R representing the entire image region, a predicate Q must be selected to make decisions on whether splitting or merging is to be carried out
Region Splitting and Merging

• Approach summarized:

  1) Split into four disjoint quadrants any region $R_i$ for which $Q(R_i) = \text{FALSE}$

  2) When no further splitting is possible, merge an adjacent regions $R_j$ and $R_k$ for which $Q(R_j \cup R_k) = \text{TRUE}$

  3) Stop when no further merging is possible

• Quadtree representation

• A minimum quadregion size beyond which no further splitting is carried out, is normally specified
Region Splitting & Merging

Image

Quad Tree
Example: Region Splitting & Merging

Segment ROI using predicate:

\[ Q = \begin{cases} 
  \text{TRUE} & \text{if } \sigma > a \text{ AND } 0 < m < b \\
  \text{FALSE} & \text{otherwise}
\end{cases} \]

where \( m \) and \( \sigma \) are the mean and std. dev. of the pixels.
Other Segmentation Methods

- Morphological Watersheds (textbook, pp.791-800)
  - Dam Construction
  - Watershed Segmentation Algorithm
- Motion Segmentation (textbook, pp. 800-807)
Recommended Readings

• Digital Image Processing (3rd Edition), Gonzalez & Woods,
  • Chapter 10: Image Segmentation (cont'd)
    • 10.1-10.4 (Week 12)
  • Chapter 8: Image Compression
    • 8.1-8.6 (Week 13)