Hand Restoration System using Surface Electrode Array Stimulation

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Introduction

Common stroke consequences affecting hand function are:
paralysis, finger extension deficit, muscle weakness, over activity of flexor muscles and spasticity.
Successful rehabilitation consists of performing large numbers of high-intensity, repetitive motions.
Main difficulties in stroke rehabilitation:

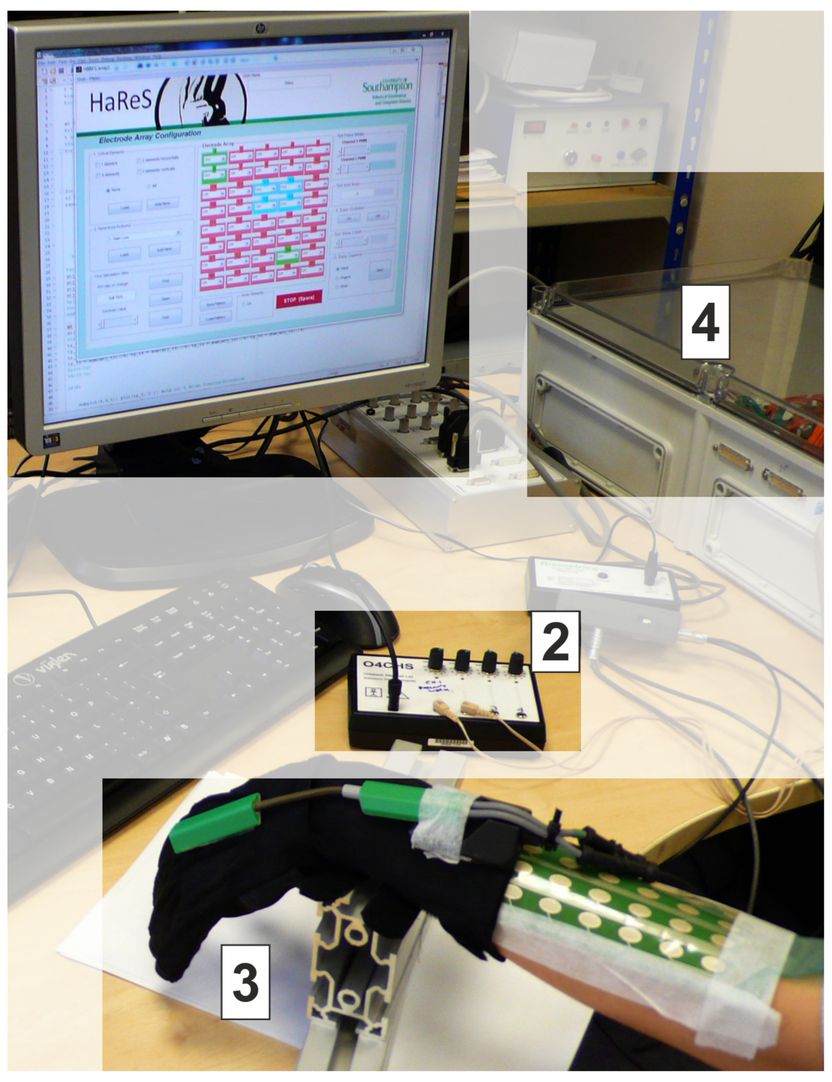
- Most of stroke patients can hardly move
- Traditional therapies are expensive and difficult to manage due to limited amount of resourses compared to the number of patients
- Study indicates that only 31 % of patients actually perform exercises as recommended by therapists.

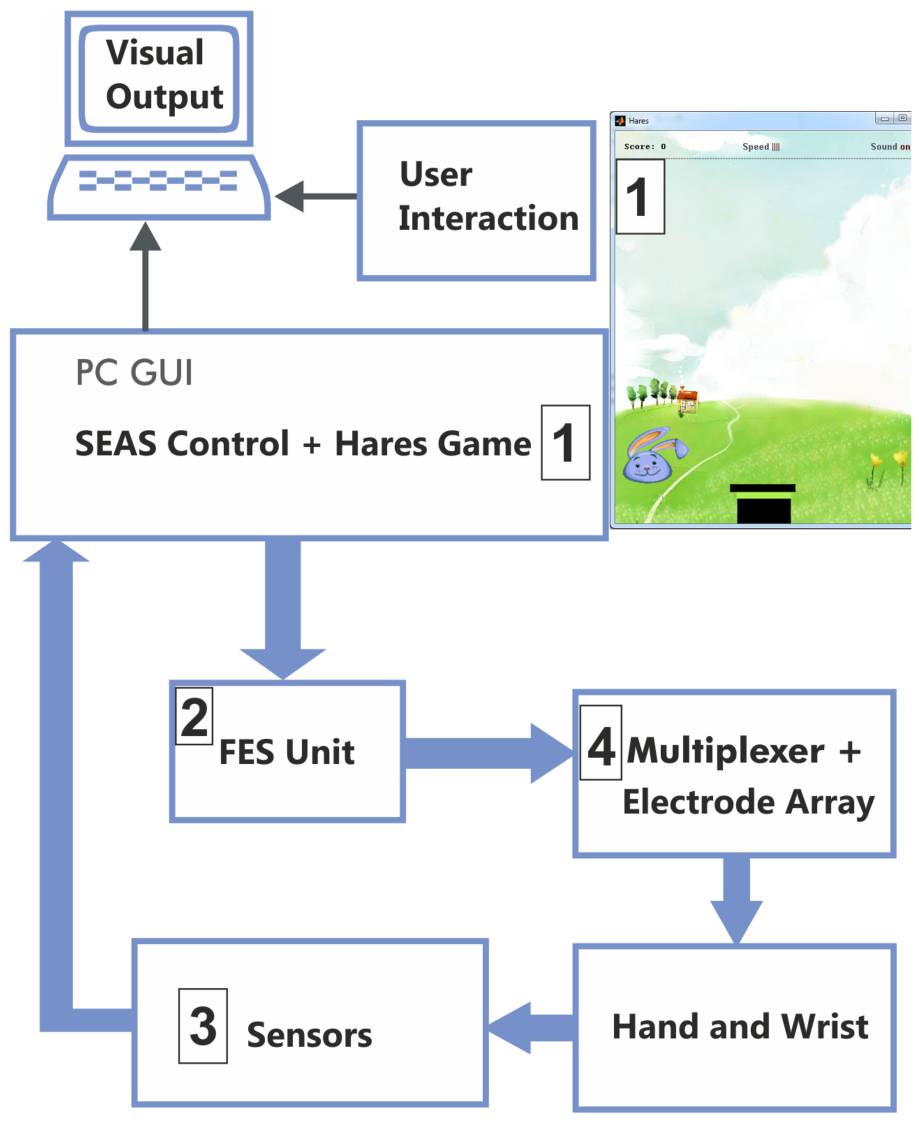
There is a pressing need for developing novel, mobile solutions

- There is a deficiency of effective stroke rehabilitation systems for restoration of hand function, with most existing rehabilitation methods concentrating on regaining reaching function in the arm [1].
- Consequently, the recovery of the wrist and fingers movement has a delayed progression compared with the rest of the upper-limb.
- Enabling home-based hand rehabilitation systems, motivating for patients may reduce costs and increase intensity and effectiveness of therapy.
- Such systems should be: non-invasive, easy to use, motivating and interactive and with simple and clear feedback to the patient.

Hand Rehabilitation System (HaReS)

- HaReS has been designed for functional and motor rehabilitation of fingers and the wrist in the early stages of recovery.
- It consists of ergonomic wearable sensors (5DT gloves and goniometers) and game-based (Hares game) training environment that provides feedback to the patient.





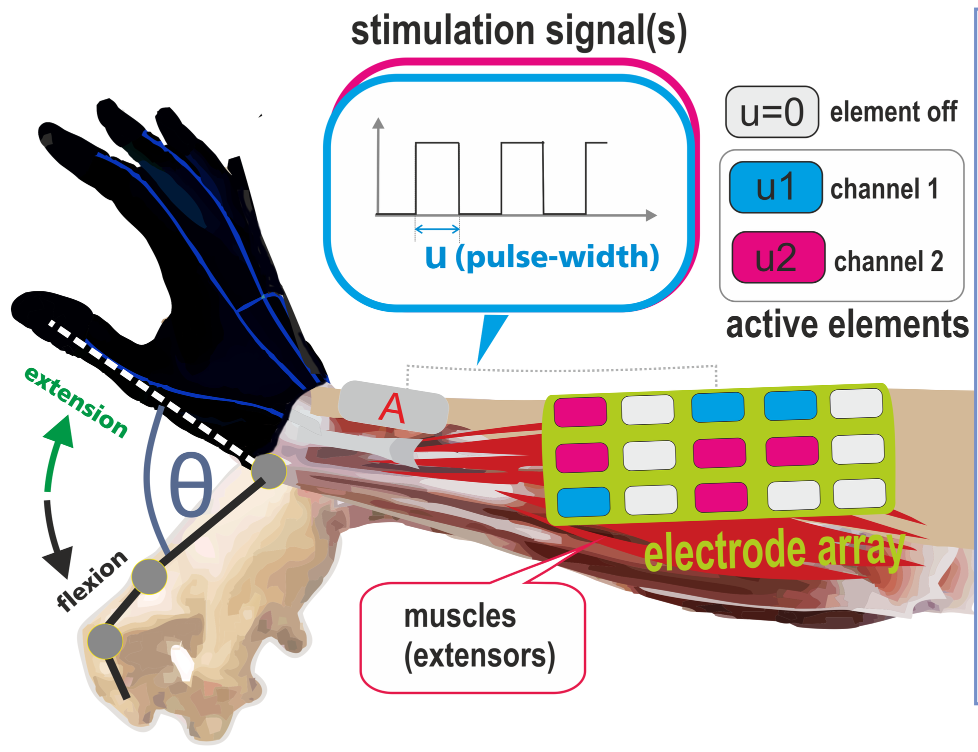
- Hares game has been designed for a wide group of stroke patients to increase the motivation and support them in performing large number of repetitive movements.
- The cognitive and motor task of the game is to control position of the pad (hat) in such a way that the number of caught objects (hares) is maximized.
- Different scenarios of the game and levels of difficulties are defined by three aspects: the number of objects falling, the position of the objects on the screen (including spatial configuration of the objects), the speed of falling.
- While playing a game, the patient interacts with a virtual universe, which receives player's responds and control inputs (hand movements) by changing its status. Information regarding the outcome of the interaction is then conveyed to player (i.e. scoring), and eventually gathered and used by him/her to decide what to do next.
- A set of reference motor tasks is specified and used in game control, i.e. wrist extention/flexion causes pad movement to the left/right.
- The key element of the system is Surface Electrode Array Stimulation based control of hand and fingers movement, which can provide assistive stimulation to a patient performing a task with impaired hand.

References

[1] C. T. Freeman and E. Rogers, A.-M. Hughes, J.H. Burridge and K.L. Meadmore Iterative Learning Control in Health Care: Electrical Stimulation and Robotic-Assisted Upper-Limb Stroke Rehabilitation In *IEEE Control Systems Magazine Vol. 32, pg 18 -43, 2012*

[2] A. Soska, C. T. Freeman, T. Exell and E. Rogers, Surface Electrode Array based Control of the Wrist and Hand In *IFAC International Workshop on Periodic Control Systems (PSYCO'2013), France 2013*

Surface Electrode Array Stimulation (SEAS)



How SEAS works

SEAS induces movement in impaired limb, by sending a series of electrical pulses to associated skeletal muscles through activation of chosen elements of electrode array (stimulation pattern).

The movement is controlled by modulating the control input u (pulse-width).

Multi-channel stimulation enables activation of selected elements with different levels of pulse-width .

Virtual Elements based Optimisation

The method utilises the concept of Virtual Elements (VE) with a constrained optimisation approach for multi-channel SEAS to find stimulation patterns and pulse-width values which produce the required posture, y_d. These can be expressed as in [2]:

$$\textbf{minimize} \;\; f(u), \quad f(u) = \|y_d - g(u)\|_2^2 \tag{1}$$

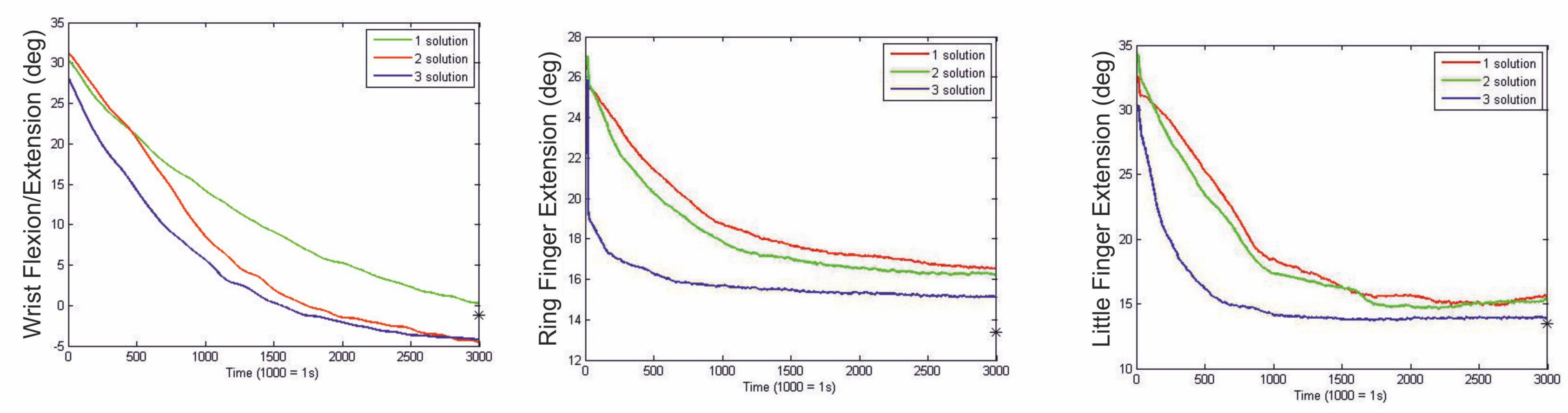
subject to constraints on u required to ensure that the experimentally applied stimulation u_i is practically achievable given the limited number of stimulation levels available. This necessitates that:

$$u_i \in \mathcal{U}_n, \qquad 0 \leq \mathcal{U}_{n,j} \leq 300, \qquad j = 1, 2, \cdots, n \tag{2}$$

where $\mathcal{U}_n$ is a set with n non-zero distinct elements with $\mathcal{U}_{n,j}$ the j^{th} element. Here n is the number of channels supported by the hardware and the function $g(u)$ is identified during experiment.
Virtual Element emulates single array element and can be defined by the number of single elements of electrode array and their spatial configuration.
VE-based method of finding best stimulation patterns can be more effective and practical for wide group of patients Appropriately selected VEs can increase the practical level of selectivity and accuracy of the stimulation.

Experimental Results

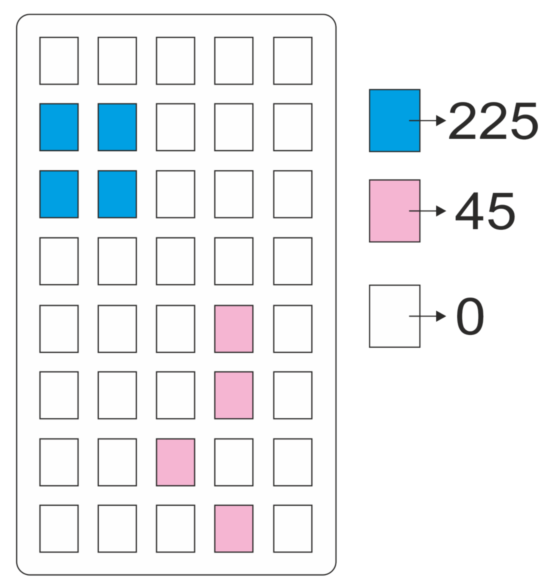
The procedure was undertaken on 3 unimpaired participants who each provided no voluntary effort. The clinically relevant task was to move the hand from an initial position which emulates a typical posture of a spastic hand to a final posture which represents the opened hand.



The method was used with 2 channel stimulation and three types of VEs. These are: 2-single elements oriented horizontally, 2-elements oriented vertically and 4 - elements respectively. The best stimulation pattern was tested 5 times and the mean error norm results are shown in table. The optimal stimulation patterns differ from person to person.

No.	Normalized Error	Standard Deviation
1.	0.3875	0.0335
2.	0.3538	0.0222
3.	0.3080	0.0530

Optimal pattern for No.1 participant



Conclusions and Future Work

A novel method of finding the most effective stimulation patterns for multi-channel stimulation has been developed to enable the participant to perform predefined hand gestures. The algorithm is currently being extended to the adaptive approach with different models of $g(u)$. After evaluation on both unimpaired as well as stroke participants, the best approach will be incorporated into the final version of HaReS and the effectiveness of the system will be tested in clinical rehabilitation trials.