Human-Automation Study by Using a Smart Phone Controlled Inverted Pendulum Using Motorized Potentiometer

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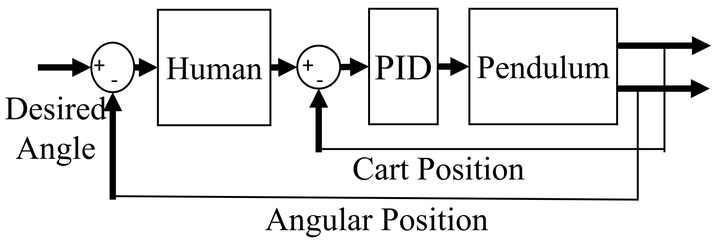
Abstract

This research proposes a methodology to evaluate the human behavior in the automation loop through a performance assessment doing a complex task, which is the position control of an inverted pendulum system using a smartphone application as human-machine interface. The inverted pendulum system employed is built using 3D printing. Likewise, the pendulum is controlled using Matlab with an Android mobile application operated by a human. The performance evaluation consists of keeping the pendulum totally straight while the system is operated by a human. A total of 20 test subjects are evaluated. Obtained results shows that not only the human beings are influenced by external factors performing the task, but also requires extensive training to complete it satisfactorily.

Human in the loop

Many industrial processes involves human operators in the automated control loop to reach the desired operating points and manufacturing goals. For this reason, understanding and modelling the human behavior in the control loop is necessary to determine how the human response in the process affects the final result of the manufacturing process.



Inverted Pendulum system

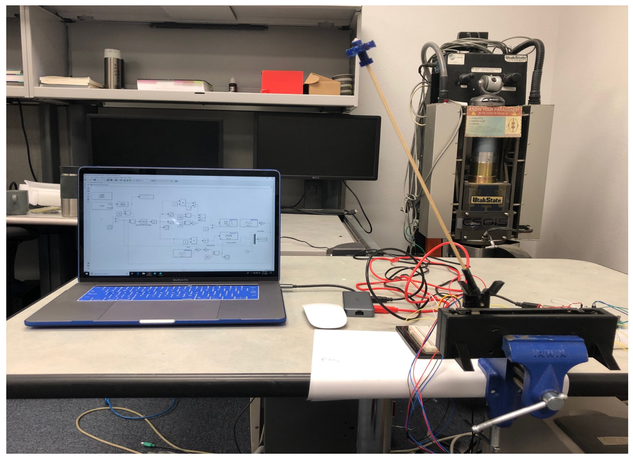


Figure 1. System prototype

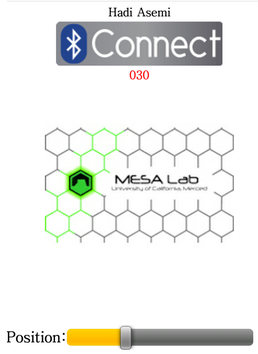


Figure 2. Android App

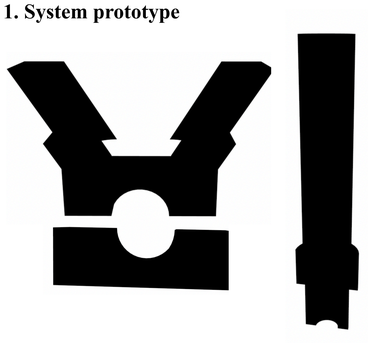


Figure 3. 3D CAD pieces design

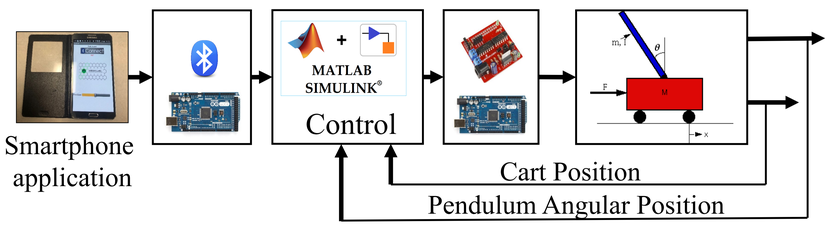


Figure 4. Inverted pendulum human in the loop block diagram

Performance indices:

$$RMS = \sqrt{\frac{1}{N}\sum_{i=1}^{N} x(i)} \qquad IAE = \frac{1}{N}\sum_{i=1}^{N} |e(i)|$$

Obtained results

Table 1. Quantitative performance analysis using performance indices

Subject	Cart RMS	Slider RMS	Angle RMS	IAE Angle
Automatic	13.855	10.166	8.167	5.539
1	57.240	53.784	19.293	17.316
2	51.920	63.662	20.991	19.497
3	65.699	60.221	21.142	19.923
4	71.985	66.214	20.890	19.495
5	68.428	62.319	21.726	20.631
6	49.688	57.585	22.537	21.704
7	61.253	52.503	22.468	21.639
8	62.658	59.102	21.282	20.135
9	61.705	63.418	20.444	18.829

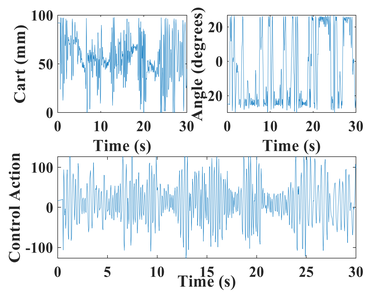


Figure 5. Human in the loop response

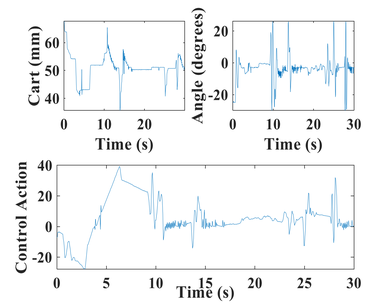


Figure 6. Automatic control response

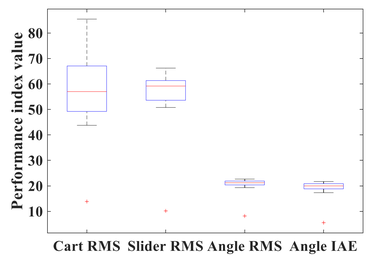


Figure 7. Human in the loop vs Automatic control

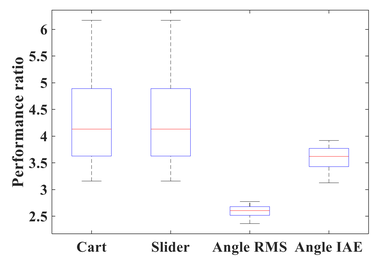


Figure 8. Human vs machine performance ratio

Conclusion

- The human behavior is strictly related with the performance of the proposed task.
- Sudden and faster changes in the human operator command signal reduces the times of the pendulum reach the desired position and increase the RMS value of the command action
- Human interaction reduce the system performance if the operator is not well trained to perform the task.

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