Assessment of 3D Template–Matching Algorithm

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I. Introduction

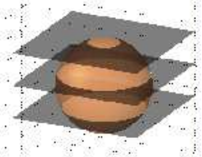
Today, most cancer patients do not succumb to the primary tumor detected, but rather to metastases in organs such as the lung and liver. Therefore, it would be beneficial to prescreen patients who are at high risk for metastatic tumors using full body CT scans. This would facilitate early detection and ablation of tumors while they are still small and enhance the probability for survival. Lung CT scans with 3mm slices alone result in over 100 slices per patient[1]. Analyzing many of these patient data sets consumes the radiologists? time and increases human error.[2] To remedy these problems, our lab has created a 3D template-matching algorithm with high sensitivity and low false positives, to automatically detect lung nodules. Ideally there would be a set of patient CT scans both before and after the development of lung metastases to provide a gold standard against which the algorithm could be tested. However, such a database is currently lacking. Therefore, our goal is to create a realistic tumor database for testing purposes by inserting artificial tumors into real CT image data sets. With this database, we can assess the limitations of our algorithm and find ways to improve upon it in the future.

II. Methods

Creation of Simulated Tumors

Simulated tumors were created with varying sizes, eccentricities, angles of rotation, and central shifts, and inserted into images with varying noise levels to mimic the variations observed in tumors treated at our clinic.

- Ellipsoidal tumor eccentricity (major axis: minor axis) ranged from 1.00 to 2.00 in increments of 0.25
- Minor axis dimension ranged from 2.25 mm to 6.75 mm in increments of 0.50 mm
- Angle of the major axis of the ellipsoid was rotated between 0 and 90 degrees in increments of 45 degrees about the y– and z-axes
- A 3D Gaussian filter, with kernel size of [5 5 5] mm³ and standard deviation of 2.0 mm was applied to each artificial tumor to smooth out the tumor edges



Insertion of Simulated Tumors

- A random index generator was used to select positions for simulated tumors within the lung volume
- To prevent an excessively bright tumor, the maximum intensity between the tumor template and lung image was used rather than summing the two
- Four separate lung images were produced using added noise with standard deviations of 0, 10, 26, and 52 HU [respectively representing the 0, average, maximum, and 2*max noise levels we measured on various CT scans]

Detection Algorithm

The following depicts processes in the detection algorithm: A. original lung image; B. mask used to extract lung volume; C. lung region cropped by the mask; D. corresponding correlation coefficient slice with red spots indicating values above the threshold.

A B C D

- For a specified radius, the algorithm matches three spherical templates to objects within the lung image. The templates correspond to tumor shifts from the center by 0, 1/3, and -1/3 of the slice thickness
- A 3D normalized cross-correlation coefficient, which measures the degree of similarity between the template and the given object, is defined by the following formula:

- A threshold of 0.73 was applied to three templates with radii of 3 mm, 4 mm, and 5 mm and a threshold of 0.76 was applied to the first two templates of radius 2 mm. The third template for radius of 2 mm was not employed.

Methods of Analysis

- Sensitivity and the Positive Predictive Value are used to assess the algorithm and are defined as follows:

$$Sensitivity = \quad Positive"Predictive Value = \frac{TruePositives}{TruePositives + FalsePositives}$$

- The same lung images and four sets of spherical templates were used for all testing, so the same number of false positives should appear for a given noise level. Therefore, the false positives were only calculated once for each noise level.

III. Results

- The overall performance of the 3D template-matching algorithm yields high sensitivity and a relatively low number of false positives without post-processing, as seen in Figure 1.
- Spherical templates with radii of 2 mm and 3 mm contribute the majority of false positives for all noise levels as seen in Figure 2.

Figure 1

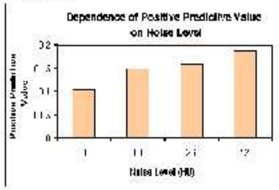
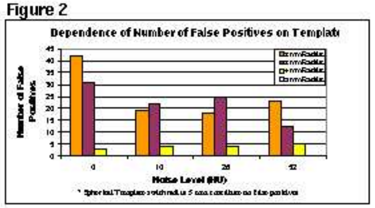


Figure 2



- High sensitivity remains even with varying noise levels and tumor shifts, as well as with changing eccentricity, as shown in Table 1.

Table 1

Eccentricity	Range of Minor Axis	Range of Major Axis	Sensitivity
1.00	2.25 mm ? 6.75 mm	2.25 mm ? 6.75 mm	100.0 %
1.25	2.25 mm ? 5.25 mm	2.81 mm ? 6.56 mm	92.9 %
1.50	2.25 mm ? 4.25 mm	3.38 mm ? 6.38 mm	93.3 %
1.75	2.25 mm ? 3.75 mm	3.94 mm ? 6.56 mm	85.7 %
2.00	2.25 mm ? 3.25 mm	4.50 mm ? 6.50 mm	100.0 %

IV. Conclusions

The creation of a database with simulated tumors has successfully assisted testing of the 3D template-matching algorithm to further its refinement. Specific findings were:

- Variations in noise levels under normal conditions do not affect the algorithm?s ability to detect tumors ranging from 5 mm to 15 mm in diameter.
- It is unnecessary to switch to ellipsoidal templates from the current spherical templates.

Following are suggestions for future algorithm analysis:

- False positives detected by smaller templates consisted largely of tubular structures such as blood vessels. It is suggested that in-plane padding be increased for smaller templates to distinguish spherical and ellipsoidal objects from tubular objects.
- A greater number of angle combinations as well as a broader range of axis dimensions for ellipsoids is recommended for future algorithm testing with this type of database.

V. Acknowledgements

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