

Gizmo Chymbal



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Executive Summary

“GizmoBand” was the theme of the Gizmo module for the MEng Design Engineering course at Imperial College London. The aim was to create an electromechanical machine that generates sound by integrating design and technology. Brainstorming and creating a mood board to gather inspiration, the team formulated specifications for the Gizmo: The Gizmo had to be musical, contained, sleek and provide a visual that harnessed the functionality of the machine. The project evolved from these initial requirements to a fully formed idea of two instruments being played simultaneously. In the final design, chimes provide a melodic sound, while the cymbal generates a continuous background noise. This report outlines the design and manufacturing process of Chymbal.

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1 Introduction

In the DE2 Gizmo module, a group coursework has been assigned where

... teams of 3 to 4 students will be challenged to weave design and technology to create an electromechanical machine that generates sound (it does not need to be musical). The unifying theme this year is "GizmoBand".

(Brand, A., 2016)

2 Inspiration and concept development

With the assignment in mind, a [Pinterest](#) mood board was created to gather inspiration in the ideation phase (refer to Fig.2A).

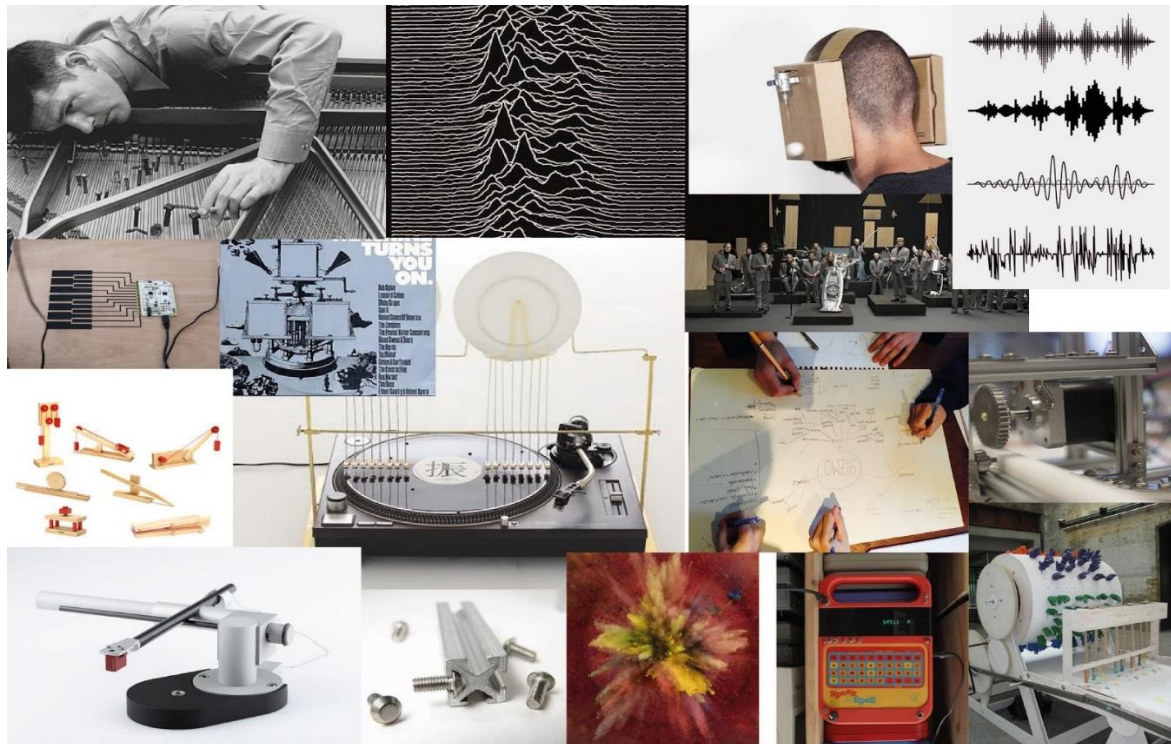
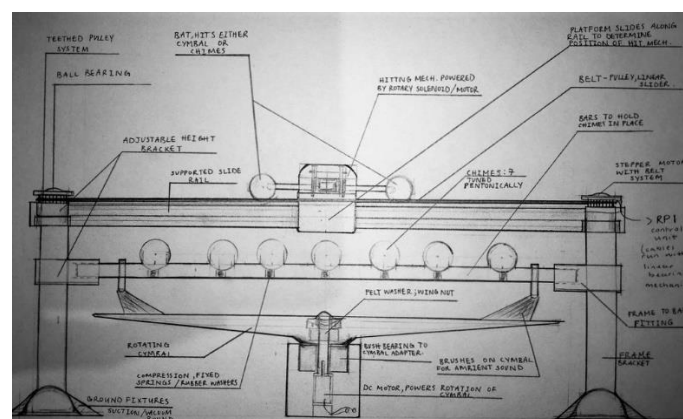
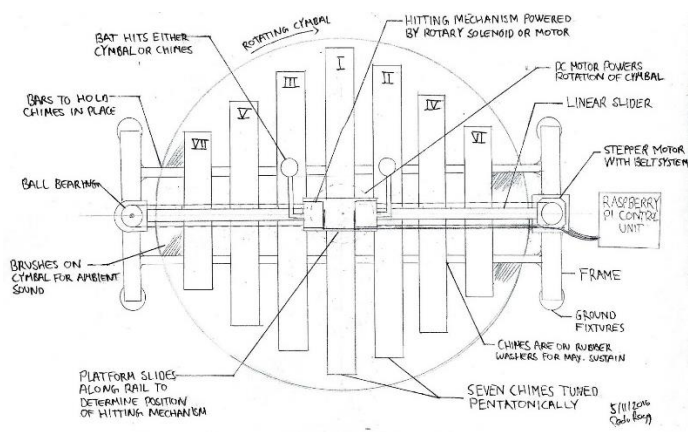


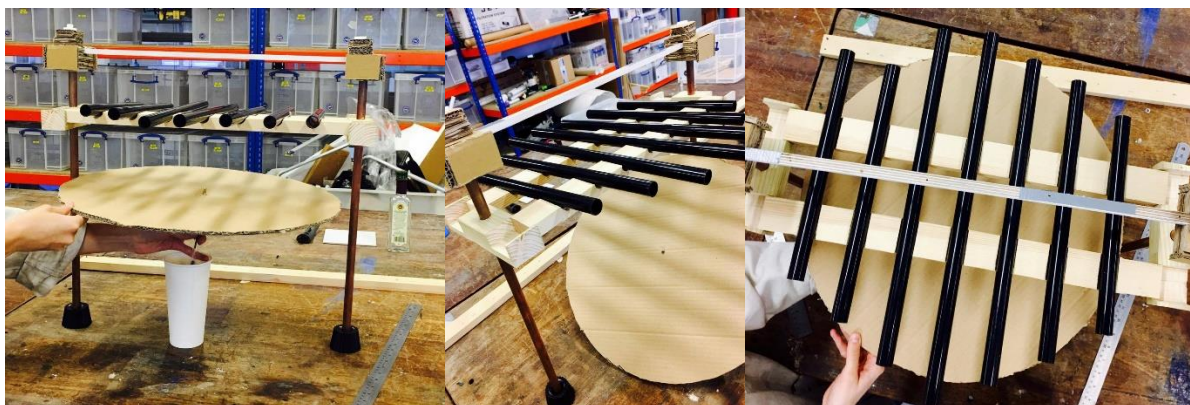
Fig.2A Gizmo Moodboard

After applying divergent thinking by brainstorming different ways sounds can be made, looking at helpful mechanisms and visualising ideas, the team agreed on some specifications. The Gizmo had to be *musical, contained, sleek and provide a visual that harnessed the functionality of the machine*.

More detailed ideas were generated by individual group members based on the agreed specifications. Through convergent thinking, an idea was agreed upon. The idea was to have two instruments being played, the chimes and the cymbal. The chimes were to be played using a hitting mechanism, which runs along a slider railing, and the cymbal was to be brushed by spinning the cymbal against brushes. The hitting of the chimes would provide a melodic sound while the brushing of the cymbal would generate a background sound. The concept was further developed through multiple sketches (with examples shown in Fig.2B and Fig.2C).



The team created a one-to-one, low-fidelity prototype and presented it to a panel of experts. Feedback given during that interim review was examined and minor changes were made.



3 Design Process

Chymbal was divided into five main subsystems: (i) the chimes, (ii) the slider and frame, (iii) the hitting mechanism, (iv) the controls, and (v) the spinning cymbal and stage. The controls subsystem consists of the circuit, the user interface and the code. Each of these subsystems were analysed and iterated individually, and, later on, integrated into the larger system. This modular approach allowed for equal work distribution between team members and fast-paced iteration. This section of the report outlines our design process, which is sectioned into analysis (section 3.3) and iterative development (section 3.4). While subsystems, such as the sound design of the chimes (section 3.3.1) and the circuit element of the controls (section 3.3.2), underwent analysis at the beginning of the project. The two central high risk subsystems, the hitting mechanism (3.4.1) and the cymbal (section 3.4.3), as well as the frame (section 3.4.2) went through multiple iterations.

A risk assessment was created (section 3.1) and the allocation of physical resources was recorded as a part of the design process (section 3.2).

3.1 Risk Assessment

Category	Risk Name	Risk	Probability (1-5)	Impact (1-5)	Risk Score	Mitigation Strategy	Contingency	Score Post Mitigation	Action When
Hardware	Linear Bearing construction failure	1.1	4	5	(4x5) =20	Examine all Components and ensure supporting joints withstand forces from belt system	Design and Build more durable and stable joint design, lubrication added for ease of bearing mount transportation	(2x5) =10	Previously planned verification; If necessary
	Stepper motor failure	2.1	3	4	(3x4) =12	Examine reason behind failure	Obtain new stepper motor if necessary	(2x4) =8	Post planned verification; If necessary
	Hitting Mechanism failure	2.2	3	5	(3x5) =15	Simplify design and limit to backup pivot design	Remake mechanism, using pre-tested prototypes as templates	(2x5) =10	Post planned verification; If necessary
	Chimes failure	2.3	3	2	(3x2) =6	Strength of hit stays same. Check lengths and elastic supports.	Optimise tension and elastic supports, recut chimes and control solenoid hit/change weight of hitting strike shaft	(2x2) =4	Post planned verification; If necessary
	Cymbal Construction failure	3.1	4	4	(4x4) =16	Source main problem area and develop to re construct	Build mitigation design, start again if necessary with extra reinforcement	(2x4) =8	Post planned verification; If necessary
	Cymbal Mechanism failure	3.2	2	1	(2x1) =2	Develop 2 nd reliable prototype	Build, iterate and configure	(1x1) =1	Post planned verification; If necessary
	Dimension error	4.1	3	5	(3x5) =15	Test height adjustment of cymbal shaft to frame. Allow adjustments of layout.	Adjust design of problematic component. Design adaptable parts which combine bought parts	(1x5) =5	Continuous
	DC Motor Failure	6.1	3	3	(3x3) =9	Trial and error of torque to overcome friction	Obtain a new motor With higher torque	(2x3) =5	If necessary
	Solenoid Failure	6.2	3	5	(3x5) =15	Observe Failure	Obtain new solenoids; if necessary	(2x5) =10	If necessary
	Frame Failure	6.3	2	3	(2x3) =5	Construct initial lower frame sides	Reinforce joints to linear bearing mount	(1x3) =3	If necessary
	Stage/ Platform Failure	6.4	3	2	(3x2) =6	Addition of bar brackets to motor mount	Rebuild	(2x2) =4	If necessary
	Circuit and Cable Management Failure	6.5	3	3	(3x3) =9	Find Source and disconnect	Add a runner that is parallel to linear bearing, re-solder connections	(2x3) =6	If necessary
Software	Code	8.3	2	4	(2x4) =8	Find Source Error	Simplify and test separately before combining	(1x4) =4	Continuous and iterative when necessary
Human Resources	Illness of team member	10.1	2	3	(2x3) =6	Keep team members well and informed	Ill member should notify team as soon as possible. Reassign tasks that can be completed while the member recuperates.	(1x3) =3	Continuous
	Team member unavailable	10.2	2	3	(2x3) =6	Have team members organise their schedule appropriately.	Reassign tasks to available members.	(2x2) =4	Continuous
Schedule	Lab unavailable	13.1	4	5	(4x5) =20	Schedule lab sessions as soon as possible.	Push forward components that do not require lab access.	(3x5) =15	If necessary
	Supplier Delays	10	3	5	(3x5) = 15	Contact Supplier and get information, re-order if necessary	Push forward other components that do not require materials/ parts ordered	(3x5) = 15	If necessary

Table 3.1A Risk Assessment

3.2 Allocation of resources

PHYSICAL RESOURCES	USE	SOURCE	COST(£)
Adafruit 15 mm Slide Railing Platform	Slider Components	Makersify	25
Linear Bearing Supported Slide 15 mm Wide Rail			30
Radial Ball Bearing 608zz - Set of 4			8
Timing Belt Gt2 Profile 2 mm Pitch, 6 mm Wide, 1164 mm Long			11
Stepper Motor - NEMA-17 Size - 200 steps / Rev, 12V 350 mA. Datasheet			15
Aluminium Gt2 Timing Pulley 6 mm Belt, 36 Tooth, 5 mm Bore			13
Wood, Acrylic, Basic Workshop Tools	All Parts	Ideas Lab	-
Copper Pipe 3 m, 28 mm, OD 1 mm thickness	Chimes	Screwfix	20
Cymbal 20 inch	Cymbal Mechanism	Amazon	33
DC Motor		ICL	-
Brushes		Kensington Chimes	27
12 V Solenoid, Transistor	Hitting Mechanism	Amazon / ICL	14
Paint	Surface Finishing	Cass Art	8
TOTAL			204

Table 3.2A Table showing information of the physical resources used

3.3 Analysis

3.3.1 Chimes - Sound design

It was decided in the original specifications (refer to section 2) that the Gizmo should not only create sound, but also create harmonies and be musical. At the very centre of the sound design were therefore the notes that the Gizmo was intended to produce. The frequencies produced by a chime are generally dependent on diameter (D), length (L), wall thickness (W), density (ρ) and Young's modulus (E) of a pipe. The dominant frequency of the chime is given by:

$$\nu_1 = \frac{22.3733}{4\pi L^2} \sqrt{\frac{E}{2\rho}} \sqrt{D^2 + W^2}$$

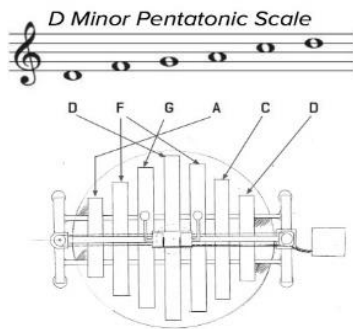


Fig.3.3B Arrangement of the D Minor Pentatonic chimes

Through low-fidelity prototyping, it was established that a metal pipe would produce the best sound and have optimal resonant properties. An initial Matlab study was performed to determine which material would give the lowest frequencies for a length no longer than the diameter of the cymbal (≈ 50 cm). Fig.3.3A shows that copper would give the best result for the metals examined.

The next step was to determine the lowest base note achievable, seeing that chimes could not exceed the diameter of the cymbal. This turned out to be D5

with a frequency of 587.33 Hz and a length of 46.63 cm. From that note, a minor pentatonic scale containing five notes was built up (see Fig.3.3B). In essence, a pentatonic scale is a minor scale without the half-steps. As a consequence, all the notes within the scale can be combined without creating any dissonance. This was great for the purposes of the project, as it was unknown which notes would be played together and how long the pipes resonated for. It was therefore essential to choose inherently harmonious notes. The notes and corresponding pipe lengths are shown in Fig.3.3B.

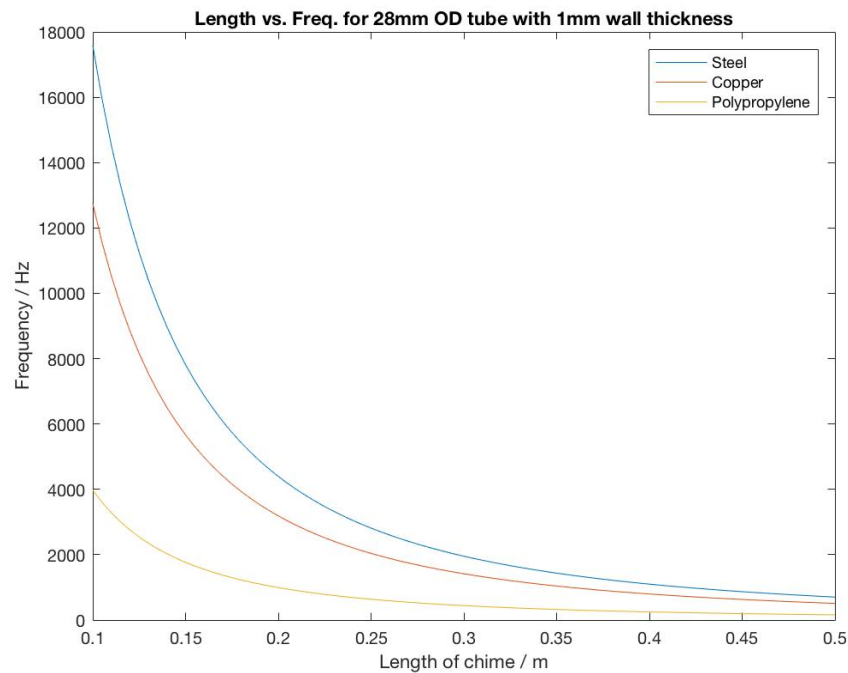


Fig.3.3A Graph showing different potential materials for chimes

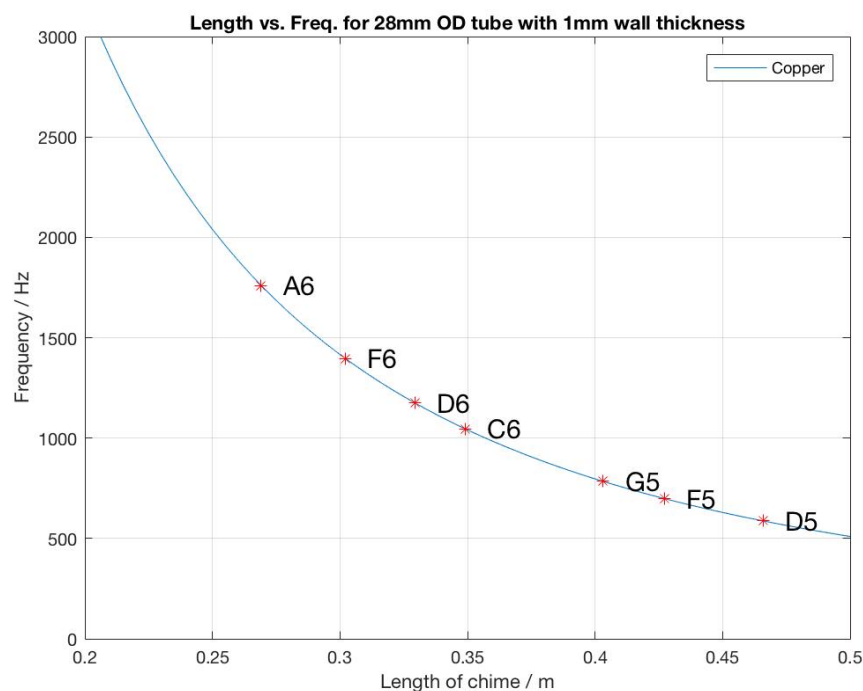


Fig.3.3B D minor pentatonic notes for sound design

3.3.2 Controls – the Circuit

During the development of the controls, which consist of the circuit, the user interface and the code, analysis was mainly done for the circuit. In the Gizmo, the chime hitting mechanism uses two solenoids and the slider uses a stepper motor. More information about the design of the hitting mechanism and the slider are described in the later sections of this report. In the circuit, all three actuators are connected to the Raspberry Pi (see Fig.3.3.2A).

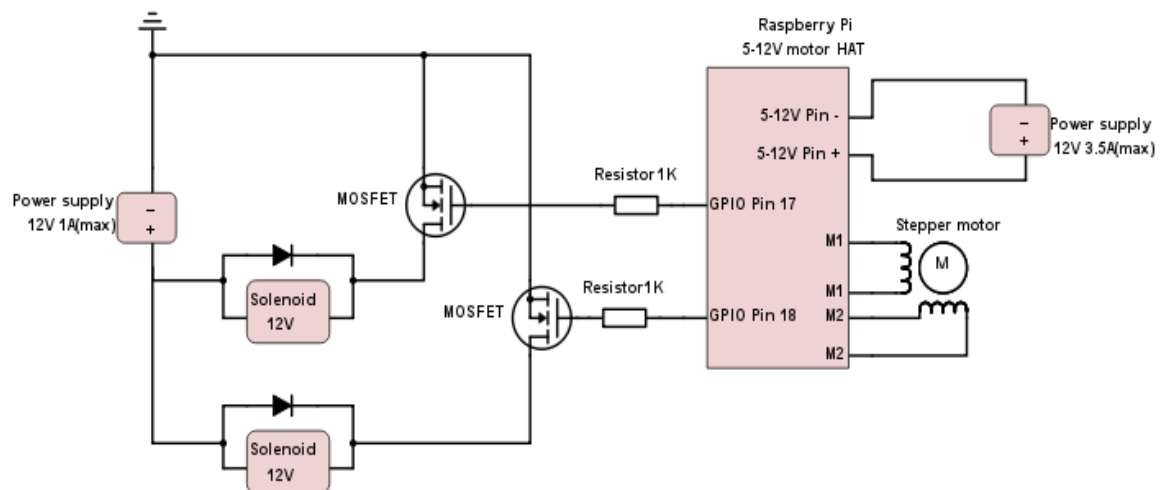


Fig.3.3.2A Schematic circuit diagram to control the solenoid and the stepper motor. Right side shows the stepper motor circuit. Left side shows the solenoid circuit. GPIO pins were accessed through the motor HAT, but are controlled by the Raspberry Pi directly.

Analysis was done to determine what transistor would be suitable for the solenoid circuit. A transistor is used to control the solenoid. It acts like a switch turning the solenoid on and off. The Raspberry Pi controls the transistor by controlling the amount of voltage given to the transistor (0 to 3.3 V) and in turn switches the solenoid. The specific transistor, IOR IRLZ44NPbF, was chosen because of its maximum gate threshold voltage (2 V), maximum drain voltage (16 V) and maximum drain current (47 A). The values were taken from the data shown in Table 4.4A. The maximum drain current and maximum drain voltage of the transistor exceed the current and voltage of the circuit, ≈ 1 A and ≈ 12 V respectively, making the transistor acceptable to use. The Raspberry Pi provides a HIGH voltage of 3.3 V, which exceeds the transistor's maximum gate threshold voltage. When the signal provided by the Raspberry Pi is HIGH the transistor is able to activate the solenoid. With all three parameters examined, the chosen transistor was considered appropriate.

	IRLZ44NPbF MOSFET Data	
	Gate Threshold Voltage, $V_{GS(th)}$	1-2 V
	Max Gate-to-Source Voltage, V_{GS}	16 V
	Max Continuous Drain Current, $V_{GS@10V}$	47 A

Fig.4.4B Circuit for one solenoid

Table 4.4A International IOR Rectifier, n.d.

3.4 Iterative Development

3.4.1 Hitting Mechanism

The hitting mechanism must have enough power to generate sufficient volume and be able to bounce off the chime to allow the chimes to ring. Furthermore, it has to be small and light to fit the slider platform, that measures 47 mm by 60 mm.

Consideration of many possible designs were made. Murphy, J., Dale, A.C. and Kapur, A. (2014) explored a design shown in Fig.3.4.1A. Because the rotary solenoid being expensive (approximately £60 online), the design was not used. A much cheaper approach was to design a hitting mechanism powered by a DC motor. The first prototype (Fig.3.4.1B) were created to test whether the rotary motion of the motor could be transferred into a linear oscillating motion. The second prototype was designed to include more detailed dimensions (Fig.3.4.1C, D and E), which ensured that the chimes would be hit and the mechanism would fit on the slider's platform.

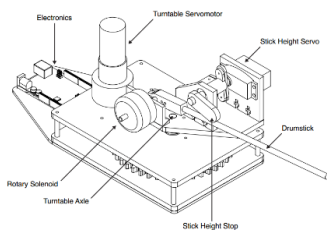


Fig.3.4.1A Diagram of Nudge



Fig.3.4.1B First prototype of a motor-driven hitting mechanism. Left shows front view. Right shows back view.

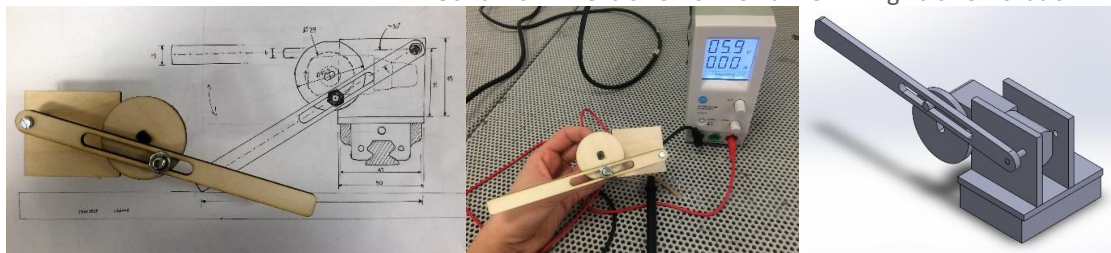


Fig.3.4.1C, D and E Sketch, CAD and second prototype of the motor-driven hitting mechanism

After further discussion, the motor hitting mechanism design was abandoned. Indeed, while this design was inexpensive and effective, it was difficult to control, compromising any effort to create melody. In order to control the mechanism to only hit a chime once, the motor would need to be controlled with great precision, where one rotation is equivalent to one hit. Due to the uncertainty and inconsistency of a DC motors, that would not be possible.

Next, linear solenoid hitting mechanisms were explored. A simple hitting mechanism design is the direct tapping of a solenoid's head on the chimes, which lacks the visual appeal of the hitting movement. Another solenoid design can be identified as a third class lever with the pivot and the output force in either sides and the input force, from the solenoid, in the middle. Calculations considering many important parameters of the design were made to create Fig.3.4.1F. The movement of the solenoid was considered to calculate the gap size between the slider and the chimes. This ensures that the solenoid's plunger will not hit the chimes as the

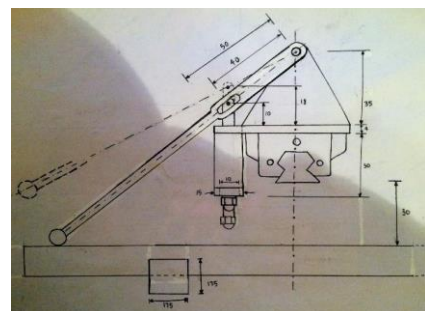


Fig.3.4.1F Solenoid hitting mechanism

solenoid is activated. From the calculated gap size and the stroke of the solenoid, the length of the hitter and the position of the pivot was determined. The shortest chime is included in the sketch to provide a visual idea of the hitting mechanism's proportions and to ensure that the shortest chime can be struck.



Fig.3.4.1G Solenoid hitting mechanism prototypes and iterations

The hitting mechanism was optimised in three ways through iterative development (showcased in Fig.3.4.1G). Firstly, the visual aspect of the hitter is optimised by using acrylic as the material of choice, rather than wood, and by using the solenoid lever design. Secondly, the ringing sound of the chimes was optimised by ensuring that the hitter could simply rebound from the chimes. This is accomplished by providing sufficient clearance between the hitter supports so that the hitter could move freely. Lastly, the time taken to hit another chime is minimised by integrating two hitting mechanisms on the platform. Not only can more sounds be generated in a fixed period of time, but more variations of sound can be generated as two chimes can be hit in unison.

3.4.2 Frame

The primary function of the frame structure is to hold in place the other subsystems and provide necessary clearances between the components. Originally, it was decided that the frame should be made from metal and be adjustable. The latter was assumed essential, as the team had little information on the dimensions of the subsystems. The main requirements were achieving sufficient clearance between the cymbal and the suspended chimes as well as between the hitting mechanism and the chimes. Finally, the frame also needed to suspend the chimes in a way that maximised resonance when struck.



Fig.3.4.2A Interim review frame prototype

Fig.3.4.2A shows the interim review prototype of the frame. The chime suspensions were further developed by adding rubber bands to minimise the contact area and maximise resonance. The rest of the frame was changed completely, as the slider and chime subsystem turned out to be dimensionally accurate. This meant that a fixed frame structure could be used. The final frame build will be examined in section 4.

3.4.3 Cymbal

The cymbal needed to spin at a slow and constant rate. It is the interaction between metal bushes and the spinning metal surface that generates sound. At the core of the spinning cymbal mechanism is the challenge to transfer the motor's rotation efficiently. Maintaining the cymbal's resonance was done by eliminating the need for holes in the cymbal and ensuring minimal contact between cymbal and support.



Fig.3.4.3A CAD of first prototype

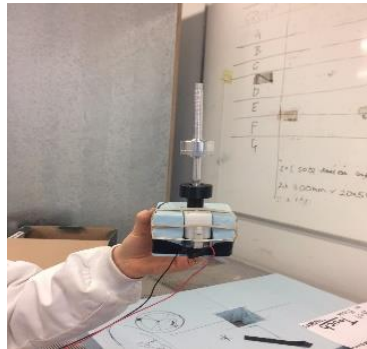


Fig.3.4.3B First prototype with blue foam motor housing

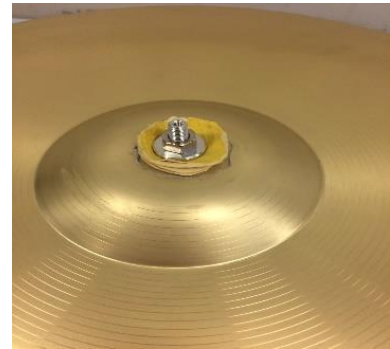
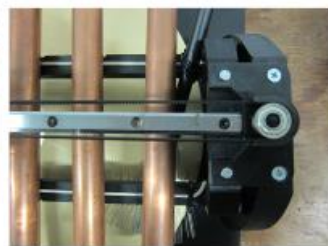
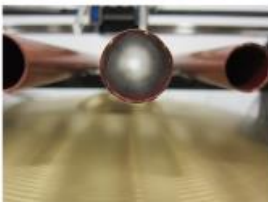
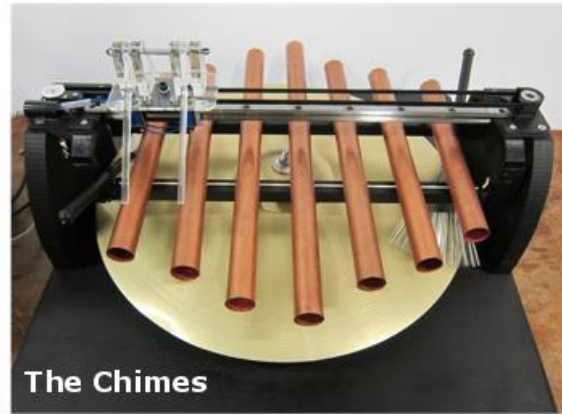
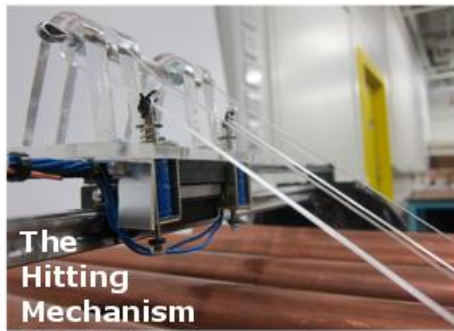


Fig.3.4.3C Photo of kitchen glove rubber washers

The starting point of research about the cymbal was investigating cymbal stands in use today. These incorporated a shaft collar to hold the cymbal and a tight compressive joint accomplished with a layer of felt and a tightened wing nut. The design of existing cymbal stands first inspired us to create a motor adaptor with a threaded end and a shaft shoulder to support the cymbal. The first cymbal stand prototype was composed of a machined metal shaft, 3D printed motor adaptor, and a nyloc nut that joined the two. Initial designs for the motor housing were made out of blue foam. It became evident early on that our design did not provide sufficient clamping force. By prototyping new stands with duck tape, double sided tape, and rubber washers made from kitchen gloves, ways to limit slip between cymbal stand the surface were explored. Simultaneously, testing on the motor was conducted.

4 Final build

In this section of the report, each subsystem (as introduced in section 3 Design Process), (i) the chimes, (ii) the slider and frame, (iii) the hitting mechanism, (iv) the controls, and (v) the spinning cymbal and stage, is explained. A video of the Chymbal functioning can be accessed through [Vimeo](#). Fig.4A showcase photos of Chymbal.



CHYMBAL

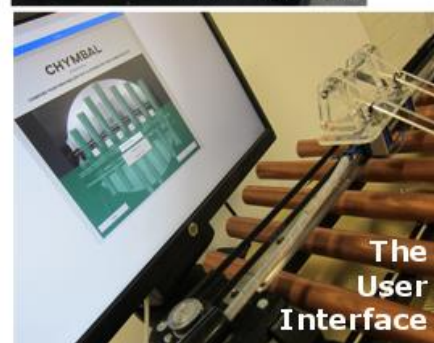
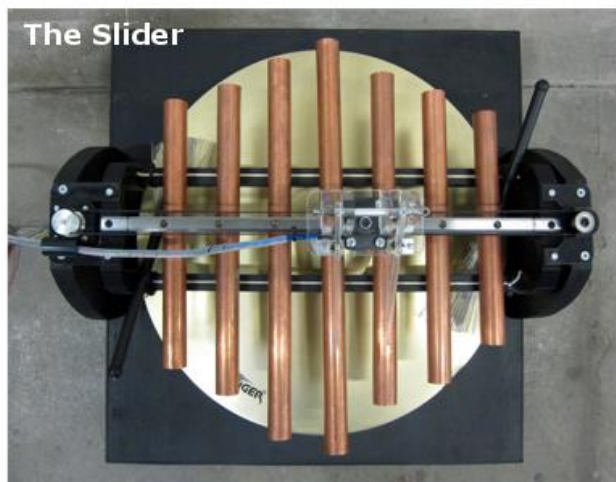
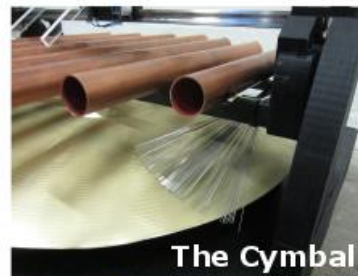


Fig.4A Photos showcasing the final Gizmo – Chymbal

4.1 Chimes

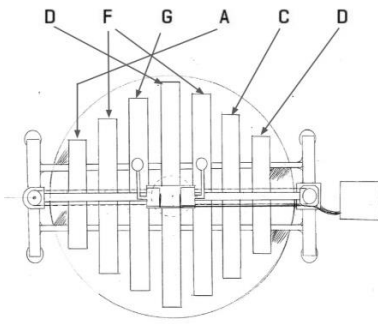


Fig.4.1A Arrangement of chimes

The chimes were machined in the STW workshop at Imperial College London. They were first cut to approximate length using the chop saw, and then further machined using the mill. In the end, the chimes were fine tuned by ear, which means that they may deviate from the exact frequencies specified, but harmonise nicely. Fig.4.1A shows the arrangement of the chimes resembling the cymbals circular form and creating a contained aesthetic.

4.2 Slider and Frame

The linear slider consists of several components, including rail, linear bearing (i.e. platform), belt, rolling element bearing, stepper motor, and corresponding frame elements. Please refer to section 2 for technical details and sources. Instead of building the system from scratch, the team followed an online Adafruit tutorial. With slight adaptations, [‘Bluetooth Controlled Motorized Camera Slider’](#) (Brothers, 2015) was used for our build.

The team benefited from the component list specified in the online tutorial. It was confirmed that the stepper motor proposed in the tutorial, coupled with the pulley, could achieve a sufficient belt speed, and was compatible with the provided Stepper Motor HAT.

The slider components were held in place by 3D-printed PLA frame elements that were also found on the Adafruit online tutorial. Some of the parts had to be modified in order to suit the project, such as removing some geometry from the motor mount or enlarging the bore in the timing belt clip. The 3D-printed frame elements are shown in Fig.4.2A.

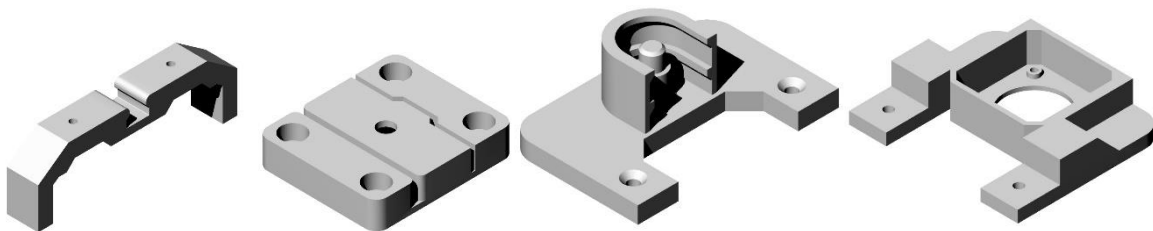


Fig.4.2A From left to right: rail foot, timing belt clip, bearing mount, motor mount (shown from below)

The 3D-printed parts, together with the bought in components, were assembled to make up the slider. As the stepper motor rotates, it drives the belt through a pulley. The belt transmits the power to the timing belt clip, which is fixed to the platform on one side, but not on the other. Finally, the belt is supported through a rolling element bearing on the other side and thus achieves linear motion of the platform. The linear slider was subsequently integrated into rest of the Gizmo. It must be noted that the slider and frame were from that stage onwards considered one subsystem, not in terms of function, but in terms of form. In the following discussion, the two subsystems will be looked at simultaneously.

The main frame requirement was to ensure that the hitting mechanism can hit the chimes, but doesn't interfere with them when changing position. From the calculations made for the hitting mechanism, the team was able to determine how low the chimes had to be suspended from the rail to achieve the clearance. The team designed an adaptor which connected the wooden chime suspension to the PLA rail foot. Fig.4.2C shows the adaptor and how it was connected to the frame elements. The adaptor was held in place by interference fit and was further fixed to the frame using superglue.

The last component of the slider and frame subsystem was the wooden ground fixture, which was designed to give sufficient clearance between chimes and cymbal. The final slider and frame were assembled using threaded fasteners and are shown in Fig.4.2D.

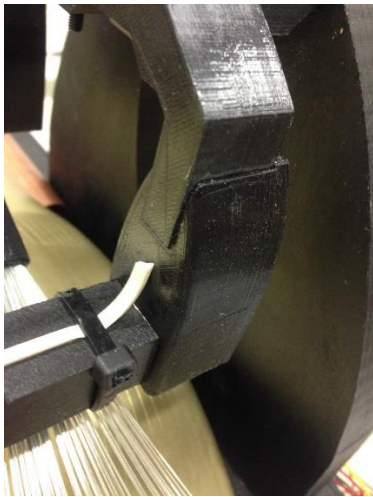


Fig.4.2C Adaptor linking rail foot chime suspension

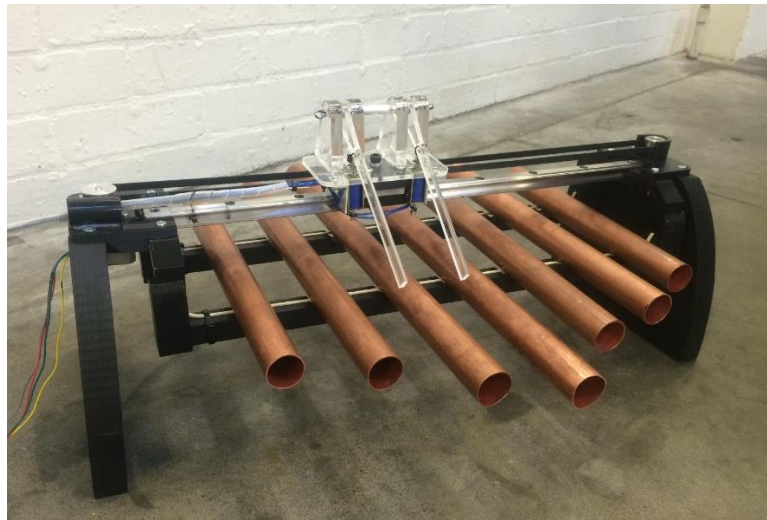


Fig.4.2D Final slider and frame with chimes and hitting mechanism also shown

The rail was lubricated with WD40 spray oil to ensure smooth movement, minimal friction, and in turn, faster belt speed. The stepper used Double steps to maximise belt speed and was run at 50 RPM at approximately 200 pulses per second (PPS).

4.3 Hitting Mechanism

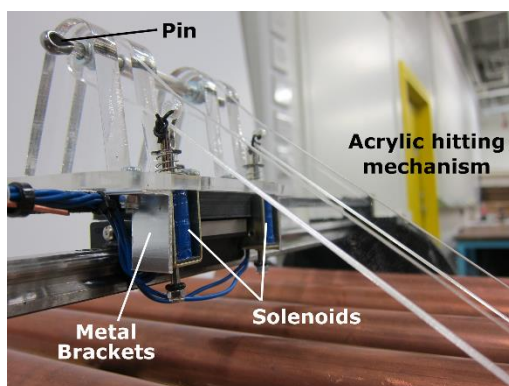


Fig.4.3A Annotated photo of final hitting mechanism

The design of the hitting mechanism was developed through iterative development which is described in section 3.2.1 of this report. Components were all manufactured by laser cutting clear 5 mm and 10 mm acrylic, which were assembled using super glue. The hitters are attached to the supports using a pin. The solenoids are fixed to the platform a combination of interference fit, bolted aluminium brackets and super glue. The final device can be seen in the assembled figure with the slider (Fig.4.3A).

4.4 Controls

With the circuit built as shown in the schematic diagram in Fig.3.3.2A, Python code was written to control the position of the slider and to trigger the hitting mechanisms. In preparation to coding, measurements of the number of steps taken between positions were taken (see Fig.3.3.2A). Since the code has no defined initial position of the hitting mechanism platform, the platform position needs to be initialised manually before running the program. A block of wood was manufactured to calibrate the platform position.

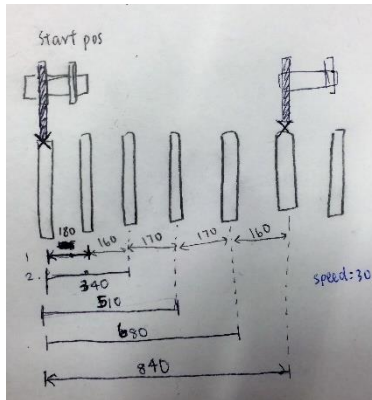


Fig.4.4C Note of steps in between hitting positions.



Fig.4.4D The User interface

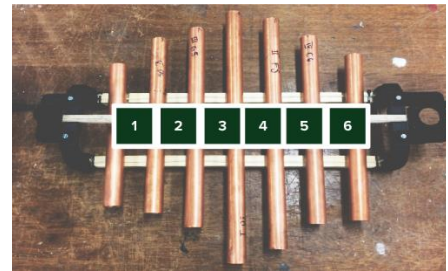


Fig.4.4E Hitting mechanism positions

Finally, a code and a Qt user interface (seen in Fig.4.4D) were developed to allow for user interaction. Viewers can create their own composition and instruct the Gizmo to play it. They compose a melody by creating a sequence of characters provided by the user interface. The integers correspond to the position of the hitting mechanism as illustrated in Fig.4.4E. Upon having moved to the correct position, the hitting mechanism is programmed to hit both adjacent chimes at the same time. To provide more composition variety to users, hitting patterns A and B, which are triggered by the respective characters 'a' and 'b', were also made. The relevant code can be accessed through a [shared GitHub repository](#) in a file called "compose.py".



Fig.4.4F A white PC spiral cable wrap and a black tube were used for cable management. Slacking of the cable can be seen.

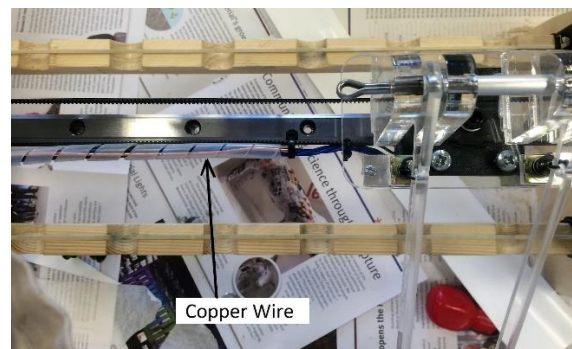


Fig.4.4G Copper wire was added amongst the wires to increase overall cable stiffness solving the slacking problem (Fig.4.4F)

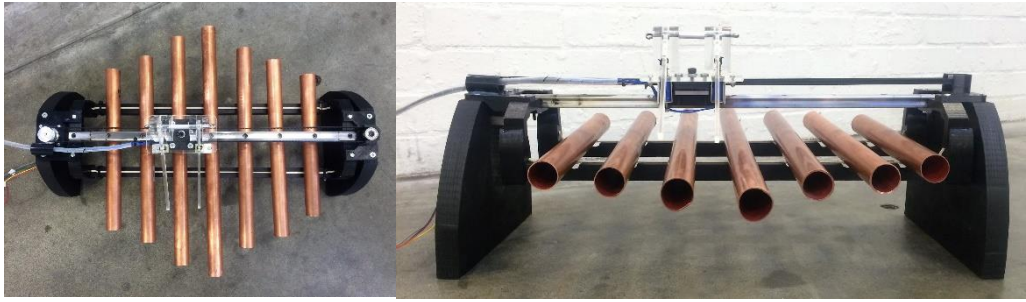


Fig.4.4H & I The chime subsystem, which consists the chimes, the hitting mechanism, the slider, and the frame

Finally, cable management is shown and described in Fig.4.4F and Fig.4.4G. With the chime subsystem of the Gizmo completed (shown in Fig.4.4H and Fig.4.4I), all that remained was the cymbal subsystem, which is described below.

4.5 Spinning Cymbal and Stage

The final design of the cymbal subsystem was optimised by minimising the torque needed to spin the cymbal. A ring with three wheels bears most of the cymbal's weight, reducing the inertia (proportional to cymbal mass). Thus, the motor only needed sufficient torque to overcome the friction of the rubber washers.

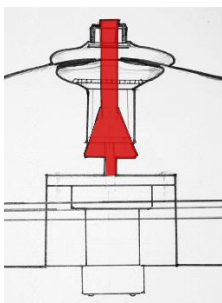


Fig.4.5A Highlighted tapered collar

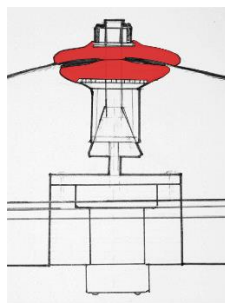


Fig.4.5B Highlighted rubber washers



Fig.4.5C Picture of final design ring with wheels

The cymbal is supported by the tapered collar and by a wheel mounted ring support. The tapered collar ensured grip to the motor shaft and clamped the cymbal with a downward force. Moreover, to ensure no slip, bespoke rubber washers were created for both sides of the cymbal. The washers provided a tight fit on the curved cymbal surfaces. The wheel support structure was manufactured out of two laser cut, 4 mm MDF rings. Holes were drilled into the sides to accommodate the wheels that were mounted on bolts. The wheels were repurposed from a skateboard, and featured rolling element bearings. The combination of the tapered collar, rubber washers, and wheels established efficient translation of rotation from the motor shaft. The motor used in the final design was a RH 158.12.250 brushed DC motor. In the final design, this motor is not controlled via the Raspberry Pi, but directly connected to a bench power supply (5 V, 0.45 A). The motor was mounted onto a laser cut plywood structure that was designed to raise it by 56 mm in order for the cymbal to sit both on the motor shaft and wheeled support.

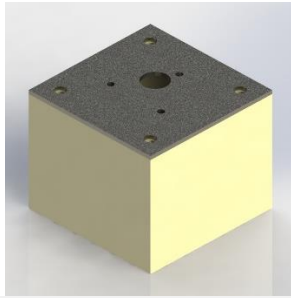


Fig.4.5A CAD of motor housing

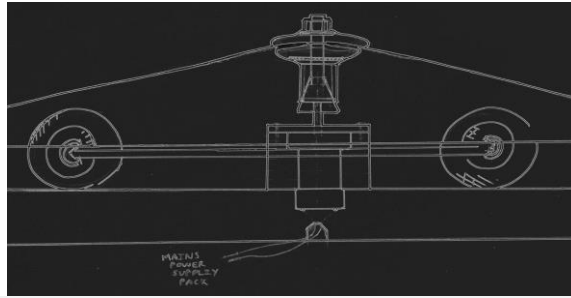


Fig.4.5B Sketch of cymbal subsystem

This subsystem generates noise as metal brushes mounted on the frame come into contact with the moving cymbal surface. The brushes were fastened onto the frame with black electrical wire in a diagonal direction to maximise contact with cymbal surface. In addition to a continuous background noise, this subsystem also provides structural support for the Gizmo. The platform measures 600 mm by 600 mm and is 55 mm tall. This ensured for a design which accounted for the cymbal, linear bearing, frame and motor housing. The platform is a plywood box with a 12 mm top and 3 mm sides. It was reinforced with blue foam. It allowed for strength in all directions. This was key to withstand the combination of forces resulting from the spinning cymbal, movements from the linear bearing and the striking of the chimes when the machine plays. The motor was mounted inside the platform and motor mount, and was positioned centrally.

5 Statement of Individual Contribution

In the ideation and concept development phase, everybody worked together. Frequent meetings made it possible to progress quite rapidly.

In a group of four, the work was divided up according to the different subsystems (further explained in Section 3). People worked on more than one part and specialised in the Gizmo subsystems they had interest in. On average, there were two people working on the hitting mechanism and the spinning cymbal, which were seen as high failure potential mechanisms, while the rest only had an average of one. Each team member contributed to the creation and assembly of each subsystem of Chymbal. The following table shows who was mainly responsible for which subsystem. Needless to say, this project is the achievement of the whole group and would have never existed in its form without the contribution of all members.

Subsystem	Main responsibility
Chimes	Paolo
Cymbal	Connie & Josephine
Slider	Paolo
Frame	Connie, Josephine & Paolo
Code	Grace & Paolo
Hitting Mechanism	Grace & Connie
Circuit	Grace
User Interface	Connie & Josephine

Table 5A A table showing the contribution of team members toward different subsystems

6 Group Reflection

Chymbal was created by team of four second year design engineering students. From the beginning of the project, emphasis was placed on elaborating shared goals for the project: we decided to create harmonies rather than noise. This common aim ensured both team cohesion and individual achievement. The intersection of good organisation, communication, appropriate division of tasks allowed the team to work in an effective way. Moreover, the use of off-the-shelf components saved us time in the early stages of the project allowing for multiples iterations of the key mechanisms.

If given the chance to continue working on our Gizmo, we would focus our efforts on three points. First, we would work to reduce the dependency on power supplies by designing a new circuit and using buck converters to power our Gizmo from a single power supply. Secondly, we would include a sensor to determine the hitting mechanism's initial position to limit the need for human intervention when the Gizmo is in use. Finally, we would work to improve the following:

- Sound experience by silencing the cymbal motor and solenoids.
- Faster belt speed using a stepper motor with equal torque, but increased pulses per second (PPS) and a constant step angle (1.8 degrees).
- Using a microphone to amplify the cymbal's sounds.

The Gizmo could be altered to include more chimes and play more complex melodies as well as feature ways to interact with the cymbal.

7 References

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