CHARACTERIZATION OF ELECTRO-MECHANICAL SWITCHES FOR THE OPERATION OF ASSISTIVE DEVICES

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Abstract: This paper presents the initial results obtained after modeling the electromechanical switches used by disabled people in direct-selection or scanning control of assistive devices. The effect of the different switch parameters on the overall response of the switch have been studied by means of computer simulations based upon the proposed model.

Introduction

Besides of the great development on the design of assistive devices (AD) for people with disabilities [1], most of the final success achieved in social integration and work inclusion relies on systems as the one depicted in figure 1.

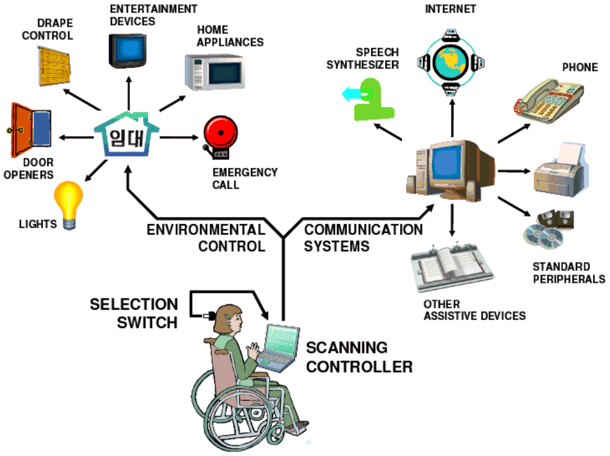

Figure 1: Scanning AD for the Inclusion of the Severely Motor Impaired

As it may be seen, a dedicated switch has to be chosen taking in to account several factors such as the type, location and intensity of the disability as well as the remaining functional capabilities of the disabled user (the so-called 'residual' or 'remaining' functionalities, RF).

This switch, used as a binary input channel, enables disabled users to operate systems for completing tasks that other while would not be possible to carry on (such as accessing to computers through scanning keyboards or operating automatic page-turners for reading), through the available RFs.

For this purpose, a large number of solutions have been developed for granting this input, such as contact switches (e.g. electromagnetic, pneumatic), proximity detectors (e.g. capacitive, optical), biosignal processing (e.g. EMG, EEG) and artificial vision (e.g. eye-trackers, face recognition), among many others.

From those, electromechanical are the ones most widely used, as these low cost devices can be easily operated by users with limited movement control.

These are used for accessing to communication and speech aids (voice synthesizers, predictive scanning keyboards), environmental control systems (X10, EIB, etc.) and many other Ads [1].

The requirements for operation are imposed by the mechanical properties of each switch, such as the total travel or active run length range (from 0.2 to 3 cm) and activation force (20-300 grams).

These figures were initially used for selecting the right switch for each subject based upon the past experience of the specialist in charge of this process.

As this method, which has proved to be valid for years, cannot be documented in a formal way in order to promote knowledge diffusion, scientific methods are now being applied for finding the theoretical basis for defining the adequacy of a certain set of switch mechanical characteristics to each kind and degree of disability.

This is especially important when considering the switch susceptibility to involuntary activations caused by spasmodic movements and tremors, as appear in certain disabilities (e.g. high spasticity, Parkinson, etc.).

The errors induced by these undesired activations of the switch, affecting the application under control, are especially dangerous when scanning access systems are used, reducing the global operation speed in many tasks, as happens with word processing, communication aids and similar applications.

For the study of the behavior of different electromechanical switches (see figure 2), a software tool was developed under Matlab, enabling the study of different models in function of the mechanical parameters considered (dead-spaces, elastic and viscous forces, and inertial masses)[2].

Materials and Methods

This work will be centered on a simplified mechanical model for switch, as characterized by the following elements:

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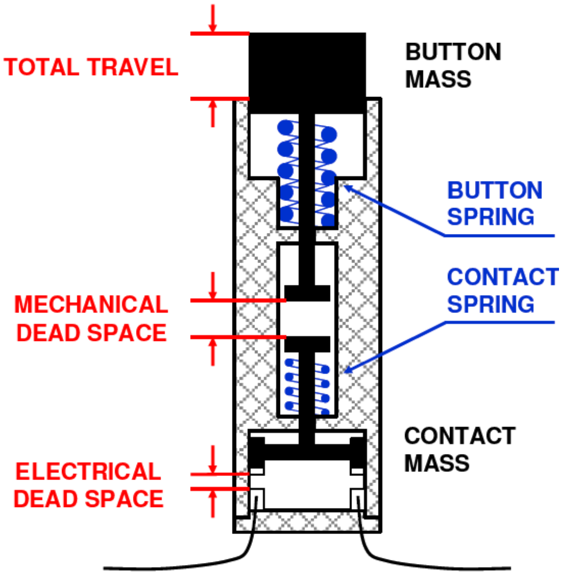

Figure 2: Electromechanical Push-button Model

Resistive (or Frictional) Forces: Composed of both, elastic and viscous components.

Dead Spaces: Two different dead-spaces have been considered, the one associated with the actual mechanical run of the switch activator (L_1) and the other one comprised by the distance between the electrical contacts of the switch (L_2).

Inertial Masses: Two different elements have been considered at this point. M_1, mass associated with the switch activator (the most relevant one) and M_2, associated to the electrical contacts (negible, when compared to the other one).

Under real operation, the disabled users should apply, through the RF, an input force F greater than the resistive force offered by the switch in order to displace the switch activator. This system may be modeled by the following equation:

$$M_1 \cdot \ddot{X} = F - K_1 \cdot X - B_1 \cdot \dot{X} \qquad (1)$$

where X stands for the actual displacement of the switch activator K_1 and B_1 the elastic and viscous constants of the switch, respectively.

Once that the switch actuator reaches the end of the first dead-space (X greater than L_1) and touches the first electric contact, the system may model by the following equation:

$$(M_1 + M_2) \cdot \ddot{X} = F - (K_1 + K_2) \cdot X - (B_1 + B_2) \cdot \dot{X} \qquad (2)$$

where two new constants, K_2 and B_2, are introduced to model the elastic and viscous and viscous forces offered by the electric contacts of the switch.

Finally, the switch will close when the total run of the switch reaches the end of the second dead-space (X greater than $L_1 + L_2$).

From these two equations, it is possible to state that an intentional activation of the switch by the disabled user may lead to one of the next three results (if tremors and involuntary movements are not considered)[2]:

If the applied force F is lighter than required for the switch activator to reach the end of the first dead space, the system will only be affected by the elastic and viscous forces of the first segment. In this case, the output of the system would be given by equation (1).

If the applied force F is lighter than required for the switch activator to reach the end of the second dead space, the system will be affected by the elastic and viscous forces of the both segments. In this case, the output of the system would be given by equation (2).

If the applied force F is strong enough for the switch activator to reach the end of the second dead space, the system will be affected by the elastic and viscous forces of the both segments, but displacement would be limited by the maximum run defined by the sum of both dead-spaces. In this case, the output of the system would be given by equation (2).

After this first results, it seems possible to combine equations (1) and (2) to model each one of the possible results by means of an additional binary control constant C, which indicates if the switch activator has reached the end of the first dead-space ($C=1$ if X is greater than L_1 and $C=0$ otherwise).

$$(M_1 + CM_2) \cdot \ddot{X} = F - (K_1 + CK_2) \cdot X - (B_1 + CB_2) \cdot \dot{X} \qquad (3)$$

It is obvious that in order to perform the required simulations, all of the physical parameters of the switch should be known.

As far as our knowledge extents, the only characteristics offered by switch manufacturers on their datasheets (if present) are just the activation force and the total run length. This fact lead us to carry out some lab work in order to find the actual values of the rest of the parameters for real switches, prior to running the simulations.

As an example, the determination of the elastic constant, K, of one of the steel springs used in the switches under study was done through the next equation:

$$K = \frac{d^4 \cdot G}{8 \cdot D^3 \cdot N} \qquad (4)$$

where d stands for the wire diameter, D the spring diameter, N the number of active turns and G the shear modulus. In our case $d=0{,}25$ mm, $D=5$ mm, $N=10$ and $G=79{,}3$ MPa for spring steel, leading to a elastic constant of $30{,}97$ N/m.

At this point, it is very interesting to point out that a reduction of the spring diameter from $D=5$ mm to $D=4{,}8$ mm may reduce the value of K in as much as a 50%, which is very useful for adjusting the response of a certain switch.

Results

In order to test the model, a first simulation was run, observing the step response of the system (similar to a hold activation of the switch). For this purpose, two different models where considered.

The first one, the real model, was described by equation (3) and took the effect of the finite second dead-space into account.

The alternative model, or ideal model, was also described by that same equation but did consider the second dead-space as infinite, in order to study the oscillations of the system, as these were truncated most of the times in the real model.

An example of the response of both models to the same input (1N step) may be found in figures 4 and 5, while simulation parameters are summarized in table 1

Table 1: Parameters for Real/Ideal Model Comparison

Type	Variable	Value	Units
Mass	M_1	0,8	Kg
Dead-space	L_1	0,005	m
ElasticConstant	K_1	10	N/m
Viscous Constant	B_1	5	$N\cdot s/m^2$
Mass	M_2	0,001	Kg
Dead-space	L_2	0,0005	m
ElasticConstant	K_2	5	N/m
Viscous Constant	B_2	1	$N\cdot s/m^2$

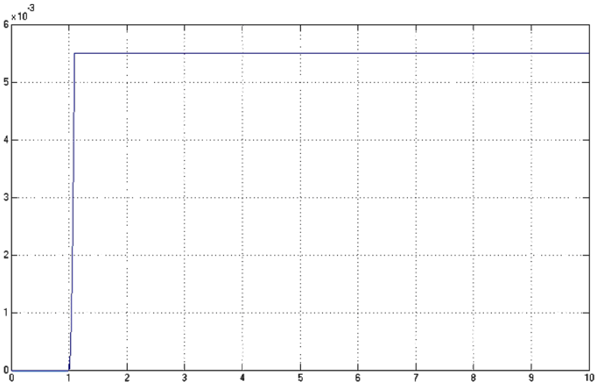

Figure 3: Real Model Step Response

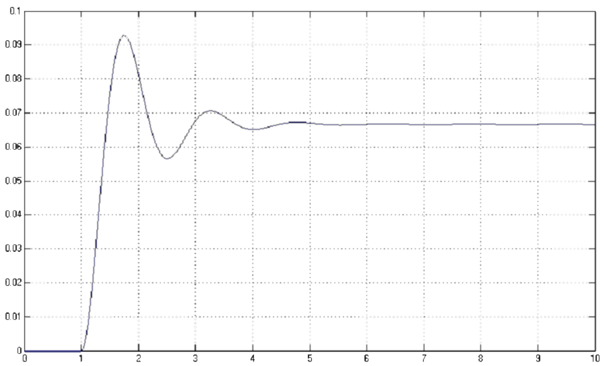

Figure 4: Ideal Model Step Response

Next, a standard foot switch was analyzed and the values obtained at the lab were use for the simulation (see table 2). As the manufacturer data indicated a required force of 10 g for activation, the simulation studied the response of the switch when 0,05 N and 0,1 N were applied (associated to 5 and 10g forces).

Table 2: Model parameters for foot operated switch

Type	Variable	Value	Units
Mass	M_1	0,02	Kg
Dead-space	L_1	0,005	M
ElasticConstant	K_1	10	N/m
Viscous Constant	B_1	5	$N\cdot s/m^2$
Mass	M_2	0,001	Kg
Dead-space	L_2	0,0005	M
ElasticConstant	K_2	5	N/m
Viscous Constant	B_2	1	$N\cdot s/m^2$

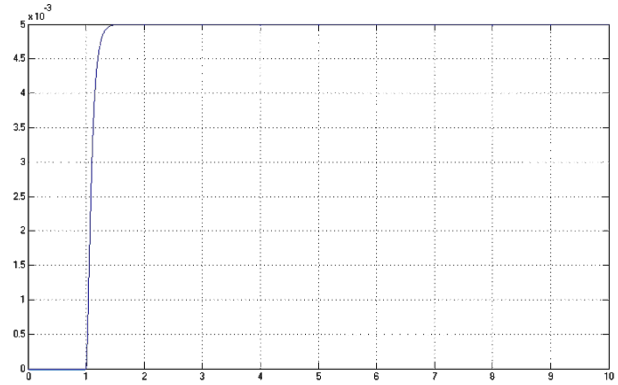

Figure 5: Foot Switch Step Response (Force = 0,05N) Ideal model

As it may be seen in figure 5, the switch is not able to complete a whole run as the maximum displacement is 5mm , smaller than the total run (5,5 mm). In this case, the switch does not activate.

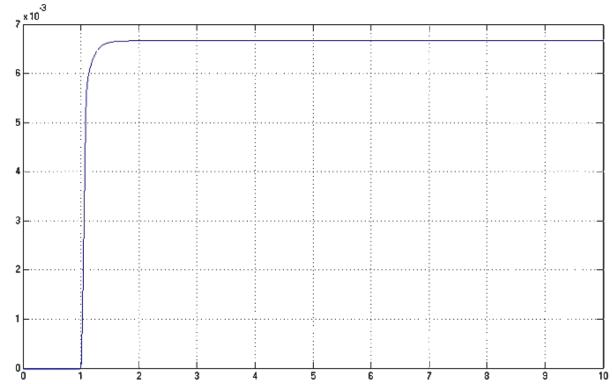

Figure 6: Foot Switch Step Response (Force = 0,1N) Ideal Model

If the activation force is increased up to 0,1N (as suggested by the manufacturer), the total displacement is around 6,75 mm, bigger than the run, so that the switch activates.

After these results, a set of simulations was performed in order to study the effect of the different elements of the mechanical model on the overall step response of the system. Such simulations included the study of the effect of the switch spring characteristics (by sweeping the values of the elastic and viscous elements, while keeping constant the values for the rest of the parameters) and that produced by the dead-spaces (again, sweeping these values, while keeping constant the values for the rest of the parameters).

The results of these tests made evident that the variation of the dead space of the second segment (L_2) does not significantly affect the overall response.

On the other hand, an increase on the viscous component of the switch actuator (B_1) may slow the system, reducing the system overshoot.

After this phase, our work focused towards the study of the effect of the different mechanical parameters of the switch over its sensibility to involuntary movements and tremors, as seen in figure 7.

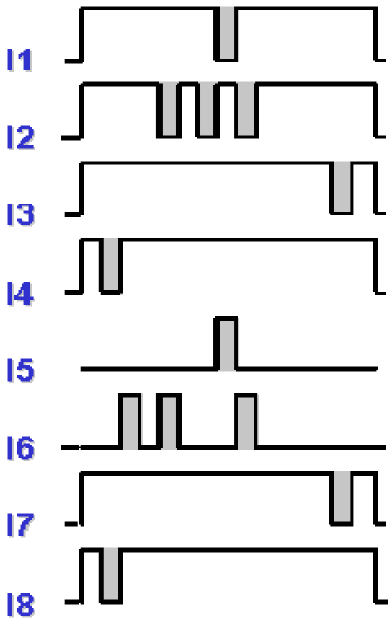

Figure 7: Non-desired Switch (De)Activations

The most common types of no-desired switch response after involuntary movements or tremors may be classified as follows:

Notched Activation (I1 to I4): These are produced when an involuntary movement produces a non-desired release of the switch while it is supposed to keep activated.

Popup Pulses (I5 to I8): These are originated when an involuntary movement produces a non-desired activation of the switch while it was supposed to be non-activated.

The next simulation shows the effect of the switch parameter when a I1 notched activation occurs. In this case, two rising edges may be detected by the AD controlled by the switch, leading to a momentary disconnection of the device (in case of direct control) or to the selection of an additional option (in case of scanning control).

The switch properties are summarized in table 3, and the input signal was a step of force of 1N, with a notch of 0,1 s.

Table 3: Model parameters for notched activation

Type	Variable	Value	Units
Mass	M_1	0,1	Kg
Dead-space	L_1	0,005	M
ElasticConstant	K_1	135,34	N/m
Viscous Constant	B_1	5	$N \cdot s/m^2$
Mass	M_2	0,001	Kg
Dead-space	L_2	0,001	M
ElasticConstant	K_2	30,97	N/m
Viscous Constant	B_2	2	$N \cdot s/m^2$

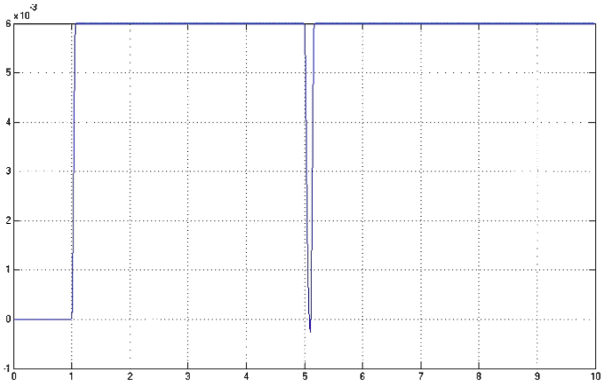

Figure 8: Effect of Notched Activation
Real model

As may be seen, the output signal follows the input, leading to a non-desired operation of the assistive device controlled by the switch. In order to minimize this effect, the values of B_1 and B_2 where increased (up to 30 and 15 $N \cdot s/m^2$, respectively) making the system response slower. The results of this simulation may be seen in figure 9.

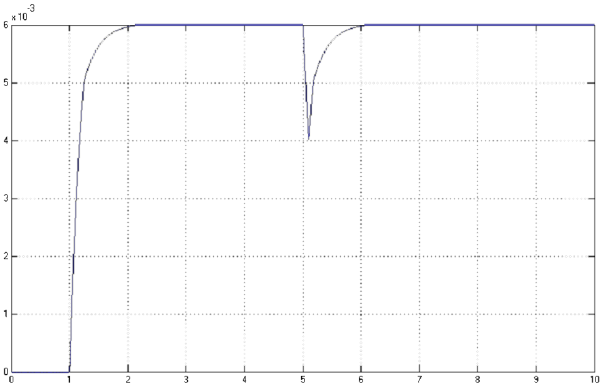

Figure 9: Effect of Notched Activation
Real model

As it may be seen in figure 9, this last change did no improve the system output, since it enlarged the time of the notch on the activation. Other trials included, decreasing the value of M_1 but the result of the simulations demonstrated that the achieved results were not significant.

After the application of the previously explained methodology to all of the types of Non-desired Switch (De)Activations, the following results emerged. While short popup pulses (less than 200ms long) may be eliminated by increasing the mass of the switch actuator M_1, notched activation pulses cannot be eliminated by these means.

Discussion

The developed simulation models have proved useful for the analysis and design of electromechanical switches.

On the one hand, a previous evaluation of the final user is recommended, in order to determine the optimum switch placement, maximum force that the disabled may exert at that location, the maximum displacement and activation time, and finally, the presence of involuntary movements and tremors.

On the other hand, a standard outline of this process may be proposed as follows:

- Use known standard values for all of the model parameters. If this not possible, use measured values.
- Set the required force for activation to the 80% value of the one that the disabled used may exert.
- Adjust the elastic constant of the spring in order to grant the complete run of both of the switch dead spaces.
- Adjust the value of the activator mass (M_1) in order to minimize the influence of short popup pulses.
- Step response is reanalyzed in order to assure proper operation.

This approach, however, presents some limitations, as it may increase the size of the switch, reduce the response speed and raise the cost. Additional techniques such as pulse analysis algorithms (built-in within the embedded controller at the assistive device) may reduce the influence of these activations by means of temporal debugging of the incoming pulses and/or adaptive filtering. Since most of these just use software resources, an increase on the final cost should not be expected.

References

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[2] GARCIA-PÉREZ, A. (2004): 'Switches for the Disabled', M.Sc. Dissertation. (Universidad Politécnica de Cartagena, Cartagena).