Advances in Multi-Modal Data Analysis:
The ANALYZE Software Environment

Neil Robinson

CNSoftware, The Old Post Office Worthing Road, Southwater, UK, RH13 7DT

neil@cnsoft.com

Abstract

As more data modalities have developed to the point where 3d data sets are now available interest has increased in the possibility of combining information from two or more imaging modalities. This development offers unique benefit especially where the contributing modalities are able to uniquely visualise a particular tissue or property. An example of this would be bone from X-ray CT and soft tissue from MRI . A number of registration algorithms are now available which allow for geometric registration of data sets based on 3D rigid body transformations. These include: Fiducial marker alignment; surface registration and voxel to voxel registration. In choosing the registration method account must be taken of the data type and the time required for the registration. Increasing interest is being shown in the registration of data to standard anatomical frameworks for tissue classification.

Key words: Registration, Multi-modal, Software

Introduction

The analysis of data from multiple modalities can be enhanced and extended when the multiple data set sets are placed into alignment - registered. When this is achieved voxel to voxel analysis can be undertaken and values in widely different modalities can be compared and correlated.

A key element in the application of multi-modal registration is the time required for registration to be completed before comparison can be undertaken. In the current paper we describe a software environment which allows for rapid registration of data from any data modality to allow routine use of multi-modal data comparison. The emphasis throughout will be on cost-benefit analysis of the processing time against the results obtained. Two methods of image registration will be compared in detail and mention will be made of work in progress on a third method.

Methods and Uses

In order to make effective choices about the method most applicable for registration consideration must be made of the type of data available. In general three types of data can be recognised:

1. Complete volumetric data.
2. Partial volumetric data
3. Sparse or point data.

Examples of each type include:

1. MRI (T1, T2 etc.); CT X-ray; SPECT blood flow.
2. SPECT or PET receptor ligand studies.
3. EEG or MEG data.

Each data type may be better suited to one of other of the registration methods.

Surface Matching

Where full volumetric data is available surface matching provides the fastest method of matching without a priori inclusion of fiducial registration indicators in the study. The only requirement is that a significant 3d object with unique curvature in all three planes can be visualised in all data sets to be matched. Surface matching uses the cloud of voxels which comprise the surface voxels of the object to be matched (1). Implicit in this is the requirement that only surface voxels are declared to the matching algorithm. The simplest method of achieving this is to use a series of morphological procedures to isolate the object and remove any internal structural "holes". Whilst this is the simplest representation of a "surface only "cloud an alternate does exist which allows for the exclusion of "error " surface points within the data. In this case the "solid:" object is eroded such that a single voxel is removed from the outside of the object and this new mask may then be subtracted from the original mask to create a model including only surface voxels. Error voxels , such as might occur with a blood flow deficit in SPECT, may now be excluded from the matching process. Registration is achieved by a series of solid body manipulations - translation and rotation to minimise the mean square distance between the base surface voxels and the match surface voxels. Scaling is best controlled from the voxel geometry so that small differences in the exact real world location of the boundaries used in the match are not removed during the matching process. An example of this would be the "skin"

surface from MRI and CT X-ray are not an exact match in the real world but the error in location is relatively constant throughout the volume.

Point List registration

It is quite common that one data set to be used in the matching process is a full volume data set whilst the matching data set may only have partial or incomplete surface available for segmentation. In this circumstance "Point List" registration can be extremely useful.

Point List registration allows the user to define the complete surface in the base data set but then create a point list of representative locations as the matching data set. This has the advantage that segmentation of the matching data set is not required. Only a list of surface points need be declared.

Fiducial marker registration.

In some data comparisons there are not contiguous similar structures. In such cases the location of representative points in the two data sets can be located and used as a linked list fro 3d registration (2). A simple example of this would be the surface sampled EEG record. This is a discrete set of point recordings which are located on the skull surface but have no equivalent representation in either a MRI or CT scan. However the location of the recording sites is controlled via a defined anatomical landmark system - the 10-20 system. This is based on the surface topology of the scalp. The main reference points of the inion, nasion, vertex and auricular processes can be found on the scalp and in a skin rendering of the MRI or CT. Once the co-ordinate system has been harmonised the linked list of points can be used to register the EEG with the MRI and surface; dipole or computed fields used as co-registered data. A similar situation may occur with ligand binding studies but in this case fiducial reference capsules must be applied and maintained between the scans to be registered..

Voxel to voxel registration

In this procedure the local voxel to voxel differences are characterised and a map of the local similarity generated. Irrespective of the modality used to capture the structure. The "self organisation" of the regions within the data and their local similarity is much greater than any more distant similarities to other structures. This is in some ways self evident a "brain" structure may be segmented and isolated from MRI, CT, PET, and SPECT even though the actual data values may be very different. It is this local self similarity which is used as the template for voxel to voxel matching. Inevitably the computational overhead in voxel to voxel matching is much greater than with surface matching. However it can prove very valuable especially when surfaces may be difficult to define within the data.

Methods of analysis and comparison of multi-modal data.

Once data sets are in co-registration two main classes of analysis are performed:

1. Use of anatomical segmentation within a functional data set.
2. Use of modality co-variance to produce a segmentation profile.

In the first case one data set is considered to contain the anatomical region profile and another certain functional information. The normal example is the registration of MRI T1 data with PET or SPECT metabolic data. The anatomical detail within the MRI can be used to create an Object Map which can then be applied to the PET or SPECT data set. An extension of this approach is the creation of standard or reference segmentation maps. These may be registered to individual data sets by the application of a number of solid body transformations. An example of this is the use of Tallairach space, in this case the individual data is transformed to fit Tallairach space however the reverse may be applied with a Tallairach or any other model.. One advantage of moving the model into the individual data space is rogue classifications can easily be identified and corrected. In this form of classification representative class values can be readily computed for group statistics an "*ONLY*" class . If the class contained the complete voxel record for a region is required the "*ALL*" class is required other methods must be used which are usually more time consuming and computationally more demanding.

In the second case where multiple representations of each point in 3D space are available, through multi-modal imaging, the relationship between in two different modalities may be plotted as a scatter graph. This graphical presentation offers the possibility of interrogating the graph by drawing ROIs on the graph the graph and then seeing the location of the selected data points displayed on the images. For example cluster regions may be defined on the graph and the locations seen on the images. Equally if a unique grey scale linkage exists between data in two modalities, for a particular pathology, the graphical data cluster associated with the pathology may first be identified, by defining a region on an image, and then the cluster fully marked on the scatter graph and the whole volume interrogated to find other regions of the same data characteristics and possibly pathology. The ability to move easily between images realised from different modalities and graphical presentation of the cross modal correlation is a totally new approach to data analysis in medical imaging and still awaits clear clinical protocols to be established. At present it is being tested as a powerful research tool. One of the great advantages of multi-modal imaging based around object registration is that data classification can be used to directly create new objects for volume rendering and analysis. This direct linkage allows for very complex analysis of large datasets to be performed very rapidly and limits the inevitable increase in diagnostic time requirements as data sets increase in size and additional modalities are added.

Conclusions

Registration of multi-modal data is now a practical proposition in a realistic computational time. A number of algorithms are available which lend themselves with differing applicability to data of various types. Care must be taken when choosing the registration method to check that it is suitable for the data in question. When this is properly done 3d registration may be achieved in times of 3 to 5 minutes offering significant potential for future analysis and research.

References

1 Jiang H., Robb R.A., Holton K. 1992 A new approach to 3D registration of Multi-modal Medical Images by Surface Matching. SPIE vol 1808. p196.

2 Hawkes D.J., Hill D.L.G., Bracey E.E.C.M.L., Multi-modal data fusion to combine anatomical and physiological information in the head and heart. Kluwer Holland 1991