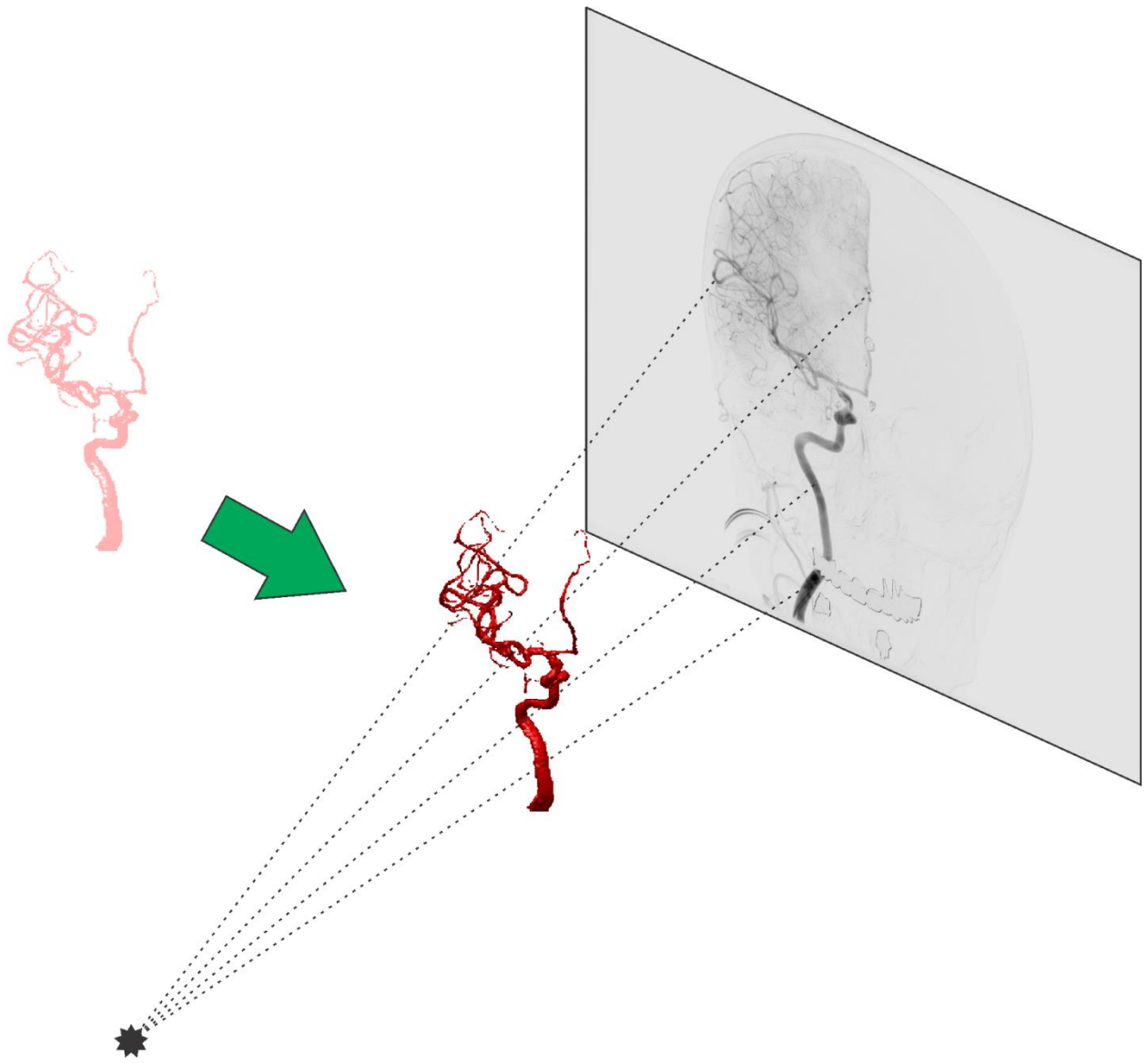


"Gold Standard" Data for 3D-2D Registration of Cerebral Angiograms

User's Guide



Authors:

Uroš Mitrović, Žiga Špiclin, Boštjan Likar, Franjo Pernuš
Laboratory of Imaging Technologies
University of Ljubljana, Faculty of Electrical Engineering
Tržaška 25, 1000 Ljubljana, Slovenia
Tel: +386 1 4768 248, Fax: +386 1 4768 279
E-mail: {uros.mitrovic, ziga.spiclin, bostjan.likar, franjo.pernus}@fe.uni-lj.si

The all rights to "gold standard" data posses the Laboratory of Imaging Technologies. The non-authorized distribution of this data is strictly forbidden. This gold standard data can only be obtained and used after signing the agreement form between the user and Laboratory of Imaging Technologies.

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1. INTRODUCTION

Entering of a 3D-2D registration method into clinical theater requires evaluation on clinical images related to the corresponding clinical context and associated highly accurate "gold standard" registration. To further motivate development of new and evaluation of state-of-the-art methods in context of cerebral endovascular interventions, we made this image database publicly available [1]. The database consists of 3D-DSA, 2D-DSA and 2D-MAX images of ten patients with two cerebrovascular pathologies. Highly accurate "gold standard" registrations were obtained by aligning fiducial markers with estimated mean target registration errors between 0.033 and 0.077 mm. Matlab codes for loading 3D and 2D images, and codes for producing tables and plots according to [1] are also available.

1.1 3D-2D registration problem

Rigid 3D-2D registration considers finding six rigid-body parameters \mathbf{q} of a 3D image in order to achieve best possible spatial alignment between corresponding anatomical structures present in 3D and 2D image(s). Prior to 3D-2D registration, the imaging system needs to be calibrated, meaning that transformation matrix \mathbf{T}_s which relates the coordinate system of 2D image \mathbf{S}_s to world coordinate system \mathbf{S}_w and position of X-ray source \mathbf{r}_s in \mathbf{S}_w are known (Fig. 1).

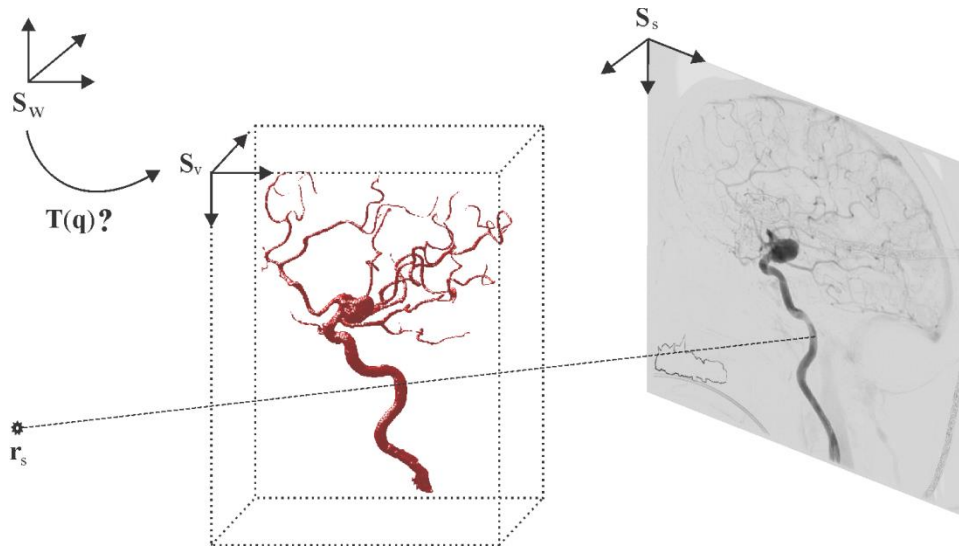
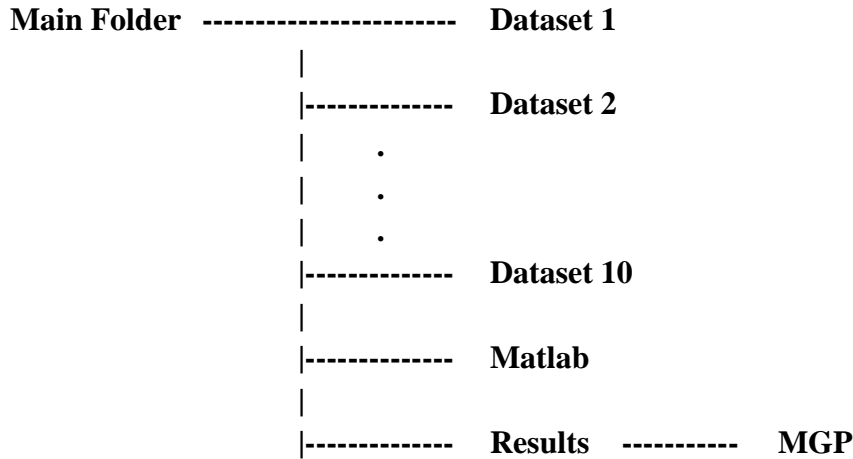


Fig. 1. Geometrical setup of 3D-2D registration, with world coordinate system \mathbf{S}_w , coordinate system of 3D image \mathbf{S}_v , coordinate system of 2D image \mathbf{S}_s and X-ray source \mathbf{r}_s .

2. ORGANIZATION

The "gold standard" database is organized as follows:



Folders **Dataset 1,2,...,10** contain the 3D and 2D images, initial displacements and target points. Folder **Matlab** contains matlab codes for loading images and calculation of registration results presented in [1]. The subfolder **MGP** of the **Results** folder holds transformation matrices obtained by the MGP method [1].

3. DATA

3.1 3D images

The 3D-DSA image data are confined in two files, the header file **Dataset?_3D-DSA.mhd** and the raw data file **Dataset?_3D-DSA.raw**, where the symbol ? indicates the dataset number (1...,10). The header is written in ASCII format as a standard meta header file with following characteristic items:

```

DimSize = Nx Ny Nz
ElementSpacing = Δx Δy Δz
Position = tx ty tz
Orientation = nx sx ax
            ny sy ay
            nz sz az
ElementType = MET_SHORT
    
```

where N_x , N_y and N_z are sizes of the volume image in voxels along x , y and z axes, respectively. The Δ_x , Δ_y and Δ_z are voxel sizes in millimeters. The raw file is written in signed 16 bit format, i.e. short. The position and orientation are the translation and rotation part of "gold standard"

transformation \mathbf{T}_g which relates the coordinate system \mathbf{S}_v of 3D image to world coordinate system \mathbf{S}_w :

$$\mathbf{T}_g = \begin{bmatrix} n_x & s_x & a_x & t_x \\ n_y & s_y & a_y & t_y \\ n_z & s_z & a_z & t_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

The raw file is comprised of $N_x*N_y*N_z$ **signed 16 bit** values representing volume intensities. The offset i for a given voxel's intensity value in the raw data is calculated as:

$$i = i_x + N_x i_y + N_x N_y i_z$$

where i_x , i_y and i_z are indices along x , y and z axis of the volume grid, respectively (Fig. 2). To import 3D images into Matlab, use the subroutine "CT_read_mhd.m" in **Matlab** folder.

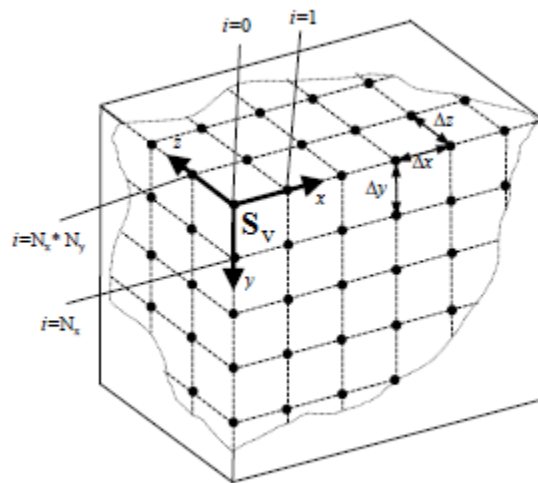


Fig. 2. The coordinate system \mathbf{S}_v of a 3D-DSA image.

3.2 2D images

In each dataset folder, four different 2D images are present. Two of them are DSA images acquired at pure lateral (LAT) and approximately anterior-posterior (AP) views. The other two are MAX images, taken at the same views, which depict also other anatomical structures besides blood vessels and interventional tools. The 2D image data is contained in the header file **Dataset?_2D_Modality_View.rad** and the raw data file **Dataset?_2D_Modality_View.raw**. The symbol ? indicates the dataset number, **Modality** can be either DSA or MAX and **View** can be either LAT or AP. The header is written in ASCII format as in-house *.rad file with following characteristic items:

```

Size[pixels]: Nx Ny
Step[mm]: Δx Δy
DataType: float
TPosition:
nx sx ax tx
ny sy ay ty
nz sz az tz
0 0 0 1
SourcePosition[mm]: xs ys zs
    
```

where N_x and N_y are sizes of 2D images in pixels, Δx and Δy are the sizes of each pixel in millimeters, the feature `DataType: float` describes that the raw file is written in float format, the numbers after the `TPosition:` describe the rigid transformation matrix \mathbf{T}_s which relates the 2D image coordinate system \mathbf{S}_s to world coordinate system \mathbf{S}_w and x_s, y_s, z_s are coordinates of the X-ray source \mathbf{r}_s in the world coordinate system \mathbf{S}_w .

$$\mathbf{T}_s = \begin{bmatrix} n_x & s_x & a_x & t_x \\ n_y & s_y & a_y & t_y \\ n_z & s_z & a_z & t_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

The raw file is comprised of $N_x \cdot N_y$ **float** values representing the 2D image intensities between 0 and 1. The offset i for a given pixel's intensity value in the raw data is defined as:

$$i = i_x + N_x i_y$$

where i_x and i_y are indices along x and y axes of the 2D image grid, respectively (Fig. 3). To import 2D images into Matlab, the subroutine "Xray_read_DT.m" in **Matlab** folder is used.

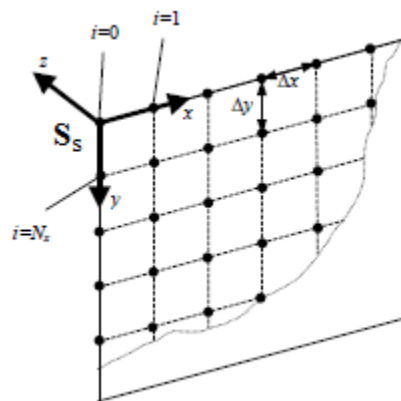


Fig. 3. The coordinate system \mathbf{S}_s of 2D image.

3.3 Target points

Target points are stored in files **Dataset?_3D_DSA_Target_Points.txt** written in ASCII format and containing $N_{TP} \times 3$ matrix defining x , y and z coordinates of each of the N_{TP} target points in the 3D volume coordinate system S_v . Symbol ? describes the corresponding dataset number. As explained in [1], target points are 3D vessel centerline points which are used to calculate the mean target registration error (mTRE) [2].

3.4 Initial displacements

For each datasets the 3D image was 400 times randomly displaced from the "gold standard" position, with displacements in range of [-20, 20] mm and [-10, 10] degrees [2]. This resulted in 0-20 mm range of mTRE with 20 initial displacements per 1 mm subinterval. The initial displacements are stored in files **Dataset?_3D_DSA_Displacements.txt** written in ASCII format as a 1600 x 4 matrix and define 400 4x4 transformation matrices. Symbol ? indicates the corresponding dataset number.

3.5 Database Info

The excel file "database_info.xls" located in the main folder, contains information about patient pathology, accuracy of the "gold standard" registrations, VOIs and ROIs for each dataset of the image database (Fig. 4).

	A	B	C	D	E	F	G	H
1	Pathology	Aneurysm						
2	mTRE of "Gold Standard" [mm]	0,043321						
3	VOI $i_{x_{min}}$, $i_{x_{max}}$, $i_{y_{min}}$, $i_{y_{max}}$, $i_{z_{min}}$, $i_{z_{max}}$	236	405	141	342	2	328	
4	ROI LAT $i_{x_{min}}$, $i_{x_{max}}$, $i_{y_{min}}$, $i_{y_{max}}$	335	2050	215	1895			
5	ROI AP $i_{x_{min}}$, $i_{x_{max}}$, $i_{y_{min}}$, $i_{y_{max}}$	785	2000	230	1900			
6								

Fig. 4 The database_info.xls and its items.

Note: Values for VOIs and ROIs in the "database_info.xls" are determined by minimal and maximal indices along each axis of the image grid assuming that indices start from "0". For Matlab users "+1" should be added to each of these values.

4. RESULTS

In order to analyze results as presented in [1], two matlab codes are available in the **Matlab** folder. By "registration_results_mRPD.m" the accuracy, success rate and capture range using either LAT or AP 2D image can be computed (Table III in [1]). Besides, the accuracy of a 3D-2D registration method across twenty accumulative subintervals can be also portrayed (Fig. 6 in [1]). Analogously, code "registration_results_mTRE.m" serves for producing the results when both LAT and AP views are used for registration (Table IV in [1]). Both codes, require transformation matrices of the evaluated method in the subfolder with a method's name in the folder Results. Transformation matrices obtained by applying evaluated method to 400 initial displacements should be stored as a 1600 x 4 matrix written in ASCII format with filename **Method_Dataset?_View_Modality.txt**. **Method** describes the method's name, **?** dataset number, **View** is either LAT, AP or LAT_AP and **Modality** is either DSA or MAX. As an example, the transformation matrices of the MGP method are given in the **Results** folder.

Note: Subroutines "meanTRE.cpp" and "meanRPD.cpp" required by codes for analyzing the results are written as **MEX** files. These files must be compiled before running the codes for analyzing results. Information how to compile **MEX** files may be found at http://www.mathworks.com/help/matlab/matlab_external/building-mex-files.html.

REFERENCES

- [1] U. Mitrović, Ž. Špiclin, B. Likar, and F. Pernuš, "3D-2D Registration of Cerebral Angiograms: A Method and Evaluation on Clinical Images," *IEEE Trans. Med. Imaging*, vol. 32, no. 8, pp. 1550–1563, 2013.
- [2] E. van de Kraats, G. Penney, D. Tomažević, T. van Walsum, and W. Niessen, "Standardized evaluation methodology for 2-D-3-D registration," *IEEE Trans. Med. Imaging*, vol. 24, no. 9, pp. 1177–1189, Sep. 2005.