

Micro-Surgical Anastomose Workflow recognition challenge report

Arnaud Hualmé^{a,*}, Duygu Sarikaya^b, Kévin Le Mut^a, Fabien Despinoy^a,
Yonghao Long^{c,d}, Qi Dou^{c,d}, Chin-Boon Chng^{e,f}, Wenjun Lin^{e,f}, Satoshi
Kondo^g, Laura Bravo-Sánchez^h, Pablo Arbeláez^h, Wolfgang Reiterⁱ, Manoru
Mitsuishi^j, Kanako Harada^j, Pierre Jannin^{a,*}

^aUniv Rennes,INSERM, LTSI - UMR 1099, F35000, Rennes, France

^bGazi University, Faculty of Engineering; Department of Computer Engineering, Ankara,
Turkey

^cDepartment of Computer Science & Engineering, The Chinese University of Hong Kong

^dT Stone Robotics Institute, The Chinese University of Hong Kong

^eNational University of Singapore(NUS), Singapore, Singapore.

^fSouthern University of Science and Technology (SUSTech), Shenzhen, China.

^gKonica Minolta, Inc

^hCenter for Research and Formation in Artificial Intelligence, Department of Biomedical
Engineering, Universidad de los Andes, Bogotá, Colombia

ⁱWintegral GmbH

^jDepartment of Mechanical Engineering, the University of Tokyo, Tokyo 113-8656, Japan

Supplementary material

A. Authors' contributions

A. Hualmé was the challenge coordinator, the primary contact with the participant teams, and a member of the IMPACT team. He made the workflow annotations, collected, computed, and analyzed the results, and wrote the paper. D. Sarikaya was a member of the challenge organizers and the IMPACT team and wrote the paper. K. Le Mut was a member of the challenge organizers and made the workflow annotations. K. Harada was a member of the challenge organizers and supervised, with M. Mitsuishi, the video and kinematic data acquisition. P. Jannin was the challenge supervisor. F. Despinoy was a member of the IMPACT team. Y. Long and Q. Dou were members of the MedAIR team.

*Corresponding author

Email addresses: arnaud.hualme@univ-rennes1.fr (Arnaud Hualmé),
pierre.jannin@univ-rennes1.fr (Pierre Jannin)

C.-B. Chng and W. Lin were members of the NUSControlLab team. S. Kondo was a member of the SK team. L. Bravo-Sánchez and P. Arbeláez was members of the UniandesBCV team. W. Reiter was a member of Wr0112358 team. All co-authors participated in the proofreading of the parts concerning their work.

B. Detailed results for each team

The results for each team by sequence and task are presented on the following pages. Eight balanced scores were computed, the frame-by-frame and application-dependent version of the accuracy, precision, recall, and F1.

B.1 MedAIR

Sequence	Frame-by-Frame				Application-Dependent			
	Accuracy	Precision	recall	F1	Accuracy	Precision	recall	F1
4_1	97.81	97.65	96.83	97.08	97.81	97.65	96.83	97.08
4_2	95.10	95.93	93.81	94.53	95.10	95.93	93.81	94.53
4_3	97.59	98.00	96.71	97.14	97.59	98.00	96.71	97.14
4_4	95.71	94.88	94.03	94.20	95.71	94.88	94.03	94.20
5_1	98.31	97.99	97.61	97.72	98.31	97.99	97.61	97.72
5_2	97.69	97.37	96.58	96.84	97.69	97.37	96.58	96.84
5_3	98.23	98.13	97.63	97.78	98.23	98.13	97.63	97.78
5_4	93.90	93.56	91.36	92.02	93.90	93.56	91.36	92.02
5_5	95.96	94.64	94.01	94.10	95.96	94.64	94.01	94.10
5_6	95.02	96.79	96.48	96.50	95.02	96.79	96.48	96.50
Mean	96.53	96.49	95.50	95.79	96.53	96.49	95.50	95.79

Table 1: Results of team MedAIR for phase recognition

Sequence	Frame-by-Frame				Application-Dependent			
	Accuracy	Precision	recall	F1	Accuracy	Precision	recall	F1
4_1	83.94	88.36	84.46	84.42	83.94	88.36	84.46	84.42
4_2	73.40	79.14	78.76	77.23	73.40	79.14	78.76	77.23
4_3	92.57	92.10	89.29	89.73	92.78	92.40	89.55	89.99
4_4	84.98	87.90	82.81	82.74	84.98	87.90	82.81	82.74
5_1	85.46	87.08	84.17	83.64	85.46	87.08	84.17	83.64
5_2	82.61	91.05	67.85	68.47	82.77	91.15	67.95	68.58
5_3	81.68	82.66	77.10	74.50	81.68	82.66	77.10	74.50
5_4	82.37	85.15	81.98	82.44	82.37	85.15	81.98	82.44
5_5	79.31	80.79	75.04	74.35	79.31	80.79	75.04	74.35
5_6	91.19	93.19	91.95	92.15	93.52	94.23	93.04	93.24
Mean	83.75	86.74	81.34	80.97	84.02	86.89	81.49	81.11

Table 2: Results of team MedAIR for step recognition

B.2 NUSControlLab

Sequence	Frame-by-Frame				Application-Dependent			
	Accuracy	Precision	recall	F1	Accuracy	Precision	recall	F1
4_1	96.22	95.17	94.69	94.65	96.41	95.40	94.94	94.92
4_2	91.59	92.82	91.92	91.68	91.59	92.82	91.92	91.68
4_3	98.87	98.31	98.21	98.23	99.12	98.59	98.54	98.54
4_4	88.90	89.50	86.90	86.50	90.18	89.57	87.01	86.60
5_1	98.41	98.59	97.97	98.15	98.62	98.96	98.33	98.51
5_2	99.30	99.10	98.97	99.01	99.30	99.10	98.97	99.01
5_3	89.18	86.98	78.80	79.44	89.18	86.98	78.80	79.44
5_4	93.21	91.92	89.87	90.34	93.21	91.92	89.87	90.34
5_5	95.44	94.59	94.01	93.94	95.78	94.99	94.46	94.41
5_6	87.59	90.62	87.33	87.58	87.59	90.62	87.33	87.58
Mean	93.87	93.76	91.87	91.95	94.10	93.89	92.02	92.10

Table 3: Results of team NUSCONTROLLAB for phase recognition with multi granularity model

Sequence	Frame-by-Frame				Application-Dependent			
	Accuracy	Precision	recall	F1	Accuracy	Precision	recall	F1
4_1	78.58	80.66	77.64	77.29	79.44	81.38	78.23	77.94
4_2	87.49	92.22	84.22	86.24	88.07	92.54	84.53	86.54
4_3	89.14	87.92	80.75	79.99	89.58	88.23	81.13	80.35
4_4	69.77	76.66	51.30	56.92	71.20	78.05	52.13	57.72
5_1	76.65	80.19	72.65	70.83	76.85	80.30	73.00	71.07
5_2	63.83	46.05	47.62	45.44	63.83	46.05	47.62	45.44
5_3	72.48	89.85	43.80	43.57	73.03	91.01	44.05	43.81
5_4	89.35	91.37	86.41	87.02	91.02	92.39	87.39	87.92
5_5	57.90	46.88	52.22	46.49	58.44	47.38	52.67	46.96
5_6	54.98	63.99	49.79	50.86	54.98	63.99	49.79	50.86
Mean	74.02	75.58	64.64	64.46	74.64	76.13	65.05	64.86

Table 4: Results of team NUSCONTROLLAB for step_multi recognition with multi granularity model

Sequence	Frame-by-Frame				Application-Dependent			
	Accuracy	Precision	recall	F1	Accuracy	Precision	recall	F1
4_1	58.02	64.93	67.40	63.55	60.57	67.42	69.83	65.95
4_2	59.21	70.05	70.75	69.38	64.31	73.40	74.48	73.10
4_3	59.93	70.83	71.79	69.06	62.72	73.37	74.44	71.90
4_4	61.01	77.27	77.35	76.01	64.47	80.80	80.73	79.34
5_1	57.90	75.53	78.27	76.60	58.95	76.62	79.42	77.73
5_2	53.82	72.47	73.60	72.23	55.40	73.81	75.04	73.62
5_3	53.37	71.94	72.89	71.17	56.00	74.36	74.98	73.43
5_4	60.01	71.63	72.80	71.54	63.92	75.20	76.24	74.88
5_5	60.81	74.33	76.29	73.83	65.56	77.75	79.88	77.53
5_6	61.08	73.96	74.30	73.51	64.98	77.73	78.10	77.41
Mean	58.52	72.29	73.54	71.69	61.69	75.05	76.32	74.49

Table 5: Results of team NUSCONTROLLAB for activity recognition with multi-granularity model

Sequence	Frame-by-Frame				Application-Dependent			
	Accuracy	Precision	recall	F1	Accuracy	Precision	recall	F1
4_1	77.61	80.25	79.91	78.50	78.81	81.40	81.00	79.60
4_2	79.43	85.03	82.30	82.43	81.32	86.26	83.64	83.77
4_3	82.65	85.68	83.59	82.43	83.81	86.73	84.70	83.60
4_4	73.23	81.14	71.85	73.14	75.28	82.81	73.29	74.55
5_1	77.65	84.77	82.96	81.86	78.14	85.29	83.59	82.44
5_2	72.31	72.54	73.40	72.22	72.84	72.99	73.88	72.69
5_3	71.67	82.92	65.16	64.73	72.74	84.11	65.94	65.56
5_4	80.86	84.97	83.03	82.96	82.72	86.50	84.50	84.38
5_5	71.38	71.93	74.18	71.42	73.26	73.37	75.67	72.97
5_6	67.88	76.19	70.47	70.65	69.18	77.45	71.74	71.95
Mean	75.47	80.54	76.68	76.03	76.81	81.69	77.80	77.15

Table 6: Results of team NUSCONTROLLAB for multi-granularity recognition

B.3 SK

Sequence	Frame-by-Frame				Application-Dependent			
	Accuracy	Precision	recall	F1	Accuracy	Precision	recall	F1
4_1	56.17	80.03	82.10	81.05	56.44	80.41	82.51	81.44
4_2	54.35	80.65	77.19	77.32	54.41	80.71	77.31	77.43
4_3	59.07	86.00	87.62	86.77	59.30	86.35	87.98	87.11
4_4	62.00	88.15	90.56	89.27	62.19	88.38	90.81	89.52
5_1	62.56	89.19	91.38	90.22	62.56	89.19	91.38	90.22
5_2	56.96	84.00	84.53	84.16	57.03	84.10	84.66	84.29
5_3	63.06	92.57	93.64	93.07	63.06	92.57	93.64	93.07
5_4	55.80	78.09	80.71	79.29	55.80	78.09	80.71	79.29
5_5	58.66	80.49	84.51	82.17	59.02	80.95	84.99	82.66
5_6	59.85	78.74	83.35	80.64	60.09	79.03	83.68	80.96
Mean	58.85	83.79	85.56	84.40	58.99	83.98	85.77	84.60

Table 7: Results of team SK for phase recognition with multi-granularity model

Sequence	Frame-by-Frame				Application-Dependent			
	Accuracy	Precision	recall	F1	Accuracy	Precision	recall	F1
4_1	31.86	39.49	40.18	35.89	32.88	41.17	41.14	36.95
4_2	35.24	60.74	55.44	56.35	36.03	61.27	55.95	56.85
4_3	39.13	52.91	51.04	50.37	39.44	53.23	51.53	50.87
4_4	41.76	50.16	53.29	49.41	42.02	50.37	53.51	49.62
5_1	29.60	41.07	38.29	35.32	29.94	41.76	38.80	35.92
5_2	32.06	60.35	44.38	46.51	32.52	60.72	44.64	46.69
5_3	36.48	61.51	59.18	55.73	37.31	61.93	59.53	56.17
5_4	34.94	51.11	39.44	34.96	35.06	51.36	39.67	35.31
5_5	32.21	37.76	41.10	36.69	32.61	38.22	41.71	37.24
5_6	40.72	51.76	44.13	41.05	40.72	51.76	44.13	41.05
Mean	35.40	50.69	46.65	44.23	35.85	51.18	47.06	44.67

Table 8: Results of team SK for step recognition with multi-granularity model

Sequence	Frame-by-Frame				Application-Dependent			
	Accuracy	Precision	recall	F1	Accuracy	Precision	recall	F1
4_1	46.44	61.27	58.09	52.68	50.39	66.65	61.49	56.62
4_2	50.09	66.19	65.42	61.98	55.28	69.81	69.05	65.84
4_3	50.32	64.04	64.05	59.47	54.87	67.99	67.64	63.60
4_4	48.63	68.86	64.98	61.29	54.52	73.13	69.77	66.64
5_1	46.85	66.06	67.40	64.30	48.82	68.44	69.26	66.36
5_2	43.12	65.07	67.08	62.39	44.83	67.33	68.58	64.06
5_3	45.47	66.97	66.51	60.23	49.19	69.94	69.12	63.52
5_4	53.16	66.33	67.35	62.99	56.08	69.72	69.98	66.02
5_5	47.49	63.91	65.48	60.88	52.56	67.90	69.12	65.22
5_6	53.14	63.77	63.49	60.19	57.40	67.90	67.65	64.71
Mean	48.47	65.25	64.99	60.64	52.40	68.88	68.17	64.26

Table 9: Results of team SK for activity recognition with multi-granularity model

Sequence	Frame-by-Frame				Application-Dependent			
	Accuracy	Precision	recall	F1	Accuracy	Precision	recall	F1
4_1	44.82	60.27	60.13	56.54	46.57	62.75	61.72	58.33
4_2	46.56	69.19	66.02	65.22	48.57	70.60	67.44	66.71
4_3	49.50	67.65	67.57	65.54	51.21	69.19	69.05	67.19
4_4	50.80	69.06	69.61	66.66	52.91	70.62	71.36	68.60
5_1	46.34	65.44	65.69	63.28	47.11	66.46	66.48	64.16
5_2	44.05	69.81	65.33	64.36	44.80	70.72	65.96	65.01
5_3	48.34	73.68	73.11	69.67	49.85	74.82	74.09	70.92
5_4	47.97	65.18	62.50	59.08	48.98	66.39	63.45	60.21
5_5	46.12	60.72	63.70	59.92	48.06	62.35	65.27	61.71
5_6	51.24	64.76	63.66	60.63	52.74	66.23	65.15	62.24
Mean	47.57	66.58	65.73	63.09	49.08	68.01	67.00	64.51

Table 10: Results of team SK for multi-granularity recognition

B.4 UniandesBCV

Sequence	Frame-by-Frame				Application-Dependent			
	Accuracy	Precision	recall	F1	Accuracy	Precision	recall	F1
4_1	78.49	80.74	69.74	65.90	78.49	80.74	69.74	65.90
4_2	81.92	83.19	63.01	63.15	82.10	83.28	63.37	63.56
4_3	90.97	91.30	88.49	88.53	91.01	91.40	88.56	88.60
4_4	87.12	85.76	79.49	78.88	87.12	85.76	79.49	78.88
5_1	94.98	95.34	93.94	94.14	94.98	95.34	93.94	94.14
5_2	95.28	95.66	94.46	94.66	95.39	95.78	94.59	94.79
5_3	89.31	91.57	89.59	89.24	89.50	91.73	89.78	89.46
5_4	89.92	90.04	87.45	87.49	90.53	91.22	88.37	88.43
5_5	90.75	89.02	87.66	87.43	90.75	89.02	87.66	87.43
5_6	94.38	95.76	93.71	94.14	94.67	96.35	94.21	94.64
Mean	89.31	89.84	84.75	84.36	89.45	90.06	84.97	84.58

Table 11: Results of team UniandesBCV for phase recognition

Sequence	Frame-by-Frame				Application-Dependent			
	Accuracy	Precision	recall	F1	Accuracy	Precision	recall	F1
4_1	57.23	83.48	84.13	82.60	57.57	83.83	84.61	83.11
4_2	56.97	84.65	85.82	85.22	56.97	84.65	85.82	85.22
4_3	63.35	92.06	93.76	92.88	63.35	92.06	93.76	92.88
4_4	59.86	86.50	87.95	86.66	59.86	86.50	87.95	86.66
5_1	62.93	89.97	90.94	89.89	62.93	89.97	90.94	89.89
5_2	62.37	91.50	92.17	91.71	62.37	91.50	92.17	91.71
5_3	63.95	93.09	93.24	92.78	63.95	93.09	93.24	92.78
5_4	59.05	82.62	84.86	83.41	59.05	82.62	84.86	83.41
5_5	64.65	88.27	92.19	90.03	64.65	88.27	92.19	90.03
5_6	63.33	83.27	87.37	84.58	63.76	83.74	88.05	85.21
Mean	61.37	87.54	89.24	87.98	61.45	87.62	89.36	88.09

Table 12: Results of team UniandesBCV for phase recognition with multi-granularity model

Sequence	Frame-by-Frame				Application-Dependent			
	Accuracy	Precision	recall	F1	Accuracy	Precision	recall	F1
4_1	53.51	48.33	42.29	36.86	54.15	48.53	42.77	37.16
4_2	47.82	60.60	44.62	46.94	47.82	60.60	44.62	46.94
4_3	65.77	68.74	67.91	65.65	65.77	68.74	67.91	65.65
4_4	65.34	74.67	65.99	66.07	65.34	74.67	65.99	66.07
5_1	68.01	70.85	64.00	63.93	68.64	72.07	64.74	64.71
5_2	57.81	78.08	58.97	60.98	58.32	78.59	59.38	61.32
5_3	57.99	51.96	61.11	53.11	58.69	52.13	61.36	53.31
5_4	60.93	64.04	55.21	47.25	60.93	64.04	55.21	47.25
5_5	56.34	57.78	54.81	49.72	56.48	57.88	54.98	49.85
5_6	65.28	75.69	56.92	55.27	65.94	75.93	57.34	55.53
Mean	59.88	65.07	57.18	54.58	60.21	65.32	57.43	54.78

Table 13: Results of team UniandesBCV for step recognition

Sequence	Frame-by-Frame				Application-Dependent			
	Accuracy	Precision	recall	F1	Accuracy	Precision	recall	F1
4_1	29.57	26.01	24.35	17.31	29.57	26.01	24.35	17.31
4_2	38.44	49.47	48.02	46.95	38.65	49.60	48.14	47.03
4_3	54.32	69.90	70.82	69.31	54.32	69.90	70.82	69.31
4_4	44.08	55.93	48.26	50.99	45.19	56.91	49.17	51.83
5_1	41.18	54.09	49.70	49.46	41.18	54.09	49.70	49.46
5_2	30.99	49.44	24.91	26.64	31.01	49.51	24.94	26.69
5_3	40.54	70.48	63.31	63.06	40.66	70.60	63.50	63.33
5_4	42.09	53.95	49.63	51.00	42.91	54.63	50.32	51.64
5_5	36.73	43.42	41.22	39.82	37.19	44.48	41.83	40.51
5_6	38.22	51.01	51.97	51.09	38.41	51.22	52.18	51.30
Mean	39.62	52.37	47.22	46.56	39.91	52.69	47.49	46.84

Table 14: Results of team UniandesBCV for step recognition with multi-granularity model

Sequence	Frame-by-Frame				Application-Dependent			
	Accuracy	Precision	recall	F1	Accuracy	Precision	recall	F1
4_1	50.50	62.47	60.85	59.72	53.81	65.65	63.75	62.75
4_2	51.94	68.28	64.45	65.07	57.60	73.13	69.39	70.07
4_3	58.08	65.81	65.11	64.78	62.67	70.42	68.98	68.84
4_4	57.09	69.32	67.20	67.52	64.87	75.02	72.82	73.13
5_1	55.67	69.92	66.29	66.62	58.51	72.45	68.54	68.89
5_2	58.95	72.92	69.41	70.17	63.84	76.34	72.94	73.62
5_3	57.23	71.73	68.90	68.80	62.90	76.04	72.82	72.91
5_4	53.05	64.67	60.30	59.76	59.18	69.54	64.81	64.61
5_5	62.26	68.99	67.72	67.56	67.94	74.23	72.78	72.72
5_6	52.64	64.48	60.51	60.57	61.79	71.35	67.02	67.38
Mean	55.74	67.86	65.08	65.06	61.31	72.42	69.39	69.49

Table 15: Results of team UniandesBCV for activity recognition

Sequence	Frame-by-Frame				Application-Dependent			
	Accuracy	Precision	recall	F1	Accuracy	Precision	recall	F1
4_1	54.60	62.20	63.02	60.74	56.37	64.05	64.80	62.48
4_2	51.35	65.57	63.22	62.82	56.31	70.48	67.36	67.02
4_3	57.43	66.44	66.64	65.60	59.81	68.51	68.60	67.55
4_4	58.35	69.51	68.77	68.07	65.12	74.04	72.97	72.18
5_1	57.25	70.50	69.78	68.87	59.34	72.20	71.32	70.46
5_2	61.13	74.26	73.37	73.15	65.64	76.74	75.61	75.48
5_3	57.52	72.45	72.45	71.27	61.10	75.23	74.92	73.85
5_4	53.11	62.70	60.50	60.27	57.53	67.52	64.76	64.83
5_5	60.56	68.54	67.35	66.98	66.53	72.91	71.42	71.07
5_6	57.26	67.97	64.67	63.75	63.06	70.92	67.69	66.93
Mean	56.86	68.01	66.98	66.15	61.08	71.26	69.95	69.18

Table 16: Results of team UniandesBCV for activity recognition with multi-granularity model

Sequence	Frame-by-Frame				Application-Dependent			
	Accuracy	Precision	recall	F1	Accuracy	Precision	recall	F1
4_1	47.14	57.23	57.17	53.55	47.84	57.96	57.92	54.30
4_2	48.92	66.57	65.69	65.00	50.64	68.24	67.10	66.43
4_3	58.36	76.13	77.07	75.93	59.16	76.82	77.73	76.58
4_4	54.10	70.65	68.33	68.57	56.72	72.48	70.03	70.22
5_1	53.79	71.52	70.14	69.41	54.48	72.08	70.66	69.94
5_2	51.50	71.74	63.48	63.83	53.01	72.58	64.24	64.63
5_3	54.00	78.67	76.33	75.71	55.24	79.64	77.22	76.66
5_4	51.42	66.42	64.99	64.89	53.16	68.26	66.64	66.63
5_5	53.98	66.74	66.92	65.61	56.12	68.55	68.48	67.20
5_6	52.94	67.42	68.01	66.47	55.08	68.62	69.31	67.81
Mean	52.61	69.31	67.81	66.90	54.15	70.53	68.93	68.04

Table 17: Results of team UniandesBCV for multi-granularity recognition

B.5 Wr0112358

Sequence	Frame-by-Frame				Application-Dependent			
	Accuracy	Precision	recall	F1	Accuracy	Precision	recall	F1
4_1	96.70	96.08	95.94	95.93	97.00	96.52	96.38	96.38
4_2	88.69	85.29	78.97	79.69	88.69	85.29	78.97	79.69
4_3	93.13	92.39	91.25	91.08	93.13	92.39	91.25	91.08
4_4	80.57	89.94	89.80	89.72	80.77	90.22	90.09	90.00
5_1	99.02	98.58	98.51	98.53	99.31	98.89	98.87	98.87
5_2	94.97	94.68	94.10	94.02	95.08	94.80	94.23	94.15
5_3	94.22	96.86	96.65	96.69	94.22	96.86	96.65	96.69
5_4	93.54	91.88	91.08	91.28	93.87	92.32	91.48	91.70
5_5	87.60	85.84	83.50	82.93	88.12	86.37	84.18	83.70
5_6	85.38	94.29	94.17	93.93	85.83	94.78	94.67	94.44
Mean	91.38	92.58	91.39	91.38	91.60	92.85	91.68	91.67

Table 18: Results of team wr0112358 for phase recognition

Sequence	Frame-by-Frame				Application-Dependent			
	Accuracy	Precision	recall	F1	Accuracy	Precision	recall	F1
4_1	92.02	93.30	92.77	92.77	92.49	93.94	93.47	93.47
4_2	87.22	86.33	85.79	85.54	87.22	86.33	85.79	85.54
4_3	92.55	89.82	88.26	88.42	92.55	89.82	88.26	88.42
4_4	79.75	90.87	90.01	89.84	79.97	91.34	90.38	90.19
5_1	80.68	81.36	67.18	65.60	80.79	81.47	67.31	65.71
5_2	82.18	82.42	68.26	67.40	82.18	82.42	68.26	67.40
5_3	86.15	88.25	82.26	82.91	86.33	88.34	82.44	83.03
5_4	88.28	86.37	81.00	81.05	88.28	86.37	81.00	81.05
5_5	80.45	82.80	72.17	70.41	81.29	82.85	72.29	70.51
5_6	73.54	82.42	70.05	69.86	73.84	82.57	70.55	70.42
Mean	84.28	86.39	79.77	79.38	84.49	86.55	79.97	79.58

Table 19: Results of team wr0112358 for phase recognition with multi-granularity model

Sequence	Frame-by-Frame				Application-Dependent			
	Accuracy	Precision	recall	F1	Accuracy	Precision	recall	F1
4_1	48.31	60.44	44.32	39.87	48.74	60.67	44.58	40.31
4_2	53.56	70.44	58.83	60.73	53.83	71.00	59.47	61.44
4_3	74.05	74.11	66.28	66.19	75.26	75.29	67.58	67.55
4_4	63.96	75.81	73.81	71.93	64.22	76.04	74.02	72.13
5_1	63.12	71.99	66.20	63.11	64.18	72.57	66.92	64.15
5_2	55.35	72.80	48.00	51.24	55.55	72.96	48.18	51.42
5_3	66.02	77.88	75.03	72.36	66.61	78.07	75.33	72.75
5_4	68.26	74.80	62.87	61.20	70.12	77.14	64.48	62.94
5_5	67.59	69.39	67.68	67.29	69.44	71.08	69.38	69.14
5_6	69.13	75.91	74.20	72.50	69.46	76.24	74.58	72.88
Mean	62.93	72.36	63.72	62.64	63.74	73.11	64.45	63.47

Table 20: Results of team wr0112358 for step recognition

Sequence	Frame-by-Frame				Application-Dependent			
	Accuracy	Precision	recall	F1	Accuracy	Precision	recall	F1
4_1	52.21	53.95	53.06	50.55	53.24	55.07	54.32	51.74
4_2	54.59	63.70	53.70	53.39	55.50	64.55	54.51	54.20
4_3	60.68	58.14	49.27	48.19	60.94	58.32	49.62	48.59
4_4	47.58	43.71	47.21	42.09	50.91	44.78	48.52	43.18
5_1	48.80	32.67	37.34	29.55	49.40	34.75	38.11	30.64
5_2	46.35	51.18	36.89	29.77	46.76	51.33	37.11	29.94
5_3	54.31	64.53	56.11	57.04	54.50	64.63	56.28	57.21
5_4	56.16	49.91	47.55	43.04	57.97	51.24	48.76	44.28
5_5	44.17	45.69	41.14	36.42	44.53	45.75	41.26	36.51
5_6	38.39	36.22	35.70	32.18	40.37	37.59	36.91	33.39
Mean	50.32	49.97	45.80	42.22	51.41	50.80	46.54	42.97

Table 21: Results of team wr0112358 for step recognition with multi-granularity model

Sequence	Frame-by-Frame				Application-Dependent			
	Accuracy	Precision	recall	F1	Accuracy	Precision	recall	F1
4_1	54.33	64.72	61.89	58.69	57.55	67.86	64.23	61.38
4_2	45.76	60.17	57.61	54.57	50.98	64.38	61.32	58.58
4_3	57.34	66.99	68.38	65.72	61.73	71.67	72.02	69.50
4_4	55.34	71.18	69.68	66.83	61.26	75.84	74.25	71.74
5_1	51.78	68.94	65.28	64.34	53.93	70.81	66.83	65.99
5_2	52.43	70.06	70.57	68.71	55.06	72.44	72.50	70.87
5_3	54.57	69.93	70.44	67.97	58.59	73.28	73.41	71.18
5_4	57.23	66.64	66.80	65.16	60.91	70.14	70.03	68.55
5_5	61.67	72.55	73.28	71.74	66.59	76.59	77.16	75.86
5_6	58.41	71.08	69.31	67.92	62.94	74.76	73.09	71.97
Mean	54.89	68.22	67.32	65.17	58.95	71.78	70.49	68.56

Table 22: Results of team wr0112358 for activity recognition

Sequence	Frame-by-Frame				Application-Dependent			
	Accuracy	Precision	recall	F1	Accuracy	Precision	recall	F1
4_1	54.94	66.90	61.73	59.66	57.94	69.46	64.23	62.44
4_2	57.88	69.85	66.74	66.24	61.89	74.31	70.78	70.39
4_3	59.19	71.73	67.07	66.89	61.99	74.51	69.73	69.65
4_4	54.62	73.29	69.04	68.33	59.69	77.27	73.36	72.81
5_1	46.30	69.16	59.19	58.51	47.50	70.27	60.22	59.62
5_2	50.72	71.25	64.76	64.56	52.43	73.18	66.30	66.27
5_3	50.74	72.68	66.99	66.59	53.12	75.06	69.04	68.79
5_4	54.11	67.54	63.77	62.78	56.39	69.37	65.56	64.65
5_5	54.17	72.56	65.42	64.63	57.10	75.11	68.03	67.45
5_6	56.18	73.24	66.64	66.44	59.05	76.18	69.64	69.55
Mean	53.88	70.82	65.13	64.46	56.71	73.47	67.69	67.16

Table 23: Results of team wr0112358 for activity recognition with multi-granularity model

Sequence	Frame-by-Frame				Application-Dependent			
	Accuracy	Precision	recall	F1	Accuracy	Precision	recall	F1
4_1	66.39	71.38	69.19	67.66	67.89	72.82	70.67	69.22
4_2	66.56	73.29	68.74	68.39	68.20	75.06	70.36	70.05
4_3	70.81	73.23	68.20	67.84	71.83	74.22	69.20	68.89
4_4	60.65	69.29	68.76	66.75	63.53	71.13	70.75	68.73
5_1	58.59	61.06	54.57	51.22	59.23	62.16	55.21	51.99
5_2	59.75	68.28	56.64	53.91	60.45	68.98	57.22	54.54
5_3	63.74	75.15	68.45	68.85	64.65	76.01	69.25	69.68
5_4	66.19	67.94	64.11	62.29	67.55	69.00	65.11	63.33
5_5	59.59	67.02	59.58	57.15	60.97	67.90	60.53	58.15
5_6	56.04	63.96	57.46	56.16	57.75	65.45	59.03	57.79
Mean	62.83	69.06	63.57	62.02	64.21	70.27	64.73	63.24

Table 24: Results of team wr0112358 for multi-granularity recognition

B.6 IMPACT

Sequence	Frame-by-Frame				Application-Dependent			
	Accuracy	Precision	recall	F1	Accuracy	Precision	recall	F1
4_1	78.02	76.63	76.38	76.43	84.21	76.97	76.86	76.87
4_2	81.86	78.32	74.46	75.34	81.86	78.32	74.46	75.34
4_3	82.71	76.16	74.80	75.17	82.98	76.57	75.15	75.53
4_4	79.45	82.34	81.98	81.80	79.69	82.63	82.31	82.14
5_1	82.24	77.38	74.78	75.02	82.24	77.38	74.78	75.02
5_2	87.50	83.29	81.32	81.94	87.50	83.29	81.32	81.94
5_3	81.49	79.12	72.39	73.18	81.59	79.19	72.48	73.26
5_4	79.87	73.58	70.12	70.50	79.87	73.58	70.12	70.50
5_5	78.56	69.47	69.46	69.34	78.87	69.83	69.86	69.76
5_6	67.77	82.87	83.22	82.69	67.77	82.87	83.22	82.69
Mean	79.95	77.92	75.89	76.14	80.66	78.06	76.06	76.30

Table 25: Results of team Impact for phase recognition

Sequence	Frame-by-Frame				Application-Dependent			
	Accuracy	Precision	recall	F1	Accuracy	Precision	recall	F1
4_1	84.46	83.64	76.49	75.41	84.62	83.89	76.72	75.63
4_2	85.85	82.48	79.75	80.64	85.85	82.48	79.75	80.64
4_3	77.74	72.48	65.84	66.61	77.74	72.48	65.84	66.61
4_4	86.63	81.07	80.61	80.68	86.63	81.07	80.61	80.68
5_1	81.02	73.82	72.34	72.63	81.17	74.02	72.59	72.88
5_2	85.53	82.07	76.84	77.97	85.53	82.07	76.84	77.97
5_3	86.20	85.26	73.77	74.77	86.34	85.31	73.91	74.85
5_4	86.24	83.51	79.45	80.22	86.24	83.51	79.45	80.22
5_5	81.96	74.82	73.99	73.97	81.96	74.82	73.99	73.97
5_6	70.96	84.87	79.45	79.41	70.96	84.87	79.45	79.41
Mean	82.66	80.40	75.85	76.23	82.70	80.45	75.91	76.29

Table 26: Results of team Impact for phase recognition with multi-granularity model

Sequence	Frame-by-Frame				Application-Dependent			
	Accuracy	Precision	recall	F1	Accuracy	Precision	recall	F1
4_1	47.94	37.63	42.29	35.63	49.10	38.99	43.58	36.76
4_2	43.53	58.02	47.84	51.10	44.26	58.45	48.44	51.60
4_3	43.27	42.81	40.94	41.04	44.77	44.48	42.09	42.38
4_4	43.37	53.27	49.57	51.02	44.75	53.99	50.40	51.78
5_1	42.66	36.93	37.77	34.50	42.95	37.39	38.08	34.88
5_2	39.80	35.89	34.85	31.38	39.80	35.89	34.85	31.38
5_3	55.65	62.13	58.09	57.21	55.91	62.29	58.29	57.41
5_4	49.36	36.77	38.74	32.99	50.79	37.25	39.49	33.60
5_5	30.38	36.20	32.61	33.32	30.86	36.73	33.29	33.95
5_6	59.98	69.06	58.68	59.25	61.63	69.75	59.56	60.29
Mean	45.59	46.87	44.14	42.74	46.48	47.52	44.81	43.40

Table 27: Results of team Impact for step recognition

Sequence	Frame-by-Frame				Application-Dependent			
	Accuracy	Precision	recall	F1	Accuracy	Precision	recall	F1
4_1	60.98	60.31	57.90	52.59	61.66	60.81	58.49	53.13
4_2	55.42	64.61	56.28	55.73	55.42	64.61	56.28	55.73
4_3	56.94	48.83	51.18	47.66	57.92	49.08	51.51	47.89
4_4	61.38	55.41	56.51	54.90	62.00	56.20	57.02	55.51
5_1	54.05	47.13	42.11	40.15	54.20	47.63	42.37	40.60
5_2	53.49	53.13	40.59	40.10	53.49	53.13	40.59	40.10
5_3	59.52	65.67	59.15	53.64	59.55	65.68	59.18	53.65
5_4	59.11	56.39	47.78	43.51	60.63	57.67	48.93	44.49
5_5	52.02	51.61	51.13	49.52	52.02	51.61	51.13	49.52
5_6	53.85	58.92	42.87	38.06	53.93	58.98	42.95	38.12
Mean	56.68	56.20	50.55	47.59	57.08	56.54	50.84	47.88

Table 28: Results of team Impact for step recognition with multi-granularity model

Sequence	Frame-by-Frame				Application-Dependent			
	Accuracy	Precision	recall	F1	Accuracy	Precision	recall	F1
4_1	56.87	65.08	57.10	56.31	59.78	68.68	59.46	58.68
4_2	56.83	69.91	64.42	62.96	59.74	72.91	67.17	65.65
4_3	59.56	68.94	61.80	61.44	62.26	71.80	64.36	64.15
4_4	37.65	57.26	43.51	46.65	39.94	59.44	45.51	48.55
5_1	52.17	68.69	59.86	61.03	53.83	70.07	61.00	62.17
5_2	54.06	70.00	63.08	63.90	56.63	71.76	64.85	65.69
5_3	55.73	74.87	67.40	67.20	58.23	77.38	69.40	69.21
5_4	59.03	72.08	65.94	65.07	61.66	74.42	68.11	67.29
5_5	57.41	69.71	60.88	61.52	60.89	72.37	63.34	64.20
5_6	64.95	78.86	70.92	71.41	68.02	81.92	73.54	74.18
Mean	55.43	69.54	61.49	61.75	58.10	72.07	63.67	63.98

Table 29: Results of team Impact for activity recognition

Sequence	Frame-by-Frame				Application-Dependent			
	Accuracy	Precision	recall	F1	Accuracy	Precision	recall	F1
4_1	51.14	62.23	53.31	53.86	54.15	65.26	55.77	56.44
4_2	55.56	66.52	60.57	60.03	58.53	68.98	63.07	62.50
4_3	59.97	72.29	62.90	63.27	63.13	75.66	65.67	66.18
4_4	51.57	68.93	58.94	61.28	54.67	71.94	61.95	64.28
5_1	57.89	73.59	62.16	64.80	59.55	75.04	63.63	66.24
5_2	59.20	73.92	63.21	65.74	62.24	75.89	65.00	67.58
5_3	59.61	76.11	62.89	63.76	62.04	77.99	64.53	65.44
5_4	62.36	74.01	68.27	68.06	65.49	76.36	70.57	70.43
5_5	57.24	66.90	59.30	60.63	60.88	70.07	62.25	63.55
5_6	66.84	78.96	68.35	70.43	69.88	81.85	71.03	73.25
Mean	58.14	71.35	61.99	63.19	61.06	73.90	64.35	65.59

Table 30: Results of team Impact for activity recognition with multi-granularity model

Sequence	Frame-by-Frame				Application-Dependent			
	Accuracy	Precision	recall	F1	Accuracy	Precision	recall	F1
4_1	65.53	68.73	62.57	60.62	66.81	69.99	63.66	61.73
4_2	65.61	71.20	65.53	65.47	66.60	72.02	66.37	66.29
4_3	64.88	64.53	59.97	59.18	66.26	65.74	61.01	60.22
4_4	66.53	68.47	65.35	65.62	67.77	69.73	66.53	66.82
5_1	64.32	64.85	58.87	59.19	64.97	65.56	59.53	59.91
5_2	66.07	69.71	60.21	61.27	67.08	70.36	60.81	61.88
5_3	68.44	75.68	65.27	64.05	69.31	76.33	65.87	64.65
5_4	69.24	71.30	65.17	63.93	70.78	72.51	66.32	65.05
5_5	63.74	64.44	61.47	61.38	64.95	65.50	62.46	62.35
5_6	63.88	74.25	63.56	62.63	64.92	75.23	64.48	63.60
Mean	65.82	69.32	62.80	62.33	66.95	70.30	63.70	63.25

Table 31: Results of team Impact for multi-granularity recognition

C. MISAW data annotation protocol

The annotation protocol given to each observer is the following.

MISAW data annotation protocol

Each session of MISAW (Micro-Surgical Anastomose Workflow recognition on training sessions) dataset must be manually annotated thanks to *Surgery Workflow Toolbox* [Annotate] software to generate procedural sequences. The sequence have to be annotate at the three following levels of granularity [1]:

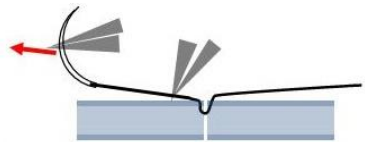
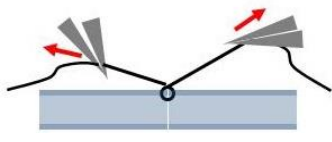
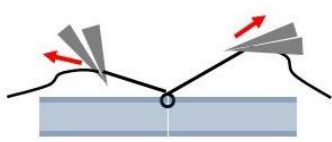
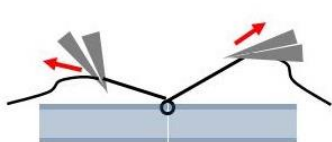
- Phases: the main periods of the intervention. A phase is composed of one or more steps.
- Steps: a step is a sequence of activities used to achieve a surgical objective
- Activities: An activity is a physical action performed by the surgeon and is composed of three components:
 - Action verb: describe the gesture.
 - Target: what is affected by the action.
 - Surgical instrument: with what the action is realized.

I. Phases & steps

The task is composed of 2 phases (in bold), each of them composed of 3 steps (in italic):

- **Suturing**: joining artificial vessels by using sterile suture material and a needle
 - *Needle holding*: Put the needle on place to allow the suturing
 - *Suture making*: Insert and pull the needle into artificial vessels.
 - *Suture handling*: Put the artificial vessels align and the wire to allow the Knot Tying
- **Knot Tying**: make 3 knots to keep the 2 artificial vessels close.
 - *1° Knot*: First knot
 - *2° Knot*: Second knot
 - *3° Knot*: Third knot

Phases	Steps	Start	End	Illustration
Suturing	<i>Needle holding</i>	First activity	When the needle is place to start the insertion	
	<i>Suture making</i>	Insert the needle on one vessel	The needle completely pass through both vessels	

	<i>Suture handling</i>	The needle completely pass through both vessels	Stop pulling the wire through vessels	
Knot Tying	<i>1° knot</i>	Stop pulling the wire through vessels	Stop pulling the 2 part of the wire to tie the 1° knot	
	<i>2° knot</i>	Stop pulling the 2 part of the wire to tie the 1° knot	Stop pulling the 2 part of the wire to tie the 2° knot	
	<i>3° knot</i>	Stop pulling the 2 part of the wire to tie the 2° knot	End of video	


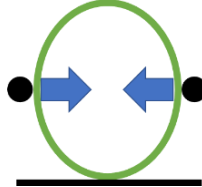
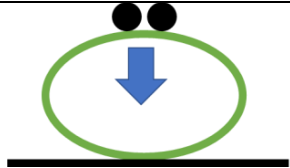
II. Activities

Activities where defined thanks to 17 action verbs, 9 targets, and 1 surgical instrument:

A. Action Verbs:

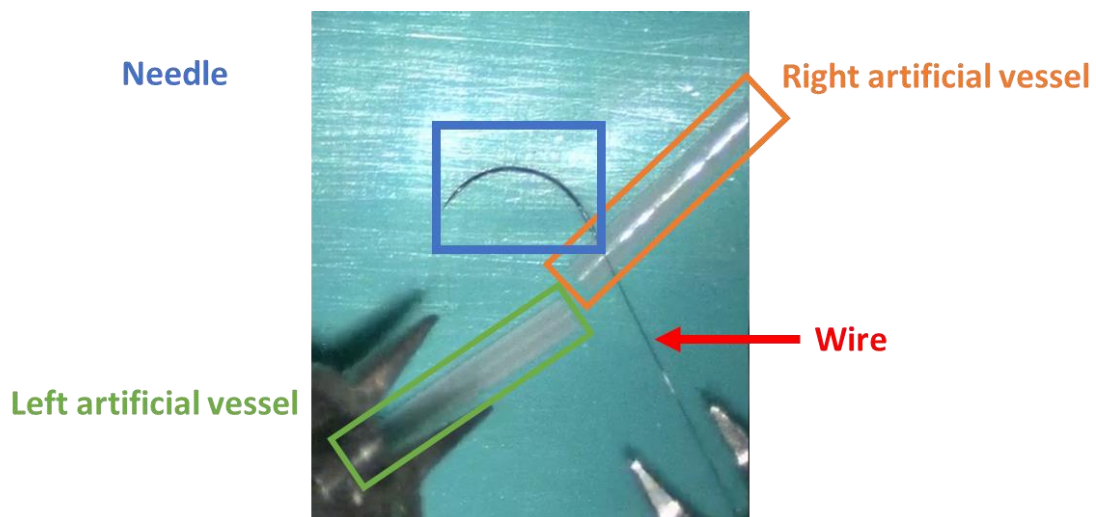
- Catch: when tooltips begin to close to grab a target between them.
- Give slack: move a target (a wire or a part of it) to have more space to work
- Hold: keep a target between tooltips (it is a transition action verb between other verbs) or block a vessel by applying a force from the target interior or exterior.
- Insert: Pierce a membrane of a vessel with a needle
- Loosen completely: undo completely a knot
- Loosen partially: undo partial a knot (generally to tighten it up without making again wire loop)
- Make a loop: action consisting to create a loop with a wire around the second tool. Both tooltips exert it at the same time.
- Pass through: action consisting to move a tool through a wire loop.
- Position: replace the needle held by a tooltip with the other tooltip.
- Pull: to exert force on a target to draw it towards the source of the force

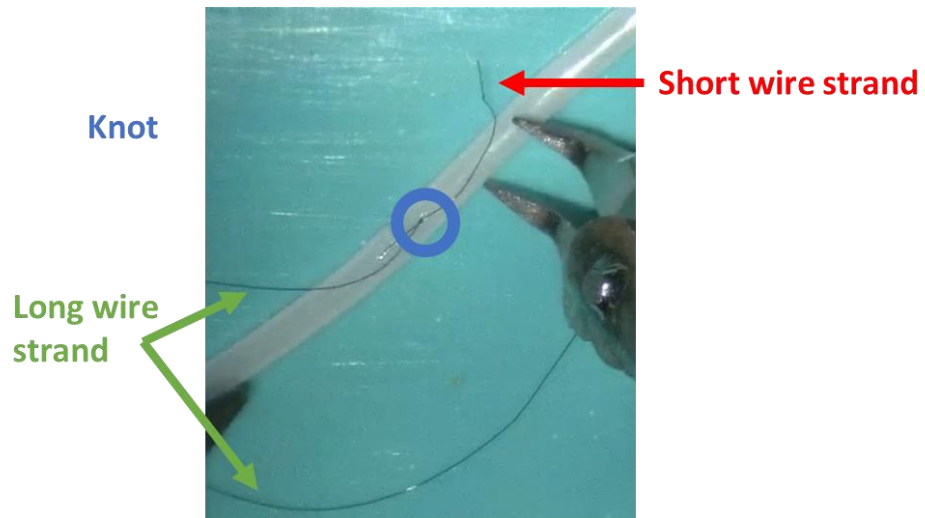
See bellow examples of holding vessels. Black do represent tool tips, green circle a vessel, black line the background.

	Cases of holding a vessel	Illustration
Hold	applying force from the target interior by opening tool	
	applying force from the target exterior by closing tool	
	applying force by pressing between tool and background.	

B. Targets:

- Needle
- Wire (defined until end of suturing phase)
- Both artificial vessels: left and right artificial vessels are the target at the same time of the action verb
- Left artificial vessel
- Right artificial vessel
- Long wire strand (defined from the beginning of first knot)
- Short wire strand (defined from the beginning of first knot)
- Wire loop: a loop creates to make the knot (only use with action verb “pass through”)
- Knot





C. Surgical instrument

Surgical instrument is always the same. No differences were done between left and right surgical instrument. Both are needle holders