Using the Model of Motor Planning in Self to Recognise Motor Action in Others

Summer Research Fellowship Program 2016

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EMBLEMS

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Preface

The ventral premotor cortex of our brain houses the motor neurons that are involved in the functioning of motor commands. A subset of these motor neurons is thought to form the mirror neuron system of the brain. These neurons have been seen to get activated not only when executing an action but also when observing the same action being performed by other individual(s).

There is a certain possibility that this nature of cognitive architecture has evolved over the course of time to conserve the resources and substrates required for the efficient execution of the process of action and learning and that feelings of emotions like empathy and others may just be nothing but a very useful consequence of this unique kind of architecture.

Through our research, we attempt to find the validity of the above stated possibility by creating a model for recognising the motor actions of another individual by using the model of action recognition, planning and execution in self.

We are approaching this from various aspects, the progress of which will be elaborated in detail in the following pages of the report.

Best efforts have been made to explain the complicated part of my experiments and studies clear, concise, comprehensible and to the point.

INTRODUCTION

Theory of Mind:

The ability of attributing mental states- beliefs, intents, desires, knowledge etc. to oneself and others and to understand that the others also have mental states, beliefs, desires, intentions, purposes and perspectives that may be identical or different to their own is what can be generally described to be the theory of mind.

Theory-theory and simulation theory are the two major competing theories regarding the emergence of the theory of mind.
Theory theorists suggested that individuals develop theory of mind over the first few years of their existence by testing the various given rules regarding the functions of the objects with which they interact as a child and eventually come up with more and more composite theory of what others are thinking, observing and interpreting about the surrounding people and environment.

A popular theory proposes theory of mind to be nothing but a simple outgrowth of our ability of interpretation of actions, both by the self as well as b the other through extensive and non-extensive internal simulations of the concerned action. By creating an internal simulation, individuals can step into the mental shoes of another person and understand their emotions, thoughts and intentions.

The theory of mind impairment describes the difficulty someone has with perspective interpretation, also sometimes referred to as mindblindness. This means that individuals with a ToM impairment would have difficulty experiencing phenomena from any other perspective than their own. Individuals who experience a ToM deficit have difficulty determining the intentions of others, lack understanding of how their behaviour affects others, and find difficulty with social reciprocity. ToM deficits have been observed in people with autism disorders, people with schizophrenia, people with nonverbal learning disorder, people with attention deficit disorder, persons under the influence of alcohol and narcotics, sleep-deprived persons, and persons who are experiencing severe emotional or physical pain.

Theory of Mind is one of the most vital steps of the process of cognitive developments in the infants. Most investigation of theory of mind development has focused on **3** to 4 year old children. It is evident that between the ages of **3** to 4 there is rapid development in this area. Three year olds typically fail to recognize their own and other's false-beliefs (holding beliefs that conflict with reality).

Self-other recognition, imitation, understanding intentions, t.o.m, joint attention, goal-directed action, co-operation are essential stages of cognitive development in infants. These stages are made possible by the actions of a special set of neurons called the *mirror neurons.*

Mirror Neuron System:

First found in the 1980s and 90s by Giacomo Rizzolatti's team in the lateral prefrontal cortex of the macaque monkey, these subset of motor neurons have been observed to get activated not only when performing action but also when observing another performing an action.
Hypothesises suggest its emergence to be a result of associative learning and self-other cognition and also that perceptual development leads to the emergence of the mirror neuron system.
The mirror neurons have thus been widely used to explain the functioning of complex cognitive questions of empathy, theory of mind, self-awareness, comprehension of emotion, imitation, and even autism.

In humans, brain activity consistent with **mirror neurons** has been found in the premotor cortex, the supplementary motor area, the primary somatosensory cortex, and the inferior parietal cortex. These variety of visuospatial neurons are the fundamentals of human social interaction.
It has been speculated that mirror neurons may provide the neurological basis of human self-awareness. Mirror neurons can not only help simulate other people's behaviour, but can be turned "inward" to create second-order representations or meta-representations of one's own earlier brain processes. This could be the neural basis of introspection, and of the reciprocity of self-awareness and other awareness.

The mind-body-society relationship has been always an appealing question to human beings. How we identify our body and use it to perceive our "self" and an "other" is an issue that has fascinated many philosophers and psychologists throughout history.
One of the most convincing solutions to the question has been the Body-ownership model or the Model of Illusion of Body Transfer

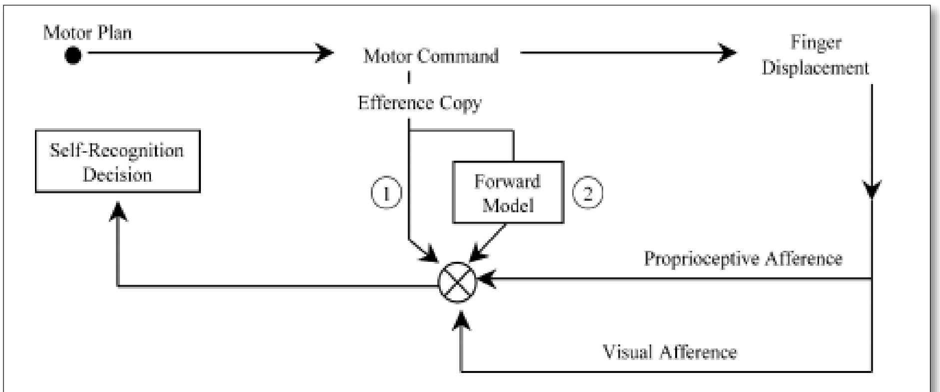


Fig. 3. A cognitive architecture for self-recognition.

Figure: Body Ownership Model for Self-recognition
(source: A specific role for efferent information in self-recognition Manos Tsakirisa,*, Patrick Haggarda , Nicolas Franckb,c, Nelly Mainyb , Angela Sirigub)

It was observed that both proprioceptive afference (i.e. confirmation of action by feeling) and visual afference (i.e. visual confirmation of action) ombine to contribute to total perception, though on occasions more only visual afference, devoid of any tactile feedback was enough for near-complete perception.

V.S.Ramachandranand his team concluded from the observation titled *Immediate Interpersonal and Intermanual Referral of Sensations Following Anesthetic Block of One Arm* (Laura K. Case, MA; Reid A. Abrams, MD; Vilayanur S. Ramachandran, MD, PhD*)* that Patients with brachial plexus blocks experienced touch sensations in the anesthetized arm when watching another person's arm being touched or when the contralateral intact hand was touched
It was concluded that the final emergence and localization of sensations And perception result from the co-activation and mutual inhibition of 4 systems like afferents from the region sensetized, tonic inhibition from null signals emerging from the unsensitised area, activation of the MNS while watching others and inhibition of MNS output, preventing it from reaching the threshold for conscious experience.

We have tried to model a similar situation of learning through body ownership and laterally inhibited mirror neuron system that gradually lead to associative learning and actions.

Experimental Studies and Observations

Matter, Method and Stages of Progress

.
We have done a very detailed and comparative study of the various research papers, journals, and thesis from the likes of Baron Cohen, Ramachandran and others in the fields of *mirror neuron system*, *theory of mind, neural networks, artificial intelligence.* We also read on the aspects of the sensory, perception and simple gesture modules of modern robots and also got accustomed to the required tools and libraries of MATLAB 2015.

Then we designed a model with computational neural network and implemented it to test if it can perform the task of identifying the action using activation of units that represent or cause the action itself.
In this design the lateral inhibition assures that only a small subset is active to represent the motor action and positive feedback using error along with noise assures activation of different units until only the correct units are active.
Inputs from the n-units along with a certain amount of noise are passed through threshold functions and a decoder to convert it into binary instruction string which is then fed to action generator. An error calculator then generates the difference in angles between self and observed and that error is then fed back to the input.

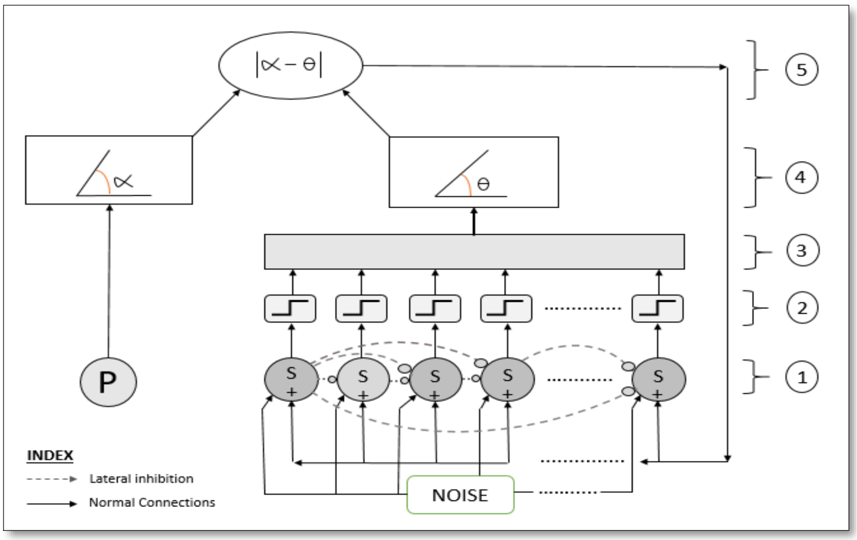


Figure:
A Schematic diagram of our model of neuronal units in continuous comparison between self action with observed action and attempting to converge to match the self action (**(4a)**) predicted action (**(4b)**).

INDEX
((1))- The Inputs: Inputs of the model self. (S) being inputs of model self. (P) being input of observed self.
((2))- Threshold Functions which convert input to 0 or 1 depending on action. ((3))- Decoder
((4))- Action State where instruction function are fed in resulting in state change, change of angle in this case.
((5))- Error Generator where the difference between the angles are calculated and fed back to the input.

The Simulink library, the neural network toolbox and programming platform of MATLAB 2015 are being used for our purpose. Inputs from the n-units along with a certain amount of noise are passed through threshold functions and a decoder to convert it into binary instruction string which is then fed to action generator. An error calculator then generates the difference in angles between self and observed and that error is then fed back to the input.

At first we attempted to realise our model by using the Simulink library and toolbox of the MATLAB 2015. After acquiring a basic knowledge of Simulink through study and repeated trials and errors, we came up with a relatively appropriate and fitting Simulink model of our actual thought model of the architecture of the MNS related imitation and learning.

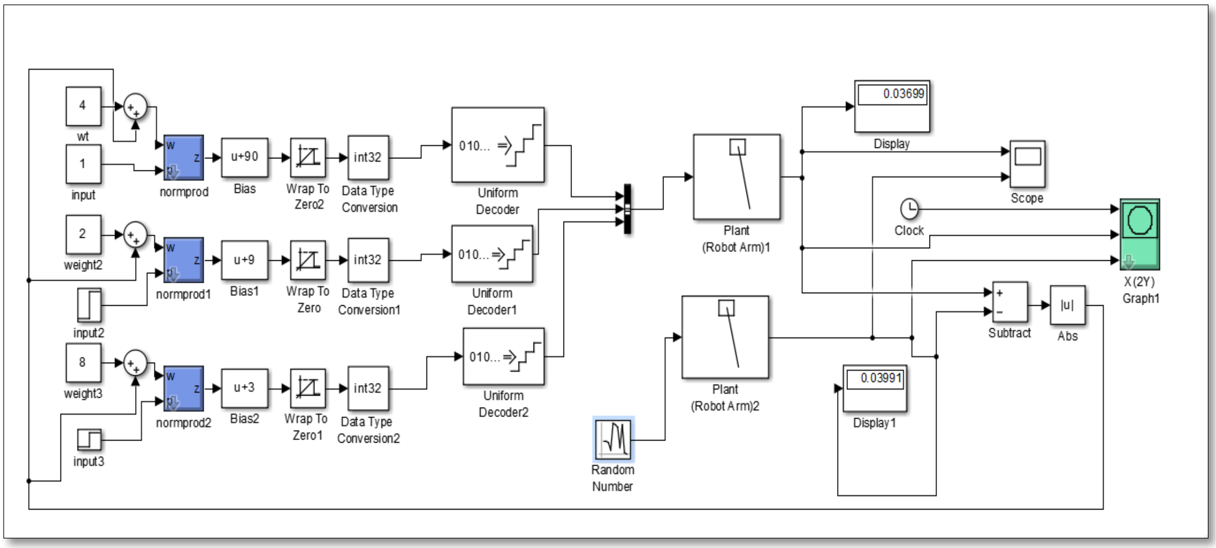
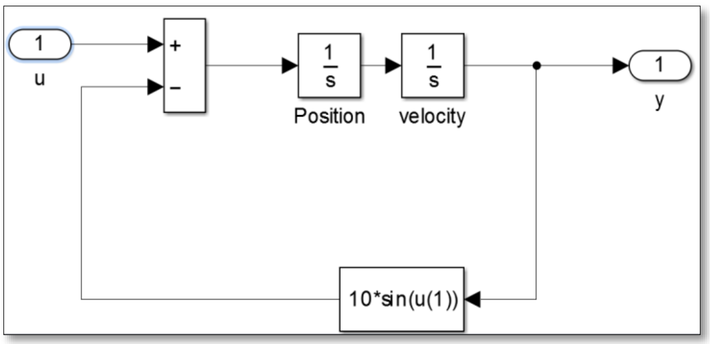


Figure: Simulink model of our model of mirror neural unit based learning of one randomised robot arm with a learner arm having inputs of neural units firing with a positive feedback continuously till equilibrium



The Plant robot arm mechanism that calculates the movement of the robot arm with respect to the inputs.

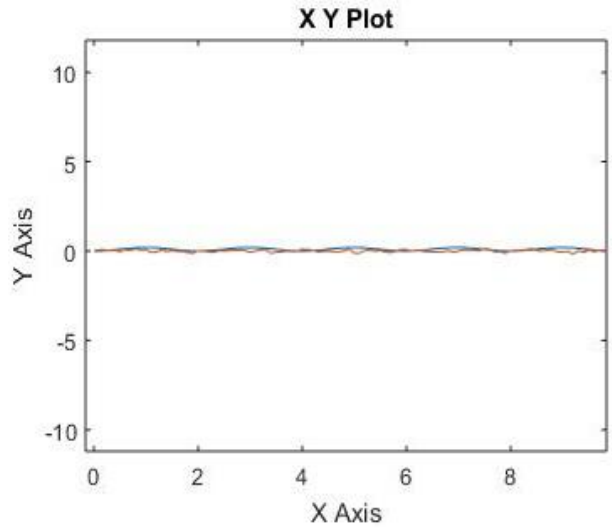


Figure:
Graph Generated from the Simulink design shows the near correct and matching action trajectories of the modelled neural network in Simulink.

Though our efforts with Simulink had relative successes, the two trajectories never converged to equilibrium and showed inconsistencies in certain conditions due to some decoder problem in toolbox.

Due to its limitations with modifiability to suit our required conditions, we also parted our ways from Neural Network toolbox in MATLAB 2015.

It was then that we decided that it would be best if we hard code our model using the programming platform of MATLAB 2015 and use optimisation approaches to find out the most optimal subset of units that will be required to be activated to act to match another independent action to fulfil our purposes of validating our model of architecture.

The optimisation code for the error cost function, where we try to minimise the difference between actions to a minimum before feeding it to the actual optimisation function is as follows:

Here<`optm=((optm*L+unifrnd(0,tht,1,N)+fbk)>thrshld);`> is the input at each successive iteration and < `ERRN=norm(optm-posn1)` > is the error calculator

```
function[ERRN]=mt1f(N,alph,bta,tht)
N=3; N=3;
L=randn(N);
thrshld=0.15*ones(1,N);
posn2=[0 0 0];
posn1=[0 1 0];

fbk=0;
n=1;
```

```
optnw=0;
optprev=1;
FLG=5;

alph=randi([1,10],1,1)
tht=rand(1,1)
bta=randi([1,10],1,1)

L=(ones(N)-eye(N))*alph;
optm=zeros(1,N);
opi=eye(N);

for i=1:1:N
   optm=opi(i,1:N)
    while FLG>0


    optm=((optm*L + unifrnd(0,tht,1,N)+fbk)>thrshld);


    optprev=optnw;
    optnw=optm;
    if sum(optprev==optnw)%==N
        FLG=FLG-1;
    else
        FLG=FLG+1;
    end
    ERRN=norm(optm-posn1)
    fbk=ERRN/(2^N);
    errstr(n)=ERRN;
    n=n+1;


    end
    ER(i)=ERRN
end
plot(errstr)
```

```
%the main opti code

N=3;
posn1=[0 1 0];
n=1;optnw=0;optprev=1;
FLG=5;

alph=randi([1,10],1,1)
tht=rand(1,1)
bta=randi([1,10],1,1)

while FLG>0

    f=fminsearch(mt1f(N,aph,bta,tht),1,[],posn1)
    if sum(optprev==optnw)%==N
        FLG=FLG-1;
    else
        FLG=FLG+1;
    end
    fbk=bta*f;
    errstr(n)=f;
    n=n+1;
end
plot(errstr)
```

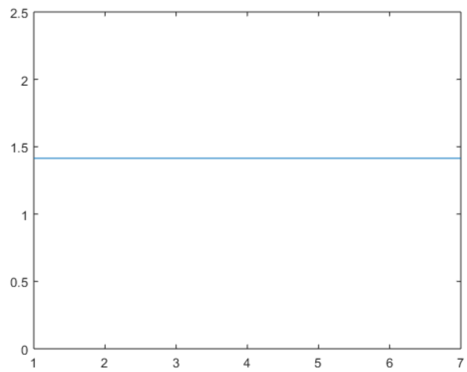


Figure: Corresponding plotted figure

Re-approaching Ramachandran

For the actual progress of our research and study, it is necessary for us to have a more proper knowledge of emotional and perception based response to social stimuli in humans. Thus it became necessity for us to have a verification of Ramachandran's conclusions about almost individualistic sensations through the mirror neuron system and the inhibitions due to null response from the cells.
Thus we decided that it was necessary to try and approach the problem in a different way by doing the experiment much differently.
Our experiment will also come in handy in many things beyond this.

Following is the most feasible and best suited protocol that we had chalked out

Protocol of experiment

Purpose: To test Ramachandran's observation on anesthetised hand on a larger sample space, i.e. on more number of subjects compared to his insufficiently less number of subjects (six in number), no matter how much it is claimed to be repeatable.

Materials: Healthy persons to be experimented upon; visual display tool which will display hand that is under the table and screen the movements through the camera system, and will be able to have another input affecting them; a screen with clip of a character getting hurt; a galvanic skin response measurer or gsr like sensory response measuring devices.

Methods:
1) First we test the hand of the subject to record normal sensation and response to touch sensation on both the hands.
2) Keep both hands under a table beneath the visual display screen.
3) The display device, preferably with a camera will simultaneously display the movements of the hands back to the user to see.
4) We test the hands again to record normal sensation and response to touch sensation on both the hands.
5) One by one the displayed hands is hurt on the display screen and the subjects reactions are recorded by using the GSR or other GSR like devices like pupil dilation checker, heart rate monitor etc.

6) Then one of the displayed hand is made to not correspond with the subject's respective hand such that there is a loss of the one-one mapping of the hand to its display.
7) Then again the hurting procedure on the display screen is repeated and the response is recorded with the sensation response measurer.
8) Next, the subject is made to watch a clip on another screen of a character being hurt in the left arm and the right one.

Thus we will try the two cases.

Control: The control1 will not be subjected to emulation of anesthetised hand so that we can ensure that there is not a conflicting observation on the second observation in the case of a non-anesthetised hand.

Data Interpretation: PreExpt:-V.S.Ramachandran's observations suggest that the response when the hand is anesthetised will be more than when it is not anesthetised.
Following our procedures of experiment we should observe that prior to loss of one-one correspondence, both the hands should have similar and near equal response at the GSR.
Then, if the left hand is and the hurting procedure is done on the screen we expect that the GSR will be more for the one-one corresponding hand because of the direct mapping between the actual left hand and the displayed one rather than the non-mapped hand and its respective displayed one.

While for the case of the clip on the second screen we expect that the GSR response from the non-mapped hand will be more than that from the one-one mapped hand (by Ramachandran's anesthetised hand observation).
This contradictory responses on GSR and the likewise devices is what we logically expect to happen.

Design Literature

For the experiment, it is very necessary that we have an efficient response measuring device. It is with that purpose in mind that it was decided to try and make a galvanic skin response.

These measuring devices use the body sweat from emotional stimuli to use as a measurement of varying resistance and thus recored varying scales of response.

Though controversial we did an extensive research of literature and the works on sensory response measurements like galvanic skin response available in the domain.

Then after repeated trials and errors we fixed on a satisfactorily stable and appropriate circuit output from which was to go to an input port of an Arduino UNO which will be further connected to a computer for proper recording.

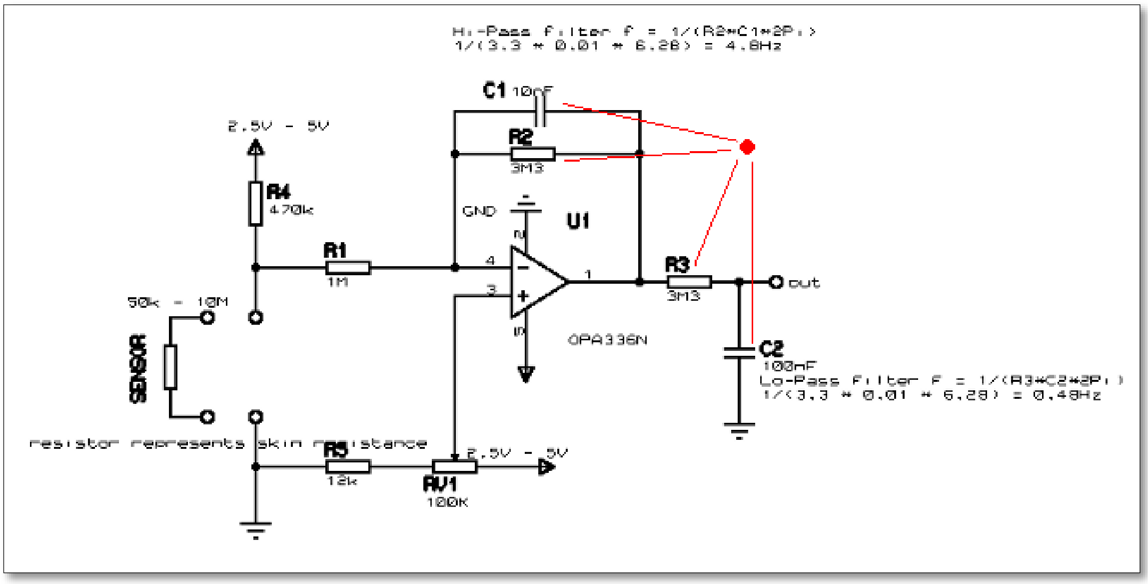
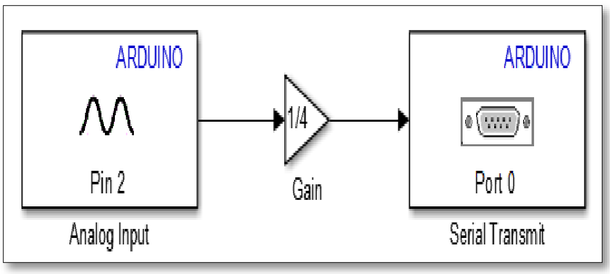
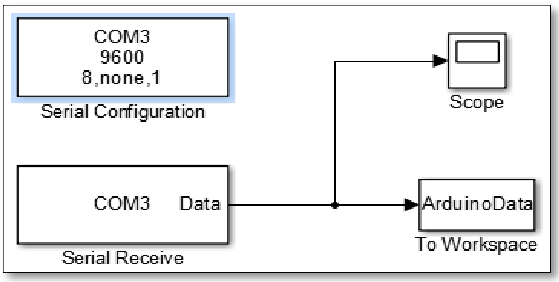


Figure: Closest representation of our modified GSR circuit (source: drumanart.com/GB_gsr.html)





FigureA:model that sends data to the UNO. **FigureB**:Model to collect & plot data(soure:Mathworks)

Actual Design

Figure: The different electrodes that i had to make for use. Though the ring electrode showed initial response, it was inconsistent due to proper grip with the fingers. The velcro electrode performed better and more dependably for a longer span of time before it became saturated with sweat and there. Atlast the finger-tip metal electrodes were narrowed down upon and used.

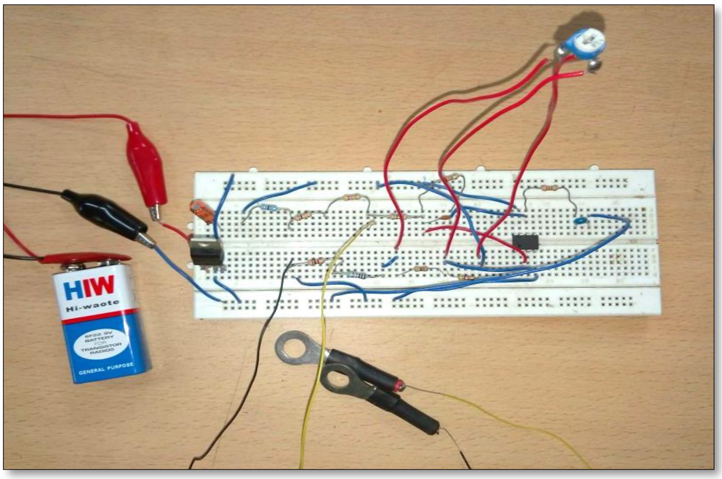


Figure: The complete circuit without the Arduino UNO. We can see the battery, voltage regulators, potentiometers, resistances, capacitors, amplifiers, and the last type of electrodes that I made.

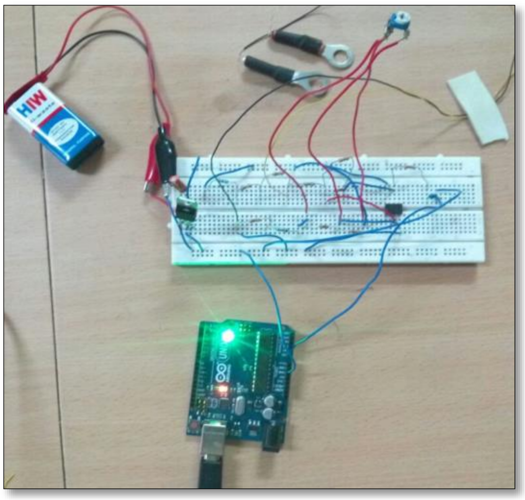
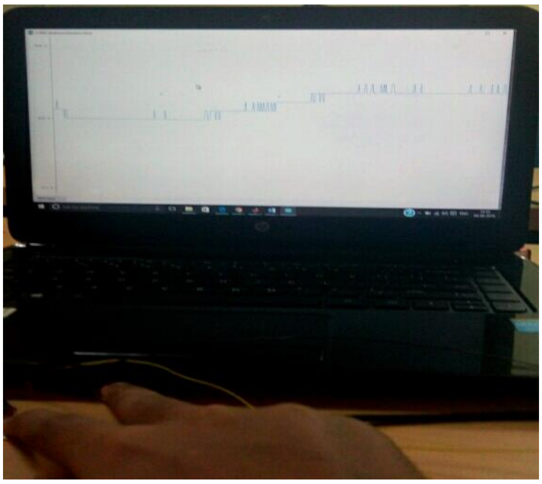


Figure: Circuit with connections to the arduino UNO board with the data collecting model deployed to it. The active green LED signifies that it is connected to the computer and the yellow LED signifies that the data collecting arduino/Simulink model is deployed to the hardware that is in this case, the Arduino UNO. The output from low-pass filter is fed into the COM3 of UNO and the required ports are grounded at the UNO Ground.

During the experiment, subjects were asked to be in contact with the electrodes (wear the electrodes) and their responses to stimuli as well as in normal conditions were recorded. Subjects were pinched minutely time and again, made to watch shocking scenes and their responses were recorded on the screen through the serial plotter. The process was done with full consent and consultation of the subject at each step of the experiment process.

```
void setup() {
// initialize serial communication at 9600 bits per second:
  Serial.begin(9600);
}
// the loop routine runs over and over again forever:
void loop() {
  // read the input on analog pin 0:
  int sensorValue = analogRead(A1);
  // print out the value you read:
  Serial.println(sensorValue);
  delay(1);        // delay in between reads for stability
}
```

Code: Arduino Code to plot the inputs in Genuino (see figure: where the response is being recoreded in Arduino)



But what we noticed with using the Arduino and data collecting was working properly and efficiently. But while plotting of serial data, probably due to mismatch in the scaling on a few instances, we were unable to derive proper plots to responses, despite several other tries.

In science, we need the results from an experiment to be consistent over instances. Thus like with our electrodes we had to adjust our approach to response recording to fit the needs too.
That is when we decided to abandon the Arduino for the time being and try the same procedure of collecting and plotting data by using an Cathode Ray Tube oscillocope. (TEKTRONIX 2014C)

The only change that happened in the circuit was the ground of UNO was replaced by ground of oscilloscope and output from the low pass filter was fitted into the input port of oscilloscope.
It immediately started showing satisfactory results with properly noticeable deviations on most instances over a larger period of time.

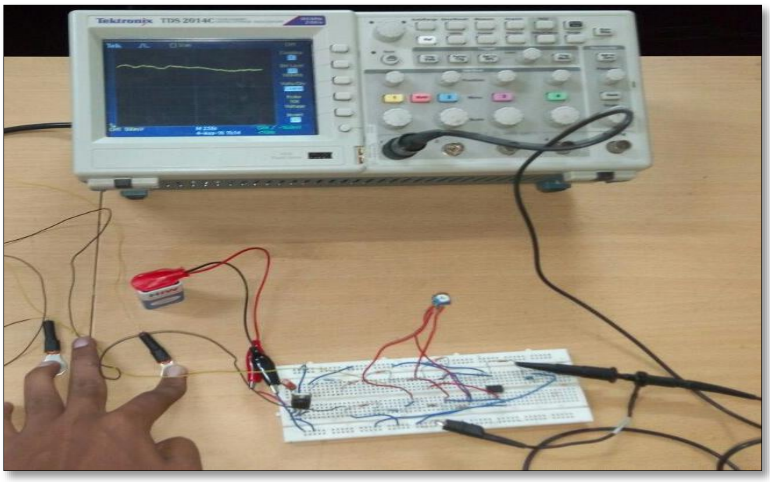


Figure: Oscilloscope reading using the finger electrodes. Even the slightest deviations while breathing and relaxing is reflected in the observations of the plotting on the oscilloscope.

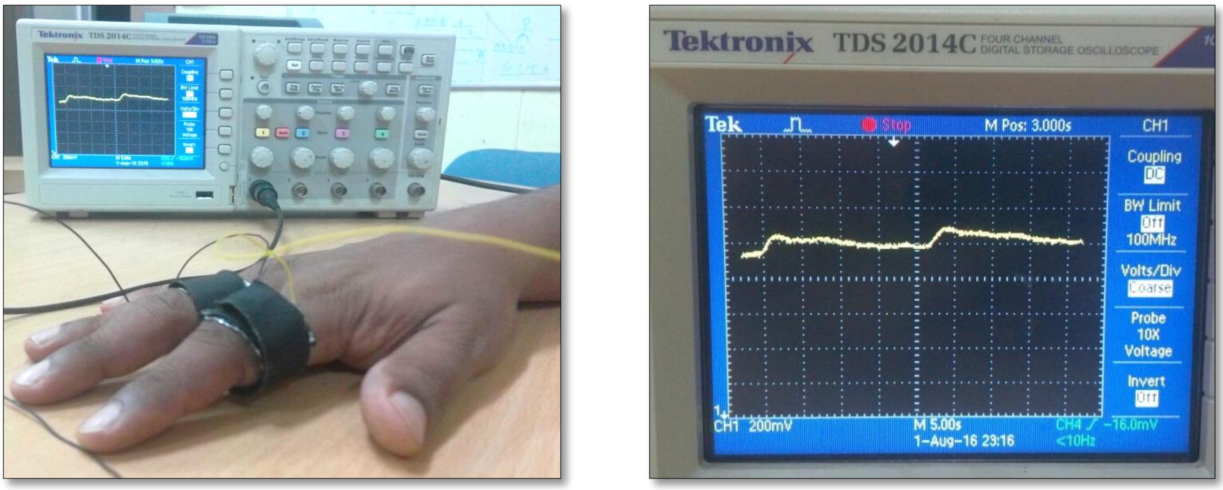


Figure:Subjects hand as he is pinched and his response his recorded in oscilloscope. The sudden peaks signify the sudden shock/ pain. The succeeding slope signifies the gradual relaxation.

It is very important to note that we have observed that in our circuit after a certain period of time the potentiometer got saturated at some intervals while recording obserbvaations for the various subjects to verify the correctness our GSR. Thus it is required that the potentiometer be readjusted at those instances so that we can continue with the experiments.

A lot depends on the correct working of the electrodes for correct measure of the GSR. Like in our case, our electrodes evolved from being ring like to being a velcro electrode to become a finger o-metal-ring electrode because the ring electrode was inconsistent. The velcro elctrode worked optimally for a very long time but it kept getting saturated with sweat and thus becoming less responsive. Thus we followed it up with an o-metal-ring electrode that tackled both the problems and showed moderately consistent results.

But as a science experiment we should assure the optimal functioning at every instance. Satisfactory outcomes at some instances and unsatisfactory outcomes in few others is not scientific enough to solve the case that we want to solve

Hence we want to also try and approach the problem with another alternative sensory response measure like heart rate monitor, pupil dilation monitor, salivary cortical response to test if we can record the results better.

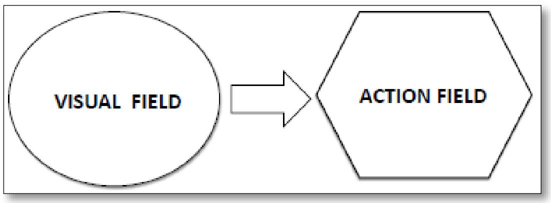
Discussions and Possible Future Works

Despite the advances, understanding the actual model of action learning and planning is still one of the most perplexing questions of cognitive science.

In our experiments, from the start we have had hinderances with our results on many stages. Simulink model with artificial neural networks did not converge totally to a complete equilibrium. We concluded that it was because of improper choice of decoder due to inavailability of proper decoder in the toolbox.
While coding our actions went into infinite loops without converging. It was figured out that it had happened due to the absence of lateral inhibitions in our initial stages of the code and development. It maybe also because of this that our Simulink model had faltered initially.
After introduction of lateral inhibition the results bettered and stopped getting into infinite loops and terminated finitely to better optimised answers.
We then realised that the input at the neuronal units as well as at the thresholds and the lateral inhibitions must be accompanied with a suitable coefficient which gives the most optimal solution.

Future Works:
This is only the initial stages of the project where we found out some of the most challenging obstacles of the project and we look forward to much progress in the coming days. We will work with an alternative sensory response measure and also set up the rest of the experiment that we have written down the protocol for. We have to experiment the more dependable set up on a larger sample space and progress to the more complicated parts of finding a relation between the different fields of cognition that helps in learning of motor action and motor planning.

Having implemented this we will have a cosine function between transformed coordinates of action to the premotor representation.
Then we want to look into the ways that these transformations can take place between the visual field and the action field.



The transformation between the visual field and the action field is one of the most important factors of t.o.m & perception and hence one of the most vital component of our study.

Remarks and Conclusion

There is one very crucial difference between our research and the actual happenings inside our brain. It is that the isolated activation of a set of mirror neurons have no significance in real perception which happens when these set of neurons upon activation simultaneously and inevitably causes partial activation of some other set of neurons, emotional or linguistics being some of them. This is the key for wholesome perception.
In our research, we are not claiming that through our model we will achieve an autonomous and wholesome perception. But we are attempting to find a module which uses the model of motor planning in the self to recognise the system of planning in others.

Ramachandran had commented that he found the brain to be of a more dynamic picture in which different regions within a map are working in unision to be in a constant state of dynamic equilibrium with each other and with other brains. And through my studies as reported gere I have attempted to understand and put forward a portion of how we use the model of motor planning in self to recognise action in others. For that I have adopted various scientific, computational and mathematical and engineering methods, to find a model which may have emerged as an efficient use of the architecture of the use of substrates required in action planning and execution.

To conclude, it must be mentioned that the t.o.m, empathy, emulation, mirror neuron system, motor action recognition and learning remains a field of science that is still a relatively unexplored and less-researched field in cognitive neuroscience. Such that many scientific propositions that are made remain to be cross checked validly, thus requiring urgent and immediate attention and research to dispell the myths and fictions and fuel the progress of knowledge about the many areas of theory of mind and cognitive science.

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