Human motion measurement method for robot programming by demonstration

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Context: Programming by Demonstration

Programming by demonstration (PbD) [1] aims at making robot programming more intuitive, faster and requiring fewer skills, based on one or several human demonstrations of a task. This work proposes a method to acquire a human demonstration which does not limit human motion and is easy to implement.

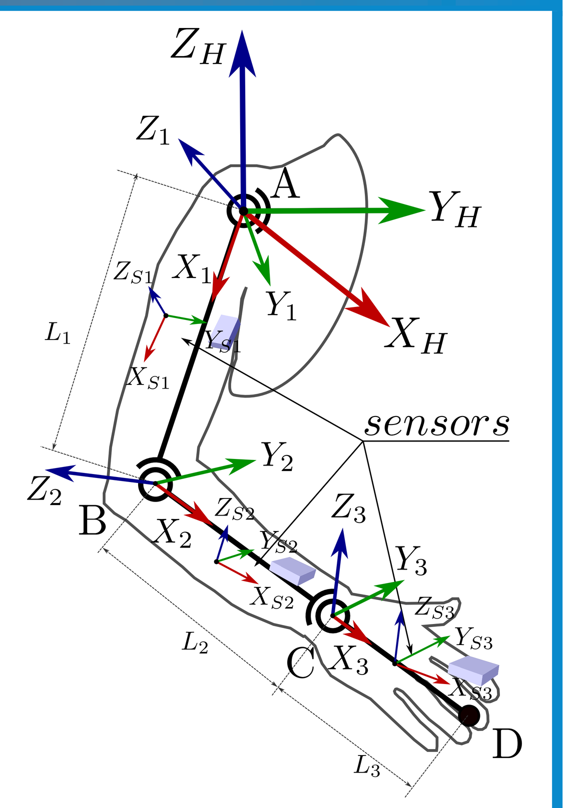
In order to guarantee the easiness of use of the method, we opt for **IMUs for human motion capture**.

Inertial human motion tracking method

According to the arm model, the human hand trajectory ${}^{H}\mathbf{AD}_n$ is estimated from the orientation of each segment (arm, forearm, hand) as

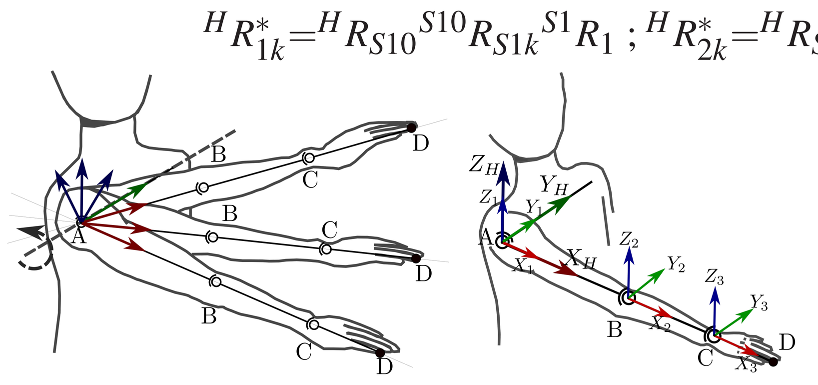
$$ {}^{H}\mathbf{AD}_n = {}^{H}R_{1n}\,{}^{1n}\mathbf{AB}_n + {}^{H}R_{2n}\,{}^{2n}\mathbf{BC}_n + {}^{H}R_{3n}\,{}^{3n}\mathbf{CD}_n $$
$$ {}^{1n}\mathbf{AB}_n = [L_1\,0\,0]^T, {}^{2n}\mathbf{BC}_n = [L_2\,0\,0]^T, {}^{3n}\mathbf{CD}_n = [L_3\,0\,0]^T $$

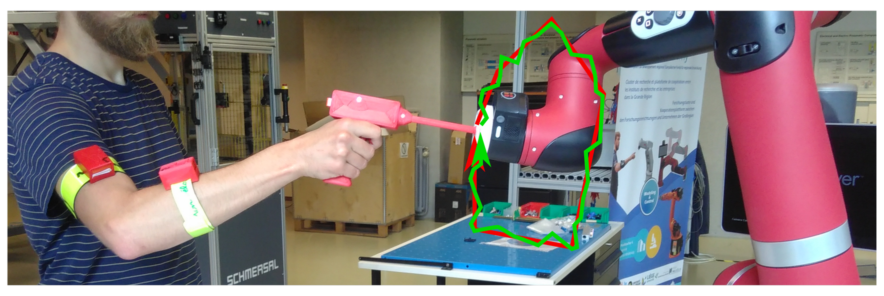
The orientation of each segment i is decomposed as ${}^{H}R_{in} = {}^{H}R_{Si0}\,{}^{Si0}R_{Sin}\,{}^{Sin}R_{in}$.



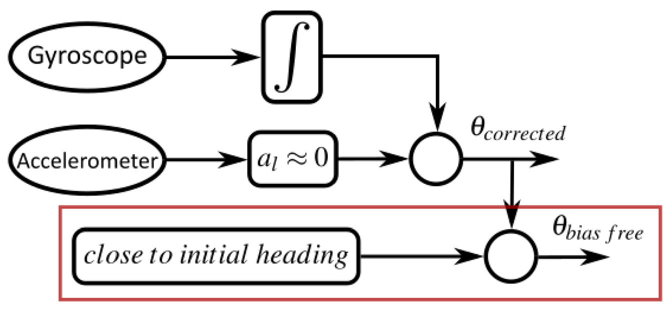
A 2-steps initialisation procedure enables to estimate ${}^{H}R_{Si0}$ and ${}^{Sin}R_{1n}$ (rotation of the arm straight and a static pose) and the transformation (${}^{H}R_R, {}^{R}\mathbf{AO}$) from human frame H to robot frame R (trajectory imposed by the robot to the operator). The parameters involved in the method are optimized through the minimization of the following function

$$ f({}^{1n}\mathbf{AB}, {}^{2n}\mathbf{BC}, {}^{3n}\mathbf{CD}, {}^{S1}R_1, {}^{S2}R_2, {}^{S3}R_3, {}^{H}R_{S10}, {}^{H}R_{S20}, {}^{H}R_{S30}, {}^{H}R_R, {}^{R}\mathbf{AO}) = \sum_{k=1}^{N} \| {}^{R}\mathbf{P}_k - ({}^{R}R_H\,{}^{H}\mathbf{AD}^*_k + {}^{R}\mathbf{AO}) \|^2 $$
$$ {}^{H}\mathbf{AD}^*_k = {}^{H}R^*_{1k}\,{}^{1k}\mathbf{AB} + {}^{H}R^*_{2k}\,{}^{2k}\mathbf{BC} + {}^{H}R^*_{3k}\,{}^{3k}\mathbf{CD} $$
$$ {}^{H}R^*_{1k} = {}^{H}R_{S10}\,{}^{S10}R_{S1k}\,{}^{S1}R_1 \; ; {}^{H}R^*_{2k} = {}^{H}R_{S20}\,{}^{S20}R_{S2k}\,{}^{S2}R_2 \; ; {}^{H}R^*_{3k} = {}^{H}R_{S30}\,{}^{S30}R_{S3k}\,{}^{S3}R_3 . $$



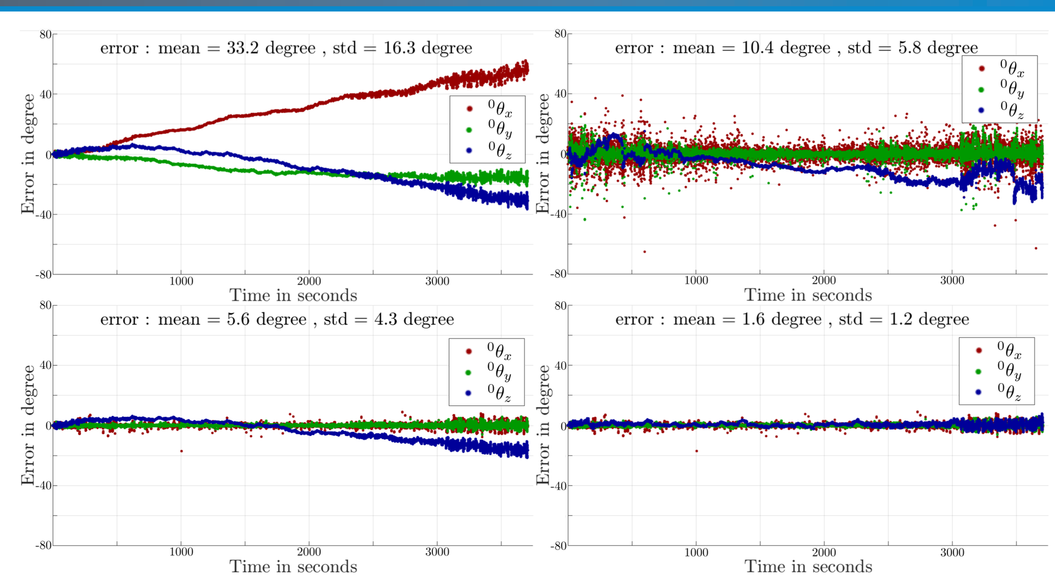


The rotation ${}^{Si0}R_{Sin}$ matrix is computed from inertial sensor data. **An original heading reset enables to limit drift** from gyroscope integration arround gravity direction.



Results: IMU orientation estimation

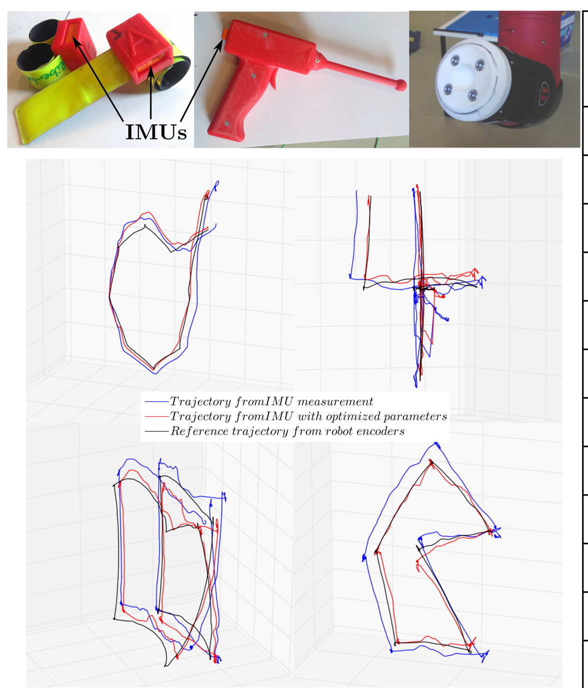
The method for IMU orientation estimation is evaluated on a robotic arm and compared to 4 others algorithms. The orientation of the end-effector, measured by encoders, is used as reference.



Sensors	Xsens algorithm [2]	Mahony's algorithm [3]	Madgwick's algorithm [4]	Fourati's algorithm [5]	algorithm without heading reset	algorithm with heading reset
1	34.8 ± 15.9	23.3 ± 9.2	24.8 ± 10.0	24.8 ±10.0	25.6 ± 10.3	**2.3**± 1.5
2	25.4 ± 13.9	118.4± 45.7	139.1 ±42.1	65.3± 36.8	64.6 ± 36.5	**8.4** ± 8.0
3	12.5± 6.3	38.4 ± 15.3	154.9 ± 4.5	33.3 ± 16.3	34.2± 16.7	**2.0**±1.5

Results: inertial motion tracking

The inertial measurement method is evaluated using Xsens IMU sensors [2]. A Sawyer robot imposes different trajectories to the operator. These trajectories are measured by the robot encoders and used as reference.



Measurement	Time (in s)	non-optimized parameters		optimized parameters	
		Error (in mm)	std (in mm)	Error (in mm)	std (in mm)
Circle 1	8.55	52.0	14.7	32.9	20.5
Circle 2	7.91	53.8	12.7	28.8	10.8
Circle 3	8.25	50.1	19.7	29.4	12.8
Cross 1	27.99	55.5	32.7	39.9	26.0
Cross 2	27.71	47.2	28.4	42.8	20.1
Cross 3	27.08	77.0	35.0	61.8	27.4
Cube 1	44.24	85.8	33.5	45.0	13.4
Cube 2	39.19	96.2	53.7	50.4	20.5
Cube 3	39.07	83.8	43.4	39.8	17.7
Hexagon 1	28.47	55.4	16.4	28.5	16.7
Hexagon 2	27.77	68.5	26.5	40.9	20.5
Hexagon 3	27.09	70.7	26.4	52.8	22.1

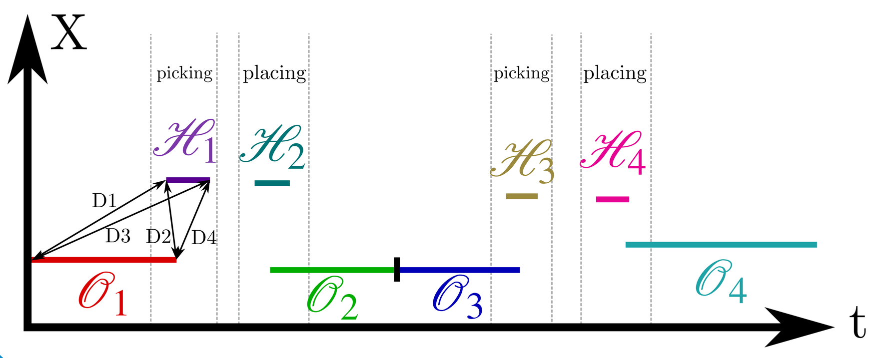
Correcting trajectory with vision

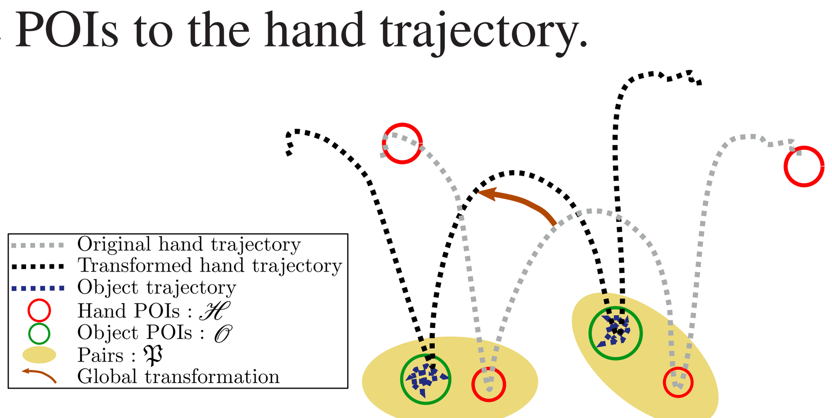
As a first step, the correction of the trajectory is adressed in a pick and place context. The method is based on matching positions of interest (POIs) $\mathscr{O}$ and $\mathscr{H}$, from vision-based estimation of object positions and inertial-based hand trajectory respectively.

1 - **Detecting POIs** based on the clustering algorithm DBSCAN.

2 - **Pairing POIs** by eliminating unecessary POIs based on point set registration by kernel correlation and then associating POIs based on their temporal parts.

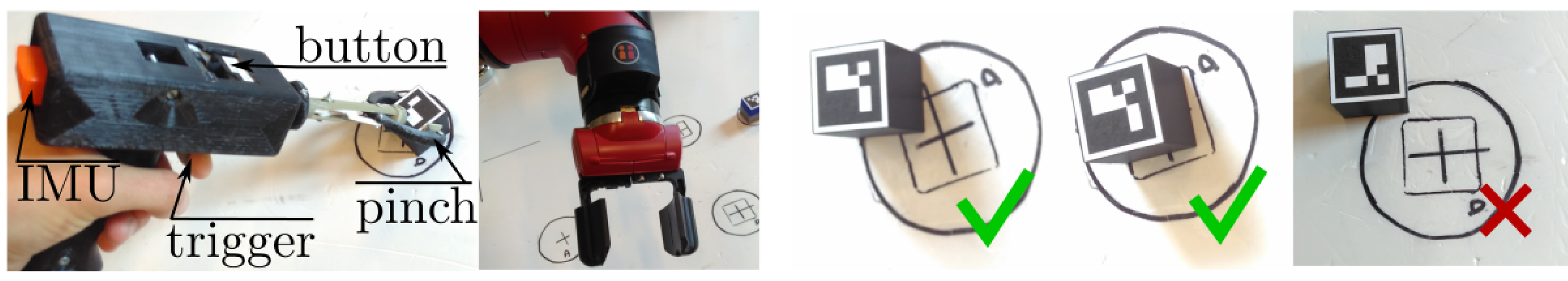
3 - **Correcting trajectory** by applying a global transformation (rotation + translation) and then a local correction close to the POIs to the hand trajectory.

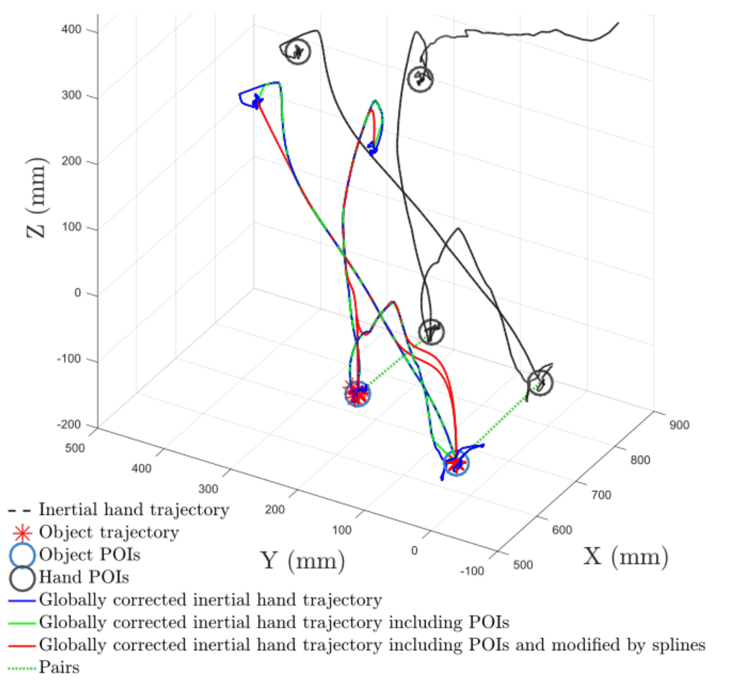




Results: application of the method

The complete method is evaluated through several pick and place tasks with 30 mm side cubes with an ARuCo marker on a face. The task is considered a success if the cubes, at their final states, are covering a part of their targeted position.





	Tasks properties			Experimental results				
	obj on table	obj moved once	obj moved twice	N_H	N_O	N_P	IMU only	Vision-based corrected trajectory
1	1	1	0	4	2	2	0	1
2	2	1	0	4	3	2	0	1
3	2	2	0	7	4	4	0	1
4	3	0	1	7	4	4	0	1
5	3	2	0	8	5	4	0	1
6	3	2	1	13	8	8	0	1
7	4	2	0	8	6	4	0	1
8	4	4	0	14	8	8	0	1
9	4	3	1	16	10	10	0	1
10	4	2	2	19	12	12	0	1

References

[1] A. Billard, S. Calinon, R. Dillmann, and S. Schaal, “Robot Programing by Demonstration,” in Springer Handbook of Robotics, pp. 1371–1394, Springer, 2008.

[2] M. Paulich, M. Schepers, N. Rudigkeit, and G. Bellusci, “Xsens MTw Awinda: Miniature wireless inertial-magnetic motion tracker for highly accurate 3D kinematic applications,” Whitepaper, 2013.

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[4] S. Madgwick, A. Harrison, and R. Vaidyanathan, “Estimation of IMU and MARG orientation using a gradient descent algorithm,” IEEE International Conference on Rehabilitation Robotics, pp. 1–7, 2011.

[5] H. Fourati, N. Manamanni, L. Afilal, and Y. Handrich, “Complementary observer for body segments motion capturing by inertial and magnetic sensors,” IEEE/ASME Transactions on Mechatronics, vol. 19, no. 1, pp. 149–157, 2014.

Acknowledgements

This work was supported by the Interreg V program of the Greater Region within the Robotix Academy project.