# EFFECTIVE SURFACE AREA OF OPERATION FOR THE TIF-HA ONSET DETECTION ALGORITHM FOR HUMAN-COMPUTER TOUCH INTERFACE

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**Abstract**- Localization of impacts on solid surface using TiF-HA onset detection algorithm was developed by Nanyang Technological University. In this paper, we are verifying the physical limitation of the algorithm at this stage of research. We would be testing with different sizes of sensors and different surface area to determine the accuracy of the localization.

**Keywords**- Area of Operation, Flexural Vibration, Human-Computer Interface, TiF-HA Algorithm.

## I. INTRODUCTION

Human-computer touch interface is becoming a standard in which we interact with devices. This technology started with the invention of the Elograph, by Elographics Inc in 1971. Next in 1983, Hewlett Packard invented HP-150, the first touch screen computer. With technology advancing as time goes by, we now have smartphones equipped with touch screens and it will only get more complex, providing users with greater accuracy and even more features to improve the quality of life.

Touch technology comes in various ways to pick up a touch input from the users. Most commonly available systems are the resistive touch screens and the capacitive touch screens being used in consumer devices. The resistive and capacitive system requires a layer of conductive material known as Indium Tin Oxide (ITO).

The material Indium is expensive and scaling it for large screens will become prohibitively expensive due to the costs incurred. Large touch screen displays would be more reliable and cheap if using optical, acoustic or infrared technology instead.

Both resistive and capacitive touch screens are manufactured in fixed sizes and are not scalable at will. However, the vibration technology that Nanyang Technological University (NTU) allows us to change the interaction area by just repositioning of the vibration sensors.

NTU developed and patented the TiF-HA algorithm in 2013. The TiF-HA algorithm first converts the propagation wave signals into the time-frequency (TiF) domain. Once the time-frequency domain signal has been attained, Hermitian angle estimation is done at all the points in the selected bins. Next, standard deviations of the Hermitian angles across the frequency bins are calculated resulting in a high value if only noise is present and a low value if signal is present. The point when the change in standard deviations is occurs is assumed to be the onset points. In order to find the transition point, a histogram is used because the standard deviation during the noise period will form one cluster (group of high standard deviations) and the signal part will form another cluster (group of low standard deviations) and the transition point will be in between these 2 clusters.

The threshold value is used to separate the samples in the determined standard deviations clusters into 2 portions where the transition is the required onset point. To determine this threshold, a cumulated histogram of the standard deviation is obtained and the point of inflection would be the best approximated threshold value.

In this paper, we are determining the best case scenario towards the physical realization of the algorithm to confirm the effectiveness of TiF-HA algorithm in a real-world usage as human computer touch interface.

## II. PURPOSE OF EXPERIMENT

The algorithm first has to pick up a signal which in this case would be given by vibration sensors that picks up surface disturbance when being interacted with a stylus or finger.

This signal is the fundamental piece in the TiF-HA algorithm. Without this input, the rest of the steps in the algorithm are trivial.

Therefore, the focus on this paper would be determining the most optimized way to generate and retrieve this signal. According to the mathematical model for flexural vibration, the vertical displacement of a plate at location (a,b) at time instant t due to an impact a location (ap,bp) on the plate surface is given by:

$$\gamma_p(a,b,t) = \frac{4}{\rho L_a L_b L_c} \sum_{\kappa=1}^{\infty} \sum_{\alpha=1}^{\infty} \frac{\Omega_{\kappa\alpha}}{\xi_{\kappa\alpha}} \left(e^{-0.5\tilde{\mu}t} \sin(\xi_{\kappa\alpha} t)\right), \quad (1)$$

where $L_a$ is length of surface, $L_b$ is width of surface, $L_c$ is thickness of surface, $\xi_{\kappa\alpha} = \sqrt{\omega_{\kappa\alpha}^2 - (\frac{\tilde{\mu}}{2})^2}$, $\omega_{\kappa\alpha} = (\tilde{\beta}^2 + \beta^2)\sqrt{\frac{D}{\rho L_c}}$, $D = EL_c^3/12(1-\nu^2)$ is the stiffness of the plate, E is the Young's modulus and $\nu$ Poisson's ratio. In addition, $\tilde{\beta} = \pi\kappa/L_a$, $\beta = \pi\alpha/L_b$ , $\tilde{\mu} = \mu/(\rho L_c)$ where $\mu$ is absorption coefficient, $\rho$ is density of material while $\Omega_{\kappa\alpha} = \sin(\tilde{\beta}a)\sin(\beta b)\sin(\widetilde{\beta}a_p)\sin(\beta b_p)$ and $\kappa, \alpha \in \mathbb{Z}^+$ are the nodes of wave propagation.

Equation (1) refers to the vibration signal that travels over the surface which will be picked up by the piezoelectric sensor. Ignoring the nodes of wave propagation, we can see that the magnitude of signal is defined by La, Lb, and Lc. This shows that the theoretical size of the surface is limited before the electrical signal converted from the current market available sensors would be too weak to be of any use and the touch interface technology will be rendered ineffective. This paper will look into the components of La and Lb as the corresponding surface length and width whereas Lc being the thickness of the surface will be kept at a constant 10mm. We will also look into the sensitivity of the sensors in picking up signals from the surface.

## III. EXPERIMENTAL PROCEDURE

The signal that is required will be obtained from 3 different sizes of contact microphone. These are piezoelectric sensor which converts the physical surface vibration to its electrical form. Since we are determining the best scenario towards the physical realization of the algorithm, we will be performing 2 different experiments to determine the overall surface area effectiveness of the TiF-HA algorithm.

1. Testing of the sensitivity of 3 different sizes of sensors as shown in Fig 1.

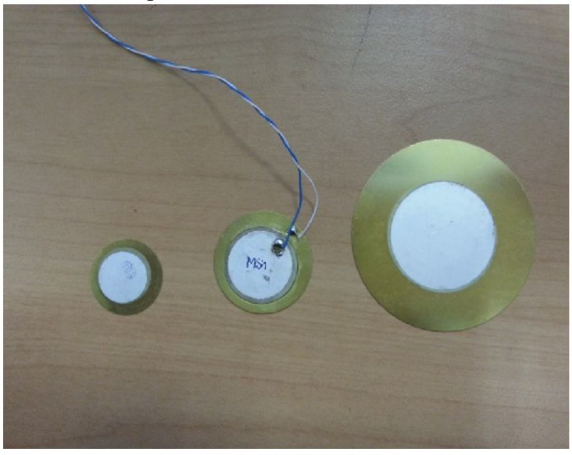


**Figure 1: Different sizes**

2. Testing of localization accuracy with an increment size in surface area.

First experiment is to compare physical size against its ability to pick up a signal at various distances. Distance is determined from the centre point of surface to the corner edge of a surface. This is denoted as Max distance in Fig. 2. We will use a 32", 42", 55" and 65" TV screen as a benchmark size for a surface. Currently, there are 3 commercially available sized piezoelectric sensors with diameters of 2, 2.7 and 5cm. This will give us the relationship between the sensitivity with respect to the size of the sensor in converting surface vibration to electrical signals.

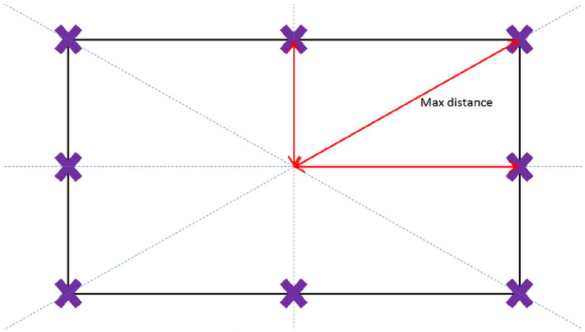



**Figure 2: Sensitivity test distance.**

We will take Signal amplitude and signal end T1 (signal strength is at noise level) as criteria for determine the better result as compared to the rest. The first reason being onset detection of touch point is differentiated between region of low signal (noise) and high signal (actual signal itself) thus the larger the amplitude of signal the less ambiguity between signal and noise. The second reason is to allow the distinction between 2 consecutive signals.

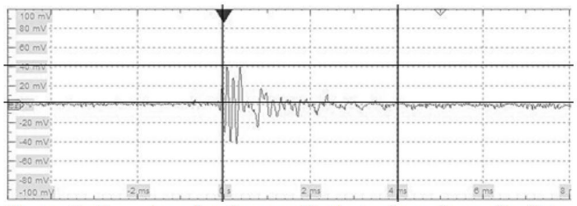


**Figure 3: $T_1$ = 4ms for the amplitude to drop from 40mV to approximately noise level.**

Second experiment will look into the localization accuracy of sensors with increasing surface size. Due to the nature of the sensors and the increasing surface size adding possible avenue of errors in the localization, we would be testing all 3 size sensors with each surface size ranging from 32", 42", 55" and 65".

| | 32" | 42" | 55" | 65" |
|---|---|---|---|---|
| Small Sensor | | | | |
| Medium Sensor | | | | |
| Large Sensor | | | | |

We would quantify them by using test accuracy software written by ITE to capture the touch points as calculated by the algorithm and verify if it is within the error margin to be of any use in behaving like a

touch interface. We have chosen 9 significant points around the screen to be used as test point which will allow maximum effective area of interaction as a touch interface. This error margin is set to be 25mm radius around the touch point.

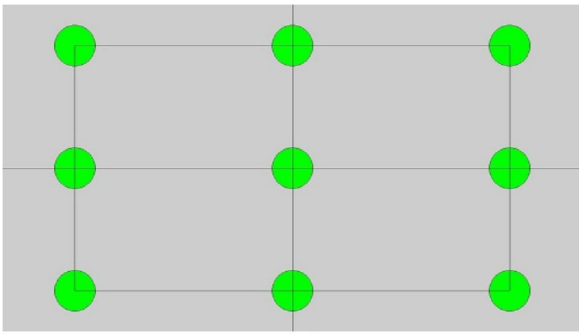


**Figure 4: Accuracy verification application**

## IV. EXPERIMENTAL RESULTS

### A. Experiment 1 – Sensitivity of various sized sensors

We have chosen distances of 16, 21, 27.5 and 32.5 inch as our testing criteria. This corresponds to the distance between a sensor and the center of the screen. The center of the screen is chosen as this is the point where it is maximum possible distance from each 8 sensors when places around the perimeter of the surface area.

The results of this experiment are shown below:

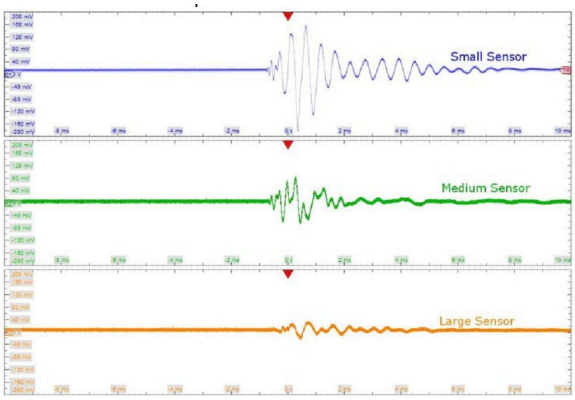



**Figure 5: Distance of 16"**

| Fig 5 analysis | Max Amplitude | Time taken for signal amplitude to reach noise level |
|---|---|---|
| Small | 160mV | 6ms – 8ms |
| Medium | 90mV | 4ms – 6ms |
| Large | 40mV | >3ms |

As we can see from the above results, the small sensor has a lower noise range as compared to the medium and large size sensors. It also performs better as the signal is easily distinguishable. However, the small sensor has a signal fall time of approximately 8ms which is much higher than the medium sensors. This will impact the system in its ability to detect 2 distinct taps in a relative short amount of time.

Both small and medium would work well in localization at this distance of 16 inches. The large sensor is not recommended for this distance as the signal strength is too close to the range of the noise itself.

Distance of 21":

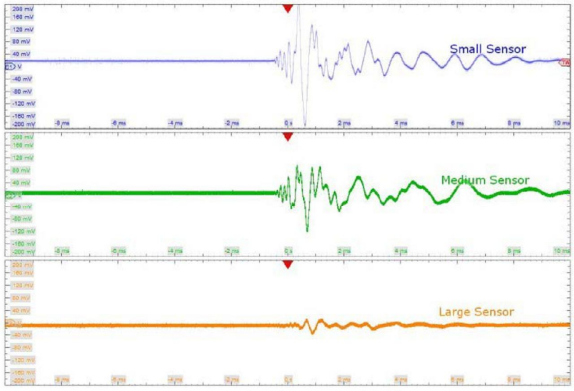



**Figure 6: Distance of 21"**

| Fig 6 analysis | Max Amplitude | Time taken for signal amplitude to reach noise level |
|---|---|---|
| Small | 200mV | >8ms |
| Medium | 100mV | >9ms |
| Large | 30mV | >3ms |

In the case of distance being at 21 inches, the small sensor has a large amplitude gain while the signal dies down after 8ms upon impact whereas the medium sensors signal still fluctuates after 9ms. The small sensors would be considered in the 42 inches screen surface experiment. The large sensor is still not recommended at this distance due to small signal strength

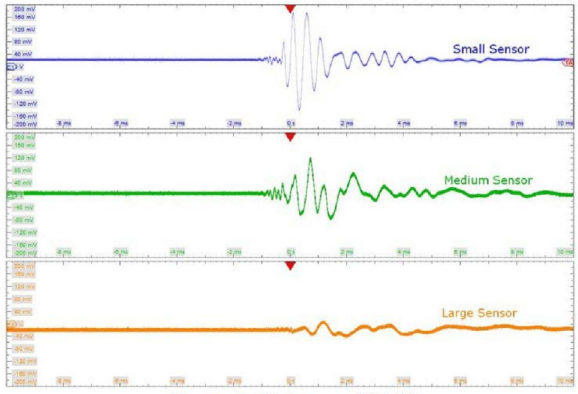



**Figure 7: Distance of 27.5"**

| Fig 7 analysis | Max Amplitude | Time taken for signal amplitude to reach noise level |
|---|---|---|
| Small | 190mV | 4ms – 6ms |
| Medium | 120mV | 6ms – 8ms |
| Large | 30mV | >4ms |

At a distance of 27.5 inches, the result does not defer much in amplitude from the results as shown in the 21 inches table. However, the signal attenuation is much smaller compared to the previous result. The

small sensor would be a better candidate for a surface size of 55 inches in this case due to the max 6ms for the signal to attenuate.

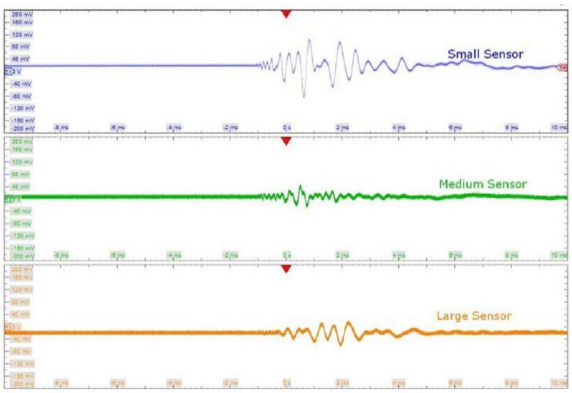



**Figure 8: Distance of 32"**

| Fig 8 analysis | Max Amplitude | Time taken for signal amplitude to reach noise level |
|---|---|---|
| Small | 110mV | 6ms – 8ms |
| Medium | 40mV | 4ms – 6ms |
| Large | 50mV | >4ms |

In the case of distance at 32.5 inches, the small sensor is still a viable candidate even though it takes 6ms for signal to attenuate; this is due to the amplitude being more than 100mV. The medium sensor at this range is not viable to be used in the 65 inches surface setup. However, the large sensor signal amplitude is large enough to be used for verification in the second experiment.

From Fig. 5 to 7, we can assume that the small sensor is highly sensitive in picking up signals as compared to its 2 other counterparts and the large sensor is better at signal attenuation.

This experiment will give us an estimation of which sized sensors coupled with the size of surface area to have the best results for the algorithm to be used as a human computer touch interface. This experiment is not a guaranteed success in implementing the interface as other factor such as surface material, inconsistency in the manufacturing of sensors, wire resistance, noise in signal processing board. It is a baseline in which the second experiment will be conducted to verify the findings in the first experiment.

B. Experiment 2 – Accuracy of localization with increasing surface size

From experiment 1, we have the following options:

| | Small | Medium | Large |
|---|---|---|---|
| 32 inches | 2nd choice | 1st choice | 3rd choice |
| 42 inches | 1st choice | 2nd choice | 3rd choice |
| 55 inches | 1st choice | 2nd choice | 3rd choice |
| 65 inches | 2nd choice | 3rd choice | 1st choice |

Even though we have a table of options which would give us the optimal condition for experimentation, we have decided to perform experiment 2 over all possible combination to verify the results in experiment 1.

In experiment 2, an application (Fig. 4) is written to verify the algorithms output with the tap input. We have chosen 8 points around the perimeter of the screen with 1 additional center point. The green circle seen in the results represents the acceptable deviation from the targeted point. We would be tapping a minimum of 15 inputs. Deviation is measure from the center of the green circle to the touch point. Please refer to Fig. 9 to Fig. 20 for the results of experiment 2.

Accuracy of 32 inches diagonal surface area

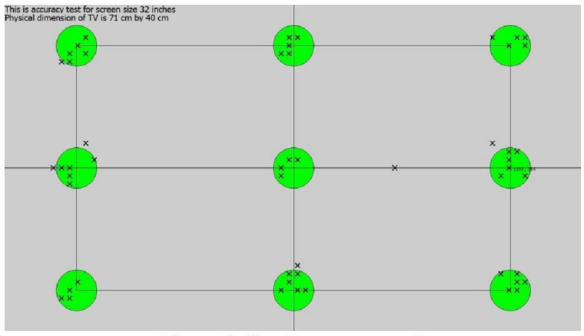



**Figure 9: Small sensors result**

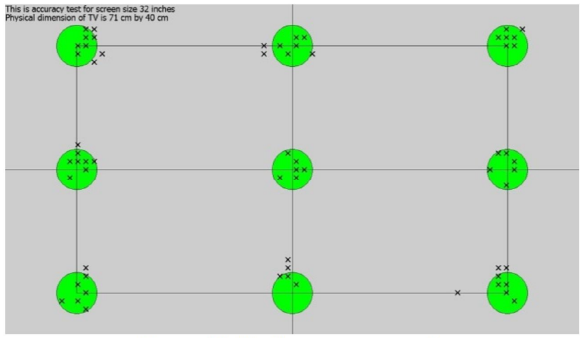



**Figure 10: Medium sensors result**

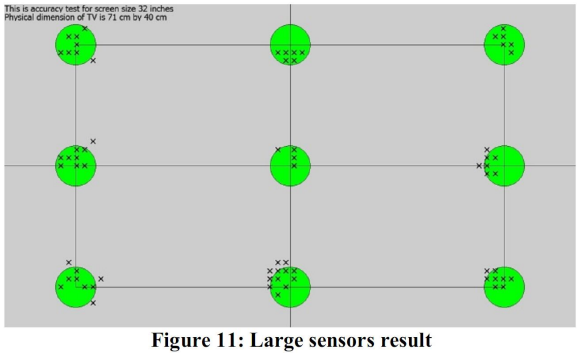



**Figure 11: Large sensors result**

| | Min Deviation | Max Deviation | Mean Deviation |
|---|---|---|---|
| Small | 2mm | 37mm | 16mm |
| Medium | 2mm | 40mm | 18mm |
| Large | 2mm | 38mm | 19mm |

As we can see from Fig 8 to 10, the medium sensor setup performs well as compared to the small and the large setup as it has tighter grouping of the points and it is much closer to the target tap coordinates. The small setup is accuracy in being close to the tap coordinates with a bigger spread of data. The large setup exceeds expectations in this case where we assumed that the signal amplitude of 40mV might be too weak for the algorithm to localize the tap coordinates however from the results above, the large sensor setup shows promising results.

Accuracy of 42 inches diagonal surface area

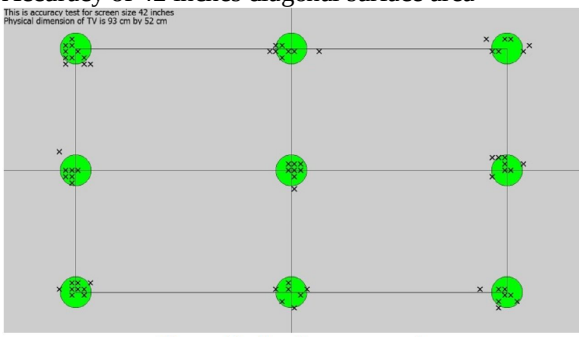



**Figure 12: Small sensor result**

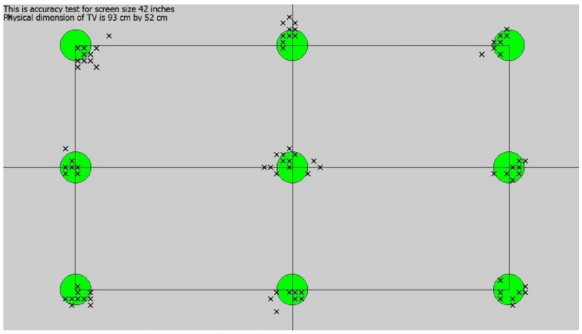



**Figure 13: Medium sensor result**

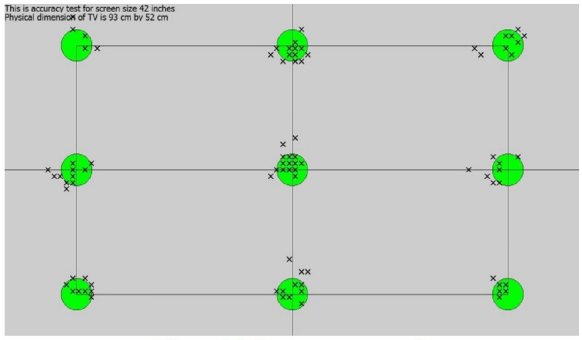



**Figure 14: Large sensor result**

| | Min Deviation | Max Deviation | Mean Deviation |
|---|---|---|---|
| Small | 3mm | 45mm | 19mm |
| Medium | 3mm | 47mm | 19mm |
| Large | 3mm | 62mm | 21mm |

In the 42 inches surface area experiment, the small sensors setup has the least spread among all the 3 sizes. The medium setup has a small offset which could be adjusted by additional improvements to the calibration.

Accuracy of 55 inches diagonal surface area

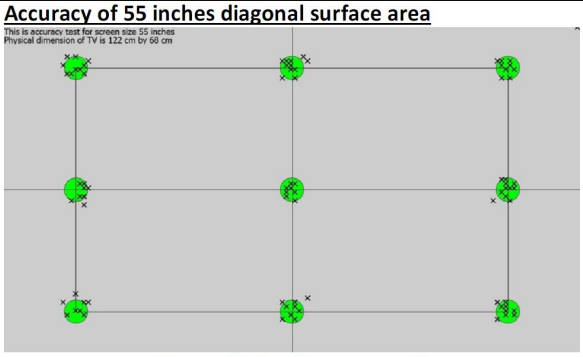



**Figure 15: Small sensor result**

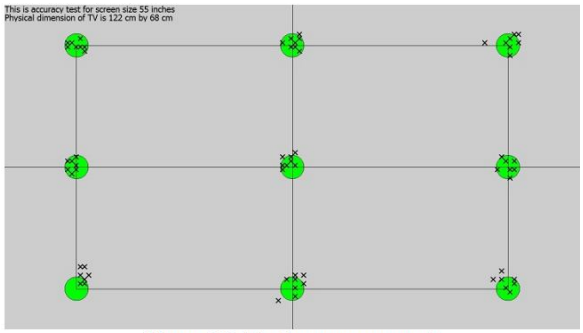



**Figure 16: Medium sensor result**

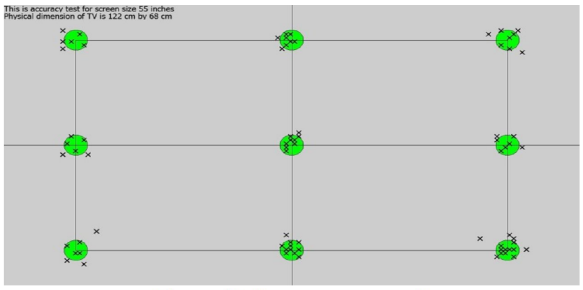



**Figure 17: Large sensor result**

| | Min Deviation | Max Deviation | Mean Deviation |
|---|---|---|---|
| Small | 3mm | 56mm | 21mm |
| Medium | 3mm | 46mm | 22mm |
| Large | 3mm | 59mm | 26mm |

In the 55 inches setup, the small sensors setup performs best with most of the grouping of the tap points within the error margin circle and the grouping being the tightest. The medium setup also display close grouping however more points are out of the error margin circle. The large setup displays the worst result of them all with a fairly wide spread grouping.

Accuracy of 65 inches diagonal surface area

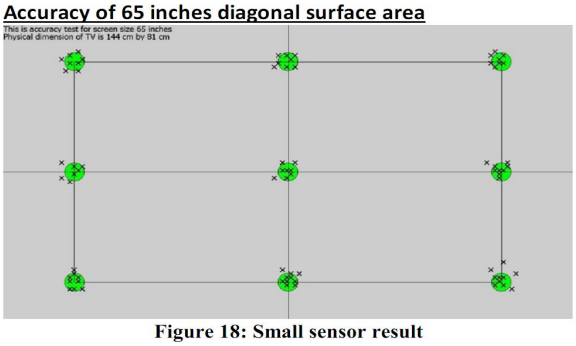



**Figure 18: Small sensor result**

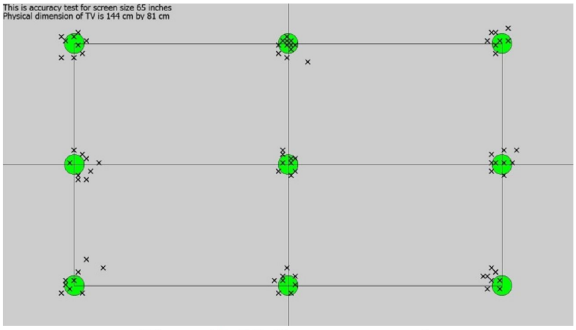



**Figure 19: Medium sensor result**

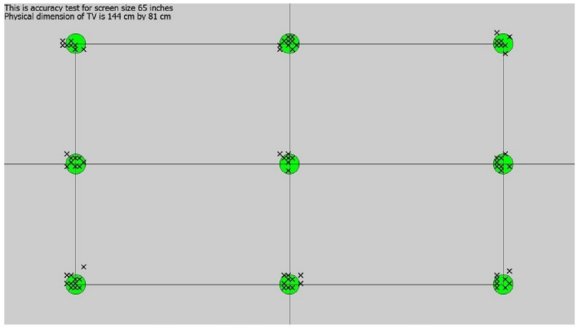



**Figure 20: Large sensor result**

| | Min Deviation | Max Deviation | Mean Deviation |
|---|---|---|---|
| Small | 4mm | 62mm | 24mm |
| Medium | 4mm | 91mm | 27mm |
| Large | 4mm | 45mm | 17mm |

In the final 65 inch surface area setup, we observed from our assumption regarding the large sensor being the best options for a 65 inch surface setup. It is verified from the results above that using large sensors has a tightest grouping and the resulting tap points does not deviate much from the target points.

## CONCLUSION

| | Small | Medium | Large |
|---|---|---|---|
| 32 inches | 2nd | 1st | 3rd |
| 42 inches | 1st | 2nd | 3rd |
| 55 inches | 1st | 2nd | 3rd |
| 65 inches | 2nd | 3rd | 1st |

From the experimental results above, we have verified that different sensors give different results dependant on the size of surface we are working on. There is not a direct correlation between size of sensor and size of surface; each sensor is calibrated differently to each surface to achieve the best possible results. Even when the surface size is at 65 inches diagonally, the output of the algorithm still gives a possible option for this system to be used a touch interface. The next challenge would be to extend the system to work on surfaces larger than 65 inches.

## ACKNOWLEDGEMENT

The authors would like to acknowledge the support given by both Institute of Technical Education and Nanyang Technological University. We would also like to thank Ministry of Education Translational R&D and Innovation Fund MOE2012-TIF-1-T-049 for sponsoring this work.

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