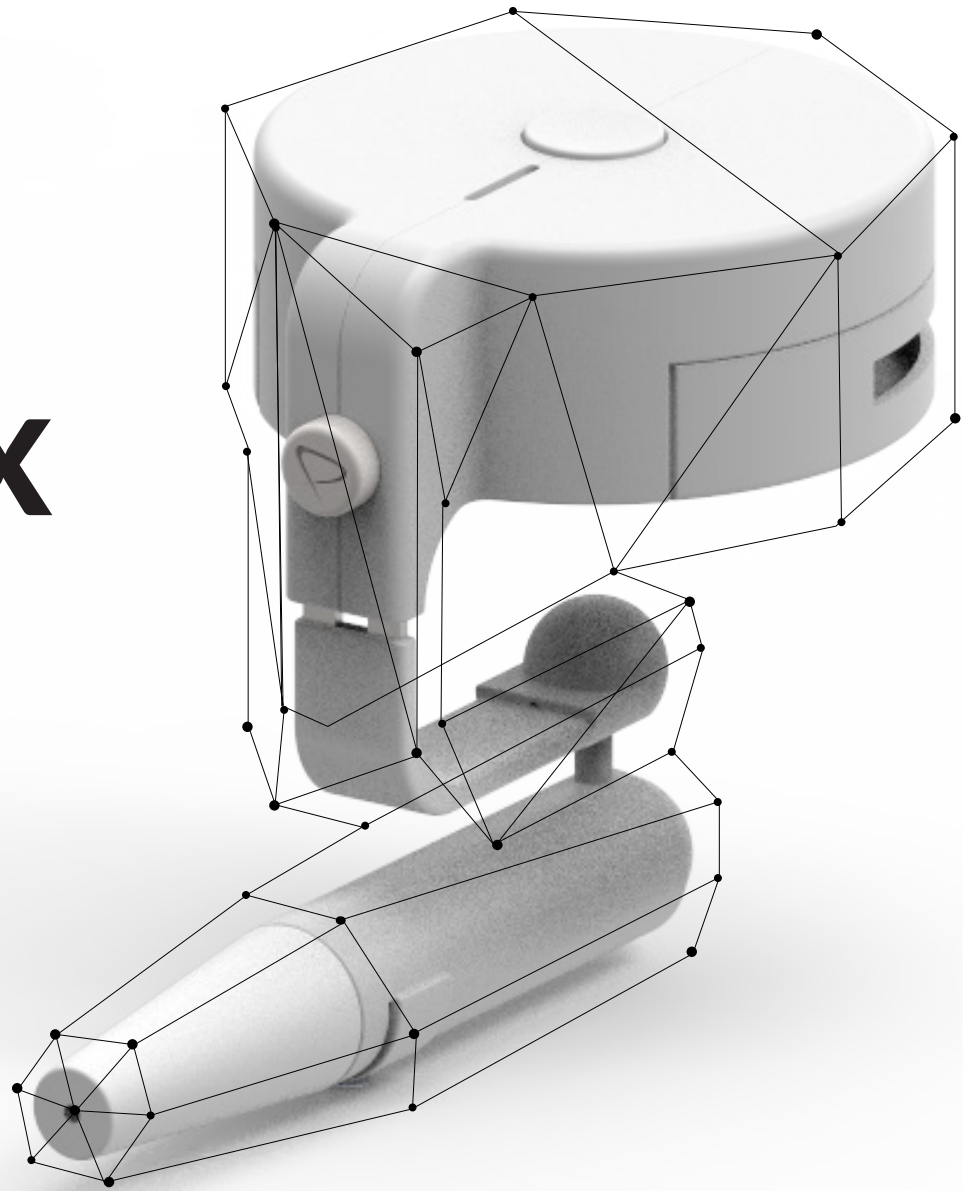



Appendix



A1, the analysis of current product

	form	property	function	need &value
	anodized unibody aluminium cap		close up the pen	easy to assemble
	anodized unibody aluminium strip yellow square	clip with strong stiffness LED light	fix with some other things indicating heat level	<ol style="list-style-type: none"> 1 enhance the portability 2 simulate normal pen 3 understand the temperature condition, feel the control of the product
	LIX logo	same colour as body	brand image	
	anodized unibody aluminium cylinder	light weight	containing most components inside	<ol style="list-style-type: none"> 4 light weight enhance the comfortability of using 1 enhance the portability, 2 similar to normal pen
	aluminium cylinder	pressable button	activating the tool	<ol style="list-style-type: none"> 2 buttons stand around the holding area, easier pressing
	anodized unibody aluminium cylinder with texture	fish scale texture, high friction, 0.47 inch long	comfortable gripping	<ol style="list-style-type: none"> 4 enhance the comfortability of holding
	anodized unibody aluminium cylinder with holes	circular holes, 0.31 inch long	ventilation of the heat	<ol style="list-style-type: none"> 5 ensure the safety of the product

Intentions

- 1 portability of the product
- 2 familiarity to users
- 3 controllability when using
- 4 comfortability when using



form

property

function

needs & values

plastic block
plastic block
plastic board
plastic tube

electric board
weak stiffness

charging
connection & fixation
transmitting electricity
transporting filament

① adaptable charging,
enhance portability

stainless steel cylinder
plastic strip
plastic cylinder

motor, noisy
plastic strip
gear box

transmitting power
route of electricity
decreasing speed

stainless steel cylinder
plastic board
stainless steel tube
stainless steel stick
plastic block

stainless steel tube
electric board
strong stiffness
strong stiffness
stiff button

transporting filament
electricity to heat
route for filament
connection
activating

decrease the thickness
of the tool, enhance
① portability and
④ comfortability

steel block
ceramic tube
stainless steel tube

200 degree
200 degree
around 100 degree

heating up
transmitting heat
route for filament

③ enhance the smoothness
of transportation

Intentions

- ① portability of the product
- ③ controlability when using
- ④ comfortability when using

A2, transcript of interviews

Joost

Do i need to push it? I am writing Ryan but

It would be nice, normal 3D printer has a heat print pad, they will stick on it very well, so maybe you place a stickers first layer stick on it very well because it is hard to start... (on the normal surface) so there might be a sticky pad that the first part stick on it very well, so it doesn't when you sum up some height it doesn't move and it falls.

Wang Tianzi

it really looks like a tool, it is not like a creative style. It is not something I want to use to create something. maybe the colour of the pen (black). This more like the tool like the hammer. I think i can not control the shape, it keep like this (the mess), I want to control it, maybe I think the amount is too much. I think it is quite stable, its nice.

Ruben

(automatically disassemble the pen)

I am just wondering what was in. and also this is (means clips) really normal pen feature, you know it is not a pen, i dont know if is it really useful for this tool. Why would you use this? I will not clip it on paper. I think I just want to know the structure. When I can open something I just try to do that.

I can feel it is warmer. oh something is coming out. how do you easily break it or something? if you want to make another piece, one of the easiest thing you can make with it is liquid poo, thats the only thing you can make right? Otherwise it is not going to work. or a period maybe.

And it will come out from back? really? It is the effect that I can no use clay maybe hah. Yes it is something totally as same as I think. Maybe I am more surprised to see clip, the thing you can put in your pocket. I didnt have it because im seeing it was something you use at specific place you dont take it with you. but I like this idea. Im wondering

what people make with it. i can only make this.

Maybe the limited capacity. it fixes the concept you describe very well.

Vans

I think It kind of magnet, because it is all metal, no plastic part means more like real and durable. It can last for a long time. too be honest, I was not expecting it could be charged with usb products. the part of the nozzle can be longer. For some professional pens, some automatic pencil, their heads of the pen are very long. you can have a better understanding of what you are drawing, more clearly. cause now there like a heat prevention guard.

another problem if you want to make something in you mind, you really need a lot of practice. I think in the very beginning I don't know where should i place of start point. if you portray it like as easy as a

pen. people will assume that you... if it looks like a pen, it should be as easy as a pen, otherwise there will be a gap between the expectation and the reality. i think now there is a gap. I'm thinking that thing (expectation) is more like glovish, the glove thing, its more like wearable stuff instead of this kind of additional things.

Cause i think by doing that you can just reduce some, like for the current product, its weight is a little bit too over to my hands so if it can change into... it (expectation) is more close to your natural behaviours, so it should be wearable.

Zhang Lei

It is more heavy than I thought. I do not mind pen heavy like this actually I prefer that, it seems that it has too much weight on the top of the pen, which is strange. Normally it should be around here (means the holding part), I prefer it has much weight on the tip. The metal finishing, shape and colour make it looks professional, and

id like to say even it is the shape of a pen, it still indicates it is not a usual pen.

If i touch it (the tip) it is still very hot. I have a lot of friends, they usually use their pen very close to the tip. I would say give it a small cap can heat up faster. just a normal cap to avoid transmission the heat. It is now working like a heater right? heat went out very fast. now it is not very warm. I really feel disgusting about the waste material. this seems to draw very easy in the commercial video. i think it should kind of paper for this kind of drawing, easy starting panel, cause now it is not very easy to stick to the paper. Actually it is better to keep pressing it, you get better control. What, is it gone already? Thats (the filament) really limited. how much sticks do you need to use to make it?

I would not say it is a problem. I am a experienced sketcher and drawer already, maybe its the way should be like just feel like drawing something with the pen not as easy as I used to drawing. I dont feel my expertness on drawing by hands. I hope this

drawing better.

It is not really a problem, maybe it is from my skills, not you put these two things together, this one (means the pen) looks very professional, and what the fuck with this (means the result). Definitely I will presee? another way of creation. I mean even though it is in this shape - a pen, the way you use it and the thing you want to create it actually nothing to with a pen. I can understand why they start, comes from a pen, because it is easy transmission for normal people, well you do the same things with a pen and you can do this (means result) with this kind of thing (means 3D pen). but i really want to divert it to a new way of creation, why dont choose another form. they need a pen because fingers can not give colours. if i can draw something on the screen then i will use the pen. it is same as this one, in this case it is more flexible to use my finger.

Why do I use this form. I would say build a pen like this thing is much more for introducing. After that, people now have more understanding about 3D,

3D pen, you can choose another form facilitate the pen. Years earlier, there are even sensitive touch screen a lot of mobile phones still have a pen when actually it is better to use the finger.

Omar

it looks like a tattooing gun. Ive seeing the devices and yes it looks like a pen. its nice to see. also you can actually reverse the plastic as well? but how does it work? after you print it or? Oh its only your filament, only this thing. i though you can melt it into your pen. the front already getting hot, its pretty hot. Im moving too fast. maybe thats also a important function that you have to be focus on the plate which 3D printers that you set up all the spots.

i want to build a beautiful stuff. I want to make a nice star but it looks like the Patrick star from SpongeBob. you have to say all the straight lines are actually taking the shape. it is difficult to draw straight lines. they made it so easy on the movie. oh now it is turning red. you expect it pretty easy but you have to like other device you practice the skill. it is something you have to learn. you know what to do, it is the learning curve. And it is pretty

fast i think, because the straight lines are pretty ok, making the structure. Maybe the problem is people think they have to straighten the lines by hands but actually it should be done by pen itself.

I think the difficulties are the skills. it is less ergonomics than pen I guess in the same way. I still think the wireless is better. it is will be more useful to walk there to do something there. before you have a basis, it is difficult to start. the first line is super quickly and difficult to make, then after having the block it is super easy to make the rest. because you can do it without efforts, because you just press it and make what you want. It is not so ergonomic. i dont there are too many disadvantages. it is limited to make for products for prototyping it is really nice get grasp of the shape, but more than that, the usefulness is not really there. make stuff for yourself.

Mark

its about 5 minutes? Oh 2 minutes is not necessary.

maybe here to make the foundation. It takes some practice, that is what I know about it. It is fun play

thing in, but not that really satisfied about this. I dont really see the direct implementation for it. so I could try to layer foundation (feel not good when detaching the material), keep pulling at it, I dont have a lot of control, the lines are very thin.

First of all, ergonomics, mine you dont have to hold like a pen, I think the pen is suboptimal, because you hold it like a pen, at least for me, I also feel the need to write with it, so I want to remain on the flow, and its also very difficult to 3D in other ways, the plastic comes out is so thin, I know it is hard to make it thicker, but at least with my option, you can more comfortable hold it, relaxing or slowly pulling it up like I did. I think it would be a bit better.

The nozzle will be quite hot you dont want to touch it, the cable is, you need it but distract my motion. I like it get cold quite quickly, so its rigid quite quickly, but not for me in the main instruction. I want to control the material with my hand, but I immediately get conscious of not getting too close when I want to pull it out. Feel a little that I have to be careful. A little bit dangerous. where the button is located, im not sure. I can understand why they put it here but I dont think it is comfortable. I dont like this. Thats what i missing, I have to press, and apply force to indeed.

I do like to have tangible use cue, it is very simple and direct to notify the users he has the possibility to activate. but here all the space in my hand is now empty, with this new revolution of design I can really use the full grip of my fingers, to apply force whenever I press it. Because applying force now come from this grip, which is less comfortable freely use it. I will be more difficult and now I can start feel the strain on my fingers. Well here (own design) im fully relaxed.

Zhang chi

I think it is a little bit heavy. The pen is not flexible. it is not super comfortable when using other gestures. and I think probably the filament is too few. It seems like I can only make a tiny thing with it. It is not precise enough. I want to make a ring for myself. If the nozzle have different shape, I want to make some other kinds of shape. It can only draw the line which can not realise some other. Also it is not too precise. if you want to draw very straight or flat, you need some assistive tool. also i need the support of the material, and it is not stable enough. Because it is not precise enough, I can not realise

what I want.

If you need to draw the surface, you need to use the pen for many times. you can only draw the line. The capacity should be more otherwise I need change the material all the time. it is not convenient to change the material. it is too heavy and limit the movement of hand. The centre of the weight. it should be on the some other parts of the hand to free the part of operation.

Jlani You

It is not fancy enough. I think the appearance should be more special. Oh actually the principle is using the gear to roll the filament. the material is too few for one time. this is not convenient. Is there a way that you can fix it on the surface? I expected it is easier before. the cooling will be quicker. Just like hold a wand that you can draw in the air but actually it can not cool quickly. I think the cooling is not quick enough. I feel in the reality you need some mould to do that. It is hard to fix it. Sometimes you need to fix it and then to draw it. I feel that it is better that if you press it harder, then it can be thicker. If you change the bigger material you can make the output bigger. The pressure sensor. maybe you can use the both side of the pen

A3, analysis of transcript

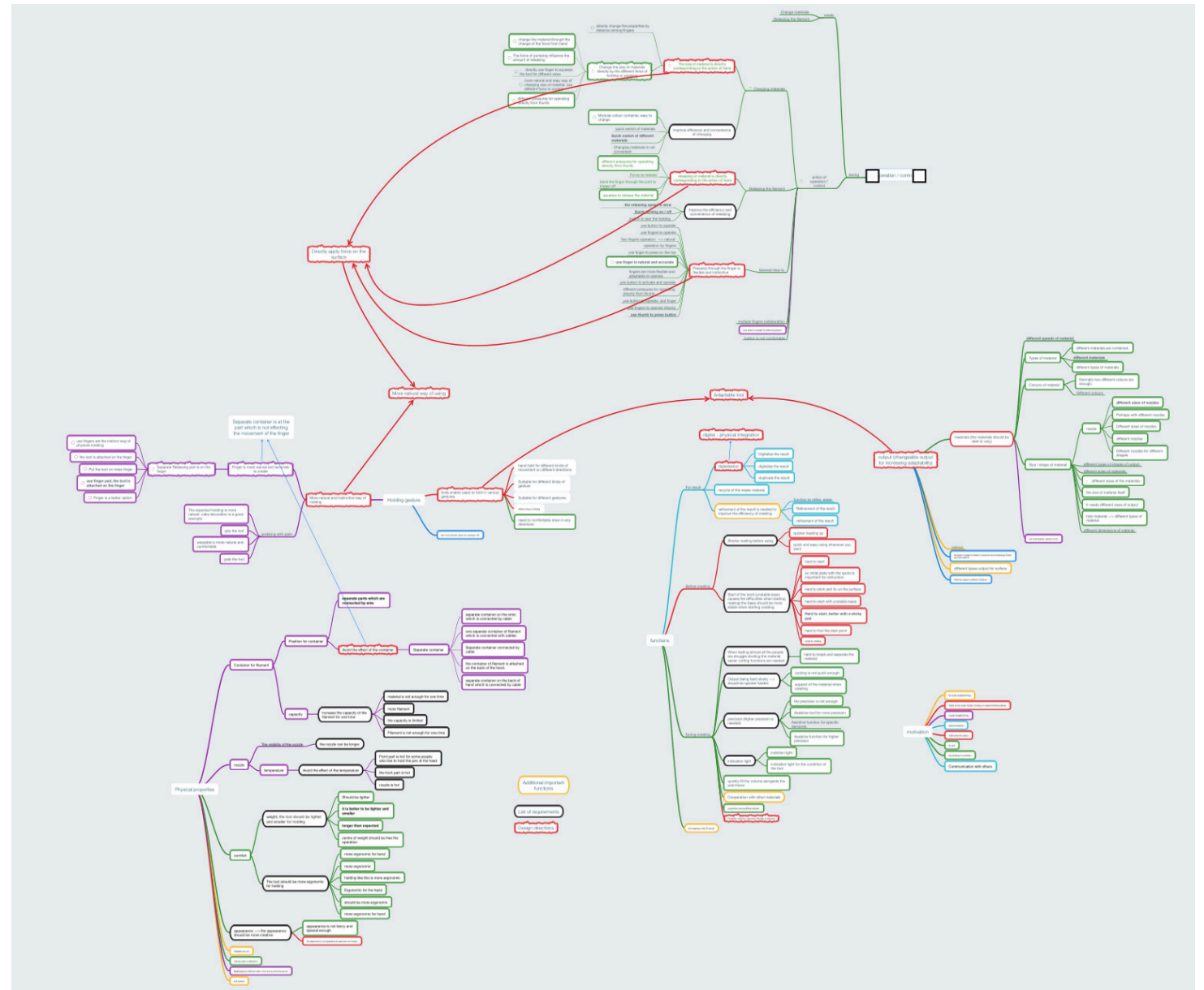
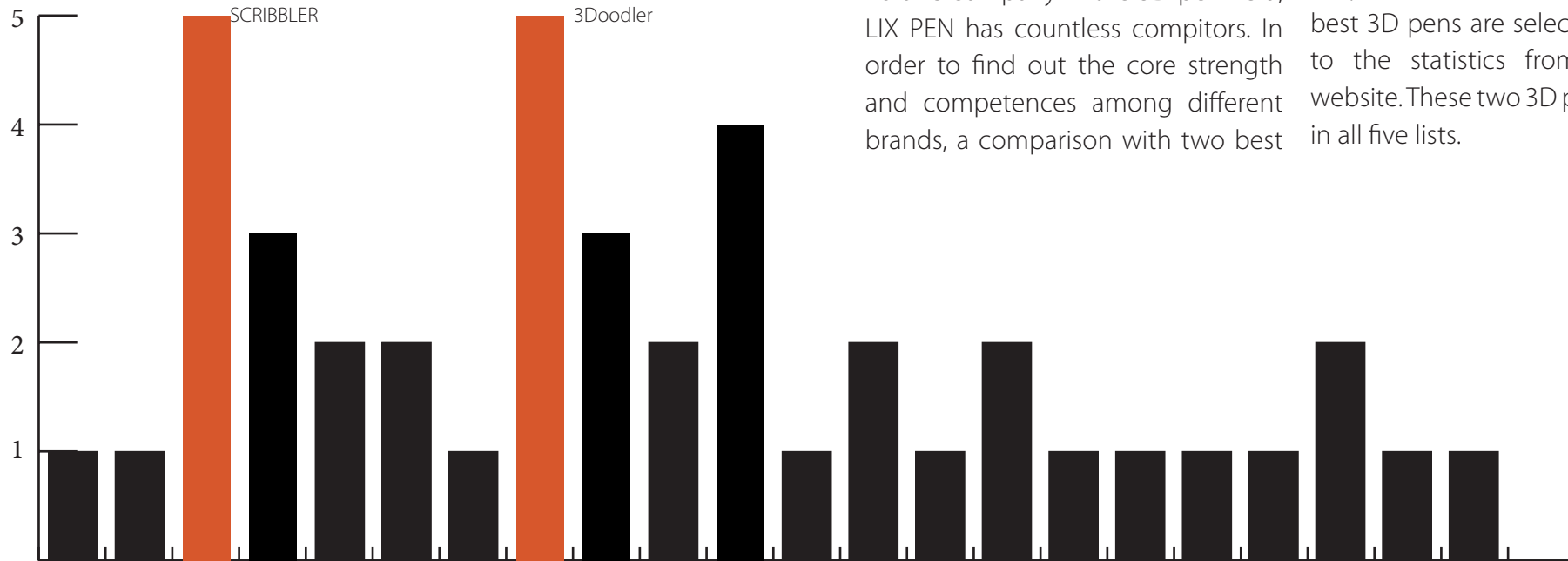


figure 1
The context mapping of transcript

A4, the frequency of different 3D pens in five separate ranking lists



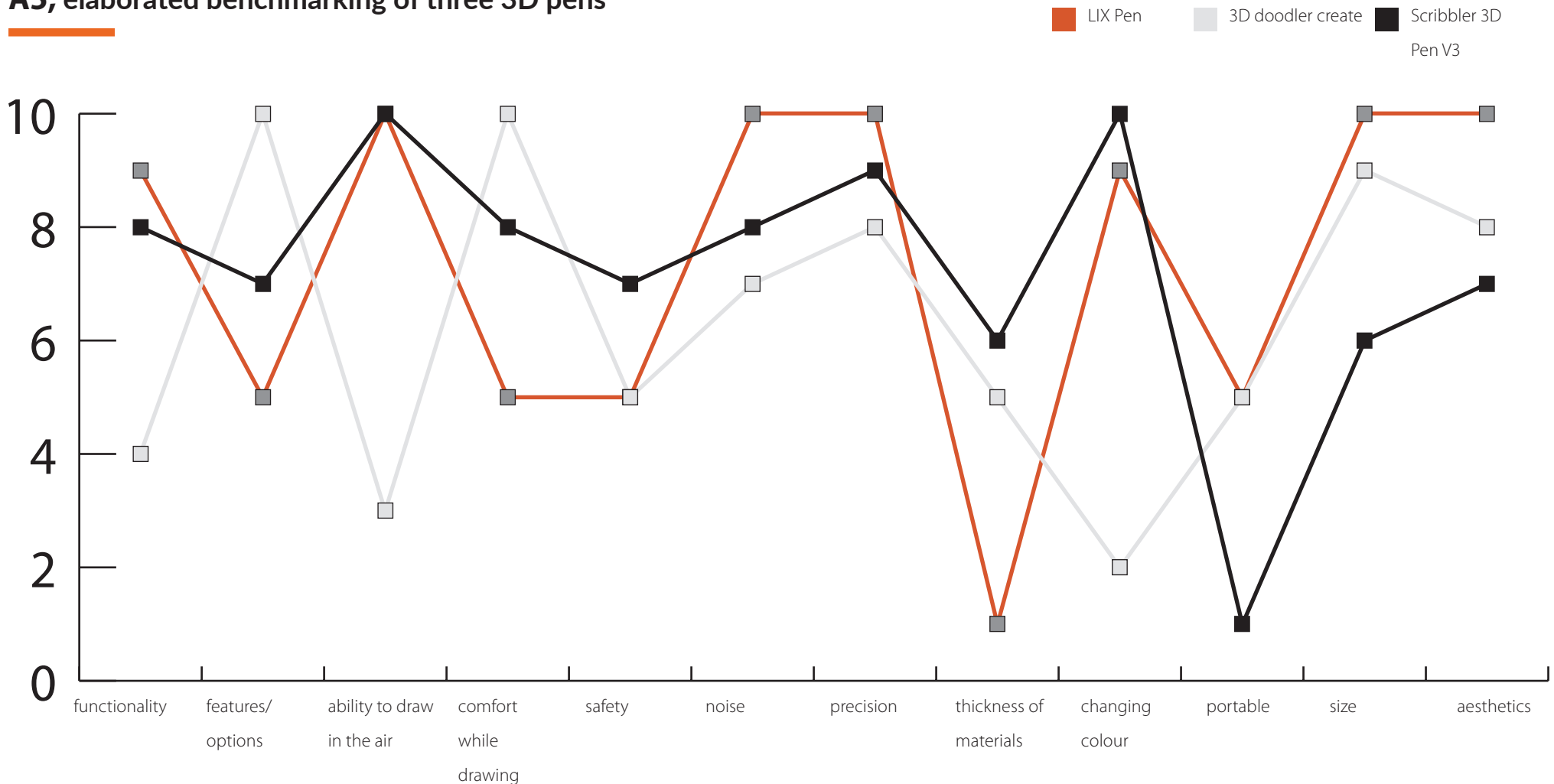
As one company in the 3D pen field, LIX PEN has countless competitors. In order to find out the core strength and competences among different brands, a comparison with two best

3D pens in the market is made. (two best 3D pens are selected according to the statistics from 5 separate websites. These two 3D pens appeared in all five lists.

figure 2

Frequency of different 3D pens in five separate ranking lists

A5, elaborated benchmarking of three 3D pens



The figure shows the comparison among 3D best or equal best in functionality, ability of drawing doodler create, Scribbler 3D pen V3 and LIX pen. in the air, low noise, proper size and appearance. For each parameter, 10 means best while 1 means worst. Functionality and ability of drawing in the air are worst. Through the comparison, LIX pen performs combined into the smoothness of using.

Functionality - 1= break often, 10 = never breaks

Features / options - 1= simple, no options, 10 = many options

Ability to draw in the air - 1= can not draw up, 10 = easy to draw up

Comfort while drawing - 1= uncomfortable, 10 = comfortable

Safety - 1= dangerous, 10= safe

noise - 1= loud and annoying, 10= quiet

precision - 1= difficult to draw details, 10 = good for details

Thickness of materials - 1= thin, 10 = thick

Changing colour - 1= difficult to change colour, 10 = easy to change colour

portable - 1= must be plugged in, 10 = long lasting battery

size - 1= big size, 10= small size

Aesthetics - 1= bulk, 10= elegant

A6, trend analysis

Technology trend

The Rise Of Soft Robotics

Robots today are hard, made of metal, and tend to operate in a deliberate and sharp manner. As humanity begins to encounter robots in our everyday lives, we will need our robots to interact with us in a human way, with a human touch.

Over the next few years, we will begin to see robots soften, using materials that closely resemble the human body. A movement is already underway to leverage soft robotics in products such as the Soft Robotics Gripper. Taking this a step further, some R&D departments are experimenting with electro active polymers, such as a dielectric elastomer, that change shapes when a current is applied. We will see applications of this in multiple industries. For example, we will want our vehicles to be equipped with soft robotics to support us and help us perform functions in transportation; in the work place, soft robotics can enhance our strength and precision for creative and thoughtful actions where human empathy, emotion, and life experiences are important to the outcome; in medicine, soft robotics may not only help us treat patients, but

may also find a home inside the body as well. The soft robotics revolution will be gradual but vast. As robots and robotics become increasingly pliable, they will fold into our everyday lives in interesting and vital ways.

Physical-Digital Integration

Mobile devices have been slowly connecting technology with our daily life. In that time no one without a smart phone giving us access to practically infinite information in the real world. The people already know about site-to-pursing things and pick up product in a physical retail location. But the next level will be integration between physical and digital realities. The physical brands Walmart will start having more digital feature, like store maps and product trials. Online brand Amazon will start more physical product, like Dash Button.

Socio-cultural trend

Craft Kits

Colouring Books and Patterns.

Blended colour

These have been popular lately and I don't see them stopping anytime soon. Colouring books for adults are on the rise and I think we will start seeing more things with a colouring theme, such as colorable fabric

Future of mobility

"In the future, people and organizations will want personal mobility (not necessarily cars or trucks) to travel from A to B, as journeys will become integrated with intelligent and smart technologies, enabled by a single ticket or membership to provide seamless travel on multi-model transport systems with the car becoming an integral part of a wider transport network." –Quoted

Personalized services

As every person is unique, a shift from a standard range of services towards a personalized service offer in housing, wellbeing, education, and healthcare. This shift to personalization demands increasing flexibility in the offered services, and other forms of interaction with civilians and another competence profile for civil servants.

Economic Trends

Companies will focus on connecting customers
The connection economy rewards value created by building relationships and creating connections, rather than building assets by industrialism. This means the most valuable companies will connect buyer to seller, or consumer to content. If you don't buy that argument, consider these facts: Uber is the largest "Taxi Company" yet doesn't own any cars.

A7, generating search areas

To create various potential search areas for further investigation, one creative session is held together with the expert from LIX PEN. The creative session is based on the foregoing qualities and opportunities. The qualities are results from strategic analyses of LIX PEN. The opportunities are distilled from the trend analysis.

After setting up the qualities and opportunities in one grid, each block indicates combination of

one quality and one opportunity. The highlighted blocks correspond to meaningful and interesting search areas.

In total, 25 search areas are created. In order to make it easier to evaluate search areas in one graph, each opportunity is named from 2 to 9 while quality is named from B to G

	precision B	high quality C	low noise D	smoothness of drawing E	proper size F	professional appearance G
the rise of soft robotics 2						
physical - digital integration 3						
rising disposable income 4						
craft kits 5						
colouring books and patterns, blended colour 6						
portability - future of mobility 7						
personalized services 8						
connecting customers 9						

figure 3
Generating search areas

Evaluation of search areas

Straightforward, search areas are evaluated based on the newness and promise of market size. The figure beside shows the evaluation of 25 search areas. Highlighted parts are the selected search areas which either are new or promise well in the market. Through the reorganization of selected search areas which combines the overlap, five search areas are generated in the end.

1. Craft kits with proper size, ensure the portability and ergonomics
2. High quality components which allow users to DIY
3. Soft robotics to improve the controllability
4. Physical - digital integration to improve the controllability
5. Additional functions with high quality.

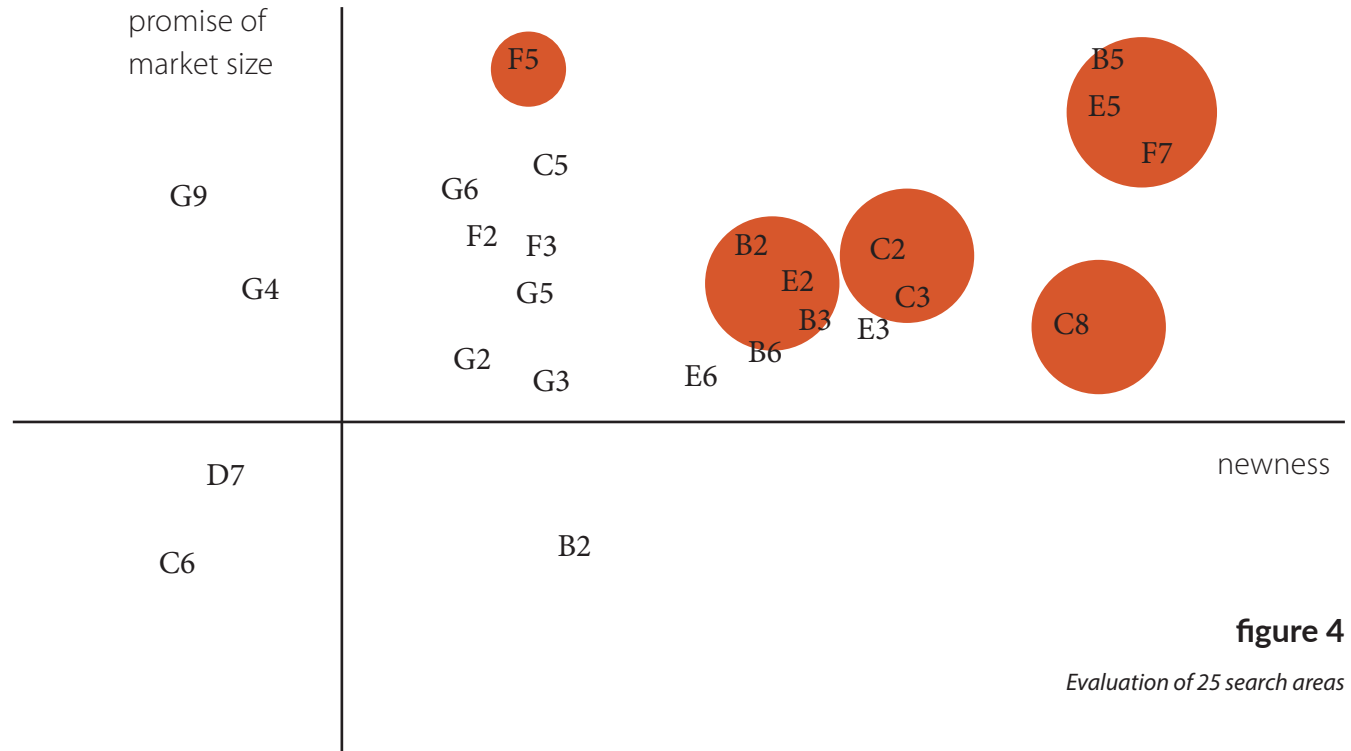


figure 4
Evaluation of 25 search areas

A8, evaluation of five search areas

Foregoing search areas represent the interest of LIX PEN towards future investigation. Following, these five search areas are further evaluated by target users, which narrow the range of further investigation accordingly. Through a questionnaire, 38 participants are required to rate search areas based on attractiveness and newness.

As a relatively novel and unfamiliar product, the opinion of 3D pen will dramatically influenced by If having experienced of 3D pen before. Therefore, participants are divided into experienced participants who have the experience of 3D pen and non-experience participants who do not have the experience.

Non-experience participants need to rate five search areas from 1 to 5 based on the attractiveness. Correspondingly, experienced participants need to rate five search areas based on not only the newness but also the attractiveness. Reasons behind the evaluation will be asked to understand participants' expectation.

Beside is the questionnaire for non-experience participants. Participants are required to experience current LIX pen for around 10 minutes. Then they need to rate the five search areas, which act as possible improvement, based on the attractiveness for them.

figure 5

Questionnaire for non-experience participants

Name: _____	Participant No. _____
Occupation: _____	Experience: no _____
Age: _____	

Handy 3D tool is the handy product with the **same nozzle and materials** as 3D printer. The materials are **released through nozzle** which enables users to **directly create 3D solid in the air.**

Here is current handy 3D tool. Could you experience it? (10mins)

Attractiveness	1				5
Portable and ergonomic craft kits with various tools.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Personalised tool with high quality	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Improved ability of using with soft robotics	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Improved ability of using with physical - digital integration	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Additional functions with high quality	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

contact info: _____

Below is the statistic for the rating of 32 non-experience participants. Portable craft kits (3.67) and high quality assistive functions (3.62) are two most attractive search areas for them, which are selected for further investigation. Furthermore, the motivations behind the selection are provided as well.

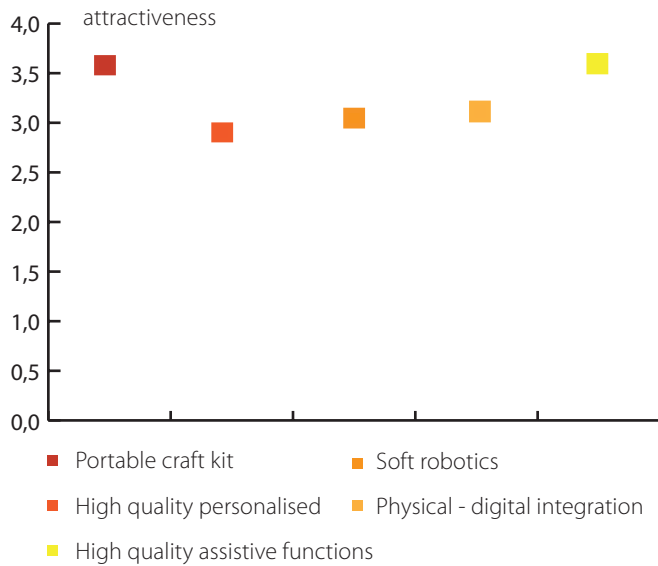


figure 6

Statistics of rating made by non - experience participants

Name: _____ Participant No. _____
 Occupation: _____ Experience: yes _____
 Age: _____

Which kind(s) of handy 3D tool have you used?

Attractiveness	1	2	3	4	5
Portable and ergonomic craft kits with various tools.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Personalised tool with high quality	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Improved ability of using with soft robotics	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Improved ability of using with physical - digital integration	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Additional functions with high quality	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Newness	1	2	3	4	5
Portable and ergonomic craft kits with various tools.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Personalised tool with high quality	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Improved ability of using with soft robotics	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Improved ability of using with physical - digital integration	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Additional functions with high quality	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

On the left is the questionnaire for experienced participants. Since they already have the experience of using 3D pen, they are directly asked to rate five search areas based on foregoing experience. Not only attractiveness but newness are rated by participants.

figure 7

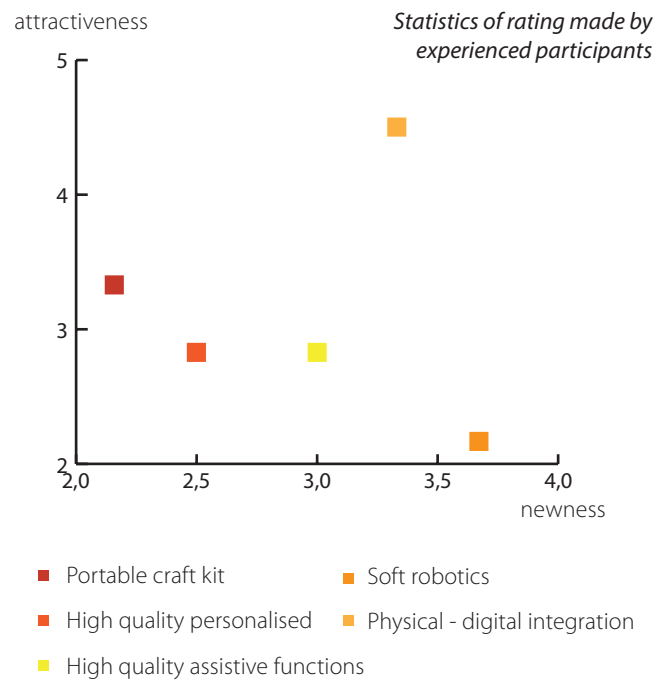
Questionnaire for experienced participants

As the result, physical-digital integration shows huge advantages overall in the average rate of newness and attractiveness for experienced participants. Therefore, physical - digital integration is selected as third search area.

1. Design a portable craft kits
2. Physical - digital integration to improve the controllability
3. Additional functions with high quality

As the conclusion, three search areas are selected accordingly which represent the common interest of both LIX PEN and customers.

figure 8



A9, the user tests and interviews about use-method and expected functions

Introduction

12 participants took part in the interview, which specifically aim at the expectations on use-method and expected functionalities. Instead of describing the tool as a 3D pen, the product is introduced as the tool of drawing in the air in order to eliminate the mislead of the word "pen". All the participants are required to physically illustrate expected form of drawing in the air. Then the use-method are explained.

figure 9

Set up of the user test

Set up



As shown in figure 9, the set-up of the user test includes one box of clay and one pen, which are used by participants to illustrate expected form, and current LIX pen, which is used to compare with their expectations.

Procedure

The user test starts with introducing 3D pen to participants. Participants are required to imagine the product that is used to draw in the air. Following, they are asked to illustrate the tool to draw in the air by the clay and pen for around 10 minutes. Meanwhile, they will demonstrate how to use the tool when illustrating. Afterwards, participants need to explain exact reasons for the form of the tool and provide three most important functions for the tool.

Then current LIX pen is provided for them to experience for around 10 minutes. The difference between their imaginations and current LIX pen is asked which reveals the gap in between.

Result

The figure below shows their expectations about use-method and expected functions. Moreover, participants are asked the reason thereof. On the right is the transcript of all the interviews.



figure 10

User test & interviews

Transcript of interviews

Joost

Illustration of the tool

“you can put it on your right finger to construct what you want, there might be a wire come from here or some. there could be some buttons on the bottom side, yes I think it will exactly like this shape if I can make things like this, press, turn on and off, it is the easier way of ... (means the button on the bottom)”

I think this use (means use with one finger) is nice to make shapes of thumb of fingers. yes, it is my instinctive way to create something. And I think you can be very precise when using one finger, can have high accuracy. Ive said the buttons, buttons on the bottom so you can press with your thumb maybe it is convenient cause other fingers.. (not convenient), it is just press it on and off, you can do it quickly when you are working

What do you think the important functions of the tool

I think the print speed is important, the material will come out continually right? if you want to draw something very precise, the material gets out slowly, and if you want to make something

quick, you will also want to let it get out very quick, different speeds of material ...

with 3D printer it is cool to have two materials you can switch, maybe it is nice if you can switch of here (means on the finger) very quick if you want one sprout bean or something you can make it quick with it. The key is quick switch. I think nozzle size can be very important as well,

its a nice box. this is bigger than I thought it, it is mainly longer, I saw a video of it.

during the heating: haha the material is already coming out (take them out with hands)

my expectation is faster

I think use the finger is more natural and more accurate, because of the weight it could move around your hand, maybe it could be a smaller pen or a lighter pen and it would help.

Wang Tianzi

I think something like, you can grab it. you know the most thing with grab by hand is pen. it should contain the materials inside, it should be like this. I think it is very comfortable you draw and directions (with this). I think like this, that should a tube inside, there is material when I was painting, I can draw in the most comfortable position with this from different dimensions. It is not like a pen that I am only with drawing on the paper, but not comfortable at other directions. Also I think i need to use the power of whole hand, it is more equal from different dimensions. So I think the round shape is the best. Just pump it to release. it is soft.

3D printer i guess you can choose the amount, thickness of the material. Thats be great if it is not only the line but also something like bubbles. maybe there are different types of the nozzle. when I am creating something, I really want to do something really thin or thick but I dont want to change, but I just want to realise it by controlling my hand (power), if I push really hard it could be thick. Also the 3D solid is not only about line, there are also some other things. it is not only like 3D printing, it could be different from 3D

printing, because 3D printing is a lot of small icons cumulative, then create the shape.

Ruben

I think it should look like a pen somehow, I just think it will be something like a marker, that is what I expect, so it would be my pen. oh and a nozzle, it would be like this you know, just like any marker. I think maybe you can make it more ergonomic for I think it should look like a pen somehow, I just think it will be something like a marker, that is what I expect, so it would be my pen. oh and a nozzle, it would be like this you know, just like any marker. I think maybe you can make it more ergonomic for hand, it would be exactly like the markers. I have seen the video that you are drawing in the air, thats something you immediately 3D print something.

you use it like a pen in the air, but you have to start from the bottom, but the material has to (be supported). it would be useful to have a button on the top (index finger), so I grip a pen, there is a tube in the back or something, you just hold it to any position you want, you press the button, and it

automatically comes out material, and you move slowly the direction you want, and then somehow liquid material comes out.

in general a round nozzle, you just use to make sticks, and maybe a really, you want something very wide to be able to make the surface. I think the support of the material is difficult, your material comes out from the pen, where does it stay. But I think it is also possible that you draw flat on the table and put it on the right place

it would be nice, it is more about material comes out, but if you can melt two pieces that you have ... pieces solid already, and you can add you one, and you can weld it on top of something. it would be nice something, if you design something, it will not be most helpful, easiest. It is easier to design something in software and make something with this. and if you record something with it, it will be helpful.

Maybe you can make a holo material, then you would make sort of tubes, nozzles as well, so it is different outputs form the tool.

Vans

Like I'm printing this kind of thing, i was thinking maybe it can be serving different functions, maybe it could be two different materials, selections, and also this one (the one on the thumb) is the base, maybe i can change the width or thickness by different distance among fingers, also i can switch a different material, maybe different functions with different fingers, three fingers is just like demonstration, you can just use single material (with two) or two materials (add one more).

It like small cover on the finger. I am thinking there will be always one comes from the found, it has to work with at least two, but this one (one not the thumb) is serving as the foundation, these two like the additional functions, maybe from different materials or colours from same material. I am thinking that these two will be the nozzles, and there will be like a small additional part with material cable, as the container of material. and the reason why i use these three fingers because these three fingers are more flexible and more adaptable, using fingers are more convenient and comparing with other two fingers, these three fingers are more flexible. the releasing maybe like a tattoo gun

or something like this, maybe you have the joint on the finger, maybe the trigger is like here (means the joint of finger), and once you bend your finger, it will like heat up the cables. this part is like glue gun.

Maybe different materials including colours, maybe like i can change the width and thickness of materials. and i need the quick switch of materials. I think I just use two different materials with nozzles. I think maybe sometimes you have to demonstrate purposes for different parts, such as distinguish different parts, highlight something or just for decoration for visual appealing.

Zhang lei

I want to make a kind of finger glove. Because it is natural to draw with you finger right? so if i start with the line, id like to use the finger to do that, cause it is more agile and accurate. when you have the structure here, i just want to close the surface, it must be covered over all, so I would like to just easily attach the face of the structure. it is more in

the VR version.

now you draw the line with same width, for me, for example, I'm gonna to use another finger, if i press or squeeze this glove, it has something goes out. if i press it harder, the line goes wider and darker, instead of drawing a consistent line, it can have shades and some other stuff. I think it is quite intuitive to use two fingers, cause it is quite natural way to draw. for the material, I don't really mind the material goes this way (means go along side the hand) and attached on my hand, maybe it is going to be a glove, so normally when i want to draw, i don't move this part a lot (means back of the hand), so it(container) can stay here, for example some people prefer to use middle finger, but i would like to use index finger, if i can choose colour, i will easily detach this one and use another one. for example it is ink box. I don't know exactly what the material is, but i can imagine if there is there is a base material without colour, then you mix it with colour module, then you can use the single liquid to make different colours, to make different colours with different modules. for example this is the basic liquid you use for drawing, and you have

a colour module, so if i want to draw, like white colour you can just use basic module, if you want to draw blue, you can just attach one, if it is liquid, it can be easily merge colours, such as put the red, then you get purple.

How do you activate it?

it can detect my pressure with pressure sensor, when you remove the thumb it automatically stop, it doesn't have to be soft material, for example when you use the wacom. or you can use the colour light here as indication let people know how thick it is.

when talking about functions?

for creating i would always use pencil instead of the pen so I would like to refine. i want to use this tool there should be a reason for that, so just like VR what is the difference between drawing something in 3D and model in software. model can not be manually twist but this one should be... If I am a user, the main benefit for me is I can first build it in 3D then I can scan it and turn it into software, thats the main benefit i can imagine.

I would like to, lets talking about turning into digital,

id like it to record my tracking. then i can move, though i don't think it is very difficult, your iPhone can do that. when i finish it i get one product here, then i put this data to computer to and i can use another printer to print it. imagine you can draw a basic shape by your hand and then put it into computer and print hundreds of it, and then you build on that, keep validating the shape, then i will definitely buy it. the benefit of digital things is you can easily duplicate.

If the pen can do what I mentioned before i will definitely buy it. to be honest, the first time i tried it, it doesn't go well. I would say about price, for example i would like to spend around 200 euros on wacom template which i dont use much. i think i would pay even 50 more on this. Now i see it more like a professional tool, which means it should be paid by my company, actually i dont really want to discuss about price. But if they can give me this as one of working instruments, I can be more motivated. it is easier to quickly express ideas and easily communicate with others, if im the student of industrial design, for example, you have kind of draft model in your computer, you dont really like somebody to modify the model. you draw in that way can not be presented as final result but ...

I am thinking if you can turn my drawing tracks into digital file, then you can open a large amount of possibilities of communication. Firstly i draw it, it is already a comunication, as i remember these two pens could work together right? then we add one like corporation drawing.

Omar

I was thinking it is something you can press (on the top) and instantly get feedback, like abstracting the plastic and how best to do that. this hand hold is best that you can have a lot of movements. and I was doubting is it suitable that you can hold like this, have a button of switch here (means on the body of the pen), so you can do this. but i think it is less ergonomic than this (the first description).

With first holding you can move with more feeling and still operate it. Indeed, no the speed but opening of the nozzle is important, how many materials come out. it depends on materials itself and also the size of nozzle. But i think the more important thing is that ergonomics or feel like natural. holding something or creating something. it is difficult cause I relate it to a pen or something

but it is exactly not a pen, but maybe it is but then a 3D pen. I think it is feeling natural to write or make something in 2D a pen more natural so it is also be like this in 3D. because you can accessibly draw in 2D and what if you can do that in 3D. This (holding like a pen) is also a good position, now I am doubting. maybe it is a even a better way of using it. yes i think it is even better than the holding before. Holding like a pen is more (comfortable). That (first holding) was my initial way of using the tool because it combines the useful and use friendly of being functional of taking out the plastic.

So if you have to activate the plastic yourself and moving then it is extracted automatically, it is more natural to use this way. it is like the cream or cake decoration. cake decoration is a good example, 3D printing is already complicated cake decoration.

I think the mobility will give more possibilities. Then you can have any movement you want. I think wireless is important. More and more then it is being able to print the 3D stuff in the air, i guess its the most important thing but it is not a really function.

Mark

how wide the filament comes out? just a standard not that wide?

make it a little bit longer, then it should be like the grip, and it could be activate button, maybe you need some more buttons, I would like something, i think like this what I can draw, maybe also hold it in different ways. I think you need two buttons, maybe this (the button on the side) could be two separate buttons, I dont know how many do you need, but one to release the filament, and one is just on and off button, in general, I would suppose something like this, and I thought the shape would be something you have multiple options to hold it depending on how large you want to get or how much precision grip you need, so thats the first thing that come to mind, you just hold it. I would suppose there is some sort of extensions, there will be somewhere here in the back I guess for power and for the filament, maybe two cables, and the button on the side will be power switch, and maybe there is a nice light next to it, when you turn it off, it just likes this, this light maybe on the top, which turns green, so you know that is activated, indication light.

Not too large object, I can exactly remember something like this or lets see, like a remote

controller that something you would want to create quick prototype and in that case, and in that case, I would think you need more than just create the wire, line, I don't know would it be possible to quickly fill volume, otherwise you have to go for very long time to create the volume, but not too large object because I think it will take too much time anyway. Maybe for architecture purpose you could do some lines to quickly 3D sketch a building. For this kind of ergonomic shape hand held devices, it really nice to have that volume. So thats two things I can quickly say the architectural quick mock-ups and more industrial design hand hold product.

Maybe i could be nice to make a wire frame model, such as a car, in the automatic thing you need to use the clay, but now you can make a wire frame model, maybe quick overlay it with other types of material of surface to get feeling of the surfacing and volume, you would get different combinations. it would be then the wire frame, you can quickly build like volume and overlay with some kind of texture layer, texture kind of surface which show at least kind of volume and surface that you are creating.

You Jiani

I think you can use the tool in different situations with different needs. Such as I need draw the line and I can also draw the surface, and probably it needs different gestures, which all the gesture should be very comfortable. also i want to make the container on my wrist instead on the hand. I think it will be a little bit weigh to hold it. I want it is very light when I am using it which I can free my hand. It it better if it is as light as the pen which I can draw all kinds of shape. the switch is better on the head, which i can stop and start whenever i want.

Zhang Chi

Illustration of the tool

Using hands is the most convenient. There are three ways of using the tool. holding like this (first holding) is like the cake decoration, I think the switch should be around here (around the little finger) which is suitable for three gestures. in this gesture, i can use little finger to squeeze it. i think this gesture is more convenient when using vertically. Actually it

Illustration of the tool

Using hands is the most convenient. There are three ways of using the tool. holding like this

(first holding) is like the cake decoration, I think the switch should be around here (around the little finger) which is suitable for three gestures. in this gesture, i can use little finger to squeeze it. i think this gesture is more convenient when using vertically. Actually it has multiple operations. It will not influence other gestures. another gesture is same as holding a pen, cause normally people write with the pen everyday, I think it is most familiar to everyone. people are skilful of holding the pen and you dont need to practice a lot. another way is best for using in the space. the switch is suitable and convenient for three gestures. The tool should be used whenever you need by just pressing. the tool is more for the rough prototype, how to improve the precision such as how to make a real straight line. you can have something like a projection here, you can see the ruler or scale or lines which you can follow with.

Some of assistive functions. But you can not use such as rulers in the air, you need some reference, it could be a laser light to indicate. and if you want to make it more precise, you can fix the tool on the 3D printer. I think if you want to make a super precise thing, such as the material or the thickness is different from 3D printer. Then it is more precise with the 3D printer. Also I think you need to refine.

such as you draw something in the air, but how to trim or add something on. What I can imaging is a scissor. I think probably you can continually use the waste material.

Xie hao

So here should be a nozzle, and if it is create by hand, it should pump out something, easy to use for hands. it will be something like this, you are drawing in the air. there should be a button here (somewhere next to the thumb), on this side as well, maybe only the thumb, use the button with thumb to release the material, and there is another button here (near index finger) to control other things, like different materials maybe, there will be two materials in one art piece, you can make a switch button here (near index finger), you can switch another material, so even multi materials you can control by your other four fingers.

maybe you can change to other materials. maybe some physical parts you can refine the structure, because accidentally you put too much material in starting point, there is a knife or something, you can just erase it. Just remove it. maybe something can help you to draw straight lines, the shift function

for your drawing, you can draw straight lines, or 45 degree, such as you want to draw a straight line from here to here, if you do it by hands you will... (shake) curly, it can help you to draw a really straight line,

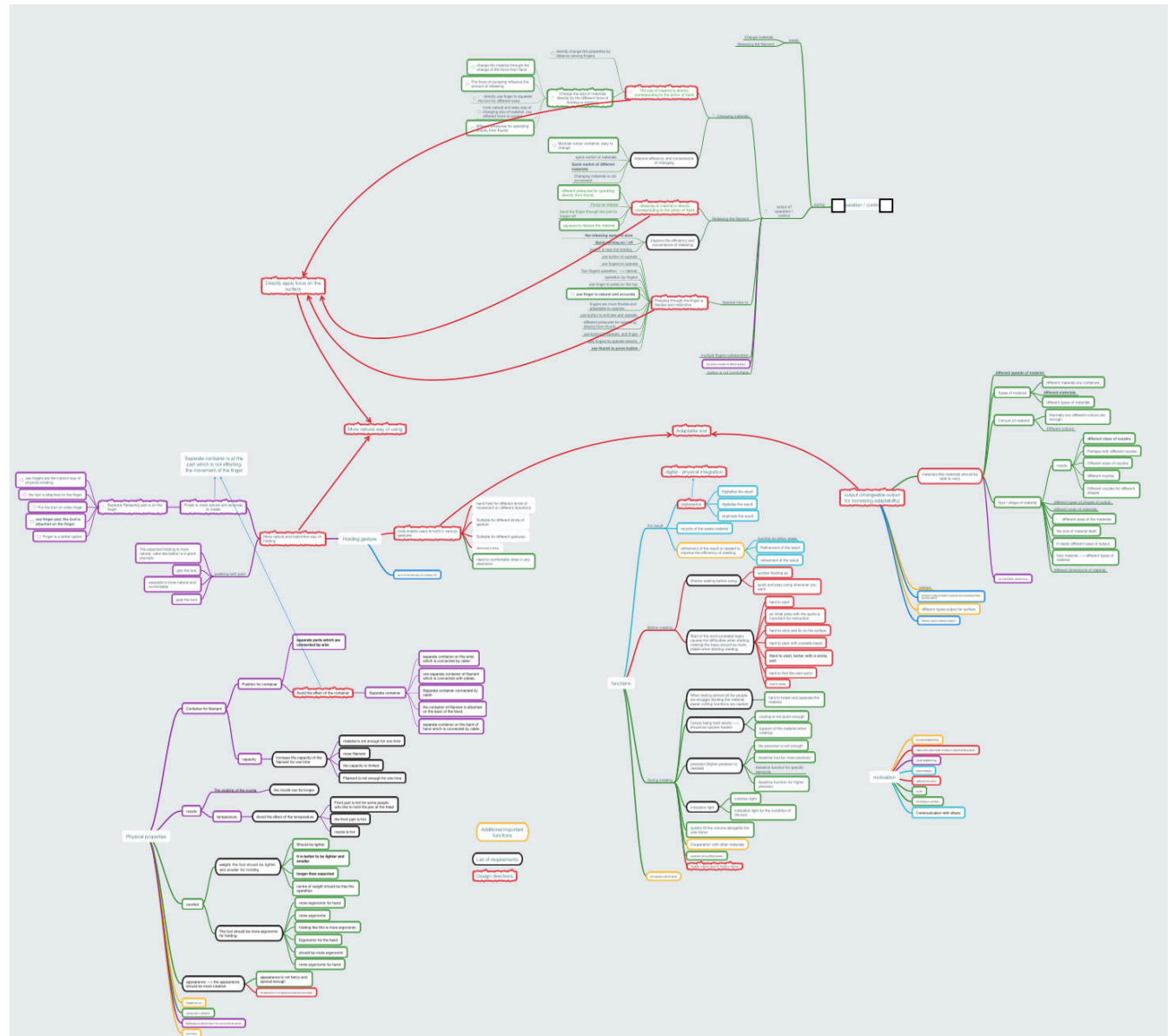
Analysis

Based on foregoing result, two approaches of analysis are made. The first analysis is made according to the form that participants create, another is for the expected functions. As shown in the figure, ten participants describe the product in a totally different way from current 3D pen, which indicates a gap in between. When explaining the reasons behind, comfortability when interacting with the product and precision of drawing are most frequently mentioned.

Moreover, participants are required to provide at least three functions that they need. All the function-related transcripts are reorganized and categorized. The process is shown in figure X. Accordingly, Different properties of the output in order to use the product among different situations are extremely needed by participants, which are reformulated into adaptability of the product.

Conclusion

As the conclusion, according to the user test, **comfortability** when holding and operating, **precision** when creating and the **adaptability** for various situations are three main expectations from bottom- up view.



A10, statements formulation

In order to reduce the broadness and ambiguity, four fundamental goals are decomposed with hierarchical trees. Each goal is divided into various statements. As the result, a series means-end chains, which indicate the relations among various statements, are presented. For either one single statement or the combination of several statements, further analysis is made.

Comfortability

The degree of comfortability highly influences the experience when using the product, which is a significant aspect to be considered.

In hand tools comfort is mainly determined by functionality and the physical interaction between the user and the product.. Since the strong internal connection between comfort and discomfort, they are regarded as one general concept instead of opposite constructs. According to L.F.M.Kuijt-Evers et al, descriptors of comfort/discomfort in using hand tools were collected from literature and interviews. Through one statistical analysis, forty descriptors were extracted and mainly distinguished in 6 comfort factors: 1.

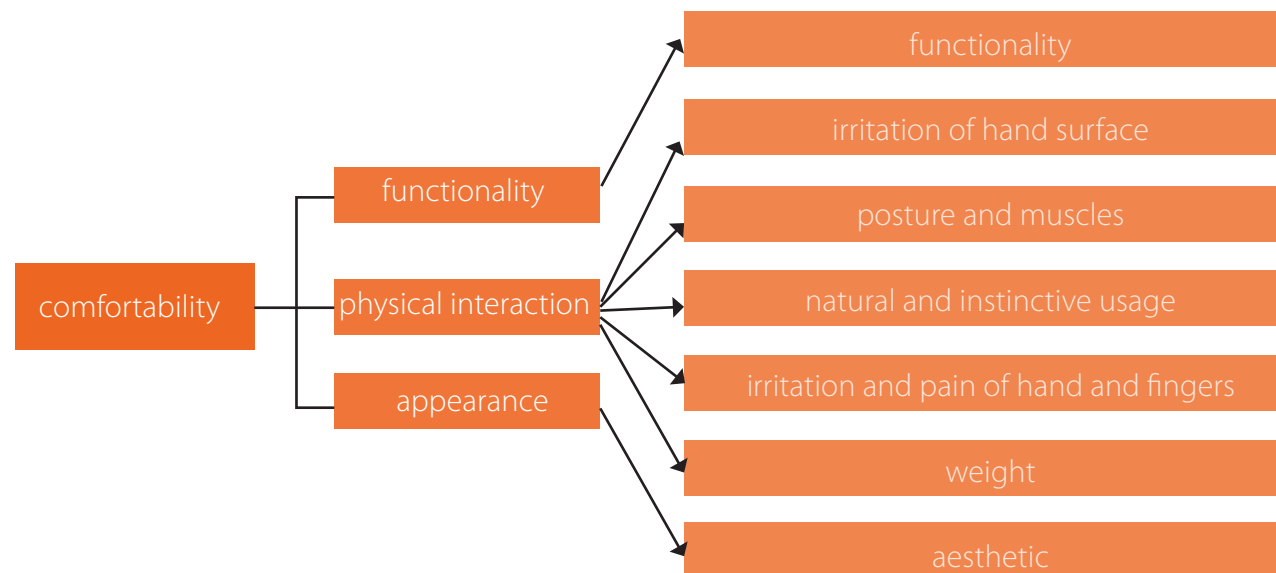
functionality, 2. posture and muscles, 3. irritation and pain of hand and fingers, 4. irritation of hand surface, 5. handle characteristics and 6. aesthetics. These factors can be classified into three groups which are functionality (consisting of factor 1), physical interaction (consisting of factor 2- 5) and appearance (consisting of factor 6).

One special attention should be made that previously mentioned research was done specifically for power gripping such as screwdriver and pliers, which requires differently from gripping for precision purpose. Descriptors which

are related to handle will be further discussed unless the certain existence of handle. Instead, other factors are needed besides foregoing ones. According to the interviews from previous phases, an important factor, which is degree of natural and instinctive of usage, should also be included in the physical interaction group. Moreover, properties which are related to weight highly influence the comfortability of physical interaction, which is selected as another factor.

figure 12

Decomposition of comfortability



Following previous division, seven factors will be specifically explained and elaborated, which result in a series of statements. All the statements are based on either literature or user test.

Functionality

Reliable, reliable product requires the product keep workable in certain period

A1, the quality should ensure the continuous usage for certain period

Functional, the function of the product should be consistent with users' requirements.

A2, the solidification of the outcome should be quicker

A3, the conveying speed should be quicker

Task performance, task performance refers to product's primary operating characteristics.

A4, The performance should meet the expectation, it should meet the expectation that users mostly want.

Easy in use, the product should ensure the ease both on handling and operating

A5, the product should be held as easily as possible

A6, the product should be operated as easily as possible

Safe, the product should ensure the safety when using the product.

A7, since the temperature around heating area should be around 200 degree, the harm caused by temperature should be avoided

High product quality, the quality of the product should be assured

A8, the quality of the product should ensure the single performance

A9, the quality of the product should ensure certain length of product's life

Easy to take along, the product should be easily take to different working places

A10, the product should be compact that is easy to be taken

A11, the size of the product should be as small as possible

Physical interaction

Irritation of hand surface, no irritation of hand surface is caused by product

A12, No pain, it should be cause the pain on the surface of hand, special protection is needed.

A13, No peak pressure on hand

A14, No inflamed skin

A15, Less friction between hand and handle

A16, Handle does not feel clammy

Posture and muscles, the product should ensure the comfort of posture and muscle while decrease the discomfort at the same time.

A17, Relaxed working posture, during the usage of the product, the posture should keep relative relaxing in specific time period

A18, Low handgrip force supply, the product can no require high gripping force which cause the tiredness and ineffectiveness.

A19, No numbness in fingers, fingers should nor feel numbness during the usage.

A20, No muscle cramp, the postures can not cause the muscle cramp.

A21, No sore muscles, the product should not make muscles feel sore.

A22, Handle hardness, the hardness should be considered to enhance the comfortability. It could not be too hard.

A23, Handle does not feel clammy

Natural and instinctive usage, the holding and operation should be as natural and instinctive as possible

A24, The posture of holding should comply with the instinct of users

A25, The operation and activating of the tool should be as natural and instinctive as possible.

Appearance

Irritation and pain of hand and fingers, no irritation and pain caused by product

aesthetics, aesthetics of the product is less important comparing to other factors, however it influences the comfortability as well.

A26, No lack of tactile feeling

A27, No pain, the handle and operation of product should not cause the pain on the hand.

A28, Professional looks, the outer appearance of the product should be professional

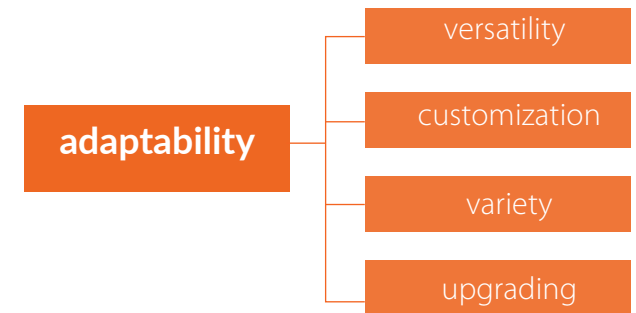
A29, Solid design, the appearance should be as solid as possible

Adaptability

Adaptability refers to the ability of a product to be adapted to various usages or capabilities. It involves four main factors which are versatility, customization, variety and upgrading.

Versatility is adaptation from one function to another does not require significant alteration of a product. Customization allows users to adjust the product to their preference. These two factors are more important from the usage of the product.

Refer to current design tools and activities, various assistive functions are potential to be added on the product, which requires the upgradable of the product in the future. As one branch that belongs to one series of products, same design elements should be kept among different products, which allows various products share same components to decrease the cost. Besides is the objective tree of adaptability.



versatility

outcomes, in different situations the needs vary, which lead to different kinds of outcomes.

B1, Users should be able to create versatile outcomes according to different situations

figure 13

Decomposition of adaptability

customization

colours, in different situations the needs vary, which lead to different kinds of colours

ergonomics, product should allow the adjustment of dimensions for ergonomics purpose.

variety, variety refers to the suitability for various series or branches

upgrading, the product should be possible to be upgraded

B2, In different conditions users should be able to change different colours

B3, Different colours, users should able to select the colour that they preferred

B4, Due to the various sizes of human hands, users should be able to adjust the suitable dimensions.

B5, The appearance should be unified in same standard and style as other branches

B6, The inner components are preferred to be designed into same dimension and specifications

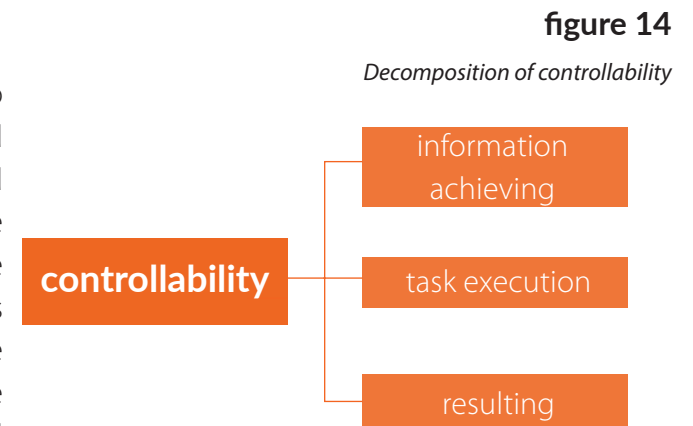
B7, The product is preferred to be designed which is able to match some potential assistive tools

Controllability

A professional tool requires complex actions in order to control the product, which demands specific considerations on controllability of the product. It refers to the ability for users to operate and interact with product. Previous research revealed users' strong expectation on enhancing the controllability of the product.

Within the design of hand tool, three controllable factors are information achieving, task execution

and resulting. These factors are corresponding to three period when using the product. Users should gain enough information to decide what and how to do with product. Then specific experience during the execution of tasks will highly influence degree of controllability. Furthermore, if results fit the expectation will subjectively influence the judgement of controllability. According three factors, a series of statements will be generated accordingly.



Information achieving

reachability, in order to allow users achieve the information, all the information should be reachable

understandability, after reaching the information, the information should be understandable

completeness, after reaching the information, the information should be understandable

C1, All the indications and information should be easily noticed

C2, The indications and information should be simple enough which allow users easily understand and remember.

C3, The meaning of the indication should be easily remembered, which leads to the simplicity of indications.

C4, The information should be enough and complete for users to understand.

Task execution

accuracy & precision, the product should ensure the precision of the usage

smoothness, the whole process of usage should be smooth

efficiency, the efficiency of the operation should be efficient.

C5, The form of the product should allow the users to precisely control

C6, The smoothness between different steps should be assured

C7, The exact actions among one step should be smooth

C8, The switch of different steps should be efficient

C9, The information should be easily understood

Resulting

matchability, the result should match the expectation

usability, the ability to utilise the result

C10, The scale should match the expectation

C11, The position of the result should match the expectation

C12, The result is preferred to be further used and reused.

Portability

Various workplaces demand the necessity of portability. It allows users take along the product with them wherever they are going to work. According to Bert Haskell (2015), the principal factors that shape the design of a portable electronic device are as follows: functionality, performance, user interface, form-factor, battery life, reliability, cost and time to market. The last two factors are less important in the conceptualisation of the product, while heavily influence the decision making in later phase. Thus, the cost and time to market will be discussed later on.

Meanwhile, these factors cover all the dimensions of the product, which overlap with fore-mentioned factors from previous chapters. In order to specifically focus on the portability, the functionality, performance and user interface are excluded from the discussion in this section.

As conclusion, form-factor, battery life and reliability are three main factors that mainly determine the portability of the product.

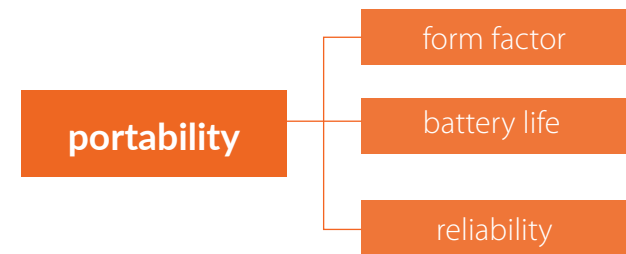


figure 15

Decomposition of portability

Form factor

carriability, the product should be carriable for users to take along

functionality, the functionality should not be affected

Battery life

continuity, the battery should ensure the continuity of the usage

Reliability

sturdiness, the product should be sturdy enough to be taken along

durability, the product should be durable that users are able to use it for longer period

D1, The form of the product should be compact to be easily carried

D2, Entire dimension should be as small as possible

D3, The functions should be cleared defined

D4, Functions should be simple and unified

D5, The battery should ensure the usage for certain period

D6, The battery should easily charged

D7, All the connections should not be loose

D8, All the components should be stiff enough

D9, The assembly of the product should be firm and well matched

D10, the product should be durable that needs fewer replacement

A11, the motivation of using 3D pen

Introduction

3D printing pen is designed as the instant 3D printing tool, which enable users directly create three dimensional object. In order to clarify specific definition of three-dimensional object in certain context, 12 designers are required to list three strongest motivations to use the product after finish experiencing current LIX pen.

Procedure

Participants are invited to experience the current LIX pen until they are familiar with it. Afterwards, current routine are roughly described especially the activities that related to design. Based on all the activities, all the participants are required to list three motivations of using the 3D pen. Furthermore, participants are asked to further describe the targets of each motivation.

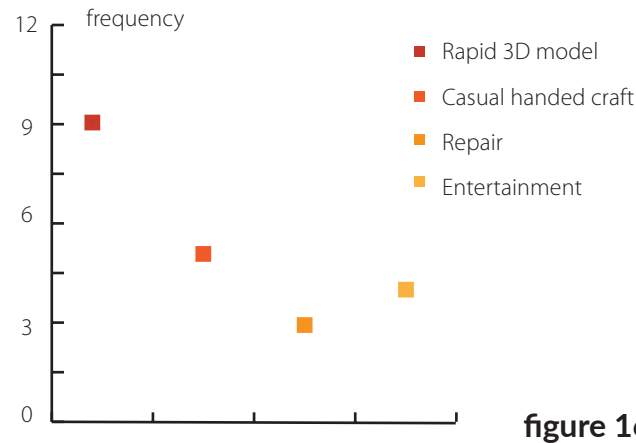


figure 16
Statistics of the motivations of using 3D pen

Result

Through organising the transcripts from the user test, the motivations are categorized based on the frequency that be mentioned. The figure indicate the frequency of each motivation of using the 3D pen.

As shown above, for designers, creating rapid 3D model is the most frequently mentioned motivation to use 3D pen. Totally, nine designers show the interest to create rapid 3D model. Moreover,

participants regard rapid three-dimensional model as the media of immediate presentation and visualisation.

Conclusion

As the conclusion, rapid three-dimensional model for the sake of immediate presentation and visualisation is the most common motivation, which is selected as main motivation of the 3D pen.

A12, operationalization of statements

In order to eliminate abstraction and ambiguity of all the objectives, the operationalization process, which function as interpreting, clarifying and empirically specifying the meaning of goal-as-intended, is made.

The operationalization process starts with the reorganization and combination of foregoing statements. Some of the statements are intersected, which can be unified that result in the same requirements. Following titles stay the same order as previous statements.

A1, A8, D6, The continuous usage of one single time should not shorter than 10 minutes, while the longer the better is. The quality should ensure the continuous usage for certain period. Priorly, the 'certain period' should be defined first. Therefore, one research with 6 designers is made accordingly.

Procedure

Designers are invited to experience current LIX pen. They are allowed to freely use LIX pen until they are familiar with it. Following, participants are assigned



figure 17

User test of duration of using 3D pen

with one ideation task, which is basically related to the presentation and visualisation. During the task, they are asked to use LIX pen as much as possible. The task ends up when they want to quit. The whole duration from the beginning of the task will be recoded.

However, exact availability of each participant for the test dramatically influences the time that can be spent on the task. In order to reduce the influence that caused by thereof, participants are required to estimate the duration on using 3D pen in real situation based on the experience during the test in the end.

Result

The figure below shows the duration that spent on the task. Each spot on the left shows the exact duration that is spent during the test, while the one on the right represent the estimation.

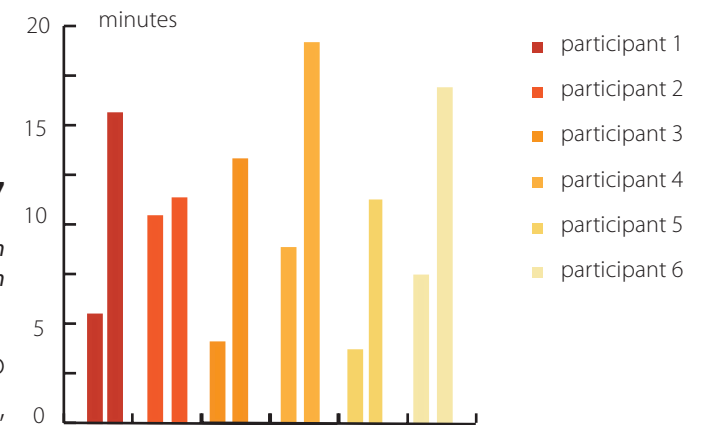


figure 18

Statistics of duration that spent on the task

The average exact duration that spent on the task is approximately 6 minutes 30 seconds, while the average of estimation is 12 minutes 40 seconds.

Analysis

Even though the difference exists among different participants, all the estimated durations are beyond 11 minutes while the longest is around 19 minutes. Positive correlations exist between exact duration that spent on the task and the estimation except participant 2. One assumption is that around 10 minutes is the time that users are willing to stop. All the estimated durations fluctuate at around 15 minutes.

Discussion

Only approximate duration are provided through the test. Exact duration probably differ in various real situations. The test only provides approximate estimation of the usage.

However, current situation that users need to refill the filament every 2 minutes is opposite to users' estimation. Therefore, the duration of continuous usage definitely need to be prolonged.

Furthermore, the waiting time in between two usages should be shorter

Conclusion

The continuous usage of one single time should not shorter than 10 minutes, while the longer the better is.

A2, C11, the solidification of new product is preferred shorter than 2 seconds.

The solidification of the outcome should be quicker. As one of the feedback from interviews, most of interviewees are not perfectly satisfied with the speed of solidification of the filament. Current solidification takes approximate 2 seconds until the harden of the filament. **Thus, the solidification of new product is preferred shorter than 2 seconds.**

A3, In order to fulfil different demands from various users, the conveying speed is preferred adjustable

The conveying speed is corresponding to the speed of motor and reducer of the product. According to foregoing research, users show discontentedness of conveying speed. The opinions include the speed is either too quick or too slow, which indicates that the conveying speed should be adjusted. In order to fulfil different demands from various users, the conveying speed is preferred adjustable, while the highest should be quicker than current situation (6000 rpm / s).

A5, the product is preferred to be able to attached on the hand.

To easiness of holding the product depends on the effort that is paid thereof. The most effortless way of holding is that the product is automatically attached on the hand, which needs no specific extra effort of holding. Thus, the product is preferred to be able to attached on the hand.

A6, making actions should be as effortless as possible

The easiness of operating product depends on the effort for making exact actions. When making actions on the product, it should be as effortless as possible.

A7, the temperature of contacting area between the product and users should be lower than 45 degree.

Since the temperature around heating area should be around 200 degree, the harm caused by temperature should be avoided. Based on the standard comes from NASA, the touch temperature should be lower than 45 degree for infinite touch (Eugene Ungar, Kenneth Stroud, 2010). Therefore, the temperature of contacting area between the product and users should be lower than 45 degree.

A8, the product life is preferred longer than 1 year, while the longer the better is.

There is no real definition on the product life of 3D pen yet. However, drawing tablet can act as a reference. For designers, drawing table is similar to 3D pen in

There is no real definition on the product life of 3D pen yet. However, drawing tablet can act as a reference. For designers, drawing table is similar to 3D pen in several aspects. First of all, they are all design tools especially for ideation period. Furthermore, they will be frequently used during that period. They are also used for fun besides professional usage.

The product life of drawing tablet is defined as the duration until the first replacement of the nib. Even though the duration differs according to different usage, normally users change the nib less than once a year according to the feedback online. Thus, the product life is preferred longer than 1 year, while the longer the better is.

A9, D1, the product should be compact that is easy to be taken

The compactness directly correlate with the easiness of taking along. Compactness requires all components to be closer and highly integrated. Moreover, if there are separate parts, they are preferred to be able to assembled

A10, D2, the size of the product should be as small as possible

The size of the product refers to the entire volume of all the components. The smaller the volume is, the easier to be taken along.

A11, soft protection should be added at the area that continuously contact with users

The product should not cause the pain on the surface of hand, special protection is needed. Soft protection such as rubber or foam should be used especially when there is hard material or sharp edge.

A12, A13, A14, A15, A16

The area that causes pressure on the hand should be soften which reduce the effect thereof. Moreover, the pressure that imposed on the hand should

be as less as possible, which reduce the friction in between. Contact areas should stay relative static with hand.

A17, A20, all the potential harm should be avoided. (scald, cut etc). Users should not consistently use large amount of the muscle

Relaxed working posture, during the usage of the product, the posture should keep relative relaxing in specific time period. The relaxation is divided into the mental relaxation and physical relaxation.

Mental relaxation means that users should be nervous or anxious when using the product. There should be no implicit danger that users worry about. Users should feel at ease of the product.

Moreover, there should be no discomfort that is caused by product. Users should not keep the muscle in tension when either holding or operating the product.

A18, A21 the smoothness of gripping area should make it easy for users to grip. Relative harsh surface is needed. The gripping diameter should be between 8 to 13 mm

Low handgrip force supply, the product can no require high gripping force which cause the tiredness and ineffectiveness. For the sake of precision gripping, the diameter of gripping area should be between 8 to 13 mm. The entire length of gripping should be longer than 100mm. Gripping force should be smaller than 100N. Moreover, total weight for gripping should be lighter than 1.75kg. If there are fast release that caused by hand, it should be activated by distal phalanges, which are the tip of the finger. (Martin G.Helander, 1943).

A19, No numbness in fingers, fingers should not feel numbness during the usage.

Current LIX pen is needed to be activated through pressing button by index finger. Through the feedback from research, users prefer to continuously press the button to better control the extrusion of filament. However, it causes the pain and numbness on the finger since the hardness and stiffness of the button.

Thus, if activation is still executed by finger, the

pressing should be easier and effortless. Moreover, other more relaxing way to activate the product should also be considered.

A24, C5, The product is handled by moving with joint of wrist in pinch grip.

Empirically, the target-reaching movement within human-size scale is primarily executed by four limbs of human beings, even though the rest of the body will also benefit the process. Due to the differences of the relative size of the areas in the cerebral motor cortex devoted to controlling the different muscle groups in the human body, different information processing capacity of various parts of the motor system exist.

As the homunculus model of the motor cortex illustrates, the muscles controlling the upper limb (hand, wrist, elbow) are heavily represented compared to the muscles responsible for the lower limb. Furthermore, the muscle controlling of shoulder is represented slightly smaller than the rest of the upper limb and roughly same as the trunk and hip, which match the experience that moving the whole upper limb by the joint of shoulder is less convenient or accurate. Therefore, the discussion of upper limb is narrowed into the joint of elbow, wrist and finger.

According to an investigation undertaken by Hammerton and Tickner to see whether there are any differences in the suitability of the different limb-segments, in the most difficult conditions, such as the target size is smaller than 3mm (Since the dimension of current filament in the market, the outcome of the product can be seen as the object within 3 mm, which determine the scope of precision), hand was superior to both forearm and thumb, which indicate higher suitability to the joint of wrist.

Furthermore, an experiment by Balakrishnan and Mackenzie indicate that the thumb and index finger working together in pinch grip have an information processing rate of about 4.5 bits/s, which performed better than the normal wrist movement. Therefore, the extrusion area is going to be mainly moved by the joint of wrist in pinch grip.



figure 19
Pinch grip

A25, The posture of holding should be palmar pinch grip. Moreover, if there are other components on the hand, the back of hand are the best option.

Introduction

As statement claimed, the posture of holding should comply with the instinct of users. As described before, pinch grip is the best options for precise reaching movement. Pinch grip refers to holding object through the fingers are on one side while the thumb on another. Basic on the description of human hand functions, there are three most common types of pinch gripping, which are tip pinch, lateral pinch and palmar pinch. Figure below shows the configurations of three different pinch grips.



tip grip

lateral grip

palmar grip

Specific pinch grip relate to different forms that to hold, which highly influence the design. Thus, in order to testify the most suitable and beneficial pinch grip especially in the precise reaching movement, an experiment was executed.

Furthermore, besides the part that to be gripped, several other components will probably stay around the hand as well, which definitely affects the experience of holding. Thus, additional parts will be attached on the hand as the simulation of other components.

Set up

Based on three pinch gripping, three simulated gripping parts are made. The thin stick, plate and cylinder represent tip pinch, lateral pinch and palmar pinch respectively. They are all made of aluminium because the aluminium is the current material for LIX pen. For each simulated gripping part, one five-millimetre long filament is stuck on, which simulates the head of filament extrusion.

figure 20

Demonstration of different pinch grip

One copper wire is randomly bent into a three dimensional free shape, which simulates the trajectory that guide spatial movement of participants' hand in the air.

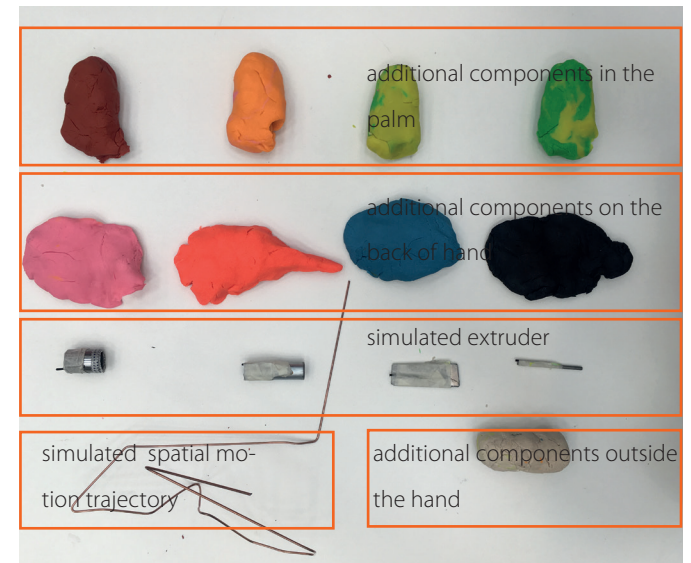
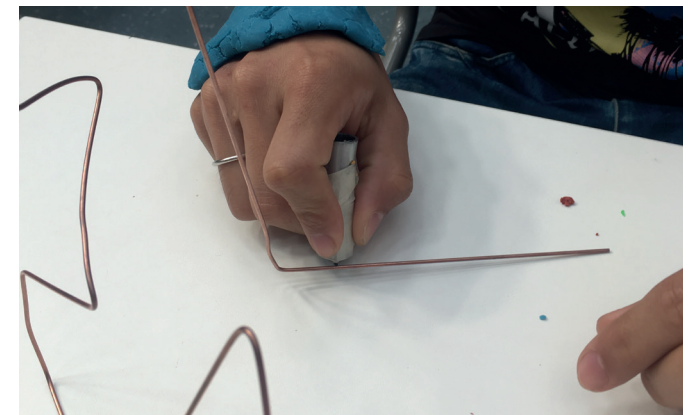


figure 21

Set-up of the experiment of gripping posture



Moreover, clays are used to simulate additional components that stay around the hand. several clays are moulded into three different forms. Since the profile of hand is not thick enough as the support of other components, the hand is considered as a supporting plate with two sides. Three relative positions can be concluded accordingly, which are the back side, the palm side and outside of hand. According to this division, clays are moulded into three forms. As shown in the figure 21, all the simulated parts are classified and demonstrated.

Procedure

Participants are required to grip one of the simulated gripping parts with specific pinch gripping, then to follow the trajectory as the action of spatial movement. In the beginning, all the participants will practise moving through the copper wire for several times until they are familiar with the movement, which avoid the effect caused by different degrees of skilled.

When following the trajectory, participants are asked to exactly touch the copper wire all the time, which ensure the trajectory of each trial is almost the

same. Furthermore, the spatial reaching movement simulates the process of spatial creation in the air, which means the trajectory does not really exist unless the filament is extruded at certain positions. Therefore, participants are only allowed to touch exact wire as long as the gripping parts reaches first.

Three simulated gripping parts and additional components will be combined in proper order, which results in nine combinations in total. The order for each participants is different in order to avoid the consequence that caused by the order of trial. Participants need to subjectively rate the experience of spatial movement after each trial based on the comfortability during the movement, the precision when following the trajectory and the smoothness of the movement especially when changing the direction at certain points. Afterwards, participants will give an overall rate for each experience, which shows comprehensive preference of the different combinations. The rating is scaled from one to seven, which corresponds to terrible to excellent. Beside is the questionnaire.

Gender
Age
Experience of drawing

no.

figure 22 Result

Questionnaire of the
experiment of gripping posture

Five participants are invited to the experiment. The figure below demonstrates results of the experiment. Each column corresponds to one combination of gesture.

smoothness - do you think this posture is smooth?

	not at all							very good						
	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7

comfort - do you think this posture is comfortable?

	not at all							very good						
	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7

precision - do you think this posture is precise?

	not at all							very good						
	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7

overall - overall rate

	not at all							very good						
	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7
○	1	2	3	4	5	6	7	1	2	3	4	5	6	7

gesture 1 - tip, palm gesture 3 - plamar palm
gesture 2 - lateral palm gesture 4 - tip, back

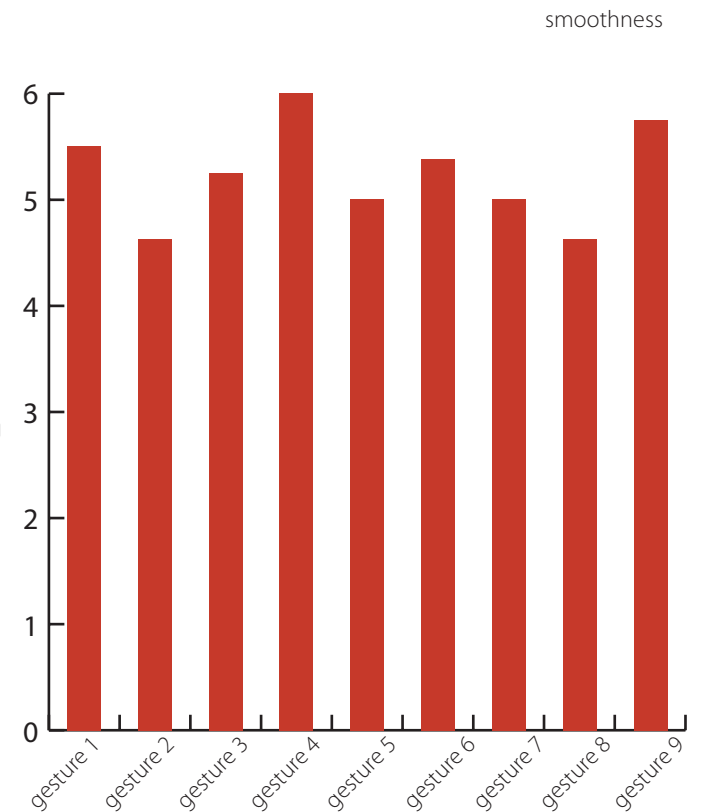


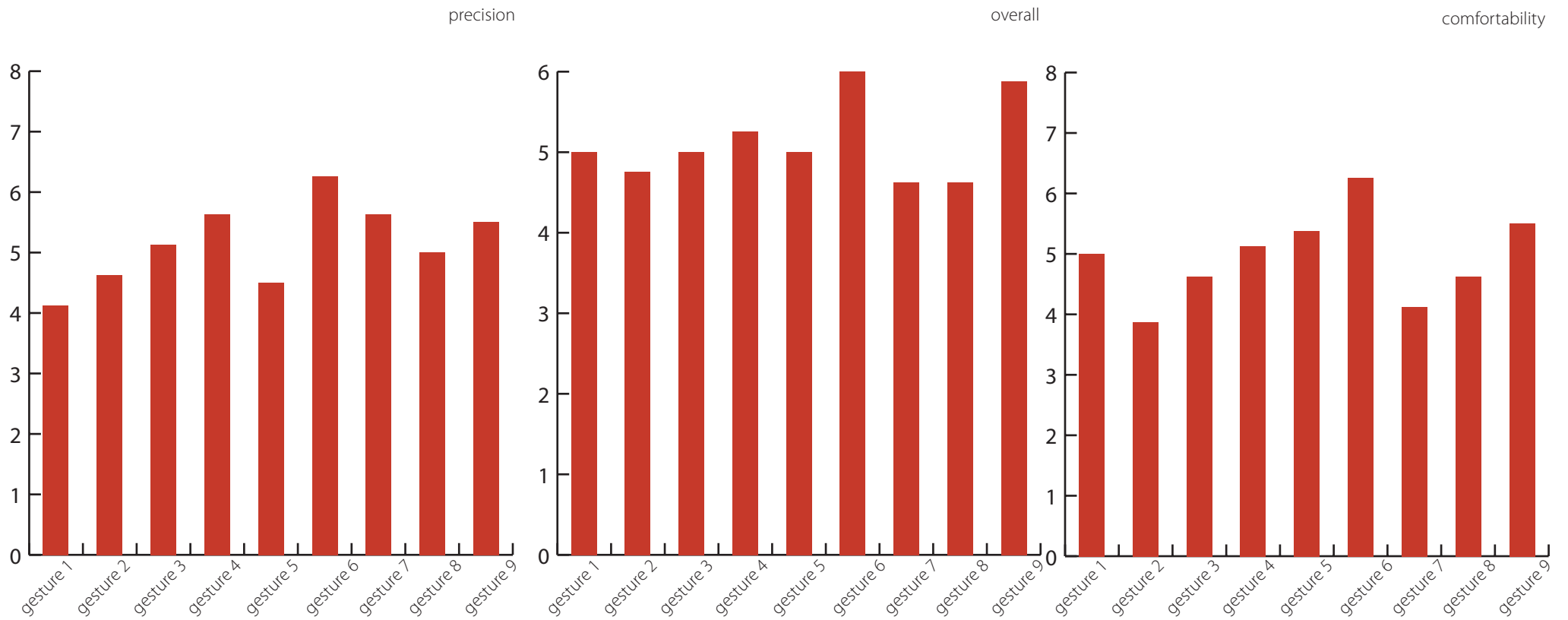
figure 23

*Results of the experiment
of gripping posture*

gesture 5 - lateral back
gesture 6 - plamar back

gesture 7 - tip, outside
gesture 8 - lateral outside

gesture 9 - plamar outside



Discussion

As the result, palmar pinch with additional components on the back of hand overwhelm other options in the precision, comfortability and the overall evaluation. In terms of smoothness, it stays on the fourth best among all the combinations, which is acceptable.

As comparison, the last combination, which palmar pinch with additional components outside the hand, gives a all-around performance. It stays on the second place except the precision.

Analysis

In comparison of these two combinations, either of them shows huge advantages. However, special attention should be paid on the gripping 9 is that, this combination is actually the way to hold the pen, which is extremely familiar to participants. As a factor that can not be ignored, participants are used to using this gripping. Nevertheless, the sixth gripping, which palmar pinch with additional components stays on the back, still performs better except the smoothness, which definitely shows larger potential.

Since this is a quantitative experiment, more participants will improve the accuracy and comprehensiveness of the result. Moreover, since participants need to evaluate nine different experiences, which probably cause the tiredness and chaos of comparing. The latter ratings were provided less carefully, which results in less accuracy. Due to the copper wire is just put on the table, as the consequence, this will slip a little when participant touching the wire, which causes inconvenience.

Conclusion

Based on the foregoing results and discussion, the palmar grip with the additional parts stay on the back of hand is selected as the using gesture.

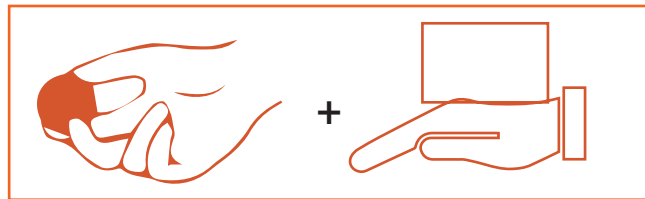


figure 24

Palmar grip with the additional parts stay on the back of hand

A28, A29 The appearance of the product should be professional for target users

Since the target of the product is the tool for designers as professional usage, the appearance of the product should be professional which match the users' expectations. Accordingly, user analysis is made first.

The target group is a mix of the designers that belong to different groups. The target group is mainly in search of a media described by "representing and visualizing ideas". Furthermore, it could be a casual entertainment that normal design tool can provide. For the people in the target group that are not familiar with 3D pen or 3D printing, it is all about the search of the same function they find with their regular modelling tools they use.

To attract also people that already user 3D printing related product, the ease and efficiency of use and mobility of the embodiment proposal should convince them to try a new type of 3D tool.

To give a better feeling about the target group, a persona about Erik Johansson is created. The persona sum up multiple personalities and



In order to analyse the factor that provide a professional look, 5 designers provide five examples that the product they think professional. Based on the appearance of these products, several key factors can be concluded accordingly. As for the form, the whole appearance should be simple without exaggerate contours. Furthermore, the shape should be symmetric. Surface finishing should be more matte.

B1, Users should be able to change the thickness / size of outcomes

Following creating line frame of the objects, users normally need to fill up the empty space that create surface of the object. Currently, users need to fill up the surface by repeating thin line, which requires a lot effort. For the smoothness and efficiency purpose, more convenient way to fill up surface is needed. It will be more convenient if the users could create wider line when scribbling surfaces. Refer to marker, which is another familiar tool for designers, wider outcome is effective when filling relative larger area.

B2, B3, functions of creation and manipulation of colours are needed for different situations

Besides sketch model, visual model is another type of three-dimensional model. It is described as the external characteristics of the product ideas, which illustrates the basic design elements of external appearance. Through interviews with various designers, they are willing to change the colour during the creation. The manipulation of the colour is beneficial on highlighting the primary part. Moreover, various colours could enrich the variety of the result.

B4, The distance between gripping point and the end of finger should range from 60mm to 75mm, while the angle stays around 67°. Users should be able to adjust dimensions according to exact needs.

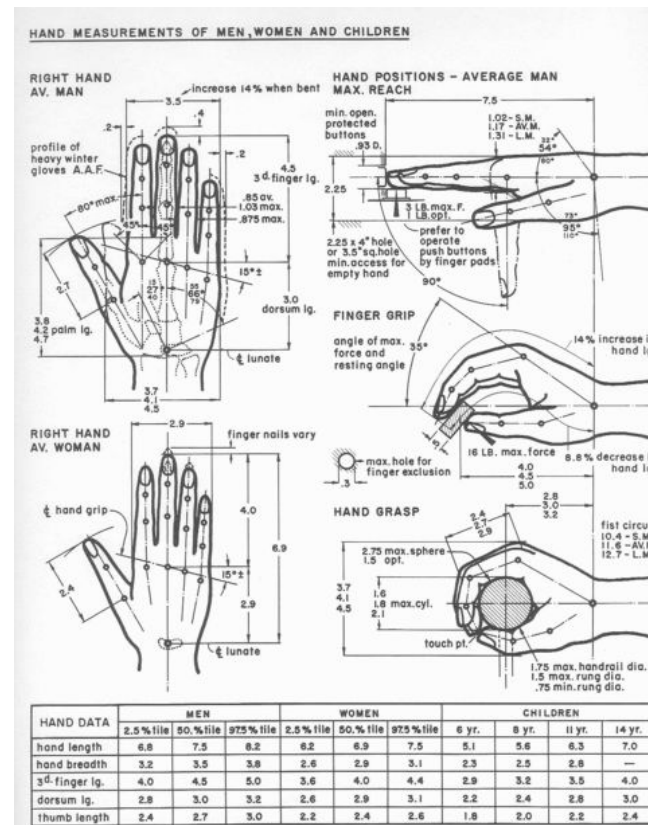
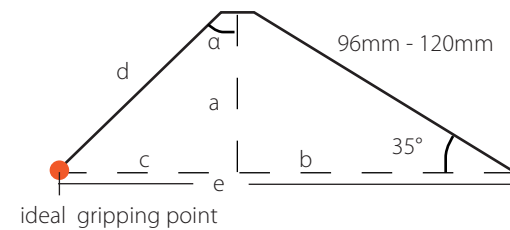


figure 24
Hand measurement of men, women and children

Due to the various sizes of human hands, users should be able to adjust the suitable dimensions. As shown in the figure X, the most resting angle that can afford maximum force is 35 degree. The distance between the centre of the object that is held and the wrist ranges from 101mm to 127mm. The range includes 97.5% men and women. Meanwhile, since other components will stay on the back side of the hand (requirement A25), the dimension of back side of hand should also be considered. The length of back of hand ranges from 96mm to 120mm, while the breadth ranges from 66mm to 96mm. Based on foregoing measurement, the calculation is made. Ideally, the gripping point and the wrist stay on the same horizontal from side view.



$$a = [96,120] * \sin(35^\circ) = [55,69] \quad c = e - b = [23-29]$$

$$b = [96,120] * \cos(35^\circ) = [78,98] \quad \alpha = \arctan(c/a) \approx 67^\circ$$

$$d = \sqrt{(c^2 + a^2)} = [60, 75]$$

The distance between the gripping point and end of the finger should range from 60mm to 75mm, while the angle stays around 67°.

C1, C2, C3, the indication will follow current form with four LED lights.

All the indications and information should be easily noticed, understood and remembered. As previously discussed, the heating is displayed through four LED lights. Currently, four LED lights have two different colours, which the red light corresponds to the pre-setting of ABS while the green one correspond to PLA. Successively lighten represents the rate of heating. Through the user test, this indication is well accepted by users. Thus, the new product will follow this form.

However, one special attention should be paid that the indication light should be easily seen by users if the shape of the product is changed.



figure 25

Indication light of LIX pen

C4, C9, more information is preferred to be displayed

Besides the type of filament and the rate of heating, there will be more information that need to be acquired. Refer to other 3D pens, LED screen is a normal way to display the important information such as temperature, speed and so on.

C6, C7, C8, the product is preferred to be used by bimanually control.

Introduction

Russell indicates that bimanual techniques has better performance than unimanual technique and, as the task becomes more cognitively demanding, the bimanual technique exhibits even greater performance benefits. (When It Gets More Diffcult, Use Both Hands – Exploring Bimanual Curve Manipulation, 2011). It indicates the advantages of using both hands when manipulation. However, Considering the difference between digital and physical manipulation, this view of point should be tested in the spatial reaching movement situation. Thus, an experiment is made.

Set up

The figure below shows the set-up of the experiment. Entire set up includes a pressure sensor, which simulates activating button on the product. The aluminium cylinder represents the pinch gripping parts of spatial movement. Six LED lights are situated on two boards. One random order is programmed that these lights will randomly flicker. Each flickering light represent one intended point that need to be reached by pinch gripping part. These LED lights are bent into different heights, which make the reaching movement more into spatial. Additionally, the time that spent during the task will be recorded as extra reference.

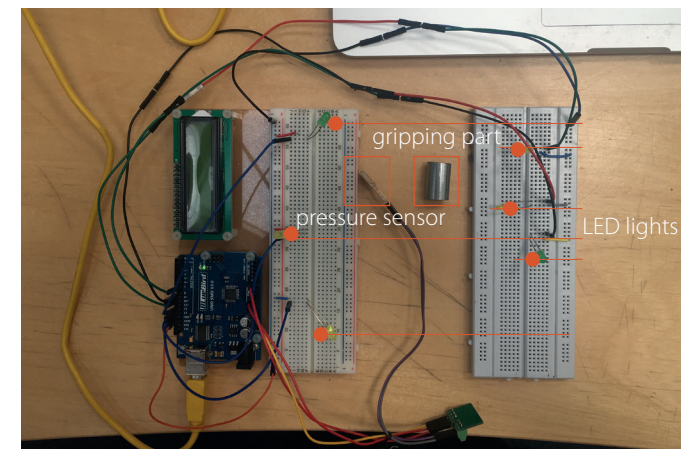


figure 26

Set up of bimanually control

Procedure

Participants are required to move the aluminium cylinder with imposing pressure sensor at the same time. The LED lights will not flicker unless the pressure imposed sensor exceeds 5. Participants need to successively move the cylinder to the LED light that is flickering. The cylinder and pressure sensor will be setted on the same hand first (the hand that participant used to use), then they are separated on different hands (the cylinder stays on the hand that participants used to use).

The experiment starts with repeating the spatial motion for several times that participants are familiar with the trajectory. It reduces the effect of familiarity with the trajectory. After 30 times reaching motion, the experiment ends and the time is recorded.

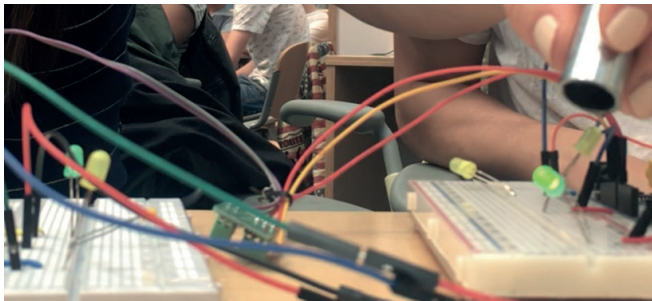


figure 27

The set-up of bimanual test

Participants are required evaluate two different tests based on smoothness, precision and comfort, then the overall rate is given. The rating is scaled from one to seven, which corresponds to terrible to excellent. Beside is the questionnaire.

Gender no.
Age

smoothness - do you think this posture is smooth?

	not at all							very good
○	1	2	3	4	5	6	7	
○	1	2	3	4	5	6	7	

precision - do you think this posture is precise?

	not at all							very good
○	1	2	3	4	5	6	7	
○	1	2	3	4	5	6	7	

comfort - do you think this posture is precise?

	not at all							very good
○	1	2	3	4	5	6	7	
○	1	2	3	4	5	6	7	

overall - overall rate

	not at all							very good
○	1	2	3	4	5	6	7	
○	1	2	3	4	5	6	7	

Results

Five participants are invited to the experiment in total. The figures below demonstrates results of the experiment. Two column corresponds to bimanually and unimanually control respectively.

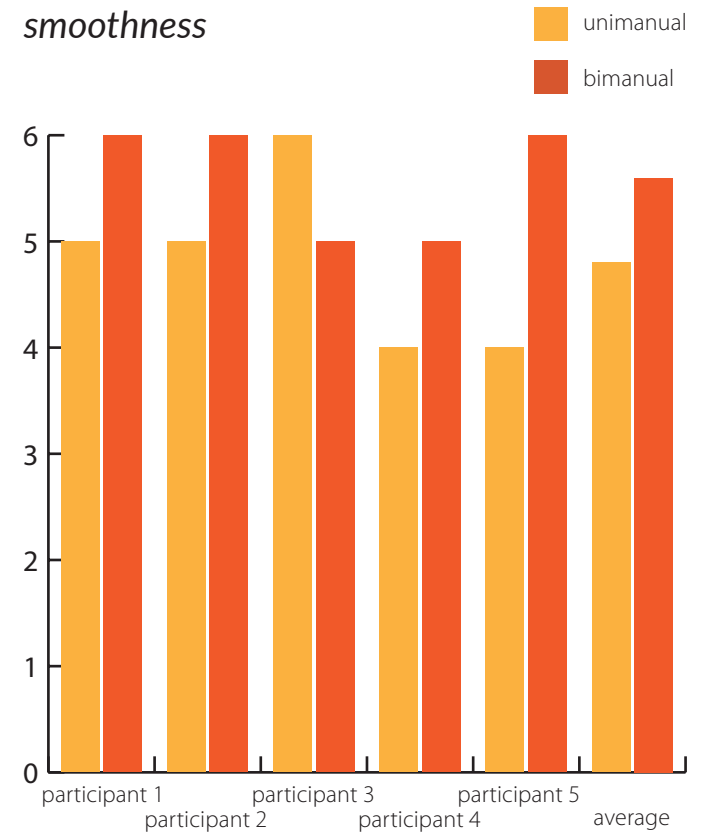
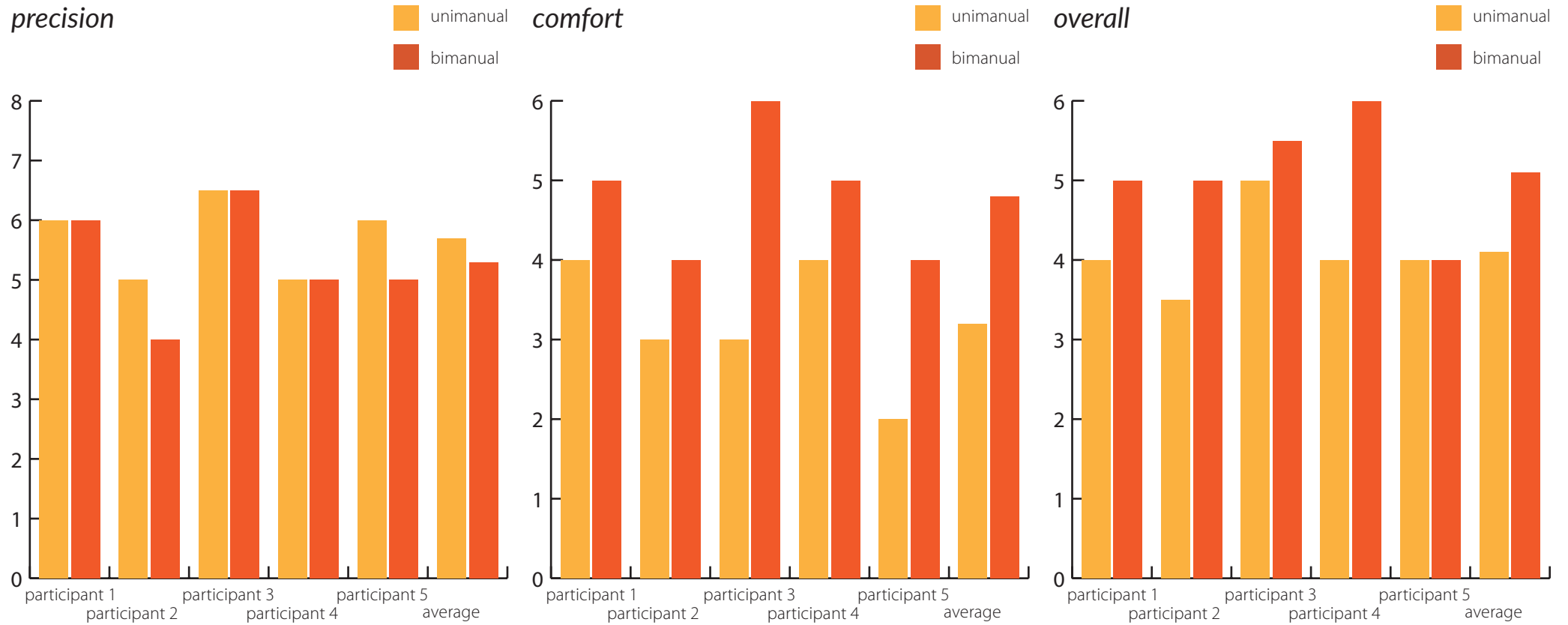


figure 28

Questionnaire for bimanual test



Analysis

As shown in the figures, bimanual control prevails in most of ratings. Controlling with same hand shows advantages on the precision of spatial motion. Participants are distracted by checking the pressure sensor, which reduces the concentration on moving. As the result, the motion is less precise. Even though, two participants are not effected by the distraction that rate them equally.

Discussion

The activating button is simulated by one simple pressure sensor. The sensor does not provide any feedback when pressing, which causes the confusion for participants that if they provide enough force on it. As long as the feedback of activating is more obvious and comfortable, users will not be extremely distracted by pressing, which will probably enhance the precision.

Conclusion

As the conclusion of the experiment, the product is preferred to be used by bimanually control.

C12, the result of creation is preferred to be able to be either further used or reused.

Through the feedback of interviews, target users expect that the result of creating can be either further used or reused. Normally, hand-crafted creation is the basis of further development in the design process. It requires that the result can be revised, which let users explore different possibilities, or duplicated, which helps users to directly compare different possibilities.

D3,D4, Various functions should be differentiated.

By fulfilling the condition of compactness, all the functions should be clearly defined in case of making confusion. Various functions should be differentiated.

D6, The battery should be either easily charged or replaced

In order to make the usage of product more smooth, the battery should be either easily charged or replaced. Meanwhile, the charging should be efficient that decrease the waiting duration.

A13, full list of requirements

Foregoing operationalization of each statements result in a series requirements that act as the foundations of further analysis. All the requirements will be divided into the requirements that the product has to reach and the wishes that the product has better gain. Requirements will be used to set guidance of conceptualization. Wishes are going to be the reference for evaluation of different concepts. Both requirements and wishes are categorized based on use, design and dimension. The numbers in the end correspond to various statements.

Requirements

Use

1. The continuous usage of one single time should not shorter than 10 minutes, while the longer the better is. (A1)
2. the solidification of new product is preferred shorter than 2 seconds. (A2, C11)
3. the temperature of contacting area between the product and users should be lower than 45

- degree. (A7)
4. the product life is preferred longer than 1 year. (A8)
5. all the potential harm should be avoided. (scald, cut etc). (A17, A20)
6. Users should not consistently use large amount of the muscle (A17, A20)
7. No numbness in fingers, fingers should not feel numbness during the usage. (A19)
8. Handle does not feel clammy (A23)
9. The product is handled by moving with joint of wrist in pinch grip. (A24, C5)
10. The posture of holding should be palmar pinch grip. (A25)
11. If there are other components on the hand, the back of hand are the best option. (A25)
12. No lack of tactile feeling (A26)
13. No pain, the handle and operation of product should not cause the pain on the hand. (A27)
14. Users should be able to change the thickness / size of outcomes (B1)
15. functions of creation and manipulation of colours are needed for different situations (B2, B3)
16. Users should be able to adjust dimensions

according to exact needs. (B4)

17. The battery should be either easily charged or replaced (D6)
18. the product should be durable that needs fewer replacement (D10)

Design

19. the product is preferred to be able to attached on the hand. (A5)
20. the product should be compact that is easy to be taken (A9, D1)
21. soft protection should be added at the area that continuously contact with users (A11)
22. Handle hardness, the hardness should be considered to enhance the comfortability. It could not be too hard. (A22)
23. The appearance should be unified in same standard and style as other branches (B5)
24. the indication will follow current form with four LED lights. (C1, C2, C3)
25. Various functions should be differentiated. (D3, D4)
26. All the connections should not be loose. (D7)
27. All the components should be stiff enough

(D8)
28. The assembly of the product should be firm and well matched (D9)

Dimension

29. The gripping diameter should be between 8 to 13 mm (A18, A21)
30. The distance between gripping point and the end of finger should range from 60mm to 75mm, while the angle stays around 67°. (B4)

wishes

use

1. In order to fulfil different demands from various users, the conveying speed is preferred adjustable. (A3)
2. making actions should be as effortless as possible (A6)
3. the gripping area should be easily gripped. Relative harsh surface is needed. (A18, A21)
4. the result of creation is preferred to be able to be either further used or reused. (C12)

design

5. The longer the product life is the better. (A8)
6. The appearance of the product should be professional for target users (A28, A29)
7. The pressure that imposed on the hand should be as less as possible (A12, A13, A14, A15, A16)
8. The inner components are preferred to be designed into same dimension and specifications (B6)
9. The product is preferred to be designed which is able to match some potential assistive tools. (B7)
10. more information is preferred to be displayed

(C4, C9)

11. the product is preferred to be used by bimanually control. (C6, C7, C8)

dimension

12. the size of the product should be as small as possible (A10, D2)

A14, the comparison of two method of changing the colour

Table below demonstrate the comparison of two colouring methods. Colorizer shows a lot of benefits. Although colorizer will affect the quality of the colour. Due to the product is used to creating three dimensional model which is mostly sketch model, tiny deviation of the colour is acceptable. Therefore, the colorizer is selected as coloring mechanism.

	<i>changing filament</i>	<i>colorizer</i>
<i>handling</i>	- The process of extracting and refilling filament is annoying through the interview with target users.	+ Only the colour cartridge need to be changed, no need for extracting and refilling filament by mechanism
<i>smoothness</i>	- polymer remains from previous filament will adhere to the inner surface of melting area. These remains will be adhesive and cover the secondary filament. As the consequence, the colour can not change immediately.	0 No negative influence. Still need to change the colorizer
<i>compactness</i>	- It causes inconvenience which users have to keep certain amount of filament with specific colour	0 Only one kind of filament needed. Colour cartridge with different colours are needed.
<i>cost</i>	- Users have to buy various filaments with specific colours in order to fulfil the need	+ colorizers are reusable for customers. Users only need to refill the ink for colorizers
<i>Required quality</i>	+ Changing the filament with different colours will not affect the quality of results	- The colour from ink will be mixed with filament. Thus the colour will differ from original ink
	- - - - +	+ 0 0 + -

A15, tests of colouring mechanism

One carrier for loading pigment and the contact area with filament are two indispensable components in the colouring mechanism.

Since colouring mechanism mixes the ink with colour from original filament, original filament is preferred white or translucent. In order to ensure the certain amount of ink which is coated on the filament, two influential factors should be specially regarded. The first one is certain size of contact area, while another is the pressure in between the filament and ink for coating.

Several tests were done in order to find proper ink and colouring mechanism. Ink from Copic marker, which is the water-base ink marker, was first used. Colour was directly scribbled all over the filament by hand.

As the result, the outcome became slightly bluish, which is quite different from original ink. Then One sponge is used for storing the colour from colour cartridge in order to coat the filament more evenly. Colour liquid is put on the sponge then the filament went through the filament. The result stay similarly light as previous one.

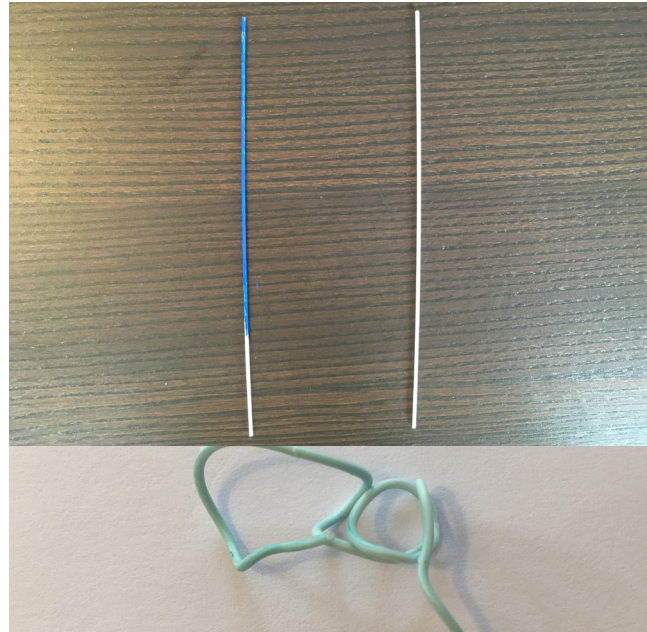


figure 28

First test with Copic marker pen

trial had the best colouring quality. The more pressure and ink that on the filament, the better the colouring. Furthermore, partly coating the filament is also workable.

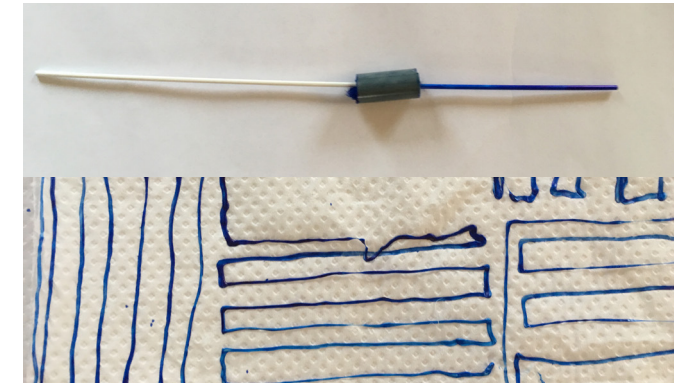


figure 29

Final test with permanent marker pen

Then ink was replaced with the ink from Staedtler permanent marker. Four progressive trials were made. The ink is scribbled on the filament first. Then the filament went through the ink sponge without the extra pressure.

The third trial was pinching the sponge by fingers as additional pressure when the filament going through the sponge. Hard felt material as the contact part in the last trial. As the result, the last

Conclusion

As the conclusion, colouring mechanism contains one route part made of hard felt material, which functions as coating and contacting. One ink storage surrounds the hard felt material for storing and transmitting ink. One outer cover is needed for protecting and sealing the ink storage. In order to ensure enough ink coated on the filament, contact part is preferred encircling the filament.

A16, the comparison of varying the shapes of die

Replaceable dies (as called as nozzles for 3D pen) are used for current 3D pen. Dies are differentiated by various shapes, such as circles with different sizes, stars, triangles etcetera. However, the result of specific shapes are not recognizable, which makes different dies less useful. By contrast, only width of the outcome matters. Thus, only the dimensions of the die need to be changed.

Currently, users need to replace the nozzle by specific tool when the nozzle is still hot, since it is hard to separate the filament that remains in the nozzle when it hardens. It causes the sense of unsafe and troublesome.

Through the comparison of both mechanism, deformable shows narrow advantage. However, the results from deformable die is not proved yet which need further discussion. Therefore, deformable die is temporarily preferable for changing the shape of the outcome.

	<i>Replaceable die</i>	<i>Deformable die</i>
<i>Efficiency</i>	- Users have to replace the die every time when they want to change the shape, which is not efficient at all.	+ Through directly deforming the shape of the die, the shape of outcome differs correspondingly.
<i>Safety</i>	0 With specific tool to take the die, it avoids most of potential danger.	0 Using finger to press the die will probably cause problems since the melting area is hot.
<i>Intuition of use</i>	- It is not intuitive at all to replace the die all the time.	+ The more force that impose on the die, the wider the outcome will be. It is compatible to the intuition
<i>Required quality</i>	0 Even though the shape of die varies, the quality of results is not as perfect as expect since the low accuracy.	- The quality of the result is totally questionable that need to be proved.
<i>Duration</i>	+ There is no evident reason that is harm for the duration.	- The more force that impose on the filament, the more possible that filament remains on the inner surface of the die, which probably causes the jam.
	- 0 - 0 +	+ 0 + - -

rectangular for easier gripping. The conveying mechanism and colourizer are positioned inside as well.

Similar as previous concept, dosing part is clipped on the hand. The angle of the clip is different in order to adapt to the holding of extruder.

Concept 3

The third concept is demonstrated on the right. The extruder and dosing part are connected by an extensible column. The length of the column can be extended by 15mm that suits for 90 percent of human hands.

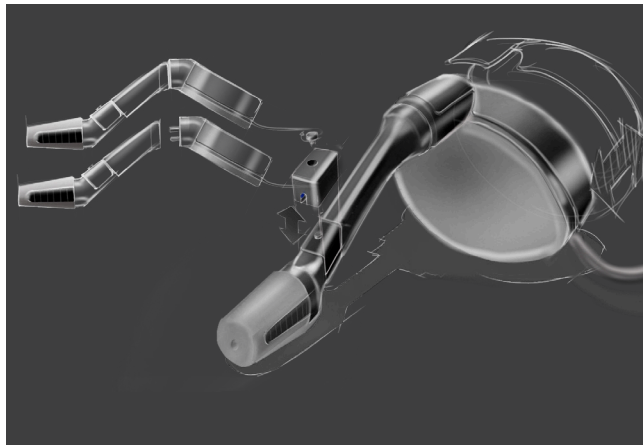
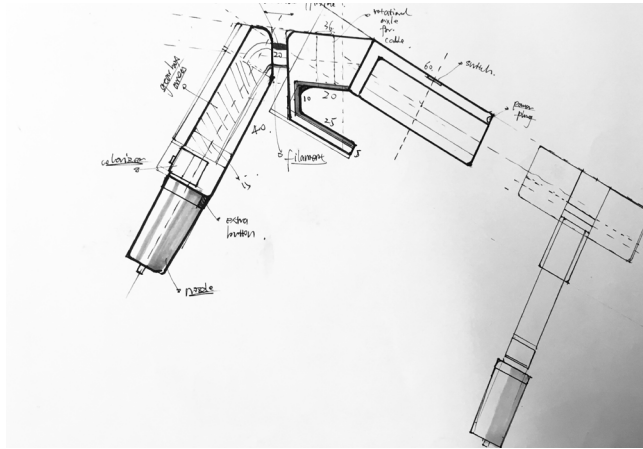


figure 32

Sketch of concept 3

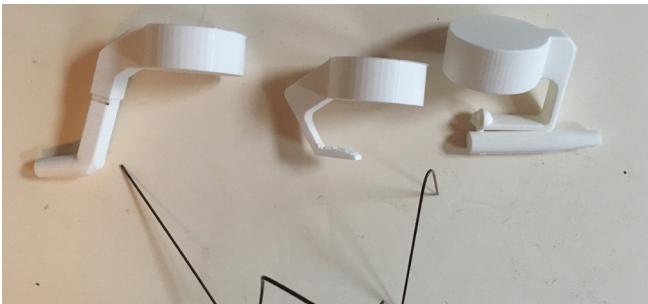
A18, user test of three concepts

Introduction

As described in appendix 17, there are three concepts are concluded in total. All of them fulfil the demand that users should be able to adjust product to adapt the dimensions for different situations. In order to select one concept for further development into embodiment phase, one user test is performed.

Set up

Based on different configurations of three concepts, three models are 3D printed. The models simulate basic principle of adjustment of dimensions. One copper wire is randomly bent into a three dimensional free shape, which simulates the trajectory that guide spatial movement of participants' hand in the air. Five participants are invited in total.



Procedure

First of all, one video of 3D pen is displayed for the sake of introducing the intention of the product. Participants are informed that the product is used to create three dimensional object through forming lines in the air.

Then three models are provided for users. All the participants are asked to freely use hold three models without any instructions. The reasons are provided by participants afterwards. Following, users are asked to hold models in the intentional way. Adaptation rated by participants.

Afterwards, participants need to move models alongside the copper wire while holding it in the intentional way. All participants will practise moving through the copper wire for several times first until they are familiar with the movement, which avoid the effect caused by different degrees of skilled.

When following the trajectory, participants are asked to exactly touch the copper wire with the model all the time, which ensure the trajectory of each trial is almost the same. Furthermore, the spatial reaching movement simulates the process of spatial creation in the air, which means the trajectory does not really exist unless the filament is extruded at certain positions. Therefore, participants are only allowed to touch exact wire as long as the extruder reaches first.

After each trail, participants are required to rate the experience based on extensibility of the product, stability, flexibility and smoothness when moving. All fore-mentioned parameters are rated from 1 to 7 that is corresponding to the terrible to excellent. The figure 34 shows the questionnaire.

figure 33

Set-up of the test with 3 concepts

Gender _____ no.
 Age _____
 Experience of 3D pen _____

stability - do you think this gesture is stable?

	not at all	1	2	3	4	5	6	7	excellent
○		1	2	3	4	5	6	7	
○		1	2	3	4	5	6	7	
○		1	2	3	4	5	6	7	

flexibility - do you think this gesture is flexible?

	not at all	1	2	3	4	5	6	7	excellent
○		1	2	3	4	5	6	7	
○		1	2	3	4	5	6	7	
○		1	2	3	4	5	6	7	

smoothness - do you think this process is smooth?

	not at all	1	2	3	4	5	6	7	excellent
○		1	2	3	4	5	6	7	
○		1	2	3	4	5	6	7	
○		1	2	3	4	5	6	7	

adapatation - do you think this gesture is ergonomic?

	not at all	1	2	3	4	5	6	7	excellent
○		1	2	3	4	5	6	7	
○		1	2	3	4	5	6	7	
○		1	2	3	4	5	6	7	

extensibility - do you think this product is estensive?

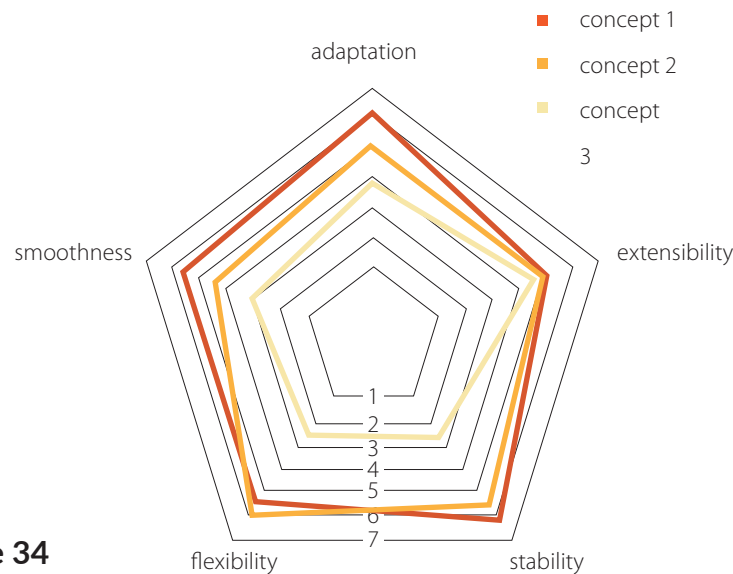
	not at all	1	2	3	4	5	6	7	excellent
○		1	2	3	4	5	6	7	
○		1	2	3	4	5	6	7	
○		1	2	3	4	5	6	7	

figure 34
The questionnaire of the test

Results

Five participants join the test. Results are based on average rate of five parameters that are evaluated by participants. Furthermore, the preference of appearance is acquired according to the selection.

Figure X illustrates the results of rating. Each corner represents one parameter that participants need to rate while black lines symbolize the rate from one to seven. The rate of each parameter is the average rate of five participants. Through connecting each average rate, the overall result is illustrated.



Analysis

As shown in the figure, concept one prevail at all parameters except the flexibility. Concept 2 performs higher flexibility since least connection in between two pars. All of three concepts achieve the requirement of extensibility. However, none of them is excellent on this factor. Concept 1 shows big advantage on the adaptation of the gesture and smoothness of the process.

Discussion

Three prototypes are rough and incomplete, which causes some possible error. There is no exact connection in between two parts for prototype of concept 1 which is different from the concept. It enhances the experience of flexibility thereof. Therefore, the rating for the flexibility of concept 2 is reduced which is seen as the same as concept 1.

Conclusion

Concept 1 is either best or equally best in all the factors, which is selected as the concept that is further developed.

figure 35

Illustration of the overall result of test

A19, test of the clip

According to the simulations the spring steel with 15mm should be able to withstand all the forces that are thrown at it.

The first test is made to approximately measure the force that produced by hand when wearing the clip. One steel plate with thickness of 1.5mm is folded to simulate the clip. The clip is connected with one mobile measure weight scale. The scale is fixed and the strip that connects with clip is tightened. One side of the clip is also fixed. When wearing the clip on the hand by imposing force on another side of the clip, the force that is needed is approximately achieved, which is less than 15N.

Then the simulation is made in the software. First starting with the static results. In the worst case scenario the force is setted as 50N. The result is shown beside. As the result, spring steel totally suffices the needs when the thickness is beyond 15mm without any damage. According to the colourcoding in the figure, the most stress is less than the maximum load of spring steel.

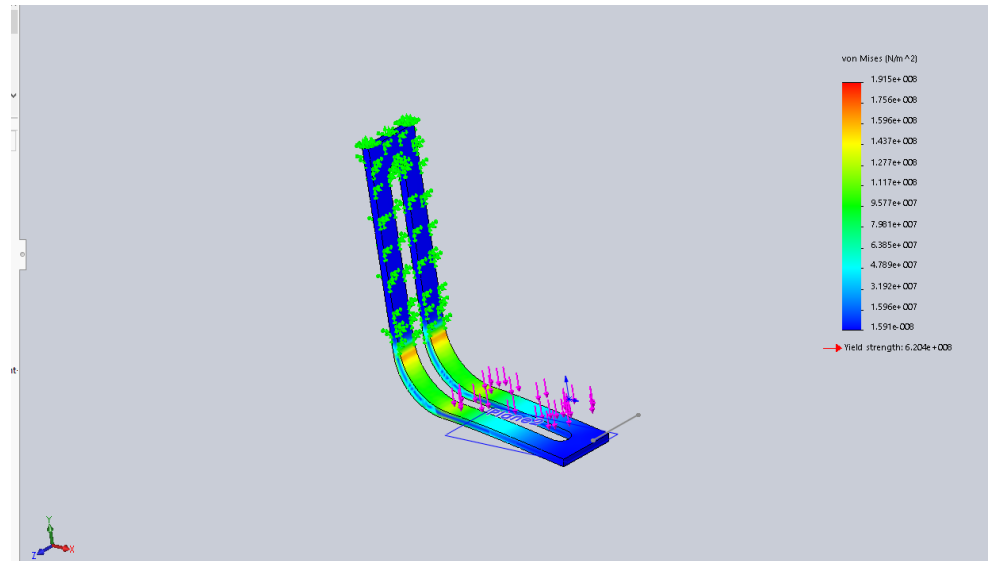


figure 36

Simulation of the force on the clip

Furthermore, another small tests with steel plates with different thickness is made, which to select the most suitable thickness. They are evaluated based on perceived effort and firmness when wearing them on the hand. The different thickness are 1.5mm, 2mm and 2.5mm respectively. As the result, the clip is setted as 1.5 mm since three plates are similarly firm but the thinner the plate, the effortless to wear.

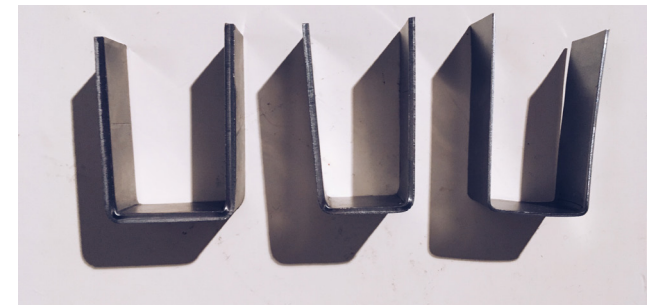


figure 37

Steel clip with different thickness

A20, questionnaire for evaluation

Gender
Age
Experience of 3D pen

no.

stability - do you think this posture is stable?

	not at all						excellent
<input type="radio"/>	-3	-2	-1	0	1	2	3
<input type="radio"/>	-3	-2	-1	0	1	2	3

flexibility - do you think this posture is flexible?

	not at all						excellent
<input type="radio"/>	-3	-2	-1	0	1	2	3
<input type="radio"/>	-3	-2	-1	0	1	2	3

adaptation - do you think this posture is ergonomic?

	not at all						excellent
<input type="radio"/>	-3	-2	-1	0	1	2	3
<input type="radio"/>	-3	-2	-1	0	1	2	3

relaxation - do you think this posture is relaxing?

	not at all						excellent
<input type="radio"/>	-3	-2	-1	0	1	2	3
<input type="radio"/>	-3	-2	-1	0	1	2	3

instinction - do you think this posture is instinctive for you?

	not at all						excellent
<input type="radio"/>	-3	-2	-1	0	1	2	3
<input type="radio"/>	-3	-2	-1	0	1	2	3

perfectionism - do you think this appearance is professional?

	not at all						excellent
<input type="radio"/>	-3	-2	-1	0	1	2	3
<input type="radio"/>	-3	-2	-1	0	1	2	3

smoothness - do you think this process is smooth?

	not at all						excellent
<input type="radio"/>	-3	-2	-1	0	1	2	3
<input type="radio"/>	-3	-2	-1	0	1	2	3

precision - do you think this process is precise?

	not at all						excellent
<input type="radio"/>	-3	-2	-1	0	1	2	3
<input type="radio"/>	-3	-2	-1	0	1	2	3

efficiency - do you think this process is efficient?

	not at all						excellent
<input type="radio"/>	-3	-2	-1	0	1	2	3
<input type="radio"/>	-3	-2	-1	0	1	2	3

stability - do you think this process is stable?

	not at all						excellent
<input type="radio"/>	-3	-2	-1	0	1	2	3
<input type="radio"/>	-3	-2	-1	0	1	2	3

adapation - do you think this process is ergonomic?

	not at all						excellent
<input type="radio"/>	-3	-2	-1	0	1	2	3
<input type="radio"/>	-3	-2	-1	0	1	2	3

instinction - do you think this posture is instinctive for you?

	not at all						excellent
<input type="radio"/>	-3	-2	-1	0	1	2	3
<input type="radio"/>	-3	-2	-1	0	1	2	3

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