Engineering Design Through Making

First Annual Progress Report
Submitted in the partial fulfilment of the requirement of the degree of
Doctor of Philosophy
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Indian Institute of Technology, Bomaby
August, 2017
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Chapter 1

Summary of Work done in First Year

1.1 Summary

The following table presents a summary of the work that I have done in the previous year. The table has been divided into four subsections where the first and the fourth section report the work that I have done in the First and the Second semester. The second and the fourth section report the work done between the semesters.

Table 1.1: Summary of work done in First Year

<table>
<thead>
<tr>
<th>Phase</th>
<th>Student</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jul to Nov, 2016</td>
<td>Course Work</td>
</tr>
<tr>
<td></td>
<td>• ET801: Introduction to Educational Technology</td>
</tr>
<tr>
<td></td>
<td>• ET806: Educational Technology Tools Lab</td>
</tr>
<tr>
<td></td>
<td>• ETE801: Cognition, Cognitive Development and Learning Theories</td>
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<td></td>
<td>Course Projects</td>
</tr>
<tr>
<td></td>
<td>• ET801 Gesture controlled car further changed to CoMBaT</td>
</tr>
<tr>
<td></td>
<td>• ET806 Course on Astrophotography in WISE</td>
</tr>
<tr>
<td></td>
<td>Other</td>
</tr>
<tr>
<td></td>
<td>• Seminar on Maker spaces</td>
</tr>
</tbody>
</table>
### Dec 2016
- Attended ICCE and T4E 2016
- Conceptualization and design of CoMBaT

### Jan to May, 2017

#### Course Work
- ET803: Advanced Topics in Cognition
- ET806: Research Methods in Educational Technology
- DE412: Human Computer Interaction Design

#### Course Projects
- ET803: Embodiment of tool use using CoMBaT for badminton players
- ET804: CoMBaT
- DE412: Conference Management System Design

#### Other
- Exploration of Myo band a physiological Sensors as a medium to enable learning by making the invisible visible.
- Wrote CoMBaT for ICALT 2017
- Contextual Enquiry for conference management application.

### Jul Aug, 2017
- Attended ICALT 2017, Romaina
- Exploration of Photography as medium for TELoTS
- Exploration of teaching Engineering Design Skills through making.

### 1.2 Projects

The following section discusses a few projects that were carried out as course projects in the first year.
1.2.1 CoMBaT

CoMBaT is a wearable technology based system that assists novices in learning of badminton shot techniques. Mastery of a shot technique is one of the important skills to be developed by novice badminton players. A shot technique includes the application of effort and swing of the arm. It is desirable for a novice badminton trainee to visualize the above parameters immediately after playing a shot. There has been an inadequate utilization of wearable technology for visualizing of these aspects. Myo armband, a wireless wearable device has the ability to sense the physical characteristics of effort and swing. CoMBaT, our Myo band based training system processes and plots the sensor data patterns of a badminton shot for reviewing the effort and swing. Additionally, in our system, Dynamic Time Warping (DTW) has been used as an algorithm to compare the trainee data with a reference data to provide corrective real-time visual and haptic feedback. This has been further described the design and development of CoMBaT along with a few studies in chapter 2.

1.2.2 Gesture Based Robotics Car

The idea of the project was to use a Haptic Controller is for the learner to be able to relate the physical force that is applied to the change in an object’s (car) characteristics of Motion. A car is used as it is a common object that is directly associated with motion by the learners of the age group. Physically moving a car with muscle force up to an extent to make observations is not feasible. The target audience consisted of students at or above the educational level of standard 9 of the CBSE board could be a potential user of this product. The Domain targeted was Physics and Law of Motion is the topic. Students who have an understanding of elements of linear motion like Distance, Velocity Acceleration and Force and would want to understand their relation. Assumption made were that the student is not aware of the Newton’s Second Law of Motion which will be tested using a pre-test which will consist of questions that test the student’s ability to determine the relations and apply the second law. Students should be aware of the equations of Motion.
Learning Objectives

The students will be able to:

1. Identify the effect of force on state of the object and interpret Newton’s First Law from it.

2. Identify the relation between the acceleration and force applied and the effect of variation on mass to interpret the Newton’s Second Law of Motion.

3. Demonstrate the First and Second Law of Motion using the system.

System Architecture

System consisted of the Controller Myo band/ Leap Motion Controller and the car mounted with a Raspberry Pi. The architecture of the system is as shown in the Figure 1.1.

- **Haptic Controller:** The controller converts the physical actions and motion to electrical signals. Our case we have the Myo / Leap motion sensor. The myo communicates over blue tooth whereas the leap motion is connected to via USB.
• **Control Unit (Raspberry Pi):** Raspberry pi’s blue tooth module will receive communication from the mayo band which will further be processed via a control script.

• **Gesture Control Unit:** Will identify the gesture from the Haptic controller and based on the logic will instruct the MCU to provide power.

• **Motor Control Unit:** The motor unit replays power to the motor based on the input from the GCU. Its extension comprises of motor controller and the motors with a separate battery as power source.

**Intervention**

*What will the user do:*

The Mayo band has to be worn by the student on the arm. The Mayo Band works on muscular electric conduction. The students will use the Haptic controller (Myo Band / Leap Motion Controller), to drive the vehicle by applying variable amount of force along with a certain gestures controls. The acceleration of the vehicle will depend on the force applied by the student. The student will be asked to form the relation between the force mass and acceleration and test their relation using the system.

*What Learning will happen:*

The student will be asked to determine the relation between the force and acceleration i.e. if it is directly proportional or inversely proportional. Once that has been determined by the student, then the student is allowed to put some mass on the vehicle and determine how force changes to accelerate the vehicle. For testing the students is not to determine the exact force but the correct relation between force mass and acceleration. Once the activity is over the student will be given word problems that will require the student to assess if the relation has been applied clearly and one last problem that will require the student to apply the relation to create a simple system that is governed by Newton’s Second Law.
Demonstration and Challenges

A demonstration of the working car was given on using Leap Motion as the controller attached to a PC. Leap Motion was chosen due to the unavailability of Myo band. Leap Motion communicated to a program on the laptop it was connected to which in turn communicated to the Raspberry Pi on the Car over WI-FI using TCP IP sockets. Certain gestures were mapped to forward backward and circular motions of the car. Limitation of the Leap motion to be able to detect only gestures and Raspberry Pi not being able to control voltage and current from the battery to the motor controller were the major challenges restricted the mapping motion of the car to the muscular force being applied by the learner. This mapping was essential for the pedagogy designed. Due to this limitation no further iterations were carried out on this project.

1.3 Maker Space

Being a tinkerer by passion I choose Maker Space as the domain to present my seminar in which I presented a preliminary investigation into makerspace as platform to teach and learn thinking skills. I also presented a literature survey of research work reported in the domain of makerspace. Based on the literature survey different aspects of maker space were discussed. The widespread movement of making things has had a huge impact on how current generation has come up with really creative and innovative solutions. Further this has become a social platform with a focus on sharing knowledge and skill for social good, but no major research has been carried out in case of effective pedagogical strategies using maker spaces. Evaluation of Makerspace as a platform for training and transfer of learning and thinking skills is another dimension not explored enough. Based on the Literature survey roles performed by students teachers and their interactions during an activity for teaching using maker space were also discussed. Finally an activity to teach computational thinking using maker space was presented. The details from this report have been discussed in chapter 3.
1.4 Photography as a medium for TELoTS

As a part of my research problem exploration and my passion as a photographer I explored the domain of photography as a technology enhanced medium for learning thinking skills. The guiding question for exploration was :-

What all pan-domain thinking skills that are transferable to engineering can be developed through my approach to teach photography?

1.4.1 The Photographing Process

Based on a lot of photography literature the photography process involves a keen observation, ability to plan the shots and analyse the the variables of the equipment and the surroundings, discipline in keeping time, patience to wait for the correct moment, flexibility in plans and tolerance to changes, an open perception and a positive attitude [42]. A lot of has been research carried out in aesthetic development i.e the ability to find meaning in imagery. It involves a set of skills ranging from simple identification (naming what one sees) to complex interpretation on contextual, metaphoric and philosophical levels. Many aspects of cognition are called upon, such as personal association, questioning, speculating, analyzing, fact-finding, and categorizing[46]. Based on such literature Visual Thinking came as a key skill that can be taught by the photographing process. Some other skills that emerged were Inductive Reasoning, critical thinking and Strategic thinking [30]. The competencies developed via this process were found to be as Imagination, Sense of Self and belongingness, Documentation of of change, reflection and multiple perspectives.

1.4.2 Activities

A few thinking skills that might emerge as a part of learning photography are discussed as follows :-

- **Inductive Reasoning:** Using lenses with variable focal length to induce the concept of Field of view based on the relation as Focal length of the lens increases the field of view decreases.
• **Strategic Thinking:** Setting that would be required to be set on a camera given a composition of an image, in a given environment and lighting conditions that could vary with time. Further extending it to the choice of gear required for the photograph to be taken.

• **Visual Thinking:** Given the picture of a location at which a session is to be performed being able to determine the parameters that might vary and the corresponding gear i.e lenses, that might be required. Being able to determine a best angle for a composition.

### 1.4.3 Discussion and Challenges

Transfer of skills from the domain of photography to engineering is a key challenge of the such an approach. The engineering problems with a visual component are the closest match when considering near or far transfer of the thinking skill say visual thinking in the domain of image processing. Still the process of being able to transfer without an enriching experience or expertises in such engineering domains turned out as the major challenge in terms exploring this direction further.

### 1.5 Report Structure

The following chapter, chapter 2 discusses CoMBaT from its conception to the current state including a few studies that have been carried out by using the system. chapter 3 presents my findings from the explorations of Makers space as domain along with a Literature Review. Further the essence of Making and its links to the domain of Engineering Design have been discussed. chapter 4 Presents the future research directions with some exploratory questions that have emerged out of these explorations concluding with with a discussion on the intended choice of direction of my thesis work. The report concludes with the bibliography followed by an appendix which has the detailed reports of some of the projects discussed in this report.
Chapter 2

CoMBaT

The following section presents the architecture and technical implementation of the CoMBaT badminton training system, discusses the training design and the results. It further discusses the studies that have shown the ability of the system to capture the difference between expert novice behavior in the presence and absence of the badminton racket and shuttle. Further, it also discusses a study which shows the positive effect of visualization on the next shot of a novice learner. This system as of now focuses on helping the trainees to learn the technique of playing the ‘long service shot’, a common beginners technique in badminton training used to push the opponent to the back of the court.

2.1 Introduction

Learning badminton is a three staged process. Trainees begin at the cognitive stage where they learn the technique of playing a shot which involves the stance, the swing of the arm and application of effort at the correct instance to execute the swing [47]. In the associative stage, the trainee focuses on the correct execution of the technique. The stance can be corrected visually but the effort applied and the swinging of the arm are not visibly apparent and require a consistent attention from the trainer. In the autonomous stage, the shot becomes second nature. The player is able to focus on varying situations and adapt the technique to instantaneous changes.

For novice learners, a key challenge in the above process is to be able to determine
Chapter 2

the correct instance to apply muscular effort and achieve the desired swing of the arm as they are not visibly apparent. Visualization of these parameters and providing feedback based on their correct execution would be a way to address these challenges. Traditionally this has been achieved by one-to-one sessions and a consistent supervision of the trainer. This apprenticeship model is time and labour intensive.

Researchers and trainers have used a variety of technological solutions to address the above challenges. For example, there exist virtual game-based solutions such as Racquet Sports by Ubisoft, available on the Sony PS3 and Wii platforms, provide a virtual environment to play badminton with visual cues for the trajectory of the shuttle. Recent and exciting developments in wearable technologies are one solution to enable trainees to visualize their muscular effort in real time and further assist in providing corrective feedback since these tools are capable of sensing such physical and hidden characteristics.

In our research, we have designed and implemented a training solution for novice badminton learners that can be used while playing a real-life game. Our training system, CoMBaT (Corrective Myo Badminton Trainer) helps the learner visualize muscular effort and swing of the arm, and provides real-time corrective visual and haptic feedback. Combat uses Internal Measurement Unit (IMU) sensors like the accelerometer and gyroscope which record the linear and angular acceleration experienced by a device [21]. In addition, it uses Electro Myo Gram, a non-invasive, surface technique used to indicate muscle group coordination while performing an action. The action potentials generated by the surface electrodes attached to the body are recorded as the action is performed [37]. The wearable device developed by Thalamic Labs, the Myo band (as seen in Figure 1), is a wearable gesture recognition device that houses 9 axis IMU and a set of 8 EMG sensors. IMU sensors enable recording of the linear and angular acceleration experienced by the arm and a set of EMG sensors record muscle activity based on which the band is able to differentiate between different gestures.

The plots of EMG and IMU data sensed by a Myo band while playing a badminton shot enables trainees to visualize the hidden aspects of applying a correct technique. Comparison of data patterns from a shot played by the trainee and the reference
pattern helps us to generate a corrective feedback. This feedback will enable the trainee to apply the correct technique while acquiring the skill and also acts as a positive reinforcement for playing the shot.

2.2 Related Work

Traditionally badminton has been taught using the apprenticeship model where the trainee observes the trainer apply the technique. Then the trainees practice the same techniques under the supervision of the trainer [47].

2.2.1 Challenges of Learning Badminton

Based on observation of skilled players an effective badminton shot is determined by the following aspects: i) stance of the player which can be corrected by visual feedback, ii) the grip of the racquet which can be visually corrected [48], and iii) swing of the arm and the effort applied to it [13]. It is difficult to determine an adequate swinging of the arm and application of the effort at the correct instance to make that swing. There is a need of making these physical parameters visible to the learner. Literature suggests the use of [11] sensors to gain insights into techniques used by players but haven’t yet been used as a mechanism of visualization for corrective feedback during everyday training. To achieve this the effort, a result of the muscular activity can be measured using EMG sensors and the swing of the arm, characterized by the acceleration it experiences can be measured by the accelerometer and gyroscope of the IMU sensors [9].

2.2.2 Use of Advanced Learning Technologies in Sports

There are several virtual game-based environments for playing such as Racquet Sports, Sports Champions for Tennis, Ping-Pong, Golf and a lot more where only Racquet Sports has the option of playing badminton. These gaming environments are built for Sony Play Station (PS), Microsoft Xbox and Wii. The motive of these environments is to make the users experience the sport by simulated playing [28]. To map the player’s actions to the virtual environment PS and Wii use a motion controller stick and a tracking camera where as Xbox uses an array of cameras to
track body movement. Sensors such as IMU have been used for motion mapping of sports players. For example, IMU sensors mapped the time sequence of motion patterns in the sensor data from the feet and arms of a tennis player to monitor full body coordination [9]. Techniques such as EMG use sensors to measure muscular activity. A review [11] of EMG research of 32 sports, covering over 100 different complex skills states that sport movement techniques are governed by highly specialized muscular activity. The knowledge of such muscular action should allow for the optimization of movement for training possibilities and of sports performance, presenting the importance of EMG in sports training. Using such a technique, researchers [33] were able to differentiate between the effects of different clubs for a set of golf shot swings and also show that muscles developed their maximal activation levels during the Forward Swing and Acceleration using EMG of the lower limb. This strongly encourages to use of EMG-based devices to help visualize the muscular effort to be applied for the swing. No one has used an EMG-based wearable solution in sports to the best of our knowledge.

2.2.3 Myo Band Based Solutions

A custom designed setup of IMU sensors and a number of EMG sensors over the arms was developed [4] for teaching skills primarily based on muscle memory, which traditionally involves a lot of observation and repetition with hours of supervised learning. The evaluation of this technique focused on the skill of pottery making and provided feedback using a LED display worn on the arm. The results strongly support the use of a combination of IMU and EMG-based devices for training that involves muscle memory but their evaluation was focused on a skill based on a sedentary activity and not in the domain of sports. Table 2.1 gives an overview of the various research goals for which Myo Band based solutions have been used. These either use data from Myo band for gesture recognition [1][7][10] or use it as a gesture-based controller [29]. Only EMG data has been used in medical solution [39]. IMU and EMG data were used for skill training in pot making but the collection of data was done using a custom-built solution [4] whereas IMU sensor data was used for trajectory mapping but EMG data was not used [45]. Though the haptic motor
Table 2.1: Summary of Myo Band Based solutions

<table>
<thead>
<tr>
<th>Research Goal</th>
<th>Accordance of Myo Band</th>
<th>Domain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand Sign Recognition[1]</td>
<td>EMG</td>
<td>Linguistics</td>
</tr>
<tr>
<td>Gesture recognition[7]</td>
<td>EMG IMU</td>
<td>Not Specified</td>
</tr>
<tr>
<td>Gesture Based Controller[10]</td>
<td>Inbuilt Gesture Recogn-</td>
<td>Cycling</td>
</tr>
<tr>
<td></td>
<td>ization</td>
<td></td>
</tr>
<tr>
<td>Self Evaluation[29]</td>
<td>EMG</td>
<td>Physiotherapy</td>
</tr>
<tr>
<td>Trajectory mapping[39]</td>
<td>IMU for joints and</td>
<td>Machine Operation</td>
</tr>
<tr>
<td></td>
<td>EMG for wrist</td>
<td></td>
</tr>
</tbody>
</table>

of the Myo band was used as a feedback mechanism in nonverbal social interaction [14].

2.3 Solution Approach

Our solution, CoMBaT, is based on the sensory ability of EMG to sense muscular activity and IMU’s ability to sense acceleration experienced by the arm. Data from these sensors enable us to visualize the muscular effort and swing of the arm. Feedback is generated by processing and comparing patterns from this data against the reference patterns. Myo band’s capability to wirelessly transmit EMG and IMU data over Bluetooth in real-time and allowing the control of its onboard vibration motor makes it our choice as a wearable device for collecting data for visualization, as well as for comparison with a reference pattern to provide visual and haptic feedback in real-time.

2.3.1 Visualisation

The effort, a result of the muscular activity, has been visualized by plotting the EMG sensors data pattern and the swing of the arm, characterized by the acceleration it experiences has been plotted using the data from the accelerometer and gyroscope of the IMU sensors. The visualization shows a plot of the EMG and
IMU sensor data patterns recorded when the shot was played by the trainee. These patterns are plotted along with the reference patterns so the trainee can gain better insight for corrective measures to be taken while playing the shot. The real-time visualization helps situate the trainee’s use of technique additionally reducing the effects of creating an incorrect schema when not under the supervision of a trainer [14]

2.3.2 Feedback

The feedback is given to the trainee immediately after the execution of the shot. Two types of feedback are given to the trainee. The first is a set of two coloured markers, one for the effort applied at the correct instance and the other for the adequate swing of the arm. A correct use of the technique is shown by the marking turning green and red otherwise. The Myo band also has an on-board haptic vibration motor which is used to provide haptic feedback by varying the length of vibrations according to the to the correct usage of the technique for muscular effort and swing of the arm.

2.4 CoMBaT

This system primarily consists of a wearable device, the Myo Band and CoMBaT application running on a computer. The Myo band provides EMG and IMU data wirelessly via Blue-tooth in real-time and is used as a platform to provide haptic feedback. CoMBaT application running on the computer enables the visualization of the sensor data patterns of muscular effort and arm swing. It also provides a marker based visual feedback and instructs the haptic vibration motor of the Myo band.

2.4.1 Architecture

The CoMBaT application interacts with the Myo band using the Myo API provided with the SDK from Thalmic Labs.

The components of its architecture as seen in Figure 2.1 are discussed below:
• **Pre - Processing:** A set of raw data from the Myo band is collected for a single shot. It consists of 8 EMG sensors the data of which is received via the API sampled at 200Hz. The resultant from the 8 values is obtained by calculating the root of the sum of the 8 squared values. This data is subsampled to 50Hz to reduce noise and to match it with the IMU’s sampling rate i.e.50Hz. The data from the IMU sensors consists of linear acceleration in 3 axes and angular acceleration in 3 axes. The resultant linear and angular accelerations are obtained by calculating the root of sum of squares of the values from each axis. The resultant values are then fused using a complimentary filter to get the resultant acceleration which has a component of the linear and angular accelerations. Both the values are then normalized to a uniform scale. The final set of values compose the two patterns for that particular shot.

• **Pattern Matching (DTW):** Pattern recognition methods allow us to provide feedback to the trainees by comparison of the sensor data patterns collected as they try to apply the technique in contrast to reference patterns. A reference pattern is derived from patterns of sensor data from expert’s execution of the correct technique. Dynamic Time Warping algorithm is used as it can compare two temporal sequences that may be spatially or temporally independent[20]
The algorithm takes two patterns and returns a warping score which is the sum of smallest Euclidian distances between every point of the two patterns calculated while traversing from the first point to the last point. Comparison of two same sequences results in a score of 0. The algorithm compares the temporally aligned IMU and EMG data patterns of the trainee with the reference patterns. The EMG and IMU reference patterns are coded into the application for pattern matching. To obtain the reference patterns the sensor data recorded during an expert’s execution of the technique of a badminton shot is pre-processed to obtain patterns. The patterns obtained are averaged to obtain the reference patterns for the EMG and IMU data as shown by the dotted lines in Figure 3. Feedback is provided based on a calculation (explained in the next subsection) on the obtained warping score. The data patterns are stored for the plot based visualization.

- **Shot Evaluation:** A threshold is used to evaluate the warping scores obtained after comparison of two patterns. Thresholds are the max warping score obtained when the reference patterns are compared to the data patterns that were used to obtain the reference patterns as all those patterns are from the correct executions of the technique to play the badminton shot so any pattern that is in proximity of those patterns is considered as a correct execution of the shot. Any warping score that is below the threshold is considered as a correct execution of the parameters. If both the warping scores are below the threshold they are considered as a good shot. If only one is below the threshold it is considered as an average shot and if neither is below it is considered as a bad shot. The threshold based evaluation also determines the color of the visual feedback marker and the length of the vibration of the haptic feedback motor.

- **Visualizer:** The visualizer shows a plot of the EMG and IMU sensor data patterns of the trainee’s shot obtained after pattern matching. These patterns are plotted along with the reference patterns so the trainee can gain better insight for corrective measures to be taken while playing the shot e.g. the instant of application of effort.
• **Visual and Haptic Feedback:** Green color on the two visual feedback markers, determine that the warping score of both the muscular effort and the arm’s swing were below the thresholds whereas a red on either would determine the warping score for that parameter is above the threshold. If the shot is evaluated to be a good shot the application uses the Myo API to activate a short pulse of vibration on the band. For an average shot, it’s a set of 3 medium pulses and a long one for a bad shot.

2.4.2 Training Design

The trainees are given a demonstration of the technique to play a shot by the trainers. Trainees then enter the training mode where they are introduced to the Myo arm band and instructed to wear the band correctly.

Further, it introduces the visualizations and the feedback mechanisms (as mentioned in the section above). After wearing the Myo band the trainee goes through a run in session when he/she is required to experience all types of feedbacks. This is to get the trainee accustomed to the visual and haptic feedbacks that correspond to the types of shot played. The training session now begins with the Pre-test where the trainee is given to play ten shots without any feedback. The data from the EMG and IMU sensors of the armband are recorded by the system. Then the trainee starts with the training session. As a shot is played the screen shows the color markers for each of the shot parameters and the trainee receives a haptic feedback on the arm. The visualization of the data pattern plots can be viewed by the trainee by the trainee. After the training session is over the trainee play another 10 shots without any feedback being presented to them where as it is recorded in the background. Figure 2.2 depicts the interactions between the trainees and CoMbaT during different phases of the training.

2.5 Research Studies

This section talks about the data sources of the experiment and the studies carried out CoMbaT. Two iterations of research studies were carried out. The first Itera-
Figure 2.2: Trainee CoMBaT Interactions Timeline.
tion was a play testing session based on which a change was made in the feedback mechanism. It was followed by two studies with different objectives which have been discussed in the following sections.

2.5.1 Data Sources and Instruments

1. **Pre-test and Post-test:** In pre-test the trainee would be playing with the training solution for ten shots without the visualization and feedback and the results would be stored. Followed by training session for thirty shots where feedback and visualization would be provided and stored. In the post-test the trainee would play ten shots without the visualization and feedback being presented but would be stored by the system. The stored results would be compared and analysed to answer each of the research questions by measuring the number of shots played with the correct technique followed by analysis of questionnaire.

2. **Open-ended interview questions:** A set of questions were prepared which were validated by fellow researchers. Responses to these questions helped to know how trainees interpret the feedback and as per their preference of feedback accommodate the design changes in the training solution so that design is conducive for participants to learn the correct technique. The questions were broadly categorized as a) participants interest in sports; b) trainee’s interpretation of visualization, haptic and visual feedback; c) trainee’s view on importance and preference of feedback and; d) trainee’s overall view of the system and experience of any change felt by trainee in own performance.

2.5.2 Play Testing

The Research Question for this study was:-

**What are the perceptions of trainees about learning with CoMBaT?**

We carried out the play testing with the long service shot primarily to inspect the working of the system and the intended user’s interactions with CoMBaT. To generate the reference, pattern an experienced badminton player played 5 shots.
wearing the Myo band which were recorded using the Myo band. The thresholds of the warping scores, as explained above, were obtained as 0.04 for IMU data and 0.03 for EMG data. The two trainees chosen for this study were novice players. We followed the same intervention mechanism as described in Figure 2.2 except for the Pre and Post Test. The findings from this study also guided the redesign of the visualisation mechanism.

**Result and Conclusion**

During the interview with the trainees after they had trained with the system we discovered preferences for the feedback mechanism. For example, one participant only looked at the visual feedback when it was an average shot, in other cases the haptic feedback seemed sufficient for them. Another participant always preferred the visual feedback. During the interview participants mentioned that they found the generated graph too confusing due to the overlapping patterns of the novice and expert. One of them mentioned that the graph did not scaffold them to translate the differences to shot. Based on this feedback a mechanism to toggle between the plots in the visualisation was made so the trainee could enable or disable a plot at will.

**2.5.3 Effect of Visualisation**

This study followed the intervention mechanism as shown in Figure 2.2. A total of four participants, three Novice and one professional (an inter college tournament player) were chosen for this study. The research question of this study was:-

**Does referring the visualisation enable the trainee to perform better?**

The sessions were recorded in video along with the feedback. Based on the video all the shots in which the visualisation was refereed by the trainee were marked. The feedback received for the next shot was classified between improved or remained same and Not improved. The perception of the novice about result of the next shot based on the visualisation was also recorded during the interview with the trainee.
Results and Conclusion

The results were reported separately for the three novice and one experienced player as the experienced player had reported being able to associate the actions performed while playing the shot which the novice were not very clear about. Based on the result obtained from the sessions a novice received a similar or better feedback in the next shot 50% of the time when they refereed the visualisation where as the same happened only 20% of the time they did not refer the visualisation. A representation of transitions of feedback from one of the novice trainee’s session is shown in Figure 2.3.

When a similar analysis was done for the professional player he received a similar or improved feedback 91% of the times he referred the visualisation where as the same happened only 50% of the time he did not refer the visualisation. A representation of transitions of feedback from the professional trainee’s session is shown in Figure 2.4. Based on the above result it was concluded the the professional was able to improve more often when he referred the visualisation in comparison. In the interview the expert did mention about being able to relate the visualisation to the actions he was performing while playing the shots. This was not in the case of novice players. The
novice players rather reported difficulty in or interpreting the visualisation in relation to actions they performed while plying the shots. One reason of this observation could be difficulty in interpreting the graphical visualisation with a large number of plots. This was even reported by some of the trainees.

It can be concluded from the study that displaying hidden characteristics like swing and effort does help the trainee in reflecting on their action to play with the correct technique. However it was found from the study that interpreting the visualization without any scaffolds makes interpreting the swing and effort difficult for the novice trainee. So this study did help us the researchers to get insight into the effectiveness of the system and further research goals to be formed.

2.5.4 Embodiment of the tool

This study is based on the fact that activity of the mind is grounded in mechanisms that evolved from interaction with the environment but could mental imagery of the environment produce the cognitive activity even when we are decoupled from the environment. The skill of mental imagery enables a person to visualise something that is not currently present in the environment [44]. From the view of the cognitive system being a part of the environment we see that the production of the cognitive activity does not come from the mind alone but is also influenced by the environment. This lead researchers to ask "Could mental imagery of the environment produce the
cognitive activity even when we are decoupled from the environment?” To answer this we explore the domain of tool use which acts as an extension of our physical body and its action space[32]. According to the research in tool use the length of our effectors (mainly the arms) limits our action space but we can use many different tools (from forks to pick up hot food to hyper-technological telesurgery devices) to extend our physical body structure and, consequently, our action space[32].

Based on the “embodied cognition hypothesis” [2] [17] conceptual processing of the tool involves the retrieval or simulation of the movements associated with the tool usage i.e the motor activations concerning the use of the tool are run in case of object recognition and are necessary to ground the conceptual knowledge of the object. Hence the imagination of the embodied object should help retrieve the motor activations concerning the use of the tool which would reflect in the activity involving the motor activations. Further this would enable us in looking at the variation in the embodiment of tool between a casual and a regular user of the tool. The details of the study are as mentioned in the report titled Practice Makes Imagination Perfect attached in appendix of this report.

Result and Conclusion

The analysis of the data presented a significant difference with the swings of the professional being more close to the expert irrespective of whether he played with a racquet or not. Moreover the novice’s shots had significant variation compared to the professional in imaginary racquet scenarios. Hence it was concluded that a regular exposure to tool based activity enables the embodiment of the tool and enforces the actions that are associated with tool to an extent where they can be activated by imagining the tool in the same context.

2.6 Future Work towards Closure

The above mentioned studies were carried out with a very limited number of participants hence one target is to contact more participants to conduct more studies to get better insights.

Secondly a major challenge that came out from the studies is the difficulty in inter-
interpreting the graph based visualisations of the shot played especially by the novice players. Scaffolding mechanisms for the existing visualisation needs to be incorporated or simpler forms of visualisations need to be explored before conducting any study targeted towards evaluating the learning of the badminton shot technique.
Chapter 3

Making

When the youth is interested in the things they are working with, they feel like their activities align with their sense of themselves and their possible futures. When they feel connected to the community they are working within, tremendous amount of learning can occur [34].

3.1 Essence of Making

Making is a fundamental Human Activity that is and has been the key characteristic which includes building tools from the stone age to the machines of the current century. Making has been an important part of the old educative practice like traditional apprenticeship and has evolved in the current generation in the form of Hacker movements, Do It Yourself Enthusiasts and now leading to the Do it Together movement. This has given rise to maker spaces through a shared interest in maintaining a semi-permanent space for solo and collaborative work in and around physical space[41].

In Contrast from the traditional educative practices making is learner driven and supports inquiry based and discovery based learning pedagogues. Ordering the immediate environment around oneself can serve a cognitive function to provide insight into problems, just as trajectory-based cultural practices [24] reduce the cognitive load for embedding meaning by seeing the world in a particular way.
As noted in the literature [6] [34], making reflects the practical, physical, and playful modes of inquiry advanced by educators such as John Dewey (1938/2007), Friedrich Froebel (1887), Maria Montessori (1912), and Seymour Papert (1980). As Paulo Blikstein argues, these theoretical approaches (and their attendant technologies, such as Logo programming and Lego Mindstorm) “revealed how the ideas and intellectual passions of children could be powerful and generative, and that the perceived difficulties of tasks were due to deficient design rather than learners’ cognitive deficiencies”.

3.2 Literature Review

This sections discusses the observations made during the literature review.

3.2.1 What is a Maker Space?

Based on the literature review over maker space I would like to define the term as

“A space were multi-skilled people solve open problems creatively by collaborating, exploring and creating physical objects or virtual resources as a final product.”

The motivating force for makers is self exploration of current systems, surroundings and experimenting which leads to discovery of new possibilities and inventions. Makers focus on skill of being able to observe, hypothesize, experiment, relate, diverge and converge, estimate, deduce and much more which evolves their ability to solve open ended challenging and critical problems. Students as makers integrate the experience and skill from making to the knowledge acquired via various means. Making is domain independent and encourages collaboration hence is a more social experience and yet provides personalized learning to the making culture [8]. The research further describes makers spaces as

“crossroads and fringes of disciplines such as science, technology, engineering, art and math”.

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In this vein, Sheridan et al. [40] define “makerspaces” as

"sites for creative production in art, science and engineering where people blend digital and physical technologies to explore ideas, learn technical skills and create new products."

Making rewards with a sense of tangible self accomplishment building confidence which ensures persistence and provides a sense of authorship. It encourages dispositions amongst learners and kindle their thinking. Teachers have been able to exploit makers spaces by contextualize stem concepts to meaningful activities like creating windmills, hydro generators using motors which involves understanding of power generation in physics along with electronics in technologies, and by creating problems that include design based decisions or making choices between multiple options they encourage interdisciplinary practice. Making the problems open ended and not constraint the solution approaches they encourage the learners to take risk and experiment to come the correct solution.

3.2.2 Why is making an essential part of learning?

From the perspective of cognitive processing among learners, with embodied cognition, philosophers and researchers posit the hypothesis of cognitive externalization, that is, that the world is its own best representation; and that certain actions need to be considered as epistemic if, as a consequence of the action, we obtain more reliable information about reality [27].

The sense of self is other cognitive factor as the learners associate them selves to the process of creation and the environment they are working in, to achieve the self placed goals [23]. Hence this in turn encourages self guided and self motivated learning along with regular self assessment and reflection.

Pedagogies involving making have an innate aspect of Positive re-enforcement but follow the theory of constructivism. Cognitive apprenticeship is the most ideal approach observed in the literature reporting maker space based learning activities [36]. Most of the time the maker / learner is actively engaged in a building activity and the learning happens based on the discovers and inquires made by the learner.
during this process. Collaboration during the making process helps the learner in acquiring new skills by observing an expert approach towards solving a problem or performing a task. The expert can be a peer or the instructor participating actively in solving the problem along with the learners.

Making by essence being an inter-Domain multi skilled task involves a set of physical skills which target construction and mental skills for problem solving. For example making a robot that could do a simple task like avoid obstacles would primarily require skills like design along with divergent and convergent thinking for choosing the platform and sensors, computational thinking for designing the algorithm where as assembling the robot would require skills like fabrication, fitting for the chassis building, and soldering for circuitry. Not limited to STEM such an approach is commonly used in teaching arts which share the aspect of physicality and a product at he end [26]. Researchers even found that connecting making to existing practices creates a more powerful and learning experience [6]. Authors have suppoerted that as [35],

"Making environments typically give youth substantial say in what and how they make”.

Based on a pilot study in which students significantly increased their understanding of key circuitry concepts, the author [38] supports the above by arguing that

" e-textiles are not only effective tools for broadening participation in computing but might also offer greater transparency into STEM disciplinary content such as circuitry”.

The makers movement has encouraged entrepreneurship and started a Community Creative movement. Availability to the means of production is one of the key factors of the entrepreneurial endeavours.[43]. Finally research on existing “makerspaces” for example, seeks to identify the forms of thinking and learning, common in these community settings, as a way to design for and evidence of learning in educative practice [8]
3.2.3 About the space

A few have looked at the aspects of the space like the placement of Tools, layout etc. and its effects in making [31]. The background of the learners is another aspect that’s influences the interaction of the learner with such a space.

3.2.4 Making as a medium of Teaching and Learning

As reported by Gutwill et al. [5], pedagogical activities integrated with maker space spark or orient learners to the space and activity at hand, while establishing the safety needed for them to take risks and unleash creativity. Participation can be sustained by offering new tools or suggestions, welcoming learners’ ideas, re-engaging participants when interest waned and re-voicing ideas to help clarify the nature of the problem. Further deepening participation by fostering reflection or challenging learners to complexity their work.

In the makers pedagogy where technology intersects with their tiny house project the students document the characteristics of the tiny house they are excited about and design their tiny house not just leaving it to the CAD but actually building a tiny model using laser cutters and 3D printers. [36]

The key principles of tinkering namely spark sustain and deepen are a guiding pathways towards developing teaching learning strategies.

The practitioners guide for tinkering describes them as finding the interest of the learner (spark). Giving problems in the same domain that are aligned to the learners background knowledge and interest to sustain that spark and gradually increasing the complexity of the problems to do make the learner perform in depth explorations[22]. The activities involved in making focus on the higher order thinking skills of the blooms taxonomy as the target. In the end a creation is involved as a part of the solution to an open ended problem posed in the beginning[12].

3.2.5 Common Pitfalls

Though makers space seems as an ideal platform there are a few things that the researchers suggest should be kept in mind. The primary concerns presented by
the author is about limiting the openness of makers definitions[34]. They caution against

"a reductive treatment of making as a set of component knowledge and skills”

and argues that

"efforts to tie making more narrowly to STEM outcomes or to assume uniform outcomes in any particular area of learning may limit the openness of maker definitions, leave less room for exploration and personalization, and erode the value youth see in participation”.

Sheridan et al [40] criticized the interdisciplinary nature of making by creating connections between art and STEM. The author states

"Art involves their own disciplinary practices and dispositions and must not be reduced to a vehicle of STEM learning.”

Authors have pointed out the misconception that power of creation is based on the tool-set available [35]. The tool centric approach might defeat the enthusiasm of making but just a tool fetish. Such a practice also conflicts with the need to integrate the socio emotional and disciplinary dimensions of learning.

In the Literature there has been an emphasis on makers spaces focus on the Middle and High schools with a very narrow focus on adults in involved in making. Researchers have pointed out that self expression and creativity are very limited in case of busy working adults who often get excluded through commitments towards work and family[16].

Though continuous funding is a key requirements not many researchers have looked into this aspects. A few have suggested that it requires an year of function for the maker-space to realize the flow of continuous funds it would need[16].

Standardized assessment is another concern which arises when integrating making to the regular curricula. Literature does does talk about formative assessment approaches like a framework based on a rubric that involves certain learning dimensions
and rating is provided based on indicators [5]. Author provides an example

For the learning dimension of "engagement" the indicators are as "spending time in tinkering activities" and "Displaying motivation or investment through affect of behaviour.

Last but not the least research studies and the emergent literature have focused on the what and how of making at large, which may risk paying inadequate attention to the why as the larger purposes of making and further explore how those purposes are tied to particular social and political values[43].

3.3 Making in Marker Space

The primary goal of a project based learning activity involving maker space is improvisational creative problem solving. The solution is obtained by open ended exploration and must have an Inter-domain collaboration. The target of the activity is a final product in from of a physical object or a virtual resource that can be used to solve the addressed problem.

Making is an iterative activity and through these iterations the makers assumes the following roles:-

- **Ideate:** Once the problem has been given the makers ideate the possibilities, by either abstracting the problem to explore the larger context or break the problems into small problems and start exploration. The exploration could even be makers trying to use some technology not in line with the main problem which could be to know its affordances. They document their findings and discuss it using common sharing platforms like spaces, on-line forums meetings.

- **Design:** Based on the Ideas makers come up with a design as the approach of their solution which is not limited to a schematic drawing but could even be a model or a rough prototype they just built. The makers are free to make
the choice between systematic modular design based approach or a hands on exploration based approach where the designs could even come out of modifications made to the object that has been hacked to solved the problem. The design phase also consists of the test cases the makers will carry out with their solution.

- **Build:** Based on the design the makers collect the materials required for building. They recognize or attain the skill required for the building process for eg soldering, milling, fabric cutting etc. The makers can ask for assistance and request the instructor to provide them with a resource or a person to help them with a specialized skill if required e.g. Glass cutting.

- **Test and reflect:** The makers test their product according to the test cases specified in the problem or the test cases that were built during the design of the problem. Based on the results the makers reflect on what they observed and what they expected. If required the makers go back to the design stage to make changes and build the changes into them.

- **Collaborate:** Makers often work in groups sharing skills and interact to share the knowledge and experience they have. They explore the space, and tools available.

- **Document:** One key requirement is to document each and every aspect at every stage. The documentation should contain all the observations made and the decisions taken along with the reasons as this helps the learners to reference when required. Moreover this document helps the learners to reflect upon their decisions.

- **Keep Safe:** Since making might involve using a lot or dangerous and hazardous material it is required that the makers follow the safety instructions and best practices.

Makers assume these roles in iterations of the problem solving process. These it-
erations could emerge out of a systematic approach towards engineering design based problem solving problem solving[17]. It could even be an iterative exploration which begins with open ended exploration by construction not necessarily directed in the direction of the problem and as the process continues the construction goals start aligning towards solutions of the problem domain where this exploration finally directs the solution to this problem.

The other key aspects of makers space are the environment and the interactions. Depending on the activity the availability resources and amenities. Makers tend to classify general tools and keep them in visual range. They also collate ideas from parts placed in the environment. These parts could range from material, tools, devices etc which play an essential role to a build big picture that leads to the desired solution. Environment enables the makers as a platform to collect ideas.

### 3.4 Role of making in Engineering Design

As pointed out in literature [18] design problems are often large and complex; Do not have the right or wrong answers and may have interactions between components; and the components of a design problem, start goal and intermediate states (sub goals) are incompletely specified.

Hence the solution approaches have to be a combination of opportunistic, Incremental, exploratory, investigate, creative, rational and Interactive approaches. Combinations of these approaches have led to different philosophies of the design process [15]. They are routine designs which focus on prototype derived from an existing solution which have some common variables, redesign involves re-purposing of an available design solution and finally non routine designs which are original ideas. Non routine designs can be further classified into Innovative designs where the variables could have some resemblance to existing solutions and the the primary goal is known but the sub goals might not be known; and Creative Design where the variables have no similarity with existing solutions and there is no prior plan for design.

Design Problems including engineering design in a whole have been classified from a fully structured problems, which can be approached using the routine design approach,
to ill-structured problems [25] which map the design philosophies like non-routine design. In case of semi-structured problems when only the goal is known they can use re-design and innovative design philosophies where as the unstructured problem where nothing is known map to the creative design philosophies. Making and makers space follows the creative culture of open ended problem solving which maps to an iterative practice of these design philosophies in making. Steps of problem solving strategies have been defined as reported as problem representation, search for solution and implementing solution [25]. Makers through these stages proceed based on available solutions models or prototypes for well structured problems and resort to construction activities for ill-structured or semi structured problems. These making activities follow a redesign approach where the break and then make a solution from an existing prototype[43]. In case of unstructured problems construction from an abstract level which initially might not be oriented to the goals of the original problem becomes an integral part for problem representation and restructuring in terms of the known or existing solution approaches[36].
Chapter 4

Future Research Directions

4.1 From CoMBaT

The exploration of physiological sensors like Myo band in combat have encouraged the use of such sensors based on their capabilities to sense physical activities which are related some key action that are abstract in nature. This property of the physical sensors allow representation of these key action. Being able to detect, and visualize these action enable reflection of these physical processes in turn enabling the learn the physical skills. This brings us to the the question if such sensors could be used to detect actions that would enable reflection of cognitive skills? If so this could enable the learners to reflect on their cognitive activities in turn could act as the technological enhancer for the learning of thinking skills.

The other aspect from the ability of these sensors in being able make the invisible visible was to use them to make visible the physical aspects of objects to the the learning of STEM based concepts for your learners.

4.1.1 Physiological sensors as an intervention for Thinking Skills

The idea here is to use of physiological sensors as part of an intervention for a specific teaching learning goal like a Thinking Skill. This key idea here is the use of sensors like IMU, EMG, EEG, ECG, eye tracker, Head tracker etc individually or in combination to to sense actions mapped to cognitive activities or enable the
learner to visualise the abstract nature of the action in the activities. For Eg the EEG sensors from the Myo Based enabled the visualisation of effort and the IMU sensors enabled the visualisation of swing of the arm which are abstract quantities in terms of physical actions. This visualisation has enabled the learners to reflect on their actions they were performing while playing the shot.

The solution would be physiological sensor based system that the learners use while doing a learning activity. The system provides them a visual representations of their actions and could provide them feedback and scaffolds based on the data received from the sensors. This could be used with a teaching learning system or in itself be a teaching learning system for some specific goal like a thinking skill.

The question that needs to be answered here is

Can physiological sensors be used to detect actions that are representative of cognitive activities?

This brings us to the next questions if cognitive actions produce physiological changes? if yes what are these changes and how can they be measured using the available set of sensors? Though literature talks about using such systems for physical skill training training the other aspect of research is about the context and domain of engineering in which such a system be essential.

Once we have an answer to the above mentioned questions for guiding the research are as follows:-

- What is the broad Problem?
- What is the specific Problem?
- What is the solution approach?
- What does the tool do?
- What are the students learning?
- What is that they are learning?
• How are we teaching it?

Challenges and Discussion

The nature of physical skills makes this as an evident solution for training. The major challenge of using this system for cognitive skill based learning is finding the context for which such a solution is effective in the engineering domain. Second challenge is mapping of feedback and scaffolds in case of multiple solutions based approaches for problems involving construction which could be one of the domains, e.g. carpentry, in which such a system could be used to assist or inculcate some essential domain based cognitive skills. Further the limitation of my expertise in such domain is limited.

4.2 From Maker Space

Making is an enriching process in terms of physical and cognitive skills as discussed in chapter 3. Strategic thinking could evolve towards solving a semi structured problem by the means of construction of an artefact as a solution when there are a lot of unknowns.

4.2.1 Engineering Design Skills through Making

The idea is in the process of building something using a building kit say Lego Blocks the builder learns about the building process, the blocks based on a lot of cognitive activities that they perform while building[3]. Engineering design skills could be a part of the skills that they learn which is still an active field of research. The advantage of such kits are their affordances that enable the maker to be able to explore and derive multiple solutions. Just to add to this process we could used scaffolding that guides the user to understand the environment better and provide suggestions when they get stuck while building the environment. This initial question to be answered in this context is

How the person goes about building?
The other direction of research can be from the basis of three parameters i.e the problem the context and the solution. In the context of problem solving and coming up with the solution we focus on a thinking skill. My focus will be on semi-structured or ill structured problems as they have a broad goal and lot of unknowns. This will involve the design philosophies like re-designing including re purposing and reusing or non-conventional design which are common in problem solving by making. The context will be a construction set / robotics kit that has been adopted from well known kits like the Lego Mind storm and construction sets. The solution of to the problem will come from the students but our focus will be on teaching the thinking skill that has evolved from the making that just the solution of the problem. Going further in the direction of teaching, say strategic thinking, the learner is provided with a kit which as said is one of or the adoption of the known kits. The learner is to solve a problem in three stages where in the first stage the learner is given a model to be built and an instruction booklet to create that model. What has to be created and how it is to be created has been specified. In the second stage the learner is given a model to be constructed which has some relevance to the main problem to be given at the end. In this stage what is given and but the learner has to figure out the how of the construction. In the third stage the learner is given the open ended problem from a specific domain where what is to be built and how it is to be built is not specified but why it has to be built has been specified. In this process the learner could develops a strategy of building towards of solution where they either develop the the skill like strategic thinking or the process of making. In this case construction/robotics kit is an intervention that I have developed by adopting it from a bunch existing Robotics/construction kits so the novelty of this approach could be the structuring of the problem, the the scaffolding for a goal directed intervention where we have pedagogy via attractive technology ,which is the novelty of the approach.

The questions that arise are

What is strategic thinking especially in terms of engineering design ?

Or is this process either the divergent or convergent thinking process? There are a lot of processes that are going in our mind hence a lot of thinking is happening so
What are those thinking processes?

This brings us to an interesting part of making itself when the act of making is not directed to the major problem goal and the initial constructions might not even be related to it but eventually in a few iterations the problem goal gets introduced. The questions here is

What basis do one start building? What is the significance of this first phase of making which is not in terms of the problem goal?

Other following questions that arise are when is such an approach taken or a necessity? One possible direction when thinking about the value of this process in making is that for problems that are very complex for me with only a broad goal specified, I would start building with the idea that come instantly to my mind from the broad area. In the process I try to restructure the problem based on the this broad characteristic. This reconstruction might happen over a lot of phases and this might not be similar to the divergent and converge thinking phases. The essence of this process could be motivation or gratification towards solving a complex problem when the sub goals are also not known. The goal could be as naive as exploring the the construction set for possibilities. So the primary goal in the research of this approach is to understand

What people do in this process and what among those is an essential process to teach?

Few other questions that would guide the research towards the pedagogical design are as follows:-

- What are the key process or activities that take place during this stage?
- When does this process stop.
- When does the goal comes into the process of design?
- How does the person bring in the goal?
• What is the benefit of teaching this process versus the other processes or its for the people for whom the structured process doesn’t work?

• What is the difference in the approach of an Export maker vs the Novice maker when following this process?

The future exploration actions and my plan to understand this process more has been explained in the next section.

4.3 Discussion

The key challenge with the first approach of teaching using physiological sensors is the skills that they target are very domain restricted and not pan-domain like Thinking skills. The complexity of the thinking skill involved in such domains is another unknown. Our expertise in such domains e.g Carpentry, is very limited for us to create an entire solution. My reason of exploring this domain was interest and previous experience with building with sensor based platforms.

Whereas the challenges of the second approach are yet mostly in the form of unknowns. The unknowns can be addressed through a detailed systematic literature review in the process of making in terms of engineering design. Further I plan to interview a few people from the domains of design and a maker spaces to get an understanding of the above mentioned questions and then maybe come out with some design of teaching this process in engineering design. During this process try to develop a better understanding of this process of making apart from the operational questions. Based on the two directions discussed I have an inclination towards the second research direction as tinkering is a way of my life and I connect to the process. Further I would want to teach this process in context of engineering design.
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Appendix


Appendix I

Documents attached are as follows :-


“Practice Makes Imagination Perfect”

A study to analyse embodiment of tool use between a professional and a novice.

Ashutosh Raina, Pratidnya S. Hegde Patil

Abstract

Activity of the mind is grounded in mechanisms that evolved for interaction with the environment but could mental imagery of the environment produce the cognitive activity even when we are decoupled from the environment. Using the concept of tool as an extension of our physical body and its action space with the conceptual processing of the tool involving the retrieval or simulation of the movements associated with the tool usage, a study was conducted to see the variations in swinging of arm (action) of a professional and a novice badminton player while playing with and without the racquet (tool). The data was collected using the CoMBaT training system for badminton. The analysis of the data presented a significant difference with the swings of the professional being more close to the expert irrespective of whether he played with a racquet. Moreover the novice’s shots had significant variation compared to the professional in imaginary racquet scenarios. Hence it was concluded that a regular exposure to tool based activity enables the embodiment of the tool and enforces the actions that are associated with tool to an extent where they can be activated by imagining the tool in the same context.

1. Introduction

The embodied approaches to cognition emphasize the role played by the direct responsiveness to a familiar environment, developed by a situated agent through “unreflective” involvement of a perceptual and motoric kind [1], without the mediation of stored heuristics, propositional contents, or encoded algorithms[2]. The six views embodied cognition [3] have been described as: 1) Cognition is Situated in the context of a real world environment, 2) Cognition is time pressured, 3) Cognitive work can be offloaded onto the environment. 4) The environment is part of the cognitive system 5) Cognition is for action and 6) Offline cognition is body based. The sixth view can be further extended into
five skills namely Mental Imagery, Working Memory, Episodic Memory, Implicit Memory and Reasoning and Problem solving.

When looking from the view of body based offline cognition which suggests when decoupled from the environment, the activity of the mind is grounded in the mechanism that evolved from the interaction with the environment, i.e. the mechanism of sensory processing and motor control. The skill of mental imagery enables a person to visualise something that is not currently present in the environment [3]. From the view of the cognitive system being a part of the environment we see that the production of the cognitive activity does not come from the mind alone but is also influenced by the environment. This lead researchers to ask “Could mental imagery of the environment produce the cognitive activity even when we are decoupled from the environment?”.

To answer this we explore the domain of tool use which acts as an extension of our physical body and its action space[4]. According to the research in tool use the length of our effectors (mainly the arms) limits our action space but we can use many different tools (from forks to pick up hot food to hyper-technological telesurgery devices) to extend our physical body structure and, consequently, our action space[4].

Based on the “embodied cognition hypothesis” [5,6] conceptual processing of the tool involves the retrieval or simulation of the movements associated with the tool usage i.e the motor activations concerning the use of the tool are run in case of object recognition and are necessary to ground the conceptual knowledge of the object. Hence the imagination of the embodied object should help retrieve the motor activations concerning the use of the tool which would reflect in the activity involving the motor activations. Further this would enable us in looking at the variation in the embodiment of tool between a casual and a regular user of the tool.

One such domain is racquet shuttle based sport, badminton. Players play with the racquet as an extension of self and the actions performed are the shots played. The way of playing a shot depends on the motor activation for the shot which is influenced by the the player’s action with the hand and the racquet i.e the the racquet embodied into the player and imagination of the
Learning badminton is a three staged process. Trainees begin at the cognitive stage where they learn the technique of playing a shot which involves the stance, the swing of the arm and application of effort at the correct instance to execute the swing [7]. In the associative stage, the trainee focuses on the correct execution of the technique. In the autonomous stage, the shot becomes second nature. The player is able to focus on varying situations and adapt the technique to instantaneous changes. Hence for a player in the Autonomous stage the actions reflecting on the embodiment of the racquet should have a prominent variation from the player in the associative stage.

The above was measured using a wearable technology based badminton training system being developed by us known as CoMBaT. The system is able to determine the use of correct technique of the shot based on two parameters namely the effort characterised by the electrical conductivity of the muscle in action (EMG) and the swing acceleration experienced by the player’s arm. Both parameters are recorded by the system and compared to the data from expert players execution of the shot to provide feedback to the trainers. The swing is a parameter that is influenced by the arm racquet combination. We designed a study with a trained player of badminton referred as professional and a casual player referred as novice and compared them based on the data we obtained from CoMBaT for the swing of their arms.

The result was then compared and verified statistically which suggests that there is a significant difference in the data obtained from the swing of the arm of both the players while playing the shot. The data from the novice’s shots has significant variations in swing when playing with the racquet or imagining the racquet where as the professional is able to maintain the performance in all the cases. Similarly the variations in the swing of the arm between the novice and the professional are significant when playing the shots, where the professional is performing better, while imagining the racquet but the variations are not significant when they are both playing with the racquet. Note the performance of the professional in a game is also measured on other various other parameters too hence no significant variation in the swing does
not mean they perform equally.

Based on the result of the study we conclude that a regular use of the tool enables the user to better embody the tool to an extent that imagination of the tool results in the activation of the motor action circuit for the use of a tool in the given situation.

Section 2 of this report discusses further about incorporation of the tool as a part of the body. Section 3 introduces the system used to collect the data and evaluate the performance of the participants along with the details of the parameters it measures. Section 4 states the hypothesis of the studies. Section 5 discusses the details of the studies conducted. Section 6 presents the results of the study conducted. Section 7 discusses the results of the studies and the report concludes by presenting the implications of the findings of the study and presents the future work in Section 8.

2. Tool incorporation

Early intuitions suggested that manipulated objects, or items of clothing [8 , 9] become ‘incorporated into the body schema’. In recent years there has been an explosion of interest in trying to verify such an intriguing hypothesis. The simple model used in many experiments discussed in the present review is to observe changes in the behaviour and/or the neural activity of monkeys and humans following the use of simple tools (for example a rake) to extend reaching space[4].

The question we ask here was could imagination of the tool while performing the task based on the use of that tool trigger the muscle memory of the body. Secondly would there be a difference in the actions based on the embodiment of the tool in a regular user compared to an occasional user of the tool i.e does practice influence the embodiment of the tool.

To ask this question in domain of sports what would the impact on the performance of a player in the absence his playing tool, the Badminton racquet is our case. The question we wanted to answer was would there be a change in performance of a player playing a shot and could imagination of the racquet trigger the muscle memory (without the racquet). The prediction to our hypothesis was there would be a difference but would it be significant or how
The second question that arose was would there be a difference between the embodiment of the racquet and could imagination of the racquet trigger the muscle memory of a professional player than a novice or a casual player of badminton.

A wearable solution for training on badminton shots was developed by us which incorporated the measurement of muscular effort and the physical characteristics like the acceleration experienced by the arm as it swings to play the shot on application of the muscular effort. Ability to measure the effects of the muscular activation allowed us to use this system to conduct a study to find variations in the performance of a shot played by imaging the racquet.

3. CoMBaT, Wearable Badminton Trainer

CoMBaT or the Corrective Myo Badminton Trainer is system being developed by us to train students in playing badminton shots.

a. Basis of CoMBaT

The system comprises of the Myo Band and the CoMBaT Training Application. The Myo band[10] is a wearable device that senses the variations in electrical conductivity during muscular activities of the participants. It additionally houses an IMU sensor (a single board consisting of an accelerometer, a gyroscope and a Magnetic Compass) that provides real time information about changes in the forces orientation experienced by the myo band or the user's arm. The EMG and the IMU data from the Myo band is transmitted over bluetooth in real time. The data can be recorded using the Myo API provided by Thalmic Labs for Myo Band. The Myo Band has a vibration motor for a haptic feedback which can also be controlled by via the API.

The CoMbaT Application [11] reads the data using the Myo Band API. It receives two forms of data. Once from the EMG sensors which are actually 8 streams of data from one each from the 8 EMG plates of the Myo Band. The second stream is from the IMU sensor that provides data from the accelerometer and gyroscope providing the acceleration (linear and angular) experienced by the arm in the 3 dimensions. The resultant of the EMG data is calculated as we are interested in the intensity of the effort irrespective of the its distributions among the muscles. The acceleration data from the
accelerometer and gyroscope is fused together to generate a pattern of resultant acceleration experienced by the arm during the shot. These patterns are compared to pre-recorded expert pattern obtained from a set of shots played by an expert player. The pattern matching is done using Dynamic Time Warping algorithm (DTW). This algorithm can match pattern which are temporally independent which a good accuracy but is process intensive with a complexity of $O(n^2)$[12, 13]. The algorithm returns a score which determines how close the two patterns were, for example to same patterns would result in a warping score of 0. Based on threshold of this score the CoMBaT determines of the patterns obtained from the trainees shot were close enough to the experts shot according to which a relevant feedback is provided.

b. Parameters of performance

The Performance of the trainees was measured under two parameters namely Swing, that is characterised by the accelerations the arm experiences while playing the shot and the Effort, characterised by the muscular activity of the arm. The accelerations are recorded using the IMU sensor of the myo band and the muscular activity is recorded using the EMG sensors. The data from these sensors is processed and compared with the data obtained from the experts. This comparison based on the EMG data [14] that represents the effort of the trainee and IMU data that represents to the swing of the trainee is used to give the feedback on their effort applied and the swing performed. The data from the myo band is recorded in CoMBaT for every shot that is played. Apart from the data the warping score for the effort and the swing are also stored.

c. Training with CoMBaT

The trainees are given a demonstration of the technique to play a shot by the trainers. Trainees then enter the training mode where they are introduced to the Myo armband and instructed to wear the band correctly. Further, it introduces the visualizations and the feedback mechanisms (as mentioned in the section above). After wearing the Myo band the trainee goes through a run in session when he/she is required to experience all types of feedbacks. This is to get the trainee accustomed to the visual and haptic feedbacks that correspond to the types of shot played. Now the trainee starts with the training session. As a shot is played the screen shows the color markers for each of the shot parameters and the trainee receives a haptic feedback on the
arm. The visualization of the data pattern plots can be viewed by the trainee by clicking on the color markers on the screen.

4. Embodiment of the Racquet

The physical characteristics that are influenced by the presence or absence of a tool are the reachability space [4]. Change in the perceived length of the arm would have an impact on the acceleration the arm produces during the swing while playing the shot. We wanted to analyze would absence of the racquet bring a significant change in the swinging of the arm as the reachability space has been reduced. A study was designed to answer these questions.

The hypothesis that we tested in this study were:-

A. H0: There is no significant change in the performance of a badminton player while playing with real or imaginary racquet.
B. H0: There is no significant variation in swing performance in play with or without the racquets for a participant who is a
   a. professional
   b. novice
C. H0: There is no variation in the the performance of the swing between a professional or a novice when playing a shot while
   a. imagining the racquet but using the shuttle.
   b. imagining the racquet and the shuttle.
   c. playing with the racquet and the shuttle

5. Research Study

A study was planned with two participants, a professional player who has been professionally trained and has played for his institution and second was a novice who is a casual player of badminton. Both are from the same age group and equally physically active. Both of them are from a similar professional background. CoMBoT was used as the tool to record the data during the study. The study was planned as a single phase study but to conform the results from the first another variation was done to make a better comparison with the same participants. The participants were called individually to an enclosed room with length equivalent to a badminton court. The participants were given the same racquets and the same set of shuttles. The were asked to play the
same shot, *Long Service Shot*. The entire sessions were video recorded. The feedbacks and the warping scores generated for the swing and effort patterns of the shots played were also stored along with the streamed data from the myo band.

1. **Study 1**

Each participant was introduced to the CoMBaT system and the myo band. The working of the system and the band was explained. The shot was demonstrated. The participant was allowed to play 3 shots to get accustomed to the system. Then the participant was asked to play 10 shots with the racquet and the shuttle for which they did not receive any feedback about their swing or the effort. Then the participant was allowed to play with the system a set of 30 shots with feedback and another 10 without feedback. These 40 shots were performed to ensure a uniform physical state of both the participants hence these were not considered in the analysis of the study. This was also to induce a temporary muscle memory of the shots for the participants. This was not done in study 2 to check for the training as a confound. After the 40 shots the participant was asked to play another 10 shots without the racquet and the shuttle and was asked to imagine both while playing the shots.

2. **Study 2**

This study was performed a week after the first study. In this study each participant was asked to play the same shot wearing the Myo band. The participant was allowed to use the shuttle but had to imagine the racquet. The objective was to hit the shuttle with the imaginary racquet while playing the shot. The shot was played 10 times and no feedbacks were given while playing the shots. There were no practice shots given in the beginning of this training.

6. **Results**

A set of 20 shots from each participant was collected from study 1 and a set of 10 shots from study 2. The total 60 shots data was populated on Microsoft Excel. For the first hypothesis the set 40 shots from study one were separated as shots played with racquet and shuttle (RS) and no racquet no shuttle (NRNS). For the second analysis the data was further sorted between the
participants. The data of 20 shots from the second study for data with no racquet but shuttle (RNS) was added here.

The data from both the studies was plotted which presented a visually significant difference between the Players. To further conform two-tailed two independent group t-Test for unequal standard deviations were performed on the warping scores of the swing patterns of the participants. Alpha was chosen as 0.05 for all the comparisons.

Based on an independent-samples t-test conducted to compare swing performance, there was a significant difference in warping scores in the NRNS case (M=0.059, SD=0.0006) and RS case (M=0.038, SD=0.0007); t (38)=2.5854, p= 0.01368. These results suggest that there was a significant difference in swing performance with racquet and shuttle (RS) and without racquet and shuttle (NRNS). Hence the hypotheses A H0 is rejected.

The warping scores of swing that are below 0.03 are considered to be close to the expert’s swing i.e the reference pattern. The swing warping scores of the professional and the novice for the three cases of RS, NRNS and NRS were plotted. In case of RS for Novice and Professional both had their swing warping scores close to 0.03, whereas in case of NRNS or even NRS the novice’s scores were a very far away from the threshold, where as the expert is still able to stay near the threshold. The plots are presented in the Appendix A.

Based on the above mentioned observation from the plots of the warping distance score for swing independent-samples t-test were conducted to compare swing performance of the professional where it was found that there was no significant difference between the swing warping scores in case of NRNS (M = 0.035, SD = 4.47 x 10^{-5}) and RS (M = 0.030, SD = 0.4.57 x 10^{-5}); t (18)=1.7960, p= 0.0892. Even in the case of RNS (M = 0.034, SD = 6.57 x 10^{-5}) and RS (M = 0.030, SD = 0.4.57 x 10^{-5}); t (18)=1.0834, p= 0.2937 shows no significant difference. This concluded that the there is no significant difference in swings of the professional with or without the racquet. Hence the hypotheses B.H0.a is not rejected.

Whereas the independent-samples t-test conducted to compare swing performance of the novice, there was a significant difference between the swing warping scores in case of NRNS (M = 0.083, SD = 3.26 x 10^{-5}) and RS (M =
Even in the case of RNS (M = 0.117, SD = 1.0 x 10^{-3}) and RS (M = 0.046, SD = 1.3 x 10^{-3}); t (18)=4.566, p= 0.0002 a significant difference is seen in the swing warping scores. This implies there is a significant difference in the swing of the novice with and without the racquet. Hence the hypotheses B.H0.b is rejected. The alternate hypothesis states the the novice is able to perform the desired swing with the racquet than when he had to imagine the racquet.

Table 6.1 gives a summary of the p values from the above mentioned t tests performed where alpha was chosen to be 0.05.

Table 6.1: summary of p values of t-tests between RS, NRNS and NRS for professional and Novice

<table>
<thead>
<tr>
<th></th>
<th>RS vs NRNS</th>
<th>RS vs NRS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Novice</td>
<td>0.0115</td>
<td>0.0002</td>
</tr>
<tr>
<td>Professional</td>
<td>0.0892</td>
<td>0.2937</td>
</tr>
</tbody>
</table>

The independent-samples t-test conducted to compare RNS performance of between the participants, there was a significant difference between the novice (M = 0.117, SD = 1.0 x 10^{-3}) and professional (M = 0.034, SD = 6.57 x 10^{-5}); t (18)=7.81, p= 0.00004. Even when considering the case of NRNS between novice (M = 0.083, SD = 3.26 x 10^{-5}) and professional (M = 0.035, SD = 4.47 x 10^{-5}); t (18)=17.1246, p= 1.37 x 10^{-12} a significant difference is seen in the swing warping scores. Hence the difference in swing performance of the professional and novice while imagining the racquet is significant. Hence the hypotheses C.H0.a and C.H0.b are rejected. The alternate hypothesis state that a professional is able to execute the swing better than a novice while imagining the racquet when compared to the professional.

But when considering the case of RS between novice (M = 0.046, SD = 1.3 x 10^{-3}) and professional (M = 0.030, SD = 0.4.57 x 10^{-5}); t (18)=1.3208, p= 0.2159 no significant difference is seen in the swing warping scores. Which implies that there is no significant difference in performance of the novice and the professional while holding the racquet. Hence the hypotheses C.H0.c is not
rejected.

Table 6.2 gives a summary of the p values from the above mentioned t tests performed where alpha was chosen to be 0.05.

Table 6.2: summary of p values of t-tests between professional and novice for RS, NRNS and NRS for Alpha = 0.05

<table>
<thead>
<tr>
<th></th>
<th>Alpha = 0.05</th>
<th>Pro vs Nov</th>
</tr>
</thead>
<tbody>
<tr>
<td>RS</td>
<td></td>
<td>0.2159</td>
</tr>
<tr>
<td>NRNS</td>
<td></td>
<td>1.37 x 10^{-12}</td>
</tr>
<tr>
<td>NRS</td>
<td></td>
<td>0.00004</td>
</tr>
</tbody>
</table>

7. Discussion

As inferred from the result section there is a significant difference between the the shots suggests that there is a difference in the performance of the swing while playing with and without the racquet. This implies that not having the racquet did not help in recalling the muscle memory to achieve the correct swing.

We further investigated into the detail by comparing the performance of a novice and professional while comparing their performance based on the ability to imagine the racquet the shuttle or both. Here we see that there is no significant change in the performance of the expert even while he imagines the racquet whereas the novice shows a significant difference in performance while playing with the racquet and shuttle compared to imagining them while playing. This suggests that the professional has been able to recall the muscle memory even while imagining the racquet which implies the professional has embodied the racquet and he is able to perform at par just by imagining it.

This is conformed by observations when the comparison of performance in the three situations for both the participants where we see a significant difference between the professionals performance compared to the novice when they had to imagine the racquet and/ or the shuttle but the difference in their
performance was not significant when they both were playing with the racquet and the shuttle.

The actual performance of a player in the game of badminton or even based on the result of the shot depends on various other parameters hence no variation between the parameters of the swing does not signify that they perform equally in the game or playing badminton are similar.

8. Conclusion
This supports the previous suggestion that the experienced worksman embodies the tool significantly enough to be able to retain the memory of its use or be able to activate the motor patterns even in the absence of the tool and hence can perform an activity involving the tool by just imagining it. This clearly enables us to claim that a repeated used of a tool embodies its experience which improves with repeated usage of the tool.

An implication of this result is that imagination of environment embodied by repeated practice by an expert enables them to activate the cognitive and motor processes associated with it. This could enable them to experiment and observe variations or effects of manipulating the environment. Hence a regular experience of the activity could enable a person with the capability to make changes and predict things about the environment better which would a hypothesis we aim to test.
REFERENCES


Appendix A

Data plots of the warping score data from the professional and the novice player. The blue line shows the variation in the scores as the straight orange line shows the threshold for the warping score for a good swing shot as set in the feedback system of CoMBaT.

Fig A.1: Novice’s Swing warping scores for RS
Fig A.2: Professionals Swing warping scores for RS
Fig A.3: Novice’s Swing warping scores for NRS
Fig A.4: Professionals Swing warping scores for NRS
Fig A.5: Novice’s Swing warping scores for NRNS
Fig A.6: Professionals Swing warping scores for NRNS
CoMBaT: Wearable Technology Based Training System for Novice Badminton Players

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Abstract—Mastery of a shot technique is one of the important skills to be developed by novice badminton players. A shot technique includes the application of effort and swing of the arm. It is desirable for a novice badminton trainee to visualize the above parameters immediately after playing a shot. There has been an inadequate utilization of wearable technology for visualizing of these aspects. Myo armband, a wireless wearable device has the ability to sense the physical characteristics of effort and swing. CoMBaT, our Myo band based training system processes and plots the sensor data patterns of a badminton shot for reviewing the effort and swing. Additionally, in our system, we have used the Dynamic Time Warping (DTW) algorithm to compare the trainee data with a reference data to provide corrective real-time visual and haptic feedback. This paper describes the design and development of CoMBaT along with a study plan to evaluate its usability and effectiveness.

Keywords—Myo band, badminton, Training, EMG, visualization, Visual Feedback, Haptic Feedback.

I. INTRODUCTION

Learning badminton is a three staged process. Trainees begin at the cognitive stage where they learn the technique of playing a shot which involves the stance, the swing of the arm and application of effort at the correct instance to execute the swing [1]. In the associative stage, the trainee focuses on the correct execution of the technique. The stance can be corrected visually but the effort applied and the swinging of the arm are not visibly apparent and require a consistent attention from the trainer. In the autonomous stage, the shot becomes second nature. The player is able to focus on varying situations and adapt the technique to instantaneous changes.

For novice learners, a key challenge in the above process is to be able to determine the correct instance to apply muscular effort and achieve the desired swing of the arm as they are not visibly apparent. Visualization of these parameters and providing feedback based on their correct execution would be a way to address these challenges. Traditionally this has been achieved by one-to-one sessions and a consistent supervision of the trainer. This apprenticeship model is time and labor intensive.

Researchers and trainers have used a variety of technological solutions to address the above challenges. For example, there exist virtual game-based solutions such as Racquet Sports by Ubisoft [2], available on the Sony PS3 and Wii platforms, provide a virtual environment to play badminton with visual cues for the trajectory of the shuttle. Recent and exciting developments in wearable technologies are one solution to enable trainees to visualize their muscular effort in real time and further assist in providing corrective feedback since these tools are capable of sensing such physical and hidden characteristics.

In our research, we have designed and implemented a training solution for novice badminton learners that can be used while playing a real-life game. Our training system, CoMBaT (Corrective Myo Badminton Trainer) helps the learner visualize muscular effort and swing of the arm, and provides real-time corrective visual and haptic feedback. Combat uses Internal Measurement Unit (IMU) sensors like the accelerometer and gyroscope which record the linear and angular acceleration experienced by a device [3]. In addition, it uses Electro Myo Gram, a non-invasive, surface technique used to indicate muscle group coordination while performing an action. The action potentials generated by the surface electrodes attached to the body are recorded as the action is performed [4]. The wearable device developed by Thalamic Labs, the Myo band (as seen in Figure 1), is a wearable gesture recognition device that houses 9 axis IMU and a set of 8 EMG sensors. IMU sensors enable recording of the linear and angular acceleration experienced by the arm and a set of EMG sensors record muscle activity based on which the band is able to differentiate between different gestures [5].

The plots of EMG and IMU data sensed by a Myo band while playing a badminton shot enables trainees to visualize the hidden aspects of applying a correct technique. Comparison of data patterns from a shot played by the trainee and the reference pattern helps us to generate a corrective feedback. This feedback will enable the trainee to apply the correct technique while acquiring the skill and also acts as a positive reinforcement for playing the shot.

This paper presents the architecture and technical implementation of the CoMBaT badminton training system, discusses the training design and the results of playtesting.
This system as of now focuses on helping the trainees to learn the basic technique of badminton, the ‘long service shot’, a common beginner’s technique in badminton training used to push the opponent to the back of the court.

The structure of the paper is as follows: - Section II presents a review of the current literature discussing the challenges in learning badminton, and use of IMU sensors and EMG to address various challenges in sports. Some solutions that have used Myo band as a wearable device have also been discussed. Section III presents our solution (CoMBaT) discussing its key characteristics. Section IV presents the architecture, discusses the interactions between the trainee and CoMBaT concluding with a play test of CoMBaT. Section V discusses the observations and implications of the design and the play testing. Section VI concludes the paper along with the possible extensions to this research.

II. RELATED WORK

Traditionally badminton has been taught using the apprenticeship model where the trainee observes the trainer apply the technique. Then the trainees practice the same techniques under the supervision of the trainer [1].

A. Challenges of learning badminton

Based on observation of skilled players an effective badminton shot is determined by the following aspects: i) stance of the player which can be corrected by visual feedback, ii) the grip of the racquet which can be visually corrected [6], and iii) swing of the arm and the effort applied to it [7]. It is difficult to determine an adequate swinging of the arm and application of the effort at the correct instance to make that swing. There is a need of making these physical parameters visible to the learner. Literature suggests the use of [8] sensors to gain insights into techniques used by players but haven’t yet been used as a mechanism of visualization for corrective feedback during everyday training. To achieve this effort, a result of the muscular activity can be measured using EMG sensors [4] and the swing of the arm, characterized by the acceleration it experiences can be measured by the accelerometer and gyroscope of the IMU sensors [9].

B. Use of advanced learning technology in sports

There are several virtual game-based environments for playing such as Racquet Sports, Sports Champions for Tennis, Ping-Pong, Golf and a lot more where only Racquet Sports has the option of playing badminton. These gaming environments are built for Sony Play Station (PS), Microsoft Xbox and Wii. The motive of these environments is to make the users experience the sport by simulated playing [10]. To map the player’s actions to the virtual environment PS and Wii use a motion controller stick and a tracking camera where as Xbox uses an array of cameras to track body movement. [2]

Sensors such as IMU have been used for motion mapping of sports players. For example, IMU sensors mapped the time sequence of motion patterns in the sensor data from the feet and arms of a tennis player to monitor full body coordination [9]. Techniques such as EMG use sensors to measure muscular activity. A review [8] of EMG research of 32 sports, covering over 100 different complex skills states that sport movement techniques are governed by highly specialized muscular activity. The knowledge of such muscular action should allow for the optimization of movement for training possibilities and of sports performance, presenting the importance of EMG in sports training. Using such a technique, researchers [11] were able to differentiate between the effects of different clubs for a set of golf shot swings and also show that muscles developed their maximal activation levels during the Forward Swing and Acceleration using EMG of the lower limb. This strongly encourages to use of EMG-based devices to help visualize the muscular effort to be applied for the swing. No one has used an EMG-based wearable solution in sports to the best of our knowledge.

C. Myo Band based solutions

A custom designed setup of IMU sensors and a number of EMG sensors over the arms was developed [12] for teaching skills primarily based on muscle memory, which traditionally involves a lot of observation and repetition with hours of supervised learning. The evaluation of this technique focused on the skill of pottery making and provided feedback using a LED display worn on the arm. The results strongly support the use of a combination of IMU and EMG-based devices for training that involves muscle memory but their evaluation was focused on a skill based on a sedentary activity and not in the domain of sports.

<table>
<thead>
<tr>
<th>Research goal</th>
<th>Affordance of Myo Band</th>
<th>Domain</th>
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</thead>
<tbody>
<tr>
<td>Hand Sign Recognition [13]</td>
<td>EMG</td>
<td>Linguistics</td>
</tr>
<tr>
<td>Gesture recognition [14]</td>
<td>EMG</td>
<td>Not specified</td>
</tr>
<tr>
<td>Gesture based controller [15]</td>
<td>Inbuilt Gesture Recognition</td>
<td>Cycling</td>
</tr>
<tr>
<td>Self-evaluation [16]</td>
<td>EMG</td>
<td>Physiotherapy</td>
</tr>
<tr>
<td>Trajectory mapping [17]</td>
<td>IMU for joints and EMG for wrist</td>
<td>Machine Operation</td>
</tr>
<tr>
<td>Haptic Feedback [18]</td>
<td>Used Vibration Motor</td>
<td>Social Interaction</td>
</tr>
</tbody>
</table>

Table 1 gives an overview of the various research goals for which Myo Band based solutions have been used. These either use data from Myo band for gesture recognition [13, 14, 15] or use it as a gesture-based controller [16]. Only EMG data has been used in medical solution [17]. IMU and EMG data were used for skill training in pot making but the collection of data was done using a custom-built solution [12] whereas IMU sensor data was used for trajectory mapping but EMG data was not used [18]. Though the haptic motor of the Myo band was used as a feedback mechanism in nonverbal social interaction [19].
Though a lot of research in sports has been carried out using EMG to gain insight, but it has not been utilized as a mechanism for assistance during everyday training. A lot of wearable devices use IMU sensors for daily activity recognition and logging [9] but do not provide training assistance for sports. Most of the solutions using Myo band exploit its gesture recognition capabilities but do not use the real-time data stream to interpret the physical parameters the band experiences as seen in Table 1. Even though suitable for sports no research has used the affordances of the data from Myo band in this domain to the extent of our knowledge.

III. Solution Approach

Our solution, CoMBaT, is based on the sensory ability of EMG to sense muscular activity and IMU’s ability to sense acceleration experienced by the arm. Data from these sensors enable us to visualize the muscular effort and swing of the arm. Feedback is generated by processing and comparing patterns from this data against the reference patterns. Myo band’s capability to wirelessly transmit EMG and IMU data over Bluetooth in real-time and allowing the control of its onboard vibration motor makes it our choice as a wearable device for collecting data for visualization, as well as for comparison with a reference pattern to provide visual and haptic feedback in real-time.

A. Visualization

The effort, a result of the muscular activity, has been visualized by plotting the EMG sensor data pattern and the swing of the arm, characterized by the acceleration it experiences, has been plotted using the data from the accelerometer and gyroscope of the IMU sensors. The visualization shows a plot of the EMG and IMU sensor data patterns recorded when the shot was played by the trainee. These patterns are plotted along with the reference patterns so the trainee can gain better insight for corrective measures to be taken while playing the shot. The real-time visualization helps situate the trainee’s use of technique additionally reducing the effects of creating an incorrect schema when not under the supervision of a trainer [19].

B. Feedback

The feedback is given to the trainee immediately after the execution of the shot. Two types of feedback are given to the trainee. The first is a set of two colored markers, one for the effort applied at the correct instance and the other for the adequate swing of the arm. A correct use of the technique is shown by the marking turning green and red otherwise. The Myo band also has an onboard haptic vibration motor which is used to provide haptic feedback by varying the length of vibrations according to the to the correct usage of the technique for muscular effort and swing of the arm.

IV. CoMBaT

This system primarily consists of a wearable device, the Myo Band and CoMBaT application running on a computer. The Myo band provides EMG and IMU data wirelessly via Bluetooth in real-time and is used as a platform to provide haptic feedback. CoMBaT application running on the computer enables the visualization of the sensor data patterns of muscular effort and arm swing. It also provides a marker based visual feedback, as seen in Figure 1, and instructs the haptic vibration motor of the Myo band.

A. CoMBaT Architecture

The CoMBaT application interacts with the Myo band using the Myo API provided with the SDK from Thalmic Labs [5].

The components of its architecture as seen in Figure 2 are discussed below:

- **Pre - Processing:** A set of raw data from the Myo band is collected for a single shot. It consists of 8 EMG sensors on the Myo band is received via the API sampled at 200Hz. The resultant from the 8 values is obtained by calculating the root of the sum of the 8 squared values. This data is subsampled to 50Hz to reduce noise and to match it with the IMU’s sampling rate i.e.50Hz. The data from the IMU sensors consists of linear acceleration in 3 axes and angular acceleration in 3 axes. The resultant linear and angular accelerations are obtained by calculating the root of sum of squares of the values from each axis. The resultant values are then fused using a complimentary filter to get the resultant acceleration which has a component of the linear and angular accelerations. Both the values are then normalized to a uniform scale. The final set of values compose the two patterns for that particular shot.

- **Pattern Matching (DTW):** Pattern recognition methods allow us to provide feedback to the trainees by comparison of the sensor data patterns collected as they try to apply the technique in contrast to reference patterns. A reference pattern is derived from patterns of sensor data from expert’s execution of the correct technique. Dynamic Time Warping algorithm is used as it can compare two temporal sequences that may be spatially or temporally independent [20, 21]. The algorithm takes two patterns and returns a warping score which is the sum of smallest Euclidian distances between every point of the two patterns calculated while traversing from the first point to the last point. Comparison of two same sequences results in a score of 0. The algorithm compares the temporally aligned IMU and EMG data patterns of the trainee with the
reference patterns. The EMG and IMU reference patterns are coded into the application for pattern matching. To obtain the reference patterns the sensor data recorded during an expert’s execution of the technique of a badminton shot is pre-processed to obtain patterns. The patterns obtained are averaged to obtain the reference patterns for the EMG and IMU data as shown by the dotted lines in Figure 3. Feedback is provided based on a calculation (explained in the next subsection) on the obtained warping score. The data patterns are stored for the plot based visualization.

- **Shot Evaluation:** A threshold is used to evaluate the warping scores obtained after comparison of two patterns. Thresholds are the max warping score obtained when the reference patterns are compared to the data patterns that were used to obtain the reference patterns as all those patterns are from the correct executions of the technique to play the badminton shot so any pattern that is in proximity of those patterns is considered as a correct execution of the shot. Any warping score that is below the threshold is considered as a correct execution of the parameters. If both the warping scores are below the threshold they are considered as a good shot. If only one is below the threshold it is considered as an average shot and if neither is below it is considered as a bad shot. The threshold based evaluation also determines the color of the visual feedback marker and the length of the vibration of the haptic feedback motor.

- **Visualizer:** The visualizer shows a plot of the EMG and IMU sensor data patterns of the trainee’s shot obtained after pattern matching. These patterns are plotted along with the reference patterns so the trainee can gain better insight for corrective measures to be taken while playing the shot e.g. the instant of application of effort as seen in Figure 3.

- **Visual and Haptic Feedback:** Green color on the two visual feedback markers, as seen in Figure 1, determine that the warping score of both the muscular effort and the arm’s swing were below the thresholds whereas a red on either would determine the warping score for that parameter is above the threshold. If the shot is evaluated to be a good shot the application uses the Myo API to activate a short pulse of vibration on the band. For an average shot, it’s a set of 3 medium pulses and a long one for a bad shot.

### B. Training Design

The trainees are given a demonstration of the technique to play a shot by the trainers. Trainees then enter the training mode where they are introduced to the Myo arm band and instructed to wear the band correctly. Further, it introduces the visualizations and the feedback mechanisms (as mentioned in the section above). After wearing the Myo band the trainee goes through a run in session when he/she is required to experience all types of feedbacks. This is to get the trainee accustomed to the visual and haptic feedbacks that correspond to the types of shot played. Now the trainee starts with the training session. As a shot is played the screen shows the color markers for each of the shot parameters and the trainee receives a haptic feedback on the arm. The visualization of the data pattern plots as shown in Figure 3 can be viewed by the trainee by clicking on the color markers on the screen. Figure 4 depicts the interactions between the trainees and CoMBaT during different phases of the training.

### C. Play Testing

We carried out the play testing with the long service shot primarily to inspect the working of the system and the intended user's interactions with CoMBaT. To generate the reference, pattern an experienced badminton player played 5 shots wearing the Myo band which were recorded using the Myo band. The thresholds of the warping scores, as explained in shot evaluation subsection of section IV.A, were obtained as 0.04 for IMU data and 0.03 for EMG data. The trainees chosen for this study were novice players. We followed the same intervention mechanism as described in the paper. During the interview with the trainees after they had trained with the system we discovered preferences for the feedback mechanism. For example, one participant only looked at the visual feedback when it was an average shot, in other cases the haptic feedback seemed sufficient for them. Another participant always preferred the visual feedback.
During the interview both the participants mentioned that they found the generated graph too confusing due to the overlapping patterns of the novice and expert. One of them mentioned that the graph did not scaffold them to translate the differences to shot. We are in the process of changing the visualization mechanism based on the feedback we have received.

V. DISCUSSION

From the visualizations obtained during the playing test, it was evident that muscular effort applied while playing the shot precedes the swinging of the arm. Though innate to the experienced players visualizing this was a reinforcement of the technique for the novice. This, in turn, builds our confidence in visualizations of these hidden aspects. We intend to make design changes to scaffold the graph interpretation and translation to actual shot. We would want to explore the feedback mechanisms in detail in the next cycle of research studies.

We were able to play test CoMBaT only with 1 experienced and 3 novice players hence we plan to conduct a usability study with 5 more novice trainees. We are in the process of contacting participants for conducting this study in the span of next six months. Feedback from the usability study will be incorporated along with possible extensions for the span of next six months. Feedback from the usability study will be planned along with a badminton training camp. The study will be done with a control group and experiment group who will undergo a pretest and post test using the CoMBaT system. The results will be analyzed to measure the skill learned.

VI. CONCLUSION

This paper presented the design of a badminton shot training system (CoMBaT) which used a Myo band, affordance of which allow collection of IMU sensor data for the accelerations experienced by the arm while executing the swing and EMG data that captures the muscular activity when applying the effort. This helps the trainee visualize these hidden aspects of a shot technique. The system further uses this stream of real-time data to find variations in the parameters that govern the correctness of the shot and uses the CoMBaT screen to provide visual and the haptic motor on the Myo band to provide real-time time feedback. The visualization reinforces the application of a correct technique while acquiring the skill and feedback acts as guidance mechanism while playing the correct shot. The future versions would aim to determine the fault and suggest corrective measures.

REFERENCES