Benchmarking framework for myocardial tracking and deformation algorithms: An open access database

GROUND-TRUTH MESH

1) we selected the short-axis SSFP frame with closest trigger time to the end diastolic 3DTAG frame; 2) we segmented the LV from the selected short-axis dataset by manually deforming a left ventricular model; 3) we registered the segmented LV mesh to 3DTAG coordinates using DICOM header information.

we registered the mesh to 3DUS coordinates as follows. 1) we selected three orthogonal visualization planes to match typical MR acquisition planes; 2) we marked three anatomical landmarks on the four-chamber view; 3) with the corresponding landmarks on the MR datasets, we performed a point based similarity transform on the LV mesh.

```
#########
# 3DTAG #
#########

The mesh was deformed for MEVIS and UPF using ($i = each volunteer)

./GT/3DTAG/phantom/MESH/VTK_COORDINATES/v$i
./GT/3DTAG/v$i/MESH/VTK_COORDINATES/v$i

The mesh was deformed for IUCL using ($i = each volunteer)

./GT/3DTAG/phantom/MESH/DICOM_COORDINATES/v$i
./GT/3DTAG/v$i/MESH/DICOM_COORDINATES/v$i

The mesh was deformed for INRIA using ($i = each volunteer)

./GT/3DTAG/phantom/MESH/INRIA_COORDINATES/v$i
./GT/3DTAG/v$i/MESH/INRIA_COORDINATES/v$i


#########
# 3DUS #
#########

The mesh was deformed for MEVIS and UPF using ($i = each volunteer)

./GT/3DUS/phantom/MESH/VTK_COORDINATES/v$i
./GT/3DUS/v$i/MESH/VTK_COORDINATES/v$i

The mesh was deformed for INRIA using ($i = each volunteer)

./GT/3DUS/phantom/MESH/INRIA_COORDINATES/v$i
./GT/3DUS/v$i/MESH/INRIA_COORDINATES/v$i

#########
# SSFP #
#########

The mesh was deformed for UPF using ($i = each volunteer)

./GT/SSFP/phantom/MESH/VTK_COORDINATES/v$i
./GT/SSFP/v$i/MESH/VTK_COORDINATES/v$i

The mesh was deformed for INRIA using ($i = each volunteer)

./GT/SSFP/phantom/MESH/INRIA_COORDINATES/v$i
./GT/SSFP/v$i/MESH/INRIA_COORDINATES/v$i
```

GROUND-TRUTH LMKS

3DTAG datasets--> 8 landmarks for the phantom and 12 landmarks per volunteer: one landmark per wall (anterior, lateral, posterior, septal) per ventricular level (basal, midventricular, apical). These landmarks were used as initialization points and manually tracked by two observers (obs1, obs2). Tracking was performed one landmark at a time (to ensure real 4D tracking).

3DUS datasets--> we registered the lmks to 3DUS using a point based similarity transform (explained above).

SSFP datasets--> we registered the lmks to SSFP coordinates using DICOM header information.

#########
3DTAG
#########

Tracking for MEVIS, was initialized with lmks from first frame ($i = each volunteer, 00)

./GT/3DTAG/phantom/LMKS/VTK_COORDINATES/obs1_groundTruth00
./GT/3DTAG/phantom/LMKS/VTK_COORDINATES/obs2_groundTruth00

./GT/3DTAG/v$i/LMKS/VTK_COORDINATES/obs1_groundTruth00
./GT/3DTAG/v$i/LMKS/VTK_COORDINATES/obs2_groundTruth00

Tracking for IUCL, was initialized with lmks from first frame ($i = each volunteer, 00)

./GT/3DTAG/phantom/LMKS/DICOM_COORDINATES/obs1_groundTruth00
./GT/3DTAG/phantom/LMKS/DICOM_COORDINATES/obs2_groundTruth00

./GT/3DTAG/v$i/LMKS/DICOM_COORDINATES/obs1_groundTruth00
./GT/3DTAG/v$i/LMKS/DICOM_COORDINATES/obs2_groundTruth00

Tracking for UPF was initialized with lmks from last frame ($i = each volunteer, $j = last frame)

./GT/3DTAG/phantom/LMKS/VTK_COORDINATES/obs1_groundTruth$j
./GT/3DTAG/phantom/LMKS/VTK_COORDINATES/obs2_groundTruth$j

./GT/3DTAG/v$i/LMKS/VTK_COORDINATES/obs1_groundTruth$j
./GT/3DTAG/v$i/LMKS/VTK_COORDINATES/obs2_groundTruth$j

Tracking for INRIA was initialized with lmks from last frame ($i = each volunteer, $j = last frame)

./GT/3DTAG/phantom/LMKS/INRIA_COORDINATES/obs1_groundTruth$j
./GT/3DTAG/phantom/LMKS/INRIA_COORDINATES/obs2_groundTruth$j

./GT/3DTAG/v$i/LMKS/INRIA_COORDINATES/obs1_groundTruth$j
./GT/3DTAG/v$i/LMKS/INRIA_COORDINATES/obs2_groundTruth$j

NOTE--> in some cases there was no visual difference (between observers) at first frame.
Therefore--> obs1_groundTruth00 = obs2_groundTruth00

#########
3DUS
#########

Tracking for MEVIS and UPF, was initialized with lmks from first frame ($i = each volunteer, 00)

./GT/3DUS/phantom/LMKS/VTK_COORDINATES/obs1_groundTruth00
./GT/3DUS/phantom/LMKS/VTK_COORDINATES/obs2_groundTruth00

./GT/3DUS/v$i/LMKS/VTK_COORDINATES/obs1_groundTruth00
./GT/3DUS/v$i/LMKS/VTK_COORDINATES/obs2_groundTruth00

Tracking for INRIA was initialized with lmks from last frame ($i = each volunteer, $j = last frame)

./GT/3DUS/phantom/LMKS/INRIA_COORDINATES/obs1_groundTruth$j
./GT/3DUS/phantom/LMKS/INRIA_COORDINATES/obs2_groundTruth$j

./GT/3DUS/v$i/LMKS/INRIA_COORDINATES/obs1_groundTruth$j
./GT/3DUS/v$i/LMKS/INRIA_COORDINATES/obs2_groundTruth$j

due to temporal miss alignment between 3DTAG and 3DUS, accuracy errors were only evaluated at final frame and end systole (see below for ES time frames per volunteer).

NOTE--> in some cases there was no visual difference (between observers) at first frame.
Therefore--> obs1_groundTruth00 = obs2_groundTruth00

#########
SSFP
#########

Tracking for UPF, was initialized with lmks from first frame ($i = each volunteer, 00)

./GT/SSFP/phantom /LMKS/VTK_COORDINATES/obs1_groundTruth00
./GT/SSFP/phantom/LMKS/VTK_COORDINATES/obs2_groundTruth00

./GT/SSFP/v$i/LMKS/VTK_COORDINATES/obs1_groundTruth00
./GT/SSFP/v$i/LMKS/VTK_COORDINATES/obs2_groundTruth00

Tracking for INRIA was initialized with lmks from last frame ($i = each volunteer, $j = last frame)

./GT/SSFP/phantom/LMKS/INRIA_COORDINATES/obs1_groundTruth$j
./GT/SSFP/phantom/LMKS/INRIA_COORDINATES/obs2_groundTruth$j

./GT/SSFP/v$i/LMKS/INRIA_COORDINATES/obs1_groundTruth$j
./GT/SSFP/v$i/LMKS/INRIA_COORDINATES/obs2_groundTruth$j

NOTE--> in some cases there was no visual difference (between observers) at first frame.
Therefore--> obs1_groundTruth00 = obs2_groundTruth00

due to temporal miss alignment between 3DTAG and SSFP, accuracy errors were only evaluated at final frame and end systole (see below for ES time frames per volunteer).

FINAL FRAME (FF) AND END SYSTOLIC FRAMES (ES)

Volunteers= "v1","v2","v4","v5","v6","v7","v8","v9","v10","v11","v12","v13","v14","v15","v16";

3DTAG_ff="22","28","25","22","22","30","30","29","26","31","23","37","28","20","24";
3DUS_ff="13","15","10","14","13","16","13","13","12","14","12","23","17","12","12";
SSFP_ff="29","29","29","29","29","29","29","29","29","29","29","29","29”, "29";

3DTAG_es="10","10","10","10","10","11","10","10","10","11","10","10","11","8","9";
3DUS_es= "6","8","6","7","5","6","5","5","6","6","5","6","7","6","5";
SSFP_es="10","11","11","11","11","9","9","10","10","9","11","9","10","11","11";

Phantom=”phantom”;

3DTAG_ff=”26”;
3DUS_ff=”18”;
SSFP_ff=”29”;

3DTAG_es=”10”;
3DUS_es=”5”;
SSFP_es=”10”;

EXCLUDING CRITERIA

After obtaining the ground-truth, we calculated the inter-observer variability. The obtained inter-observer errors were analyzed under two criteria. Criterion 1: the final position of the landmark was relatively close to the initial position. We can assume the latter since all datasets are from healthy volunteers who are expected to have cyclic motion. Criterion 2: the final positions suggested by the two observers were relatively close. A landmark was labeled as relatively close when the distance was below the 75^{th} percentile of all measured distances. Landmarks that did not follow both criteria were excluded from further quantification. The median of the inter-observer variability was computed over all time frames for the phantom dataset (0.77mm) and for the volunteer datasets (0.84mm).

For the phantom data, no lmks were excluded.
For the volunteers, excluded lmks are summarized below:

			DATASET													
			v1	v2	v4	v5	v6	v7	v8	v9	v10	v11	v12	v13	v14	v15	v16
OBSERVER 1	LMK	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OBSERVER 2	LMK	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
		3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		6	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0
		7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		9	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
		10	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
		11	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
		12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0