Raspberry Pi based Modular System for Multichannel Event-Driven Functional Electrical Stimulation Control

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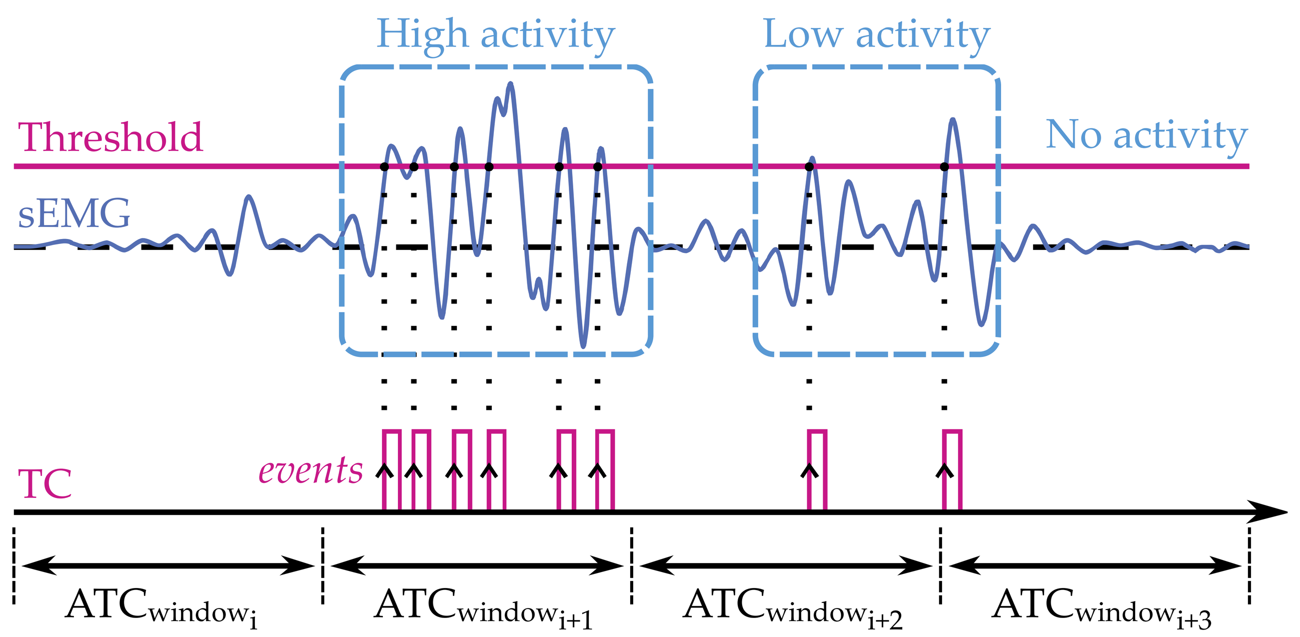
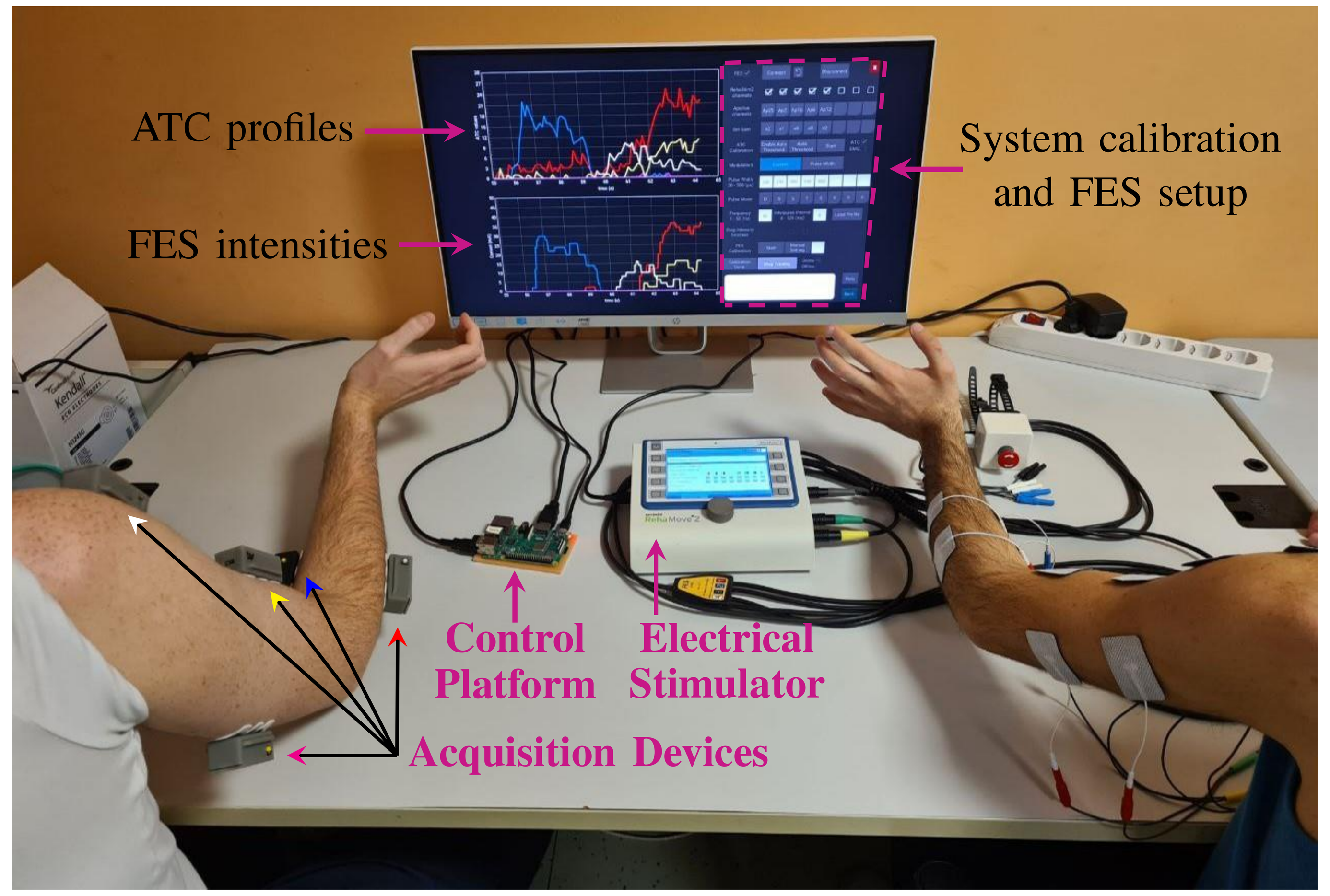
INTRODUCTION

Functional Electrical Stimulation (FES) is a widespread technique in the rehabilitation field to generate muscle contraction in paralyzed limbs, aiming to restore the ability to perform daily life activities and improve the quality of life of peoples who suffered from stroke, spinal cord injury, multiple sclerosis, or other neurological disorders. To ease the use of FES and provide efficient control of stimulation pulses, we designed a multichannel embedded system, the evaluation of whose software performance is the aim of this work.



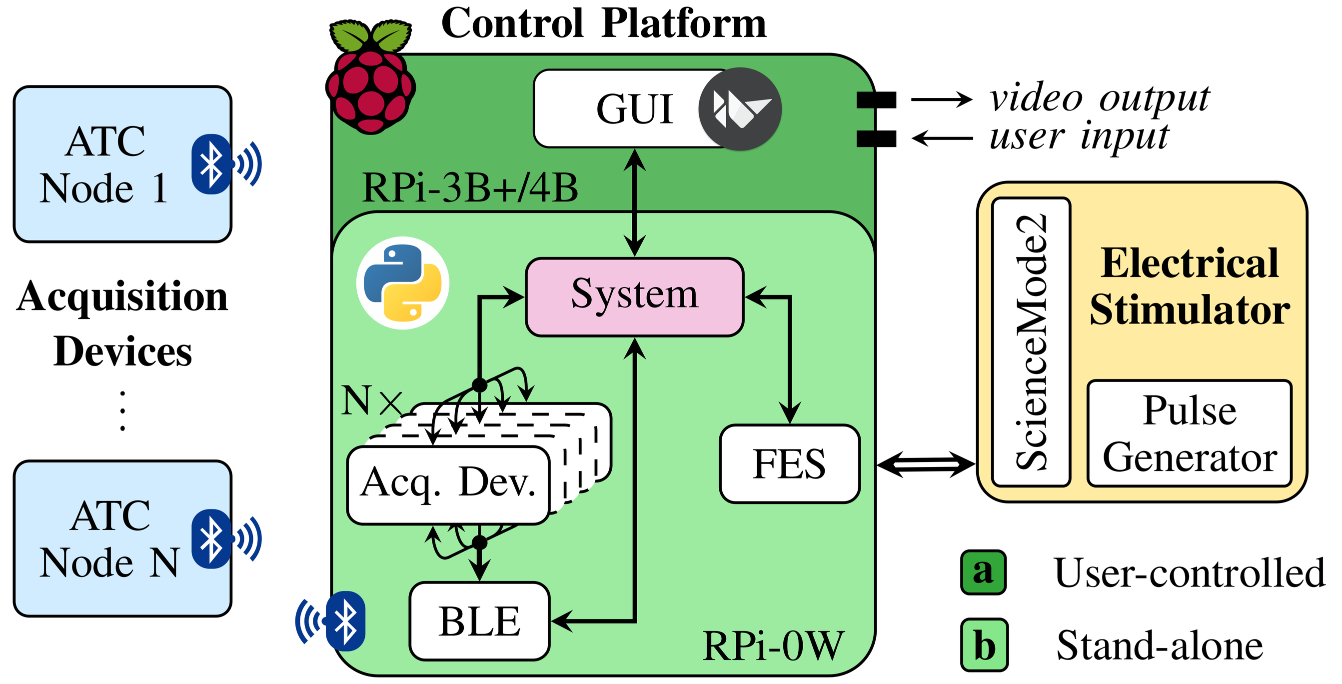
Our approach involves driving the output stimulation intensities using the hardware-extracted Average Threshold Crossing (ATC) feature as input to get muscles activity information, thus not even requiring the surface ElectroMyoGraphy (sEMG) signal sampling.



Typical system usage scenario. The muscle activity of the subject on the left is used for the generation of a biomimetic stimulation pattern to be applied to the subject on the right, enabling replication of the movement.

MATERIAL & METHODS

Software architecture

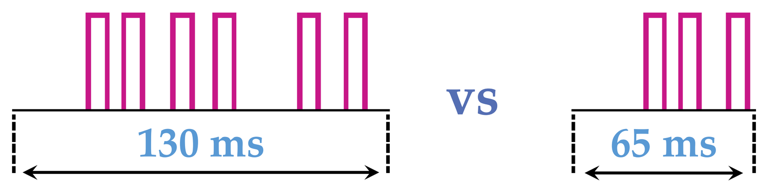


Software requirements

Sync vs async operation

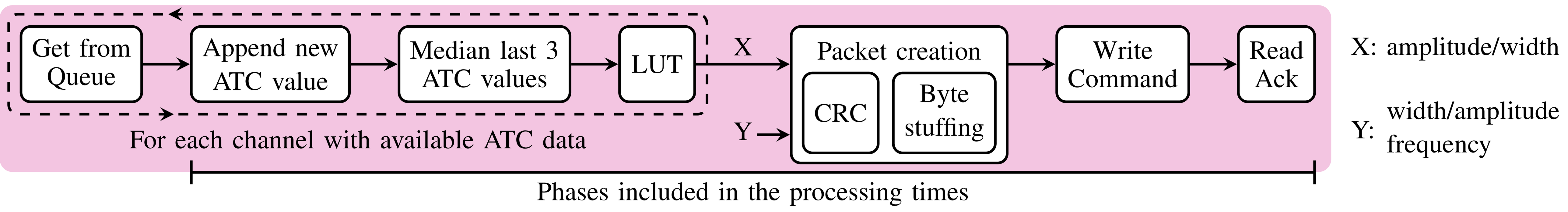
Thread-safe queues are used for inter/intra-modules communication. At the beginning of each processing cycle, the system can wait for data from all channels queues, or process only those available.

Standard vs halved ATC-window



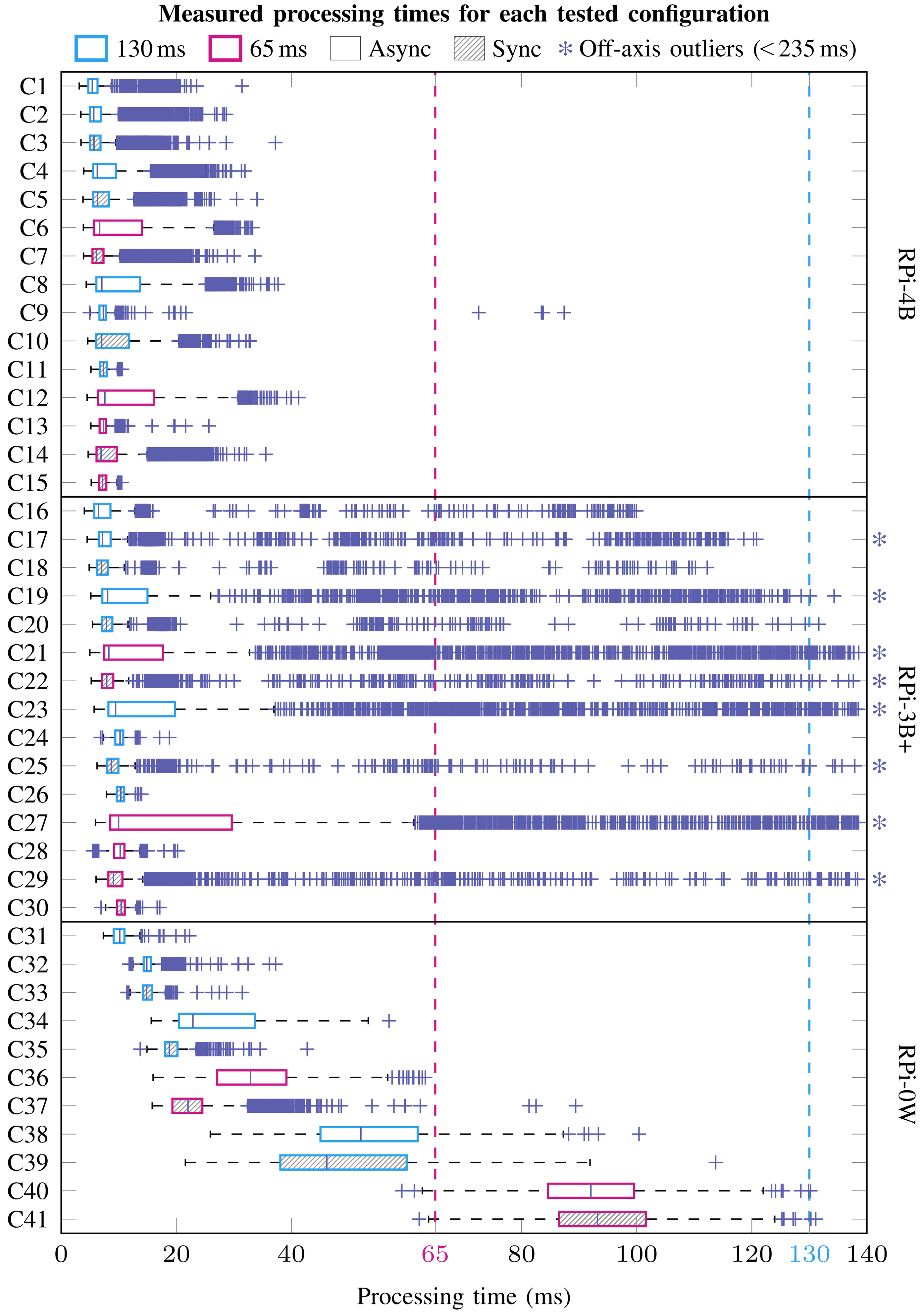
The use of shorter windows results in worse resolutions and increased computational effort but allows for a decrease in motion replication delay.

ATC-FES processing phases



RESULTS & CONCLUSION

ID	RPi	N	Sync	Win (ms)	GUI	CPU (%)	RAM (MB)	Losses (%)	Delays (%)
C1	4B	1	no	130	yes	9.55	85.01	0	0
C2		3	no	130	yes	12.35	86.32	0	0
C3			yes	130	yes	10.57	86.31	0.03	0
C4		5	no	130	yes	15.57	87.44	0	0
C5			yes	130	yes	11.93	87.3	0.1	0
C6			no	65	yes	17.35	87.36	0	0
C7			yes	65	yes	14.21	87.56	0	0
C8		8	no	130	yes	17.9	88.97	0	0
C9			no	130	no	5.6	23.2	0	0
C10			yes	130	yes	15	88.8	0.1	0
C11			yes	130	no	3.38	22.89	0.14	0
C12			no	65	yes	18.93	89.33	0	0
C13			no	65	no	6.95	22.84	0	0
C14			yes	65	yes	17.32	88.98	0.1	0
C15			yes	65	no	4.3	23.12	1.31	0
C16	3B+	1	no	130	yes	74.72	138.48	0	0
C17		3	no	130	yes	71.17	139.85	0	0.07
C18			yes	130	yes	71.83	139.42	1.53	0
C19		5	no	130	yes	67.62	139.98	0.14	0.11
C20			yes	130	yes	69.03	139.41	3.04	0.07
C21			no	65	yes	65.33	140.27	7.06	12.98
C22			yes	65	yes	66.92	139.99	12.78	5.82
C23		8	no	130	yes	63.3	140.71	0.93	3.11
C24			no	130	no	10.55	23.09	0	0
C25			yes	130	yes	65.82	140.39	3.63	0.72
C26			yes	130	no	5.7	22.92	0.18	0
C27			no	65	yes	60.45	140.95	13.4	16.99
C28			no	65	no	13.68	23.09	0	0
C29			yes	65	yes	62.88	140.41	17.87	7.08
C30			yes	65	no	8.4	23.21	0	0
C31	0W	1	no	130	no	37.6	22.99	0	0
C32		3	no	130	no	64.3	22.58	0	0
C33			yes	130	no	37.7	22.85	0	0
C34		5	no	130	no	77.9	22.98	0.02	0
C35			yes	130	no	56.2	23.21	0.02	0
C36			no	65	no	89	22.76	3.36	0
C37			yes	65	no	79.7	23.26	0.12	0.11
C38		8	no	130	no	92.8	23.19	0.03	0
C39			yes	130	no	81.4	23.55	0.08	0
C40			no	65	no	90.6	23.21	26.56	99.66
C41			yes	65	no	90.6	23.2	26.94	99.72



Different computationally demanding configurations have been tested achieving satisfactory results. Indeed, the system proved to be scalable, enabling the use of 8 acquisition/stimulation channels simultaneously, and featuring percentages of losses and computational delays always close to 0 when the standard ATC-window is used. With the only exception of the last two critical configurations with maximized computational effort, the stand-alone system use-case, although lacking the GUI module w.r.t. the user-controlled one, allows control platform with lower hardware resources, promoting system embeddability and moving toward an IoT approach for FES control.

OUR RELATED WORKS

- Rossi, F.; Motto Ros, P.; Rosales, R.M.; Demarchi, D. Embedded Bio-Mimetic System for Functional Electrical Stimulation Controlled by Event-Driven sEMG. *Sensors* 2020, *20*, 1535. https://doi.org/10.3390/s20051535
- F. Rossi, A. Mongardi, P. Motto Ros, M. Ruo Roch, M. Martina and D. Demarchi, "Tutorial: A Versatile Bio-Inspired System for Processing and Transmission of Muscular Information," in IEEE Sensors Journal, vol. 21, no. 20, pp. 22285-22303, 15 Oct.15, 2021, doi: 10.1109/JSEN.2021.3103608.
- A. Prestia et al., "Motion Analysis for Experimental Evaluation of an Event-Driven FES System," in IEEE Transactions on Biomedical Circuits and Systems, vol. 16, no. 1, pp. 3-14, Feb. 2022, doi: 10.1109/TBCAS.2021.3137027.