Physicalizing Music:

A Technical Report on Creating a Tactile and Engaging Remote – “Timbreley”

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EXECUTIVE SUMMARY

The following report looks into the case of “Timbreley”, a remote designed to work with the user’s touch and movement to control their music in a unique and original way. Although a complex product with many components, the following report covers the validation of wood as a material for the spherical form of the product (with the ultimate selection of a particular kind of wood) and the selection of touch sensing.

Initially wood as a material is indeed validated through using the Cambridge Engineering Selector (CES) database. The critical properties of both wood and plastic are compared, due to plastic’s commonplace use in robust household electronics and it is found that these properties are similar.

This same technique was then used to choose between the top two preferred woods Cherry and Iroko alongside the use of a weighted property method of material selection. This found Cherry to be the most appropriate for this application and so was chosen for the product’s spherical form.

The next portion of the report covers the electronic aspect of the user interface. After much research and through the process of elimination a system of projected-mutual capacitance was decided upon. It is then discussed that this would be implemented using a custom made grid of conductive wire which would be laid upon an inner sphere, concealed by the Cherry exterior. This technology will then detect touches and apply the positional coordinates received to a model of the spherical surface using spherical geometry. This will then be used to register gestures and touch through programming, which in turn will be used to control the user’s music.

In terms of manufacture, the report led to conclusion that the wooden sphere would be constructed using an automatic CNC rotary wood lathe and the wires to be laid on the inner sphere through the use of a semi-automated robot.

OBJECTIVES

The main objectives of this report were:

- To confirm the use of wood as an appropriate material for the spherical form of the product in question.
- To determine the touch sensing technology to be used in the product, this will need to work with the spherical form and the material which is decided upon.

This report has succeeded in justifying the use of wood from a technical perspective and the method of touch sensing to be continued with was also confirmed. This report has ended with enough information and background confirmation to allow this project to be taken to the level of developing further programming and undertake more advanced testing.

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1: INTRODUCTION

The idea of bringing back the physicality of music is an increasingly popular one. Sales in vinyl are at their highest in almost two decades (Lee, 2014) and companies like Bang and Olufsen are creating seemingly superfluous physical interfaces for their sound systems (Image 1, own property).

It shows a mass market turnaround from the recent decades of digitalisation and that the desire for "tangible music" is reappearing.

Image 1: Bang and Olufsen BeoSound Moment (own property)

Currently music is awash with commonplace symbols and commands, leading us to become detached to the decisions we are making with our music. Music has an incredible effect on our emotions and when listened to purposefully it can have a huge impact on our mental wellbeing. A study found that a group of people attempting to change their mood by listening to music reported a higher level of happiness than those who just passively listened (Ferguson and Sheldon, 2013).

From a product design perspective it seems illogical and impractical to have such an impersonal interface with which to control this deeply personal form of media. These generic methods with which we currently choose music is the inspiration behind the subject of this report.

The proposed product, "Timbreley", is a small handheld device that connects the user to the music they are listening to, physically and digitally, with physical actions resulting in digital changes in the music being listened to. This is simply an interface product, so it does not include speakers or memory, instead it connects these two things through the user to encourage personalisation, freedom and flexibility.

The hope is that by using material, form and technology to its truest potential this interface can be personalised in as many ways possible, once again reconnecting users with their music.

2: FORM AND MATERIAL SELECTION

The challenge comes from the goal to combine an object form which encourages interaction and the technology which seamlessly works.

Table 1: A description of the physical means as to achieve the ideal system.

INPUT	PROCESS	OUTPUT
Reliable and effortless interaction	Registering Gestures	Smooth, repeatable music functions
Form and Sensors	Integrated Circuit	Programming

To create this system, the product must have a surface that is enjoyable to interact with but also allows the sensors to work at their highest efficiency.

The issue of tangibility i.e. form and material, was looked at before the technology, a slight change in the common way of developing in industry, the hope being that inverting the process will lead to a more innovative solution.

2.1: FORM SELECTION

Technology has now advanced to a stage of flexibility unparalleled to any other time, encouraging a new kind of creativity and freedom in design. Rather than being limited by the weight and size of components when considering the form, form can come first, giving the multi-faceted and open-ended experience that users want without compromise.

The first part of the form development was mostly through user testing and opinion, leading to a clear direction for a handheld, spherical object with a slightly quirky geometry (Image 2 (own property)). The technical challenge to a small and spherical form is that most components dealing with user interaction, until very recently, have been created for flat surfaces. With this in mind the next step was to choose a material which allowed for this spherical form but also had the appropriate properties to accommodate technology and cope with the rough treatment that comes with being a handheld object.

Image 2: Iterations of spherical form (own property)

2.2: MATERIAL SELECTION

The user's opinion on material was undisputedly that wood was the most interesting and pleasing to the touch. This leads to the first focus of this report; the justification of this opinion through technical analysis.

It is important to find a balance between user desires and mechanical requirements, selecting a material that meets both these criteria. By looking at the likely life of this product and what this may require as a minimum, the following key properties were gathered:

DIELECTRIC CONSTANT	HARDNESS	SUSTAINABILITY (in reference to Table C 5)	FRACTURE TOUGHNESS	FATIGUE STRENGTH	COMPRESSIVE STRENGTH	PRICE

Hardness, fracture toughness, fatigue strength and compressive strength were chosen as important due to the hostile nature associated with handheld objects (being dropped, scratched, thrown etc.) to both assure the safety of the electronics inside and to avoid crack propagation or splitting. The higher these values can be the better.

The dielectric constant assures that sensors can interact with the user through the wooden layer (again the higher the value the better). A lower price for material per kg is obviously preferred but for this product not paramount, especially when compared to properties like sustainability. There is a great deal of responsibility when creating a mass market product out of any resource, therefore certain woods need to be avoided so as to reduce environmental damage and the encouragement of illegal forestry trade.

Using the Cambridge Engineering Selector (CES) material database, a comparison could be made based on these chosen properties between materials. The two families of material that were compared were plastics and woods (shown in blue and green respectively in Figure 1 and Appendix A).

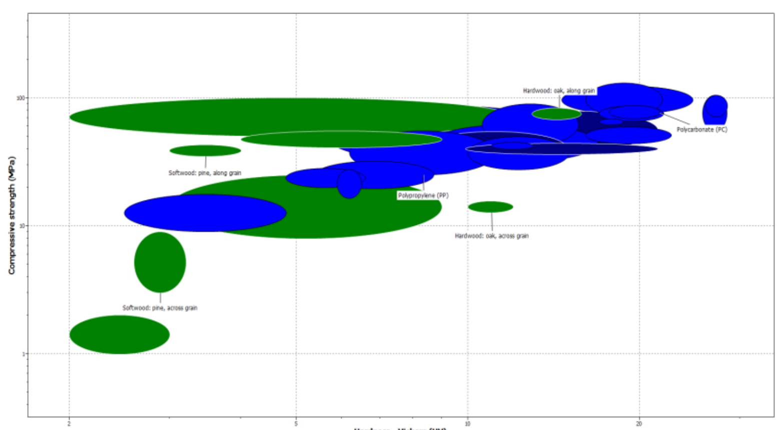

Figure 1: An example of a CES graph showing the similarity in properties between woods and plastics

This programme was also used to set limits for both sets of materials to avoid including materials that were completely unsuitable, in this specific case hardness was set at 1.5 Vickers.

It can be seen from the graphs in Appendix A that wood and plastic are relatively similar when considering the properties previously stated. This justifies the use of wood from a technical perspective allowing the product to be both equal to the user and technical specification. Next was to confirm which specific species of wood was to be chosen.

2.3: WEIGHTED PROPERTY METHOD OF MATERIAL SELECTION

After seeking the opinions of joiners and wood specialists, the choice was reduced to Cherry and Iroko for their workability and durability. After confirming their suitability compared to other woods through the CES database using the same method as before (see Appendix B), a weighted property method was taken to decide between these two valid options (see Appendix C). This method fairly compares the two materials with a scaled weighting of each property.

Each property was given a weighting factor, α, which is independent of the material and is an indicator of the importance of each property relative to the other properties. Next, the materials' specific values are compared to see which material wins out for each property, using equations in Appendix C to give β.

The weighting factor, α, and the scaling factor, β, for each property are then multiplied and summed to give, γ, with the largest value indicating which material is strongest.

CHERRY	IROKO
$\gamma = \sum \alpha\beta$ $= 84.67$	$\gamma = \sum \alpha\beta$ **$= 92.14$**

Iroko has a significantly higher value of γ so further research was done. When looking in to procuring the wood in large quantities, Iroko has been flagged by the World Wildlife Fund (WWF, 2011) and Greenpeace (Greenpeace, no date) as an unsustainable and often illegally obtained material.

With sustainability being such a large moral issue, a revision of the material properties of Cherry was done and the possibility of improving any of the properties.

A new method was found that improves the hardness of any wood considerably, with claims of up to 5.15 in term of Vickers hardness (Weyerhaeuser NR Company, 2010).

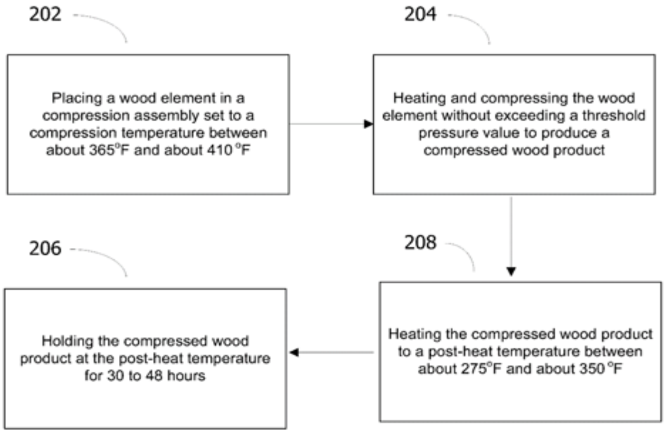

Figure 2: The process to harden wood through compression and heating (Weyerhaeuser NR Company, 2010)

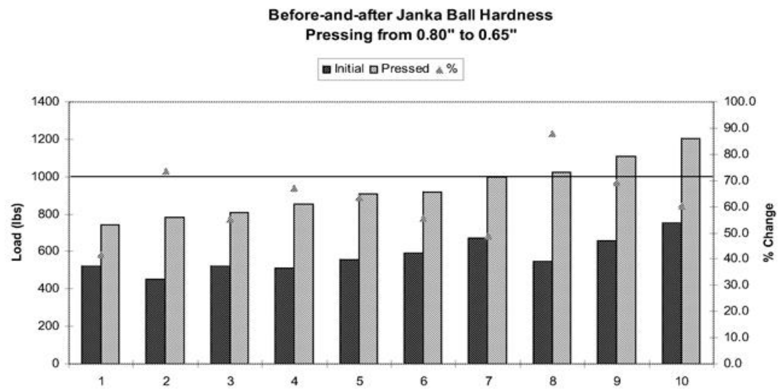

Figure 3: Different testing showing a universal increase in hardness (Weyerhaeuser NR Company, 2010)

If this technique was implemented, the Vickers hardness of Cherry would be increased from 3.85 (Table C 1 (CES EduPack 2014)) to 9, which is similar to African Rosewood and other well-known, durable hardwoods (Hayman, P.,2015).

This new hardness value for Cherry does not effect the weighting factor, α, but does effect the scaling factor β. After recalculating the scaling factors (as can be seen in Table C4) a higher value for γ is obtained.

CHERRY **= 89.23**	IROKO = 83.78

With this improved hardness, Cherry now becomes the most appropriate choice for this particular application. The advantage to this method is it takes what could be quite a subjective decision and turns it into a methodical process with a quantitative outcome that can be evaluated and shown to justify decisions.

At this stage it has now been confirmed that the spherical object can indeed be made safely and realistically out of wood and for the purpose of production and prototyping this wood should be Cherry.

3: SENSING COMPONENTS

This section of the report will look at the electronic components and system regarding the user interaction with the product.

In an attempt to create an extremely personal link between the user and product, early on in development biometric equipment was to be used including temperature sensors, heart rate monitors, galvanic skin response, and pulse oximeters.

The initial concept was to use the information gathered to decipher the mood of the user but, as found in prototyping, the biometric data returned does not always mean the same thing. For example, a high heart rate does not only mean happy or excited, it can indicate stress or fear. With such contradiction this could lead to reading errors and frustration for the user.

The idea was then to simply use this data as a means of controlling music with the user's own body. Most of these components, however, have low reliability in accuracy and repeatability mostly caused by the unstable inputs of our body functions. With uncertain inputs, a reliable process and output would be unlikely, and so it was concluded that due to both the inaccuracy of components and the erratic behaviour of our bodies this theory was still a little beyond our current technological abilities.

Looking to create a repeatable and interactive process still using the user's body and actions, more research was done which eventually lead to touch and movement sensing.

3.1: SELECTION OF MOVEMENT SENSING

The criteria of movement sensing for this application was as follows:

- must output speed and orientation
- Ability to translate into meaningful gestures which a programme could interpret

The simplest method of quantifying a change in speed and orientation is by using an Integrated Circuit (IC) containing an accelerometer and gyroscope. This measures the speed and orientation of whatever it is attached to, giving information which a modelling programme can translate to meaningful information.

As this technology is independent of the form and material of the product it is quite a simple process of placing it on the PCB and calibrating it to have a default orientation.

After research into different ICs with a range of complexity, the Triple Axis Accelerometer and Gyro Breakout MPU-6050 was chosen. It has built-in digital motion processing, which cuts out the need for external programming to register pre-designated movements like shaking and rolling (Figure D 1).

3.2: SELECTION OF TOUCH SENSING

In general touch technology is increasing in popularity for many reasons, making it superior to other techniques of sensing (proximity, infra-red, vibration), many of which apply in particular to this project. A particularly appealing aspect is the ability to create a durable interface, as the electronics are never in direct contact with the user and unlike buttons and switches there are no mechanical moving parts.

Durability is a key part of this product, intended to be a lifelong companion lasting through various hardware and software upgrades. It would be redundant to have carefully selected a hard-wearing material to protect a sensing system that due to its inherent setup is not equally as robust.

Another aspect is that no holes or openings are necessary which reduces cost in manufacture due to less parts it and creates a more clean-cut design aesthetically. Specifically in this case, it also aids in protecting the electronics from water or dust damage, useful for a product designed to be used throughout the household.

Unlike the IC for movement sensing, touch technology is very dependent on the form and material, making the process a lot more complex. The main criteria, along with impact resistance and durability, for the method of touch sensing are:

- the ability to work <u>through</u> wood
- the ability to work with a small and spherical surface

These points are uncompromisable due to the chosen form and material. This key criteria was then held up against the available methods of touch sensing and the outcome shown below: (see Appendix E for illustrations of touch sensing methods)

Table 2: Critical evaluation of touch sensing technologies regarding pre-set criteria

TOUCH SENSING TECHNOLOGY	WHAT / DISCUSSION	DECISION
Resistive Figure E1	Two conductive layers are separated by insulating strips or dots, when enough force is applied the two surfaces touch and current is allowed to flow. ✓ Must work on a small and spherical surface ✘ The ability to work <u>through</u> wood • wood is inflexible	NOT SUITABLE
Optical Figure E2	Uses light (visible, infra-red, camera) deflection/tracking to detect movement. ✓ Must work on a small and spherical surface ✘ The ability to work <u>through</u> wood • As wood is opaque, infrared or visible light cannot pass though	NOT SUITABLE
Surface Acoustic Waves(SAW) Figure E3	An audio wave is sent across the surface of material, with any disruption causing a change in the amplitude and frequency of this signal. ✘ Must work on a small and <u>spherical</u> surface • Sound waves are unable to travel along the spherical surface while being held by the user (Ishikawa et al., 2001). ✓ The ability to work <u>through</u> wood	NOT SUITABLE
Capacitive sensing Figure E4 and Figure E5	Measures the capacitance between 2 or more conductors in a dielectric environment (one in which a charge can flow) ✓ Must work on a small and spherical surface ✓ The ability to work <u>through</u> wood	SUITABLE

Out of these options the most suitable and in fact the only option for the form and material decided upon is capacitive sensing. This method of sensing continues to grow in market demand with a Compound Annual Growth Rate of 15% from 2013 to 2018 (marketsandmarkets.com, 2013), it is also a sensible choice business wise. Now to confirm it technically when applied to the application being discussed.

The general rule for capacitance is as follows:

$$C = \varepsilon \frac{A}{d}$$ (Equation 1, Fischer, D.,2010)

Where A is the area of 'plates', d the distance between them and

$$\varepsilon = \varepsilon_0 \times \varepsilon_r$$ (Equation 2, Fischer, D.,2010)

Where ε_0 is the permittivity of free space (a set value of 8.854x10^{-12} F/m) and ε_r the relative permittivity of the insulating material between plates. Equation 1 shows that the thinner the capacitive layer and the higher the relative permittivity of the material separating both plates the better.

If compared to current touch screen technology, wood can be worked to as thin a layer as the coverings currently used. An example being, PMMA which has a relative permittivity of 3.2 which is actually lower than that of Cherry, with a value of 3.49 (CES EduPack 2014).

This shows the viability of capacitive sensing in the case of "Timbreley", although more detail must be taken as capacitance is an overarching term used to describe two subsets, surface and projected capacitance.

Surface Capacitance requires an uncoated conductive material to be in direct contact with the users finger, this creates a capacitance at each corner of the coated surface. The values of these capacitors depend directly on the location of the person's finger where the larger the change in capacitance the closer the object is to that corner (see Figure E 4 for illustration). The obvious problem with this method is that direct conact with a conductive surface is not possible with the material chosen but this method also has low resolution of position and high possibility of parasitic capacitance (where a second finger, a piece of jewellery etc. effects readings).

Projective Capacitance is a grid/mesh system formed either through electrodes or etched wires in to a surface. The main difference is that an insulating layer separates the user from the sensing equipment, with the capacitance being checked over time and the approach of another conductor changes this value of capacitance, indicating a touch to the surface above This touches location is associated with some kind gird position, as in Figure 4 (Madaan, P. and Kaur, P. , 2012).

Unlike surface capacitance this technique fits with the criteria previously set, allowing the touch sensing to work though the wooden layer, similar to Figure 5 (Mercury13, 2008).

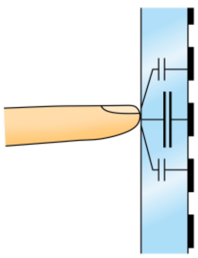

Figure 5: The alteration of capacitance through an insulator (Mercury13, 2008)

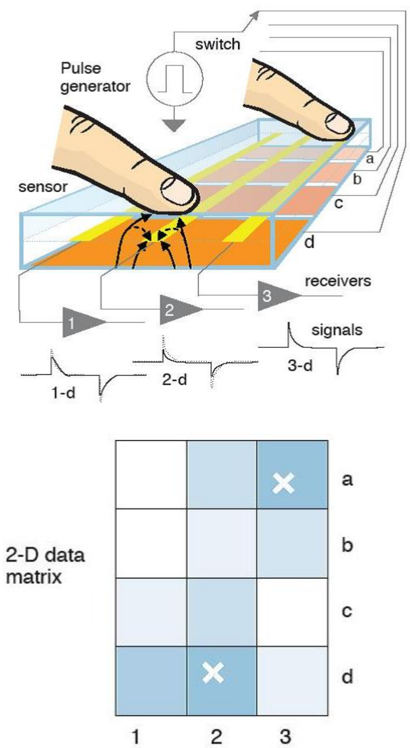

Figure 4: Showing how projected touch can be tracked (Madaan, P. and Kaur, P. , 2012)

Capacitance can yet again be divided, this time between self and mutual capacitance.

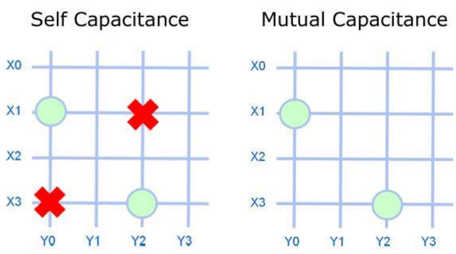

Figure 6: Ghost positions caused by self capacitance.

The main difference here being, like surface capacitance, there can sometimes be miscommunication in projected capacitance, where two X and two Y coordinates are obtained but the system cannot distinguish which go together as all wires are independently grounded (3M, 2013).

Mutual capacitance resolves this, as each X-wire transmits a signal and each Y-wire receives one. This means that the Y-outputs are directly caused by their inputting X-position, leading to an accurate read of location (3M, 2013).

Most of these advantages come from projected being the newer form of capacitance, making it a seemingly obvious but necessary decision to make.

The touch sensing portion of the product now adheres to the criteria of being able to work through wood but there is still the matter of taking this 2D technology and applying it to the spherical surface.

APPLICATION TO SPHERICAL CASE

Projected capacitance comes manly in sheet form, with the gird formation etched onto a dielectric material, if this was taken as it is and applied to the double curvature of a spherical face, the sheet would bend and deform (Duplantier et al., 1990). This leaves only the option of a custom designed and manufactured method to be developed for this particular case.

If these complex grids were simplified down to their wire by wire components, still retaining the grid-like structure just slightly deformed, it seems hopeful that a solution can be found. It is most likely to be a more time-consuming custom solution perhaps but would ultimately use the same theory, therefore has been proven to be viable.

This technique indeed exists and is known as Conductive Wire Construction which uses conductive wire to create a grid array. It provides clearer signals than the standardised sheet layout (Benko, Wilson, and Balakrishnan, 2008) and is normally only discarded due to its non-transparency, which is a problem when using on top of an LCD screen but in this case opacity is caused by the wooden layer anyway.

In terms of creating a custom mesh this is easily simulated through programming, for instance in Matlab the sphere(n) function creates an automatic mesh consisting of n number of grids.

With the complexity of the problem being kept in mind, initially the touch sensitive surface was only applied to one half of the product and due to the plastic band around the products circumference, this reduces the area needing to be analysed to a cap spanning 120º. This reduces the complexity and simulation run time in software programmes, ultimately leading to less time and money spent on analysis. An example of such code is seen in Figure 8.

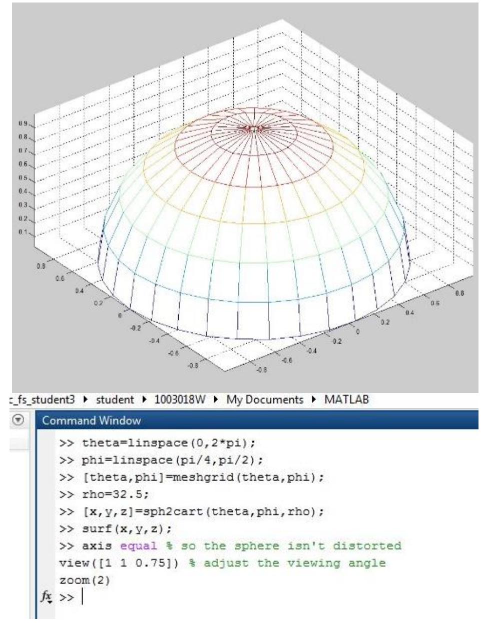

Figure 7: Example of a custom mesh made in Matlab

Using the Arduino Leonardo and its respective programming, a very low fidelity mock-up was constructed, to display the basics behind the positioning theory on a curved surface.

Here four patches of foil were connected to the Arduino board through two inputs each. One input via a high value resistor (10MΩ) and the other a simple piece of wire. The idea behind this is that the time taken for the value of both inputs to equate each other rises or falls as another capacitor (human finger) comes in to contact with the foil.

Table 3: Arduino results for capacitive touch tests

	INPUT 1 VALUES	INPUT 2 VALUES	INPUT 3 VALUES	input 4 VALUES
	TIME TAKEN			
POSITION ONE	284	277	56	56
	285	289	58	67
	288	281	55	56
	289	282	60	58
	293	279	58	54
	293	268	57	57
	286	270	54	57
	285	265	60	63
	293	253	50	56
	275	248	60	58
POSITION TWO	56	58	253	56
	67	58	248	67
	56	58	260	56
	58	56	253	58
	54	58	254	54
	57	54	261	57
	57	57	264	57
	63	54	275	63
	56	59	275	56
	58	57	265	58

Table 3 shows the time taken for values to adjust against the position of a finger for two positions.

As can be seen, the results for each input are distinct of each other for each position but without a visual the data is meaningless.

This led to the obvious conclusion that the data received from these conductive wires should be matched to some kind of 3D spherical visual.

4: SOLUTION

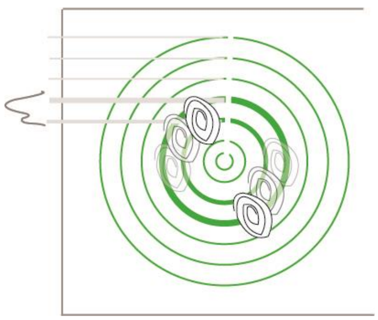

Figure 8: Only phi angle gives inaccuracy

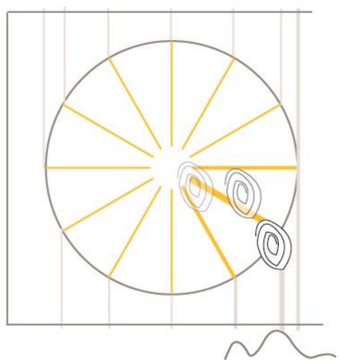

Figure 9: Only theta angle gives inaccuracy

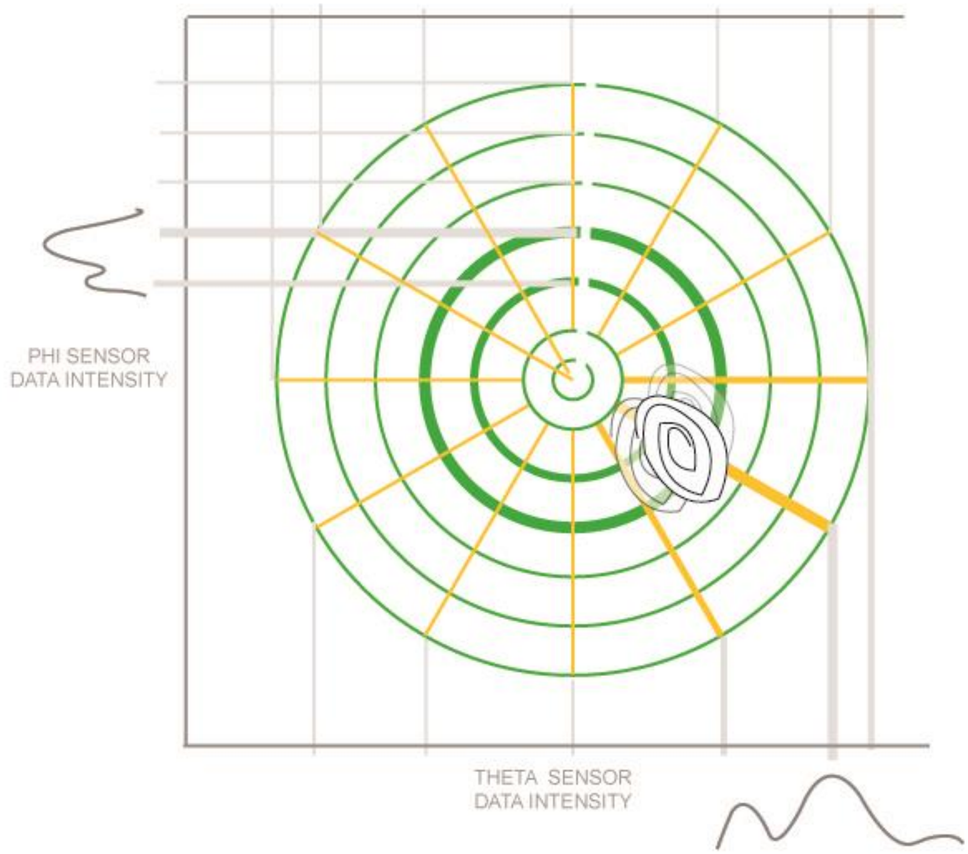

Figure 10: Combination of both theta and phi allows accuracy of touch location

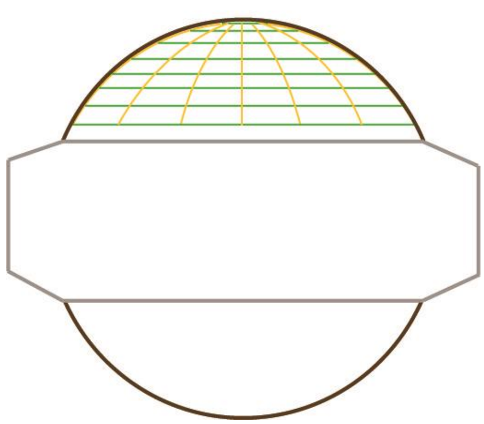

Figure 11: Location of mesh in terms of the product

Figures on the previous page show a conceptual mesh of wires to adapt the current projective mutual capacitive system for a spherical surface.

The orange wires represent the theta coordinate of touch and the green the phi coordinates, Figure 12 shows how these angles relate to the overall spherical surface. The combination of the phi and theta coordinates gives a precise location of the user's touch on the surface of "Timbreley".

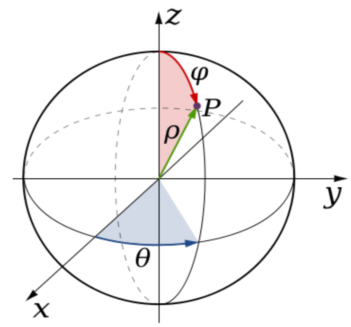

Figure 12: Representation of spherical coordinates (Wikimedia Commons, 2015).

The physical consists of only one layer underneath the wooden surface, with both the phi and theta system applied to its outer surface. This is taking inspiration from a similar project concerning a larger surface area (*Multitouch hardware. Globe with multitouch Earth application*, 2011).

As a finger approaches the wooden surface theta and phi coordinates are obtained and tracking of gestures begins. To make sense of these coordinates and turn them into meaningful data an integrated circuit must be used to take the digital information that is received, interpret the important parts of the data and send this to a programme which will control the user's music with the gestures tracked.

4.1: CHOOSING INTEGRATED CIRCUITS (ICs)

After comparing several ICs, looking at the amount of inputs available and current flexible technology, the MTCH6301 Projected Capacitive Touch Controller was chosen (Figure D 2) due mostly to its low current draw sleep setting, its sensitivity through up to 5mm of wood and its in-built touch features such as multi-touch, gesture detection and built-in noise detection(allowing for more accurate readings).

This in built intelligence will greatly reduce the complexity of the programme it feeds this information into but before finalising, the effect of having two integrated circuits on the battery life must be observed.

4.2: BATTERY LIFE

This is a large issue for any handheld object that is not connected directly to the mains. A compromise must be struck between how long the battery lasts and how long the charge time will be. The more important of the two in this situation is the battery life, as if this is too short it will interrupt the musical interaction too often, causing annoyance and aversion to use.

The device needs to be rechargeable so Nickel-Metal Hydride batteries were chosen. The voltage requirement of the circuit is ~3.5V for both components (Figure D 1 and D 2), this allows the product to use standardised batteries (AA at 1.2V) by simply stacking three to give 3.6V.

To find the battery life cycle of the product, an example will be carried out using three AA NiMH batteries rated at 1500mAh (*TGH9003 | ENIX Energies*, no date)

To see if this battery choice is suitable the current draw of the circuit was calculated to see if the battery and component combination would give enough hours of use before needing to be recharged. This is done using the following equation:

$$Battery\ Life(hours) = \frac{Battery\ Capacity\ (mAh)}{Circuit\ current\ requirement\ (mA)}$$

(Equation 3 (*Battery 101-the basics*, no date))

Table 2: Values of operating and sleep currents from Appendix D ((*MPU-6000 and MPU-6050 Product Specification*, 2011) (Microchip Technology Inc., 2012)

Movement IC	= 3.9mA Operating Current = 60µA sleep current (@check rate of 20Hz)
Capacitive IC	= 20mA Operating Current = 200 µA Sleep Current

Using the information in Table 4 (Microchip Technology Inc., 2012), the parallel current draw with both comonents fully operation would give a life of:

$$\frac{1500\ mAh}{23.9\ mA} = 62.7\ hours$$

This short time between the need for charging would become extremely irritating for the user, and NiMH batteries can only be recharged around 500 times before needing replaced (*Battery 101-the basics*, no date), therefore a closer look was taken in to the sleep settings on both integrated circuits and the battery life calculated at different configurations (operational/asleep)

Table 3: Discharge time for various configurations of sleep

	Capacitive IC	Movement IC	Capacitive IC	Movement IC	Capacitive IC	Movement IC
CONSTANT STATUS	ASLEEP	OPERATIONAL	OPERATIONAL	ASLEEP	ASLEEP	ASLEEP
Discharge time	$\frac{1500mAh}{3..92\ mA} = 382\ hours \cong 16\ days$		$\frac{1500\ mAh}{20.06\ mA} = 74\ hours \cong 6\ days$		$\frac{1500\ mAh}{0.08\ mA} = 18750\ hours \cong \mathbf{780\ days}$	

So if being constantly used for, say 2 hours a day:

$$23.9mA\ \times 2\ hours + 0.08mA \times 22\ hours = 49.56mAh\ per\ day$$

$$\frac{1500\ mAh}{49.56mAh} = 30.2\ days$$

It can be seen from Table 5 the difference that the sleep setting makes, especially when both are set to sleep. Obviously this cannot be the case all the time but to monopolise on this, both sensors should be set to sleep if no there is no change to inputs, rather than just one of the ICs.

Both sensors can also be set so that when one sensor turns on both do which would allow for smoother use of the product from the user's point of view and greater battery life. This would also be using the capacitive electrodes and integrated circuit to the fullest of their abilities as they have a built in proximity sensor which can detect a slight rise in capacitance caused by an approaching hand (Madaan and Kaur, 2012).

The advantages this brings to power saving and user enjoyment outweighs any complexity in programming. In terms of recharging there are smart chargers available that charge anywhere between 90 minutes and 3 hours, using intelligent circuitry to prevent overcharging (Maplin, no date).

4.3: MANUFACTURE

With both the technology and material decided it is possible to look at the possible and most suitable options for manufacture at a mass market level.

For the Cherry wood sphere the most economical method is to use an automatic CNC rotary wood lathe. Compared to manual lathing, the accuracy is also far better (within 0.002mm (*High accuracy CNC lathe wood*, 2012)) which is especially important on a small scale project such as this, especially when this wood is acting as the dielectric material in the capacitive sensing system.

The Cherry is then treated with the aforementioned compressing/heating process to provide the improved hardness and mechanical properties.

Image 3: Automatic CNC wood lathe (*New Machinery | Intorex CKI Automatic CNC Wood Turning Lathe*, no date)

With the configuration and method of touch sensing two methods were found that would be suitable for a small surface are, precise placement of wires:

- Semi-automated robotic laying of wire on to surface (seen in Image 4 (*Multitouch hardware. Globe with multitouch Earth application*, 2011))

Image 4: The robot and process for laying and gluing thin wire to a spherical surface (*Multitouch hardware. Globe with multitouch Earth application*, 2011)

- Submersion into the thermoplastic during the extrusion process of 3D printing through localized heating (Shemelya et al., 2015)

The latter of these two is the most recent and quite an exciting prospect as it would mean creation of the dielectric insert could be combined with inlaying the required wires, combining two processes therefore saving money and time.

From a study using this method (Shemelya et al., 2015) it was found that the theory was sound but the execution needed more investigation e.g. what types of plastic work best, most efficient temperature of operation.

The semi-automated wire-laying, at the moment and for immediate production would be the most suitable. With a 1 mm minimum distance between each wire (*Multitouch hardware. Globe with multitouch Earth application*, 2011) this process is also at a suitable scale for this application.

5: DISCUSSION AND CONCLUSION

With the material, method of touch sensing, and manufacturing decided upon this report aided the products development hugely, with not only user approval but now technical justification to assist the product to completion.

Although it was soon found that the solution would be slightly more complex than the market's current requirements it is very much a realistic concept, with support from other products (*Multitouch hardware. Globe with multitouch Earth application*, 2011) and existing technology being flexible enough to utilise its theory and adapt it to this particular product's requirements.

An attempt was made to create a lower quality test system that represented the theory and gave proof on a basic level that the system proposed was valid but to advance, further prototyping and testing needs to be done in regards to the configuration of the wire grid. It is believed that this is a realistic expectation to achieve with the remaining time of the project and the materials at hand

.

Also, although the physical interpretation of touch and the processing behind it has been largely confirmed, the method in which these gestures are programmed or configured has not been dealt with. The next steps are to decide upon the complexity of these gestures, and look into having letter recognition software to truly open up the freedom of searching through music.

This report has been vital in directing the project in the correct direction and allowing for design that is producible in the short term, by using solid theories and proven techniques.

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APPENDIX A: CES GRAPHS WOOD (GREEN) VS PLASTIC (BLUE)

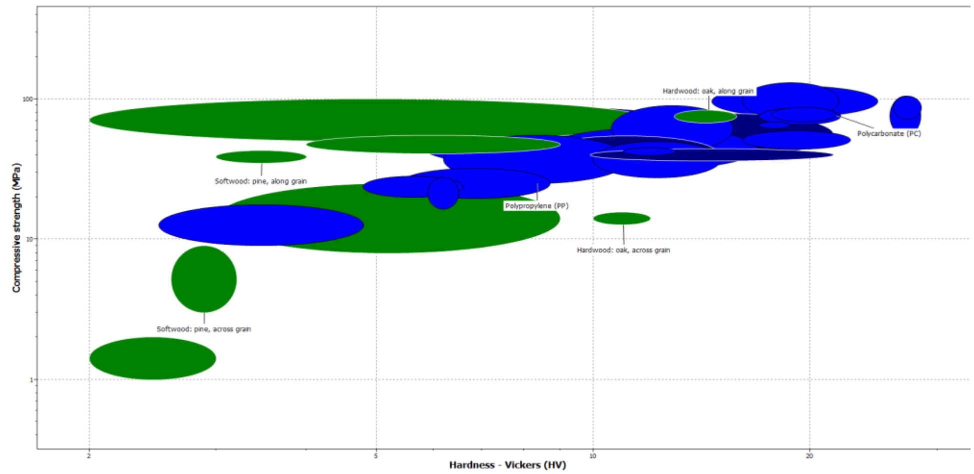

Figure A 3: Compressive Strength (Y-axis) against Hardness (X-axis)

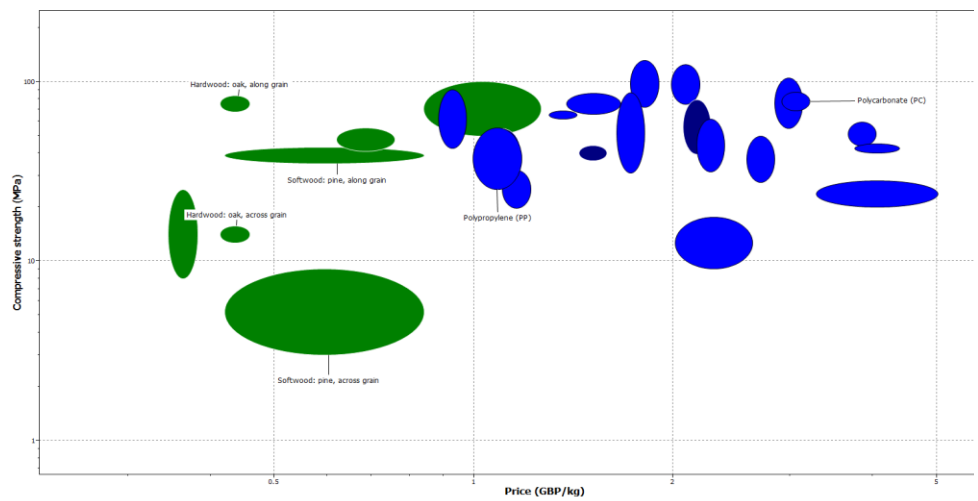

Figure A 3: Compressive Strength (Y-axis) against Price (X-axis)

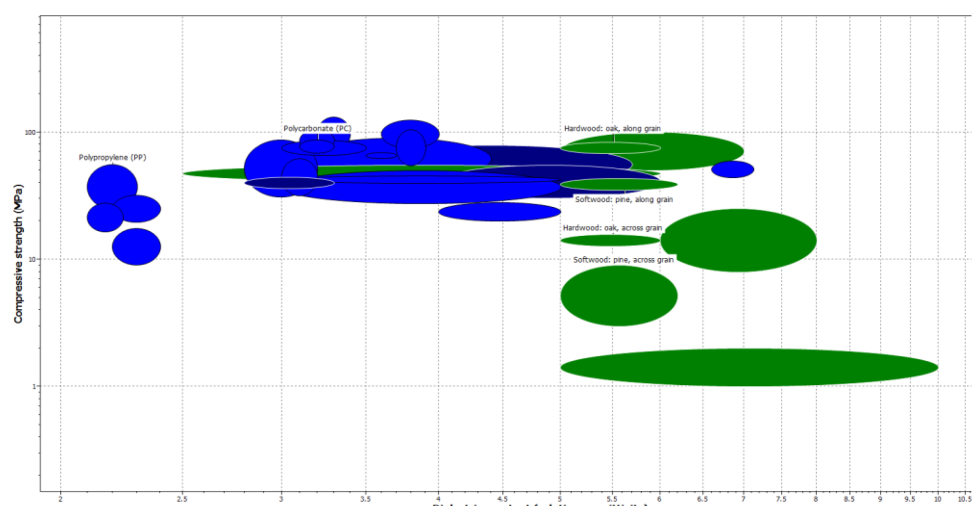

Figure A 3: Compressive Strength (Y-axis) against Dielectric constant (X-axis)

APPENDIX B: VARIOUS CES GRAPHS OF WOOD TYPES

CHERRY = YELLOW, IROKO = RED

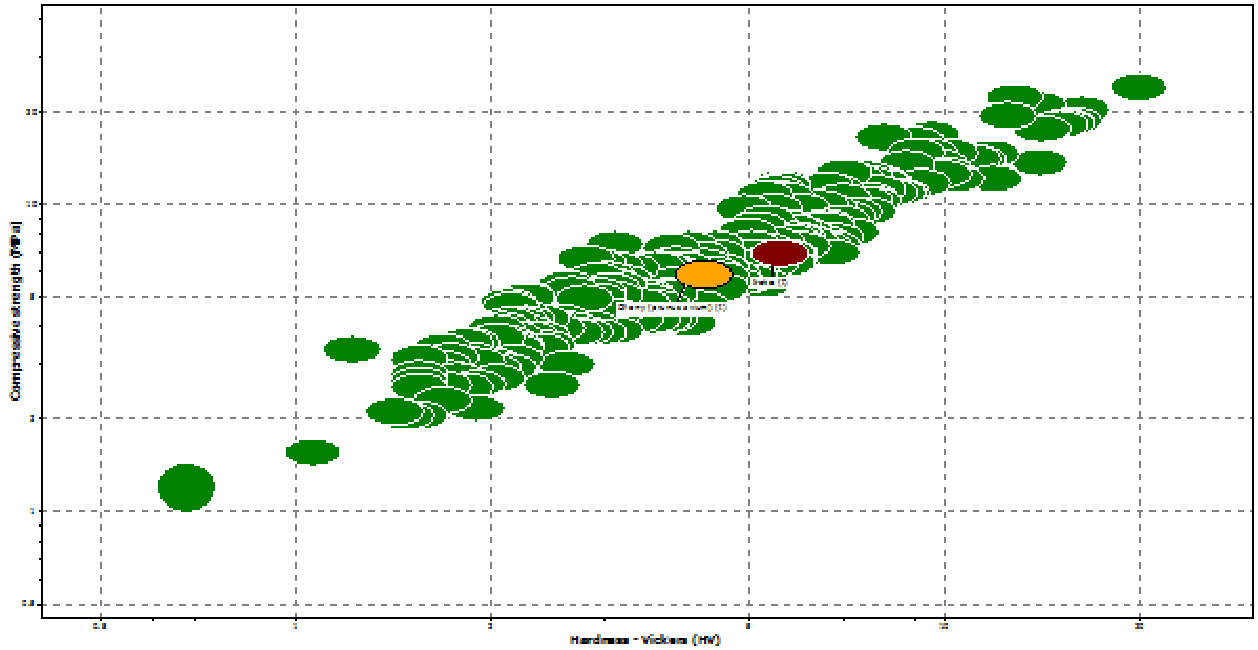

Figure B 2: Iroko vs Cherry – Compressive Strength (Y-axis) against Hardness (X-axis)

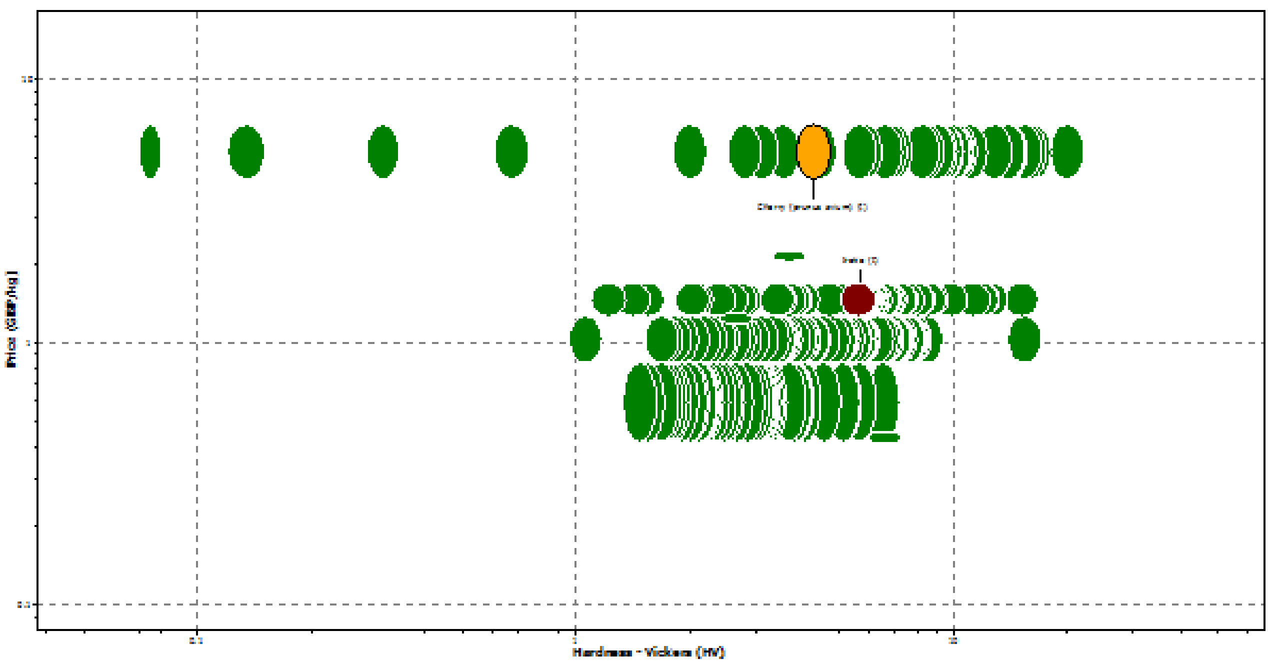

Figure B 1: Iroko vs Cherry – Price (Y-axis) against Hardness (X-axis)

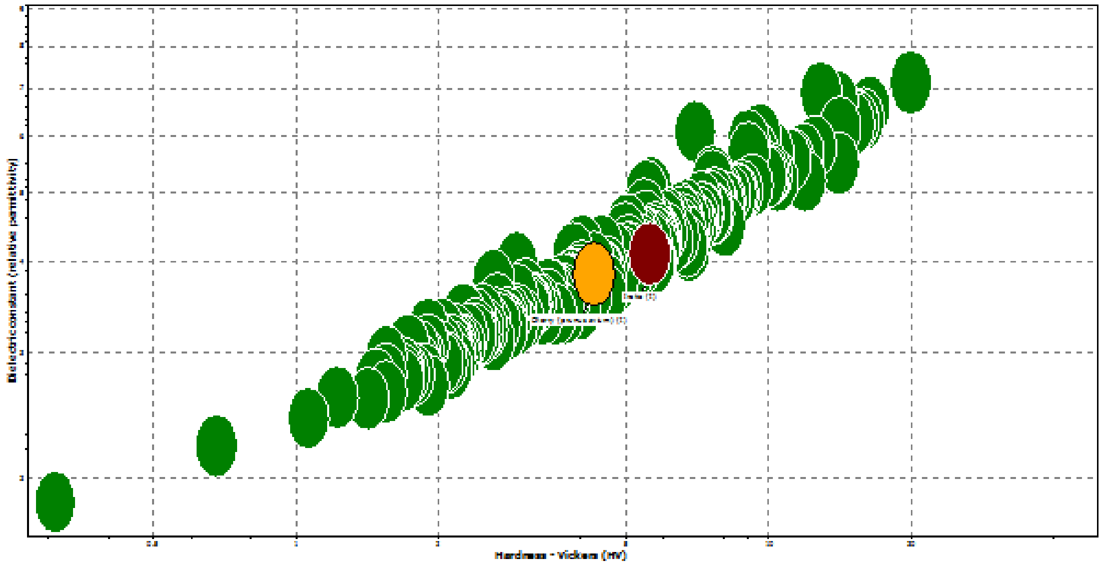

Figure B 5: Iroko vs Cherry – Dielectric Constant (Y-axis) against Hardness (X-axis)

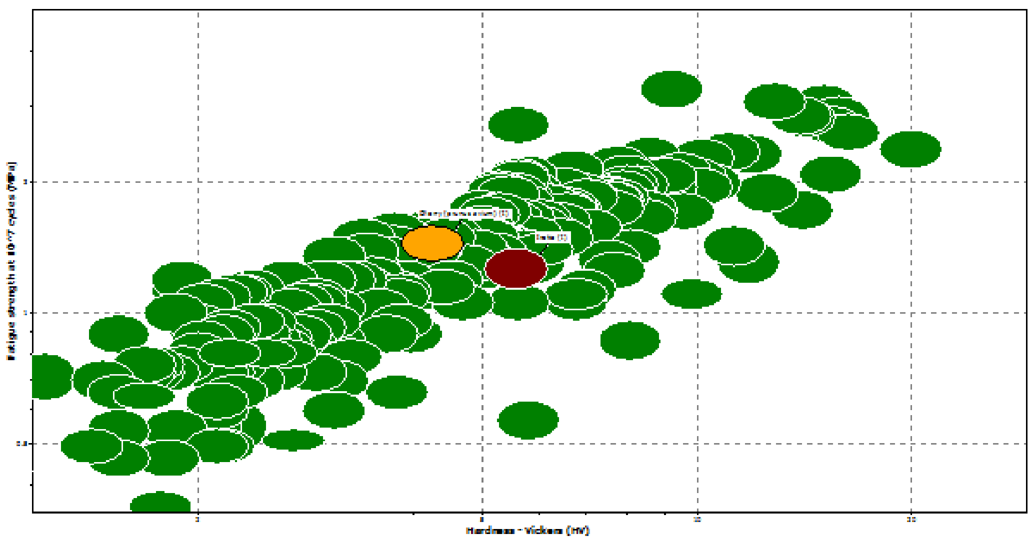

Figure B 5: Iroko vs Cherry – Fatigue Strength (Y-axis) against Hardness (X-axis)

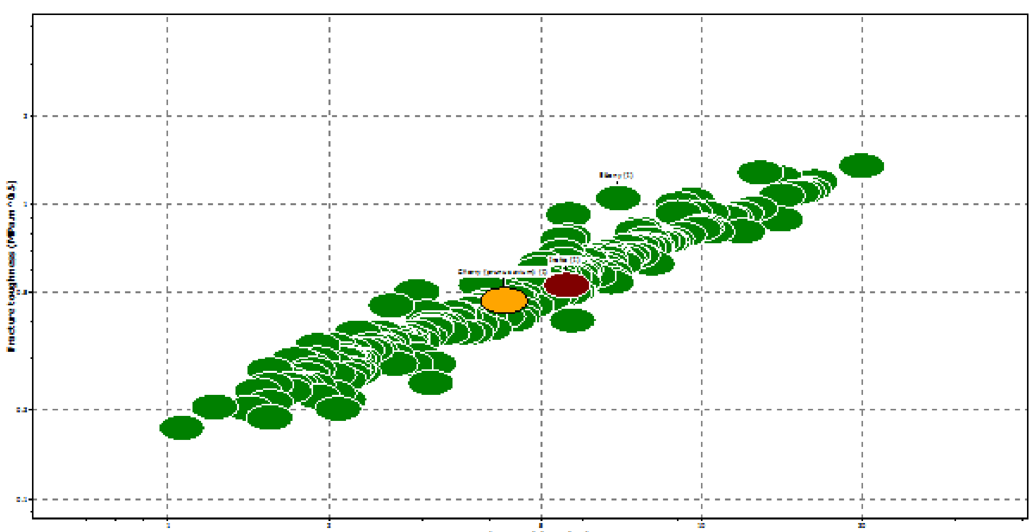

Figure B 5: Iroko vs Cherry – Fracture Toughness (Y-axis) against Hardness (X-axis)

APPENDIX C - WEIGHTED PROPERTY METHOD OF MATERIAL SELECTION

(Ourdjini, 2005)

Table C 1: The most important factors concerning the case in question

category number	1	2	3	4	5	6	7
categories	Dielectric constant	hardness	sustainability (in relation to appendix B)	fracture toughness	fatigue strength	compressive strength	price

$$\text{Number of positve decisions } (N) = \frac{n(n-1)}{2} = \frac{42}{2} = 21 \text{ decisions}$$

Table C 2: Scale factors using the digital logic method

decisions	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	# of decisions	α
cat #																							
1	0	1	1	1	1	1																5	0.24
2	1						0	1	0	1	1											4	0.19
3		0					1					0	0	1	1							3	0.15
4			0					0				1	1			1	0	1				4	0.19
5				0					1							0			1	0		2	0.09
6					0					0				0			1		0		0	1	0.05
7						0					0				0			0		1	1	2	0.09
																						∑=21	∑α=1

For properties which a low value is best (LB): $\beta = \frac{\text{min value of property overall}}{\text{numerical value of property}} x100$

For properties which a high value is best (HB): $\beta = \frac{\text{numerical value of property}}{\text{max value of property overall}} x100$

Table C 3: Calculation of weighting factors for each category, for both materials in question

	Dielectric constant (HB)	hardness Vickers (HB)	sustainability (rank)* (LB)	fracture toughness MPa.m^0.5 (HB)	fatigue strength at 10^7cycles MPa (HB)	compressive strength MPa (HB)	price £/kg (LB)
Cherry (avium)	3.49	3.85	13	0.429	1.32	5.36	4.2
β	94	76	100	88	100	85	30
Iroko	3.72	5.04	23	0.483	1.14	6.29	1.26
β	100	100	56	100	86	100	100

CHERRY

γ=∑ αβ

= 0.24*94 + 0.19*76 + 0.15*100 + 0.19*88 + 0.09*100 + 0.05*85 + 0.09*30

= 22.56+14.44+15+16.72+9+4.25+2.7

= 84.67

IROKO

γ=∑ αβ

= 0.24*100 + 0.19* 100+ 0.15* 56+ 0.19* 100+ 0.09* 86+ 0.05*100 + 0.09*100

= 24+19+8.4+19+7.74+5+9

= 92.14

Table C 4: The scale and weighting factors after adjusting the hardness of Cherry to account for post treatment

	Dielectric constant (HB)	hardness Vickers (HB)	sustainability (rank) (LB)	fracture toughness MPa.m^0.5 (HB)	fatigue strength at 10^7cycles MPa (HB)	compressive strength MPa (HB)	price £/kg (LB)
Cherry (avium)	3.49	9	13	0.429	1.32	5.36	4.2
β	94	100	100	88	100	85	30
Iroko	3.72	5.04	23	0.483	1.14	6.29	1.26
β	100	56	56	100	86	100	100
α	0.24	0.19	0.15	0.19	0.09	0.05	0.09

CHERRY

γ=∑ αβ

= 0.24*94 + 0.19*100 + 0.15*100 + 0.19*88 + 0.09*100 + 0.05*85 + 0.09*30

= 22.56+19+15+16.72+9+4.25+2.7

= 89.23

IROKO

γ=∑ αβ

= 0.24*100 + 0.19* 56+ 0.15* 56+ 0.19* 100+ 0.09* 86+ 0.05*100 + 0.09*100

= 24+10.64+8.4+19+7.74+5+9

= 83.78

Wood Sustainability Table
Of Timbers Readily Available in the UK and from Wooduchoose

WOODU CHOOSE

Note	Rank	Wood	Price Guide (1 Low - 7 Very Expensive)	Reference
Sustainable Timber	12	American Black Walnut	4	
	13	American Cherry	3	
	14	American Maple	3	
	15	American Red Oak	3	
	16	American White Ash	2	
	23	Iroko	2	
	24	Sapele	2	
	25	Utile	2	
	26	Dark Red Meranti	2	

Table C5: Sustainability ranking (Hayman, P., 2015)

APPENDIX D: DATASHEET EXCERPTS

VDD POWER SUPPLY Operating Voltages		2.375		3.46	V	
Normal Operating Current	Gyroscope + Accelerometer + DMP		3.9		mA	
	Gyroscope + Accelerometer (DMP disabled)		3.8		mA	
	Gyroscope + DMP (Accelerometer disabled)		3.7		mA	
	Gyroscope only (DMP & Accelerometer disabled)		3.6		mA	
	Accelerometer only (DMP & Gyroscope disabled)		500		µA	
Accelerometer Low Power Mode Current	1.25 Hz update rate		10		µA	
	5 Hz update rate		20		µA	
	20 Hz update rate		60		µA	
	40 Hz update rate		110		µA	
Full-Chip Idle Mode Supply Current			5		µA	
Power Supply Ramp Rate	Monotonic ramp. Ramp rate is 10% to 90% of the final value			100	ms	

Figure D 2: Excerpt from data sheet for the Gyroscope and Accelerometer Integrated Circuit (*MPU-6000 and MPU-6050 Product Specification*, 2011)

MTCH6301 Projected Capacitive Touch Controller

Description:

MTCH6301 is a turnkey projected capacitive controller that allows easy integration of multi-touch and gestures to create a rich user interface in your design. Through a sophisticated combination of Self and Mutual Capacitive scanning for both XY screens and touch pads, the MTCH6301 allows designers to quickly and easily integrate projected capacitive touch into their application.

Applications:

- Human-Machine Interfaces with Configurable Button, Keypad or Scrolling Functions
- Single-Finger Gesture-Based Interfaces to Swipe, Scroll or Doubletap Controls
- Home Automation Control Panels
- Security Control Keypads
- Automotive Center Stack Controls
- Gaming Devices
- Remote Control Touch Pads

Touch Sensor Support:

- Up to 13RX x 18TX Channels
- Individual Channel Tuning for Optimal Sensitivity
- Works with Printed Circuit Board (PCB) Sensors, Film, Glass and Flexible Printed Circuit (FPC) Sensors
- Cover Layer Support:
  - Plastic: up to 3 mm
  - Glass: up to 5 mm

Touch Features:

- Multi-touch (up to ten touches)
- Gesture Detection and Reporting
- Single and Dual Touch Drawing
- Self and Mutual Signal Acquisition
- Built-in Noise Detection and Filtering

Power Management:

- Configurable Sleep mode
- Integrated Power-on Reset and Brown-out Reset
- 200 µA Sleep Current (typical)

Communication Interface:

- I^2C™ (up to 400 kbps)

Operating Conditions:

- 2.4V to 3.6V, -40ºC to +105ºC

Package Types:

- 44-Lead TQFP
- 44-Lead QFN

Figure D 2: Excerpt from data sheet for the Projected Capacitive Integrated Circuit (Microchip Technology Inc., 2012)

APPENDIX E: FIGURES DEPICTING VARIOUS TOUCH SENSING METHODS

(All figures referenced from (Eizo, no date)

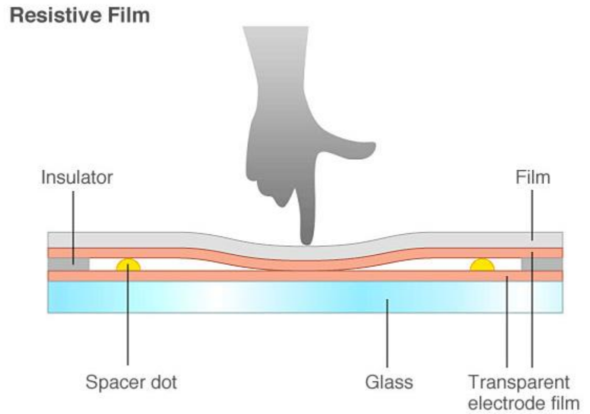

Figure E 1: Illustration showing resistive capacitance

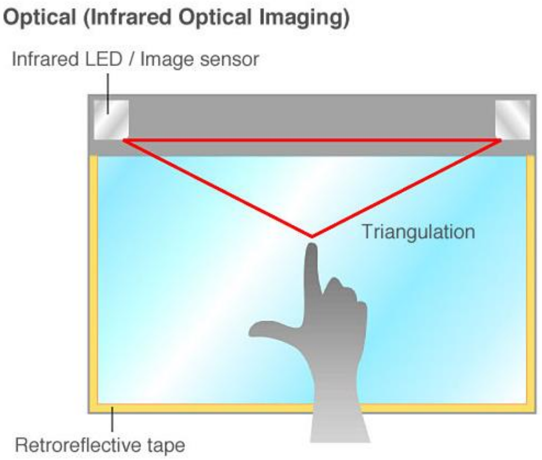

Figure E 2: Illustration showing resistive capacitance

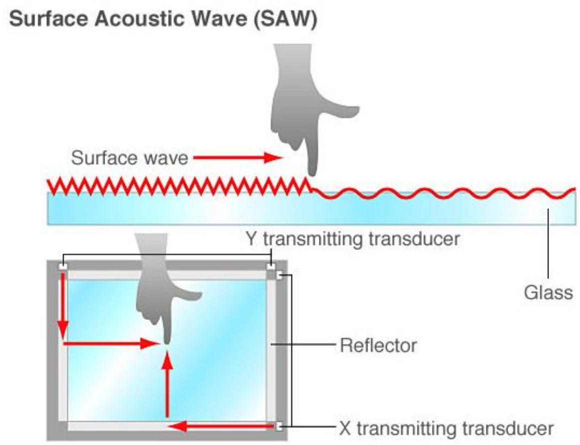

Figure E 3: Illustration showing surface acoustic wave capacitance

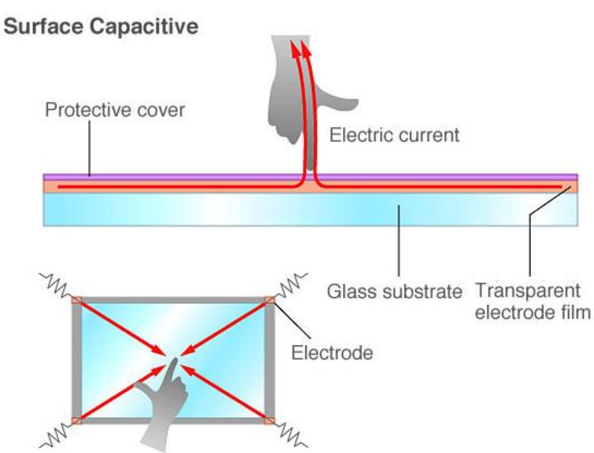

Figure E 4: Illustration showing surface capacitance

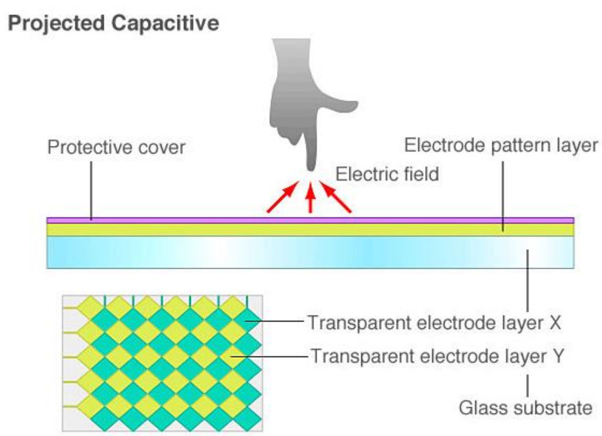

Figure E 5: Illustration showing projected capacitance