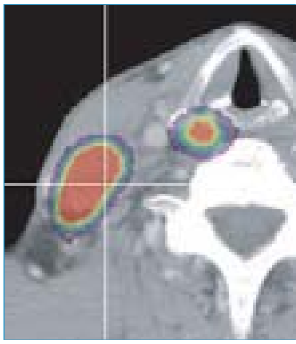

# Syntegra

## Automated image registration algorithms

Peter Rösch, Ph.D., Thomas Netsch, Ph.D.,
Todd McNutt, Ph.D, James Shoenbill, M.Sc., and
Patricia Root, Product Manager

Rapid technical advances in three-dimensional imaging (e.g., SPECT, MCD, PET, CT, and MRI) have increased the need for relating functional to morphological and anatomical information. Overlaying images in the same spatial orientations facilitates the interpretation of two or more image sets. The aim of image registration is to find a common coordinate system between two image sets in order to correlate a patient's anatomical and functional information.

Syntegra is a multi-modality image registration application for the Philips PET systems and the Philips Pinnacle$^{3®}$ radiotherapy treatment planning system. Syntegra provides manual and point-based image registration, and three automated methods of gray value-based image registration.

Generally, gray value-based methods determine the registration transformation by iteratively optimizing a similarity measure that is calculated from the gray values of both images. The following gray value-based methods offer many advantages when compared to point-based and surface-based methods. Their principal advantages are sub-voxel registration accuracy and the ability to operate automatically without user interaction.

The three auto-registration methods are defined by the similarity measure that each method uses: cross correlation, local correlation, and mutual information.

### Cross Correlation

The Cross Correlation (CC) method seeks to minimize the mean-square gray-value difference between two image sets [1]. In some cases, the images to be registered may not match in gray value but may have a linear relationship between corresponding gray values in the images. Therefore, the CC similarity measure is defined as

$$C^2(M) = \frac{\left(\sum_{i \in M} \left(I_1(i) - \bar{I}_1\right)\left(I_2(i) - \bar{I}_2\right)\right)^2}{\sum_{i \in M} \left(I_1(i) - \bar{I}_1\right)^2 \sum_{i \in M} \left(I_2(i) - \bar{I}_2\right)^2}$$

where $M$ is the region of overlap between the two image sets, $I_1$ and $I_2$ are the two image sets, $i$ is the index into the image sets, and $\bar{I}_1$ and $\bar{I}_2$ are the mean gray value in each image set.

Maximum squared cross correlation corresponds to the optimum alignment only in the presence of a global linear relationship between image gray values of reference and secondary images. For this reason, CC may be utilized when registering two single-modality image sets such as CT/CT or MR/MR using similar protocols.

CC's linear relationship between gray values across the full extent of the regions used in registration is sufficient when both images are from the same image modality and the linear relationship exists across the full range of gray values. When two images are from separate imaging modalities but represent the same information (e.g., MRI and CT both represent anatomy), it is possible to investigate the CC in local sub-regions of the images using local correlation.

### Local Correlation

Local Correlation (LC) assumes a local linear relationship between gray values. For example, although the contrast of bone and soft tissue boundaries in MR and CT images is inverted, a local linear relationship (negative slope) exists, at least close to the edges. The assumption is that in small local sub-regions of the image sets, a linear relationship between gray values in the two image sets exists. However, this is dependent on the size and position of the sub-region. If the sub-region is too large, it may intersect with more than two distinct parts of the human anatomy. In this case, the linear relationship approximation may break down.

The LC algorithm applies cross correlation to many small neighborhoods within the image sets instead of to the two image sets overall [2, 3]. The LC similarity measure is thus the sum of the cross correlations of all of the local sub-regions used in the registration, defined as

$$LC^2(M) = \frac{1}{N} \sum_{S_j \in M} C^2(S_j)$$

where $C$ is the cross correlation coefficient for the $j$th sub-region $S_j$, and $N$ is the number of sub-regions contained in $M$.

Local sub-regions are chosen by an evaluation of the voxels within an image set. Sub-regions are determined and chosen as appropriate for the registration process based on the magnitude of variance of image gray values within each sub-region. For this reason, the LC method applies increased importance to high gradient edges present in the image sets.

The LC similarity measure is attractive because it can be formulated as a least-squares problem, which allows for use of faster optimization algorithms. These faster algorithms offer substantial speed improvements (10-20 times faster) over those used in mutual information.

### Mutual Information

Mutual Information (MI) [4, 5] may be utilized for a variety of multi-modality automated registration tasks. Probability distributions of the gray values in each image set are calculated and used by the MI similarity equation. The MI algorithm does not rely on an explicit relationship between the gray values in the image sets. Therefore, MI is more suitable in cases of large misalignment or when one of the images to be registered has limited anatomical detail.

MI and normalized MI are based on the gray value histogram, defined as

$$MI = -\sum_{j,k} \left( \frac{P_{j,k}^{2D}}{V} \log \frac{P_{j,k}^{2D}}{P_j^r P_k^f} \right)$$

where $V$ denotes the volume of overlap between the images, and $P_j^r$ and $P_k^f$ are the probabilities of gray value $j$ and $k$ in the reference and secondary image respectively. $P_{j,k}^{2D}$ is the probability that gray values $j$ and $k$ occur in the reference image and at the corresponding position of the secondary image. The probabilities are derived from the bin counts of a joint gray value histogram of the image sets that does not contain spatial information.

### Automated registration in Syntegra

The three similarity measures (CC, LC, and MI) provide the capability to automatically register a broad range of imaging modalities in order to align functional and anatomical information for specific patients. Syntegra provides these methods with appropriate settings for common cross-modality registration procedures (e.g., CT-PET, CT-MRI, etc.) in addition to manual and point-based registration methods.

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**Philips Medical Systems**
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Regional Office USA
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