The main challenges of Brain-computer interfaces: reliability and usability

Aniana Cruz

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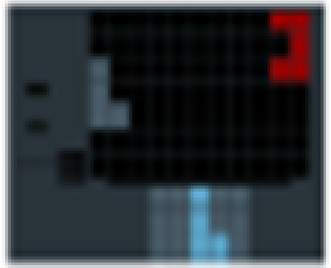
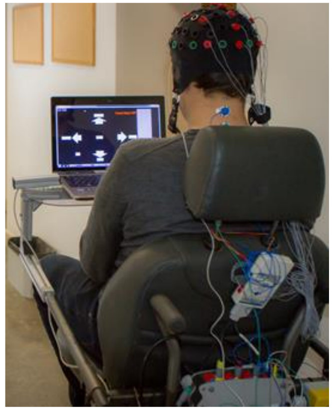
Context

Brain-computer interface (BCI) is an emerging technology with successful applications for both healthy and disabled individuals.

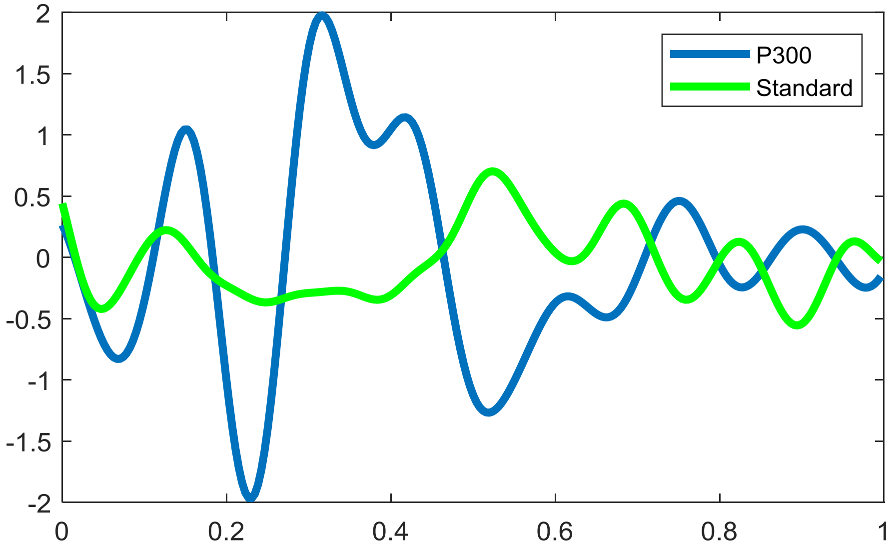
Major EEG-based BCIs challenges:

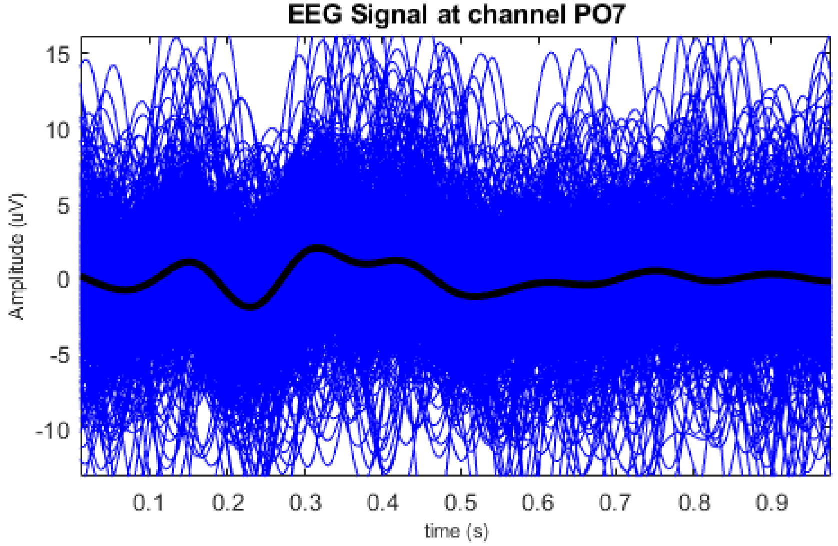
- EEG signal has low Signal-to-noise ratio (SN
- Great variability within and across subjects;
- High level of concentration and attention;
- Low reliability and usability.

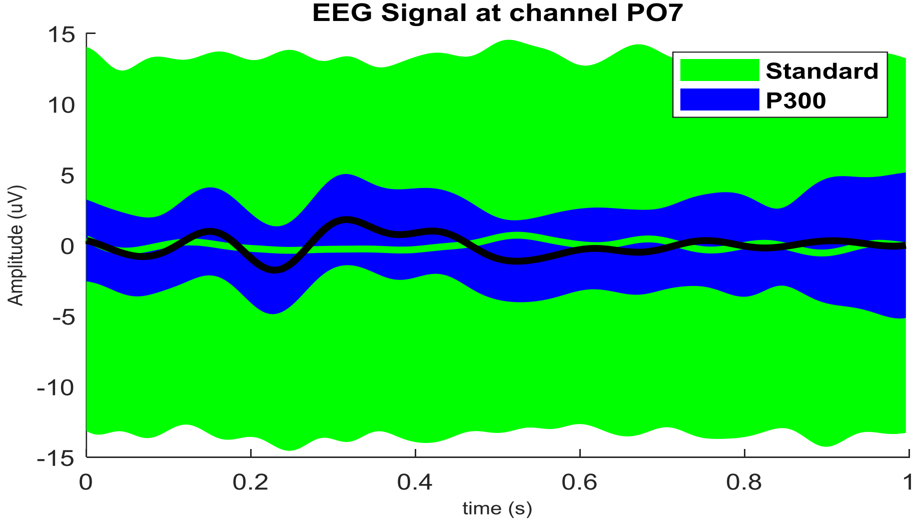




Context







Current BCIs systems have low reliability in recognizing the subject's intent.

Error-Related Potential (ErrP): Double Detection Approach

The ErrP is an event-related potential generated naturally in the brain when a person perceives a mistake.

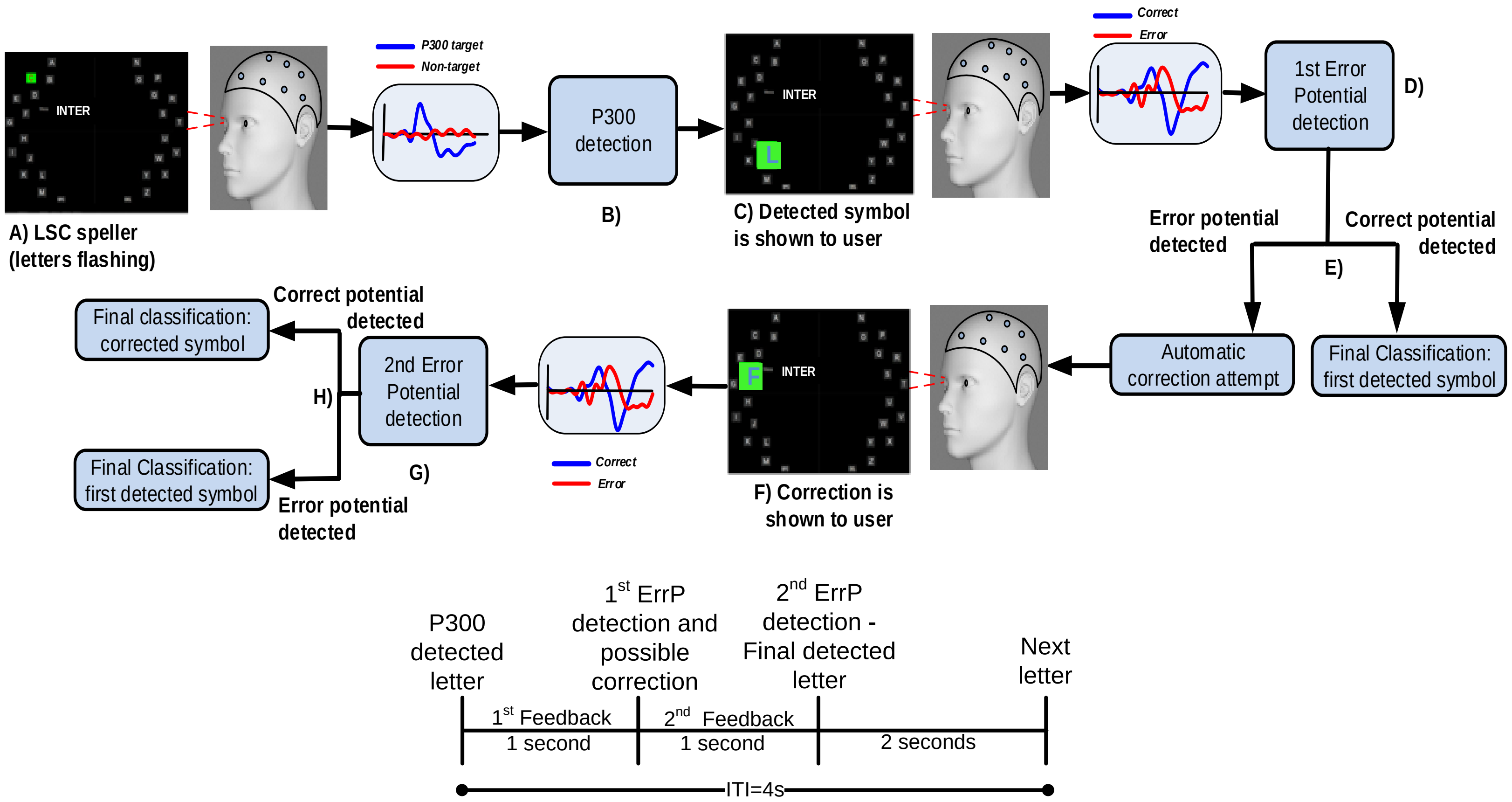
The main goal of this approach:

- Automatic detection of error-related potentials (ErrPs) in order to increase the reliability and transfer rates of brain-machine interfaces.

- The use of ErrPs in a closed-loop, allowing the user to change or confirm system decisions.

On-line operation: demonstrative video

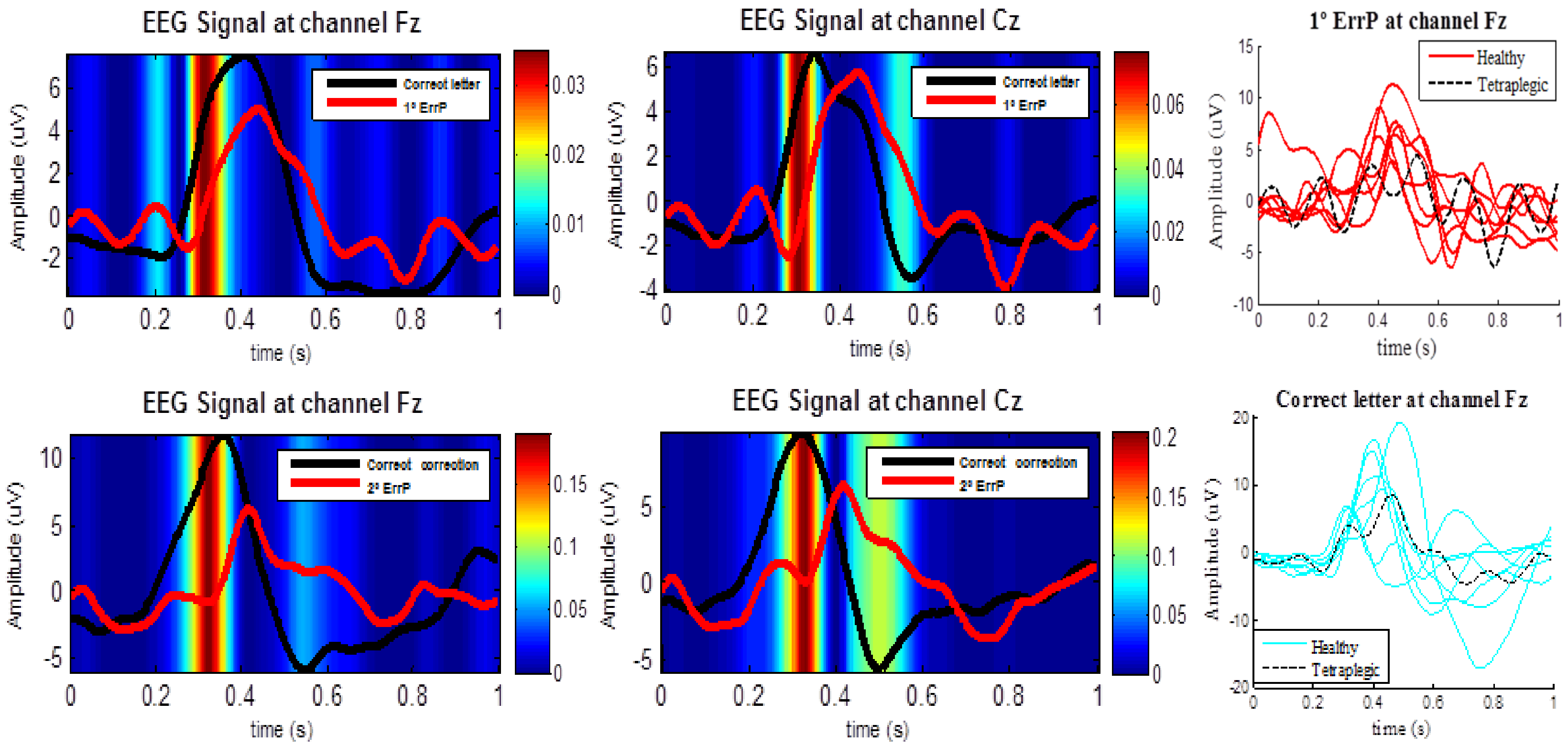
Double ErrP Detection Approach



Double ErrP detection:

- Use the information of 1st ErrP to perform the automatic correction;
- Use the information of 2nd ErrP to confirm the correction.

Evoked potentials after correct and wrong feedbacks



- The positive feedback is different from the ErrP.
- The waveform of 1st and 2nd ErrP is slightly different.

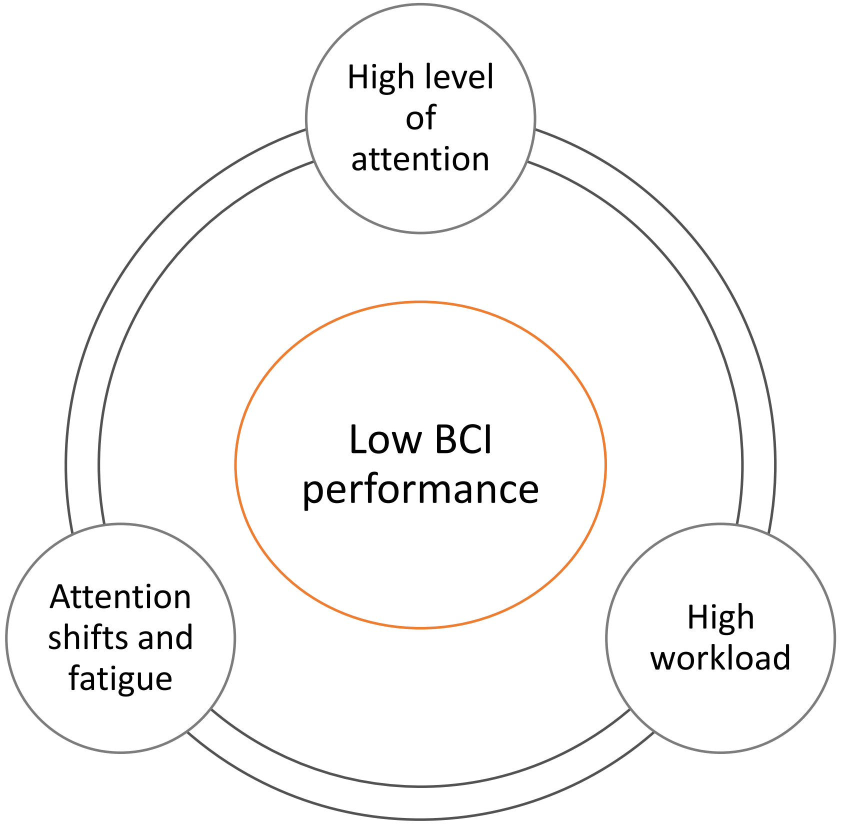
Online classification performance

		Pre-Acc (%)	Post-Acc (%)	Pre-ITR (bpm)	Post-ITR (bpm)	Pre-B_{ECS} (bpt)	Post- B_{ECS} (bpt)	Pre-eSPM	Post-eSPM	Acc-$ErrP_1$ (%)	Acc-$ErrP_2$ (%)	N_{rep}
Subjects	S1	**81,6**	**92,8**	9,87	12,45	3,00	3,57	1,92	2,6	90,8	86,1	7
	S2	93,2	94,7	15,96	16,49	4,10	4,20	3,34	3,46	96,3	81,3	5
	S3	93,2	96,3	15,96	17,05	4,10	4,25	3,34	3,59	89,5	90,9	5
	S4	84,7	89,5	11,81	13,03	3,30	3,60	2,37	2,69	75,8	80,0	6
	S5	73,7	79,6	8,30	9,47	2,25	2,66	1,44	1,8	92,1	78,6	7
	S6	95,8	95,8	14,85	14,85	4,35	4,35	3,12	3,12	76,3	92,2	6
	S9	**81,1**	**90,5**	17,02	20,73	2,95	3,50	3,3	4,3	96,8	85,0	3
	P1	**75,0**	**79,6**	**8,55**	**9,47**	**2,38**	**2,63**	**1,52**	**1,8**	**89,5**	**84,8**	**7**
	Mean	**84,8**	**89,9**	**12,79**	**14,19**	**3,31**	**3,60**	**2,54**	**2,92**	**88,4**	**84,8**	**5,80**
	Difference		**5,1**		**1,4**		**0,29**		**0,38**			

- The proposed approach increased the accuracy of 5.1%.
- The 1st and 2nd ErrP were successfully detected at a single level.

Usability of BCI

Towards User-friendly Brain-controlled Wheelchair



- We propose a minimum-effort brain-controlled wheelchair that combines:

1. collaborative control;
2. self-paced control;
3. dynamic time trial.

Towards User-friendly Brain-controlled Wheelchair

- **Self-paced control:** allows the user to issue a command only if he/she desires and the BCI detects whether the user is in a control state or in a non-control state.
- **Self-paced approach with static trial:** uses a fixed number of stimuli sequences.
- **Dynamic time trial approach:** automatically sets the number of stimuli sequences according to user's context awareness.
- **Collaborative-control:** validates user's command according to the navigation context.

Demonstrative video

Online BCW performance

	Task1: self-paced mode with static trial					Task3: non-self-paced mode with static trial-time		
Subjects	CC	NCC	TT	Acc_BCI (%)	Acc_BCW (%)	CC	Acc_BCI (%)	Acc_BCW (%)
S1	8	61	7,1	95,7	100,0	85	75,3	88,2
S2	12	72	5,9	97,6	100,0	73	97,3	97,3
S3	11	58	7,1	100,0	100,0	65	93,8	93,8
S5	10	78	7,1	100,0	100,0	71	94,4	94,4
S6	10	66	7,1	97,4	100,0	85	91,8	96,5
S8	7	57	8,4	96,9	100,0	62	82,3	95,2
S9	14	49	7,1	92,1	100,0	71	88,7	97,2
Average	**10,3**	**63,0**	**7,1**	**97,1**	**100,0**	**73,1**	**89,1**	**94,6**
P1	14	63	7,1	92,2	98,7	-	-	-
P3	23	104	7,1	94,5	100,0	-	-	-
P4	13	85	7,1	93,9	100,0	-	-	-
P7	13	68	7,1	91,4	98,8	-	-	-
P8	17	77	5,9	98,9	100,0	-	-	-
P9	12	66	7,1	97,4	100,0	-	-	-
Average	**15,3**	**77,2**	**6,9**	**94,7**	**99,6**			

- **The self-paced control enormously reduced the number of control commands, the user's workload, and consequently, it increased the BCI accuracy in 8.0%.**

Online BCW performance

Task2: self-paced mode with dynamic trial (DTT)							
Subjects	CC	NCC	TT(Max)	TT(Min)	TT(Mean)	Acc_BCI (%)	Acc_BCW (%)
S1	7	27	5,9	4,7	5,5	97,1	97,1
S2	11	31	8,4	3,5	4,9	100,0	100,0
S3	14	27	9,6	5,9	6,7	100,0	100,0
S5	10	31	5,9	4,7	5,8	97,6	100,0
S6	19	30	9,6	5,9	6,4	89,8	100,0
S8	10	23	10,8	5,9	8,0	93,9	100,0
S9	41	23	8,4	4,7	6,3	82,8	96,9
Average	16	27,4	8,4	5,0	6,2	94,5	99,1
P1	9	33	7,1	7,1	7,1	95,2	100,0
P3	36	36	9,6	4,7	6,8	81,9	98,6
P4	9	31	9,6	5,9	7,1	97,5	100,0
P7	12	79	5,9	4,7	5,7	94,5	98,9
P8	13	50	4,7	3,5	4,4	100,0	100,0
P9	8	31	7,4	5,2	6,2	87,2	100,0
Average	14,5	43,3	7,4	5,2	6,2	92,7	99,6

- **With the DTT approach, BCI speed vs. user's performance is adjusted online.**
- **DTT reduced the time to select a command in about 1 s, although it decreased the BCI accuracy in about 2%.**

Conclusion

- **Low reliability and usability are the major drawbacks of current BCIs, which limit their use outside laboratories.**

- **Using the proposed double ErrP detection there was an improvement in the BCI online accuracy around 5%.**

- **The proposed approach that combines collaborative control, self-paced control, and dynamic-time commands was extremely effective with overall accuracy greater than 99% for both able-bodied and motor disabled participants.**

Publications

- **Cruz, A., Pires, G., Lopes, A., Carona, C., & Nunes, U. J. (2021). A self-paced BCI with a collaborative controller for highly reliable wheelchair driving: Experimental tests with physically disabled individuals. IEEE Transactions on Human-Machine Systems, 51(2), 109-119.**

- **Cruz, A., Pires, G., Lopes, A. C., & Nunes, U. J. (2019, July). Detection of stressful situations using GSR while driving a BCI-controlled wheelchair. In 2019 41st Annual international conference of the IEEE engineering in medicine and biology society (EMBC) (pp. 1651-1656). IEEE.**

- **Cruz, A., Pires, G., & Nunes, U. J. (2017). Double ErrP detection for automatic error correction in an ERP-based BCI speller. IEEE transactions on neural systems and rehabilitation engineering, 26(1), 26-36.**

Acknowlegments

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B-RELIABLE

Thank you for your attention!