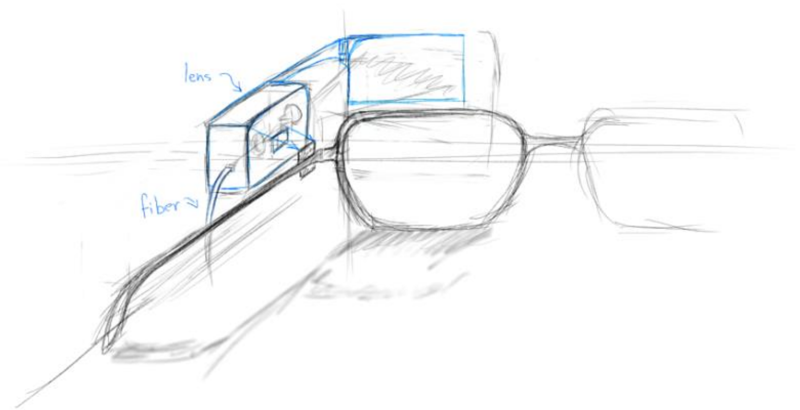

J-EYE: HEAD MOUNTED DISPLAY DEVICE

Final Report

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Abstract

This report gives a short introduction to the Head Mounted Display (HMD) device and offers the basic ideas of J-eye, which is a novel method of making a radiation free HMD device. J-eye uses a fiber bundle to transmit optical signals and two sets of lens system either to tamper or enlarge the images. So it totally get rid of embed circuits and electromagnetic radiation. The manufacture of J-eye includes designing the lens system, printing the structural parts, test and evaluation process are also elaborated in details in the report. Some engineering logic and concepts, like the magnification of lens system, the aberrations are also discussed. Additionally, the details of each possible solution and mechanical structures, the parameters of each part are elaborated in the appendix.

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1. Summary

The basic target of the project is to create a head-mounted display (HMD) device, which is radiation free and light. Realizing 3D-image is a bonus target. In the end, the device has achieve both basic and bonus targets. The 3D-image is not perfect, because of time, budget and technical limitation. Next, the project should focus on getting better image and improving appearance of J-eye.

2. Introduction

2.1. Introduction to HMD

A head-mounted display (HMD) device is a device to display images. It is usually worn on the head and put the display screen in front of users' eyes, and by adjusting the focus it projects lights into the eyes, generating a virtual image that can be easily seen.

Generally, a screen is in a fixed position, and only can be seen from one direction. With HMD, the screen could follow the user's head, and always be in front of the eyes. As a consequence, HMD often is used in activities that need moving. For example, Recon MOD[1] is a head up display (HUD, a kind of HMD) for skiing that can display altitude, speed, and time.

2.2. Problem Description

Traditional HMD devices are designed for specification fields like sports, military, or expedition. It is rare to see an HMD for daily life use. Recently, Google glass[2] becomes a noticeable product. It seems to be a good HMD solution for daily life use. However, in order to achieve numerous features like taking pictures, accessing the internet, Bluetooth connection, etc., Google glass embeds powerful integrated circuits within it, which can produce electromagnetic radiation. "IARC has classified radiofrequency electromagnetic fields as possibly carcinogenic to humans" [3]. In addition, the price is unapproachable to ordinary people.

2.3. Product Introduction

The original intention of J-eye is to produce a low-cost, radiation-free HMD for daily life use. People wear earphones for listening, but hardly find such a product for display. J-eye is designed to fill in the blank. J-eye consists two main parts:

- Image-generation part: a projector that transform electric signals from a cellphone, into optical signals to the lens system.

- Image-receiving part: another lens system that project the images into user's eye.

1 http://www.reconinstruments.com/
2 http://www.google.com/glass/
3 "Electromagnetic fields and public health: mobile phones". Fact sheet N °193. Wold Health Organization. June 2011. Retrieved 5 November 2013.

The two parts above are connected with a fiber bundle, which also deliver the image through.

2.4. Benchmarking

Information of several representative HMDs is available on the Internet. The most representative ones are shown in the Table 1. The prices of all those HMDs with display function are above $700, which is around ¥4250.

TABLE 1 : REPRESENTATIVE HMDS

Picture	Product Name	Price	Lightweight	Electromagnetic Radiation near head	Functions
 [4]	Recon MOD	$300-$400	Yes	Yes	Displays altitude, velocity, and time.
	Google glass	$1,500 for beta	Yes	Yes	Cell phone, camera, GPS device, normal glasses
	Star1200	$5000	No	Yes	Two cameras, 2-D and 3-D view
	AirScou-ter	$2,000	No	Yes	Camera, display, interphone

4 All pictures in table 1 comes from : http://www.beareyes.com.cn/2/lib/201204/25/20120425548_0.htm

	Moverio BT-100	$700	No	Yes	Android Display
	HMZ-T1	$800	No	Yes	3-D OLED equipment
	ST1080	$800	No	Yes	1080p LCD, normal glasses

2.5. Customer Requirements

Customer requirements mainly guide the design of J-eye. Reducing electromagnetic radiation is concerned in the first priority by Professor Wan. Users need to use the product without worrying about health problems.

Existing HMD devices are often too heavy, and are improper for daily life. As a result, the product should be convenient to use and comfortable to wear. People wearing J-eye could feel wearing a pair of normal glasses.

Some other requirements are also considered, and all requirements are weighted based on the importance. Among the considered requirements, comfort is the most important one, and clear image is the least important one. Table 2 lists customer requirements and their weight.

TABLE 2 : CUSTOMER REQUIREMENTS

Customer requirements	Comfortable	Clear	Easy to use	Reasonable price	Convenient	Low radiation
Weight	10	2	4	4	9	7

2.6. Engineering Specifications

Based on the customer requirements, engineering specifications can be decided. Engineering specifications are determined to meet each requirement, and are list in Table 3(next page).

TABLE 3 : ENGINEERING SPECIFICATIONS

Customer Requirements	**Engineering Specifications**
Comfortable & Convenient	Size: 2x3x2cm (image-receiving part) Weight: 40g (image-receiving part)
Clear	Resolution: 300x300px
Easy to use	Steps to use J-eye: 3 steps
Reasonable price	Cost: RMB 2000
Low radiation	Circuits embedded: 0cm^2 (image-receiving part)

The size of image-receiving part should be small enough so that it can be attached to glasses. People wear glasses would not often feel uncomfortable. So limiting the size to fit the glasses is the best way to achieve this requirement. Also, the image-receiving part should be light in weight in order not to bring any discomfort.

Resolution determines whether the images are clear. For better image, the resolution should be as high as possible. But it is limited by the fiber bundle that can purchase from the market. Since the available projector has around 320x240 pixels, the resolution is limited up to 320x240 theoretically.

J-eye is designed for daily life, and everyone could use it easily. The use-method should not be complicated. The fewer steps to make J-eye working needs, the easier to use J-eye will be.

As a product for daily life use, J-eye needs a reasonable price. The most cost part in the final product would be the fiber bundle. Other parts cost much less than the bundle.

J-eye is a product for health. Low radiation can protect user’s brain from electromagnetic field. Since the electromagnetic field is generated from electric circuits, the amount of embedded circuits is considered as an engineering specification.

2.7. Quality Function Deployment

To meet the customer requirements, a QFD chart is made to figure out which parts are most important. The results are shown in the chart, which is attached in appendix A. The conclusion is that weight and size are the two most important factors, and should be given first priority to be considered.

3. Concept Generation

In this part, concept designs with brainstorming and morphological methods are created. These designs are the solutions to the problems in order to meet the customers' requirements and engineering specification. The concept designs are candidates for the final selected design.

3.1. Function Structures

In order to apply the morphological method, the requirement is supposed to be reviewed of product and divided the whole product into several individual function parts. Also they should be compatible to each other, which adding some other concerns. The function structures and concerns are described as following:

- **Video Generator**: This part could be a smart phone, iPad or any other portable digital devices that could generate video signals. It is important to make sure that the generator has compatible connection to other parts.
- **Projector**: This part is used to convert the video signals from the video generator into optical signal. The projector should have reasonable resolution and magnification.
- **Lens System**: This part tampers the optical signal into a long fiber bundles. It should be both small and powerful. Small enough to be portable and powerful enough to tamper the optical signal from projector into the fiber bundles.
- **Fiber Bundles**: This part serves as transmission line to transmit the optical signal. Usually fibers would contribute some distortions while transmitting signals. The smaller distortion, the better the fiber bundles are.
- **Lens**: This part has the inverse function with lens system. It is placed at the other end of the fiber and it is to enlarge the image from the fiber bundle so as to make it visible and distinguishable for human eyes.
- **Mechanical Structure I**: This part is to capsulate the lens system and projector and prevent disalignment of the lens.
- **Mechanical Structure II**: This part is to fix the lens part on the glass.
- **Glasses Frame**: This is simple an ordinary glasses frame that serves as a base for other parts to fix on.

Figure 1 is the signal flow demonstration.

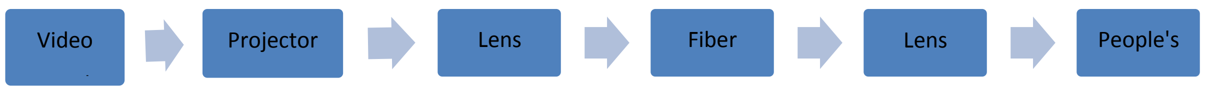


FIGURE 1 : SIGNAL FLOW

3.2. Concept Synthesis

For each part listed above, several possible solutions were considered and they are listed in Table 4.

TABLE 4 : POSSIBLE SOLUTIONS AFTER BRAINSTORMING

Function Structure	Solution #1	Solution #2	Solution #3
Video Generator	iPhone 4s	Android phones	iPad
Projector	Projector A[5]	Projector B[6]	Projector C[7]
Lens System	One convex lens	Two convex lens	Transforming an objective lens
Fiber Bundles	Square single-mode fiber bundles	Round single-mode fiber bundles	Multimode fiber bundles
Lens	A ball lens	A convex lens	Two convex lens
Mechanical Structure I*	3D print model 1 (Appendix Figure 2)	3D print model 2 (Appendix Figure 3)	3D print model 3 (Appendix Figure 4 & 5)
Mechanical Structure II*	3D print model B1 (Appendix Figure 6)	3D print model B2 (Appendix Figure 7)	Model B3 (Appendix Figure 8)
Glasses Frame	Small frames	Large frames	

*The mechanical structures are demonstrated in Solid works 3D model and hand-sketch. See detailed design sketch in Appendix B & C.

4. Concept Design & Selection

After the brainstorming, the detailed design work and select the best solution are supposed to be done. The selection including two rounds, first round is to rule out by referring to description of the components needed to buy on the internet; the other one is to design and print out, do experiments and check whether it works. The designs are compared using customer requirements.

After the first round of discussion and selection, several solutions are ruled out. The solutions with white backgrounds remain. The gray ones are ruled out. See it in table 5 below. Some comparisons are also listed in Table 5.

5 http://item.taobao.com/item.htm?spm=a230r.1.14.180.Mwb3Ye&id=35355174068
6 http://item.taobao.com/item.htm?spm=a230r.1.14.10.zFBsb9&id=35908895501
7 http://item.taobao.com/item.htm?spm=a230r.1.14.77.Y6UHiQ&id=35481791242

TABLE 5 : RESULTS AFTER FIRST ROUND SELECTION

Function Structure	Solution #1	Solution #2	Solution #3
Video Generator	iPhone 4s	Android phones[A]	iPad
Projector	Projector A	Projector B[B]	Projector C[C]
Lens System	One convex lens	Two convex lens	Transforming an objective lens
Fiber Bundles	Square single-mode fiber bundles[D]	Round single-mode fiber bundles	Multimode fiber bundles[E]
Lens	A ball lens	A convex lens	Two convex lens
Mechanical Structure I	3D print model A1	3D print model A2	3D print model A3
Mechanical Structure II	3D print model B1[F]	3D print model B2[G]	Model B3
Glasses Frame	Small frames	Large frames[H]	

A. Hard to find one type of Android phone that is widely used as iPhone & no proper projector fit Android phone
B. Too expensive
C. Too big to carry and also very expensive
D. Hard to purchase
E. Theoretically Multimode fiber has model dispersion which gives low image quality, though it is much cheaper
F. Hard to manufacture
G. Hard to design corresponding optical parts
H. No need to use large frame since small ones also work.

The second round involves experiment. The solutions with white backgrounds remain. The gray ones are ruled out. After try and error and some change in design, following are several remaining solutions in Table 6:

TABLE 6 : RESULTS AFTER SECOND ROUND SELECTION

Function Structure	Solution #1	Solution #2	Solution #3
Video Generator	iPhone 4s	Android phones	iPad
Projector	Projector A	Projector B	Projector C
Lens System	One convex lens	Two convex lens	Transforming an objective lens
Fiber Bundles	Square single-mode fiber bundles	Round single-mode fiber bundles	Multimode fiber bundles
Lens	A ball lens	A convex lens	Two convex lens
Mechanical Structure I	3D print model A1	3D print model A2	3D print model A3
Mechanical Structure II	3D print model B1	3D print model B2	Model B3
Glasses Frame	Small frames	Large frames	

5. Selected Concept Description

This part is a description for the final solution chosen and the rationale, such like equations or engineering logic.

Video Generator: iPhone 4s and iPad 2 have suitable projectors in the market and these two video generators have larger amount of customers than android phone.
Projector: Projector A projects a larger image size than expected. So its inner structure is changed and a smaller image without sacrificing resolution is available.
Lens System: The focus ability of one lens is limited and not enough to tamper the image from the projector. The convex lens in lab is very large and heavy. Thus the first two solutions failed to meet the requirement of the customers. The solution 3 transforms an objective lens in lab and it works.
Lens: Ball lens is very small and difficult to hold. Additionally, the aberrations of ball lens are very strong.
Mechanical Structure I: Solution 1 is hard to do adjustment inside it. Solution 2 becomes floppy after printed out. Solution 3 is the best design till now.
Mechanical Structure II: Solution 1 & 2 requires accurate design and manufacture. To make it simple, the team chose solution 3.
Glasses Frame: one frame is bought from the glasses shop and it works.

5.1. Engineering Design Analysis

5.1.1. Projectors

On choosing projector, it is important to select a small one to make it portable. Additionally the price is also a key factor to consider.

TABLE 7 : COMPARISONS BETWEEN THREE PROJECTORS

Solution	Picture	Price/Yuan	Size/mm*mm*mm	Resolution	Luminance/lm
Projector A	[8] 	420	57*48*16	320*240	10
Projector B		699	126*63*22	640*360	15
Projector C		1620	128*83*33	640*480	250

Projector A has smallest size and lowest price. It also has reasonable resolution and luminance. So the first projector is selected.

4.1.2 Lens System

The design of lens system is kind of like a telescope. The magnification and total length are considered as very important. The focal length of the two lenses in lens system is f_2 and f_2. According to the Telescope model, (see figure 1), the magnification and the length of the system is

$$M = \frac{f_1}{f_2},\ \mathrm{L} = f_1 + f_2 \qquad \text{Equation 1}$$

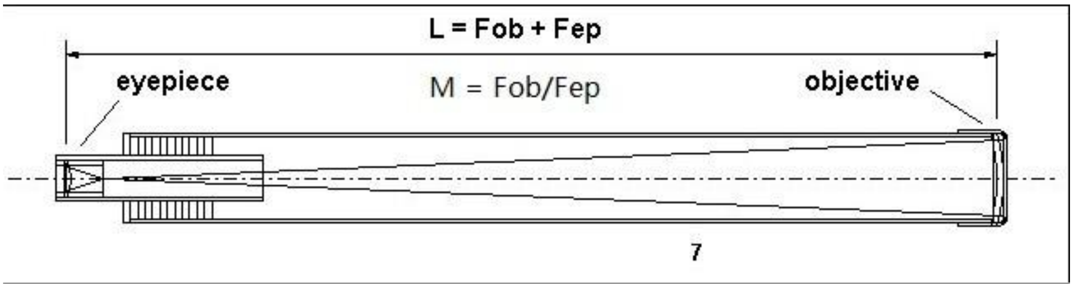


FIGURE 2 : TELESCOPE MODEL [9]

8 All pictures in the table are from Taobao.com

The size of the fiber bundle is around 1.0mm. The initial size of the image from the projector is at least 40x60mm.See Figure.3. Magnification is

$$\frac{60}{1} = 60 \qquad \text{Equation 2}$$

To meet the requirement, $f_1 = 60f_2$. The smallest focal length of lens is around 5mm. So the total length of the design is

$$\mathrm{L} = f_1 + f_2 = 61 \cdot f_2 = 305mm \qquad \text{Equation 3}$$

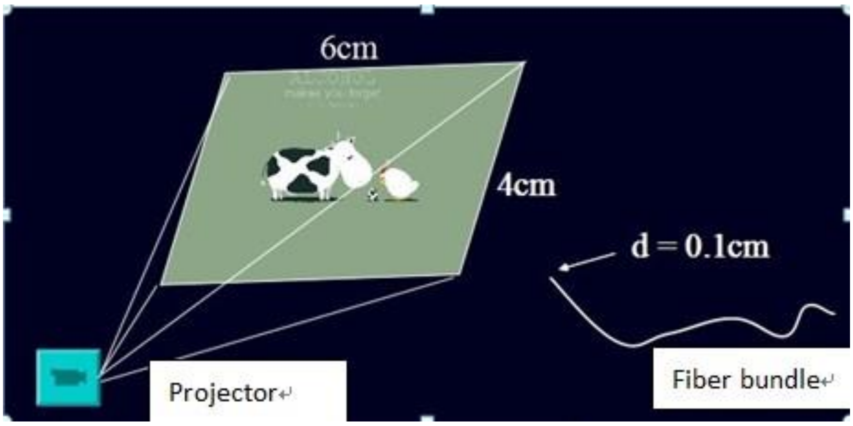


FIGURE 3 : INITIAL PROJECTOR AND FIBER BUNDLE

This is too long to be portable. In order to decrease the length, the structure of the projector is changed by taking one lens out of the projector. By doing so the minimum size of the image is reduced to 4x6mm. See Figure 4 (in the next page).In that case, Magnification is

$$M = \frac{f_1}{f_2} = \frac{6}{1} = 6 \qquad \text{Equation 4}$$

To meet the requirement, $f_1 = 6f_2$. The smallest focal length of lens is around 5mm. So the total length of the design is

$$\mathrm{L} = f_1 + f_2 = 7 \cdot f_2 = 35mm \qquad \text{Equation 5}$$

This result is more acceptable. This calculation is also proved by the experiment.

9 Picture from http://www.funsci.com/fun3_en/tele/tele.htm#1

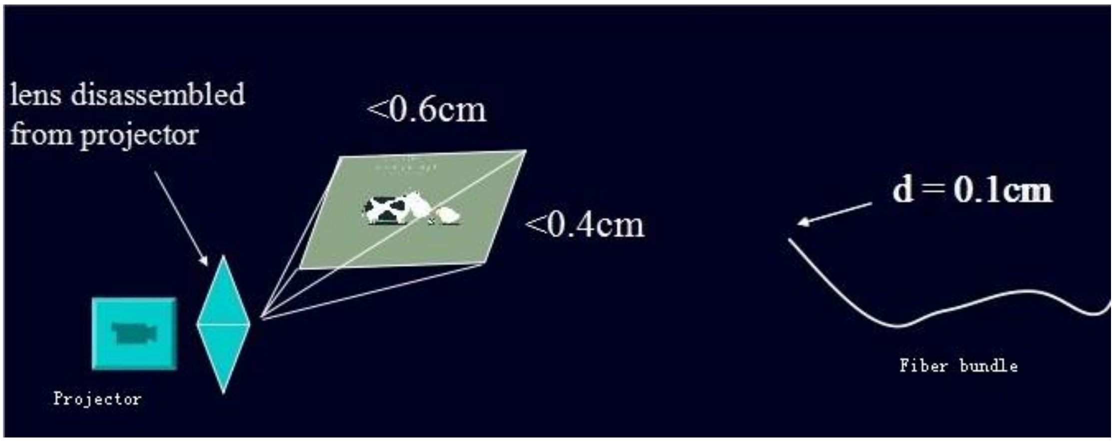


FIGURE 4 : TRANSFORMED PROJECTOR AND FIBER BUNDLE

The lens system and project in lab operation table are shown in Figure 5.

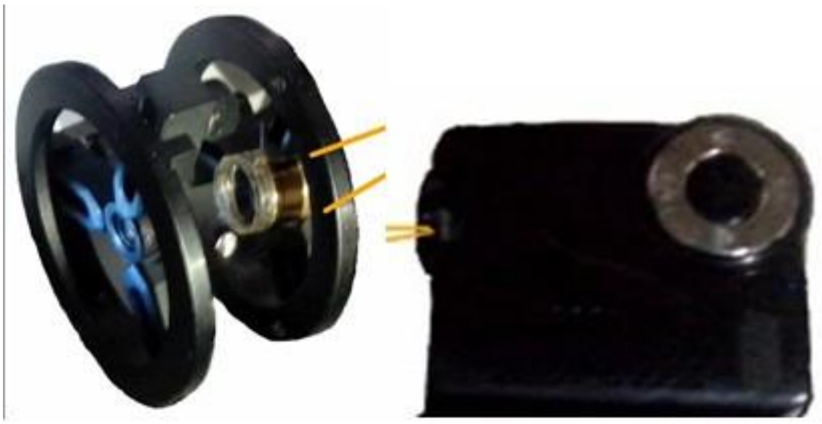


FIGURE 5: LENS SYSTEM AND PROJECTOR

4.1.3 Lens & Aberrations

The function of lens part is kind of like a microscope. The only difference is that usually people use microscope to observe cells or germs and in this product it is used to enlarge the image transmitted by the fiber bundle. The design of lens should take mainly take the field of view and the aberrations into consideration.

The field of view of a lens system is defined as the width of the final image people see over the distance between the image and people's eye.

Figure 6 in next page demonstrates a model to explain the field of view.

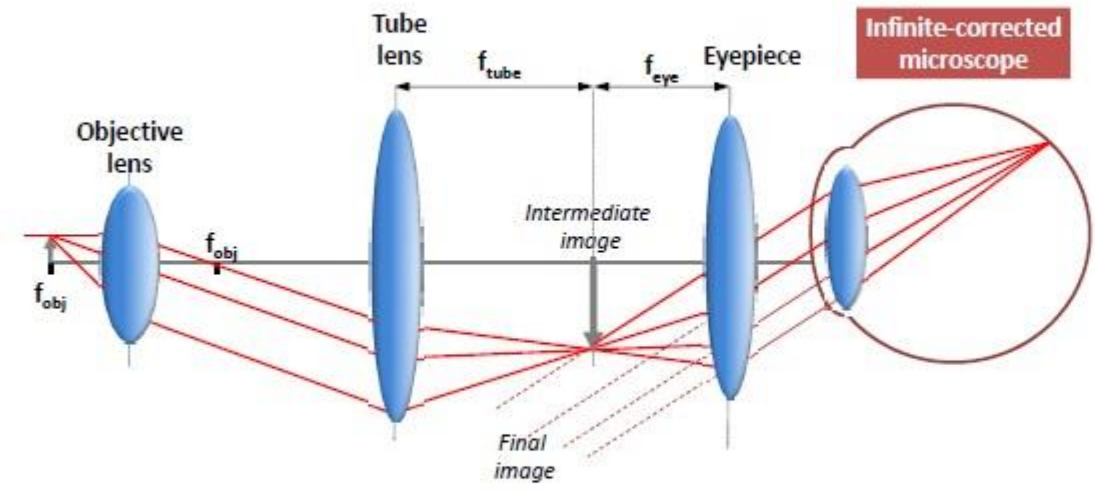


FIGURE 6 : LENS SYSTEM DEMONSTRATION [10]

While modeling the lens imaging process, usually people use paraxial approximation to calculate. That is, regarding that all light rays are close to the chief axis and use $\sin\theta \approx \theta$, where θ is the angle between light ray and the chief axis. However, this is not valid for ball lens with a small radius and small convex lens. The invalid of paraxial approximation causes the aberrations. See Figure 7.

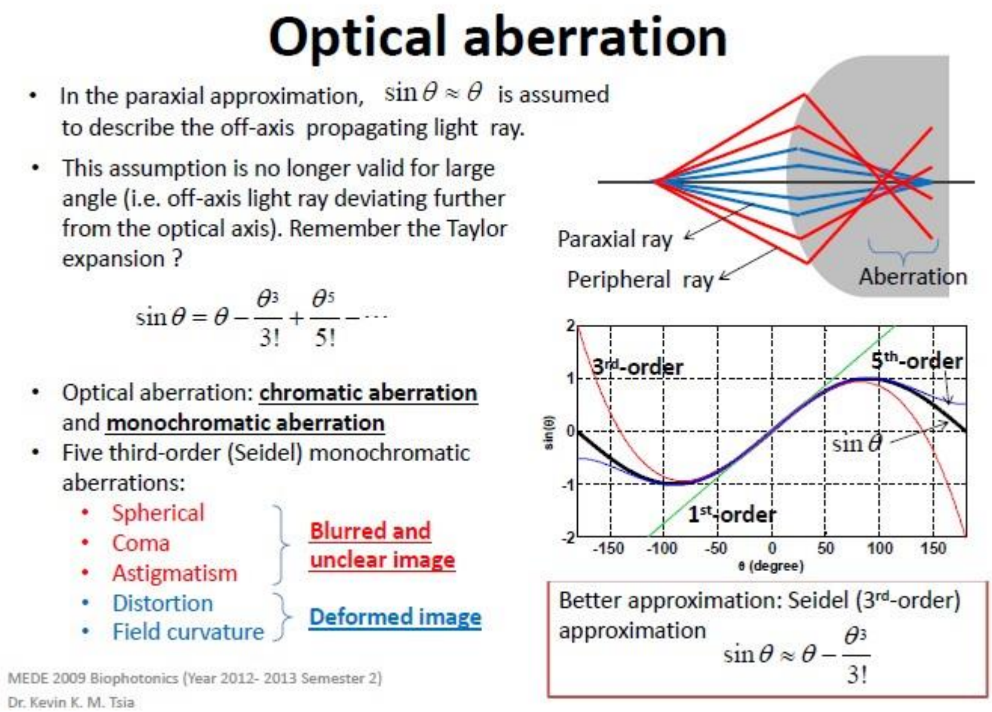


FIGURE 7: THE EXPLANATION OF OPTICAL ABERRATION[11]

10 Picture from Kevin K. Tsia's lecture note of MEDE 2009 in Hong Kong University
11 Picture from Kevin K. Tsia's lecture note of MEDE 2009 in Hong Kong University

Figure 8 below demonstrated how aberrations would affect the quality of image.

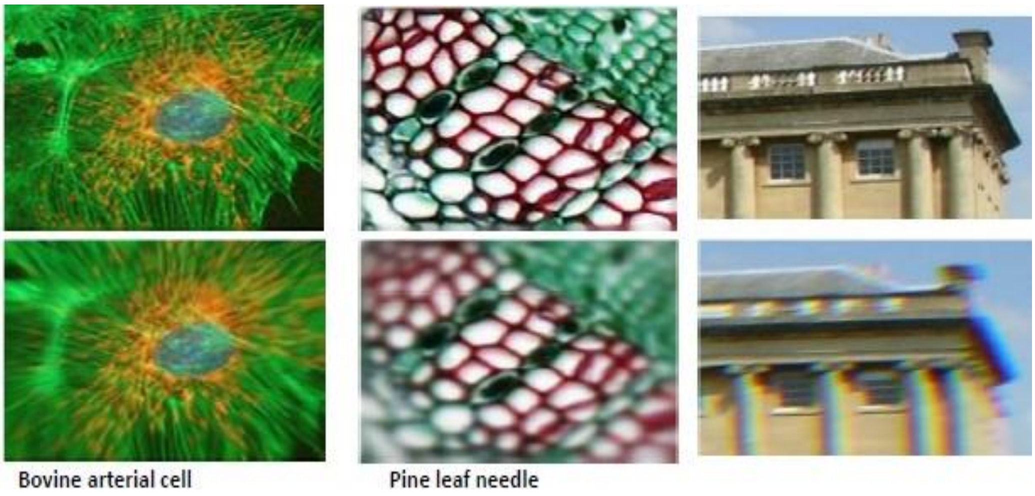


FIGURE 8: THE ABERRATION EFFECT [12]

Totally getting rid of aberrations is impossible. Only several ways are found to minimize it. Such as using aspheric lens and grin lens. Selecting or designing these kind of lens could be very complex. Several trials of some lens from discard cellphones and computers are made. It turns out to work well. The Figure 9 and Figure 10 are ball lenses and grin lenses.

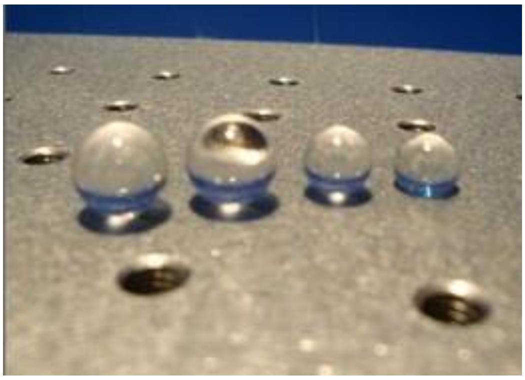


FIGURE 9: BALL LENS

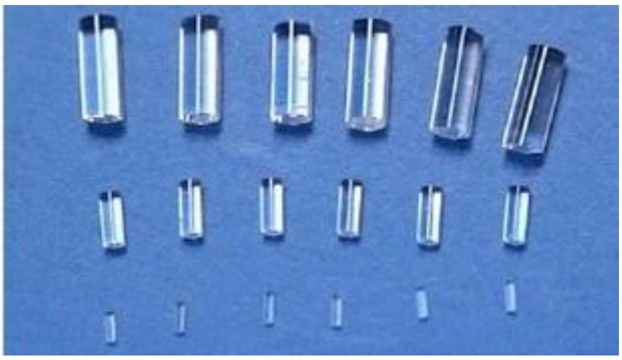


FIGURE 10: GRIN LENS

12 Picture from Kevin K. Tsia's lecture note of MEDE 2009 in Hong Kong University

4.1.4 Mechanical Structure

The main structure is the projector case for this project. It has two functions, the first one is to hold the projector and help connect with the phone. Then the second function is to provide an adjustable lens set to satisfy the optical system. As there are two lenses set inside the tube, three adjustable parts with one dimension of freedom are needed, and they are two lens sets and on fiber fixer, as showing in Figure 11:

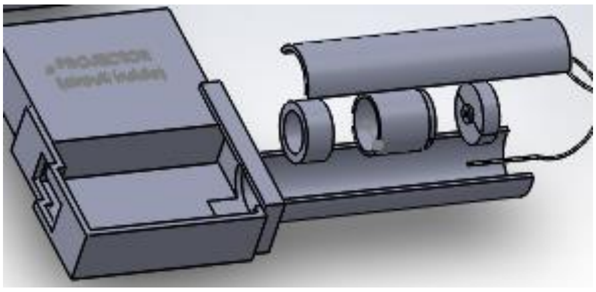
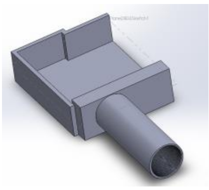
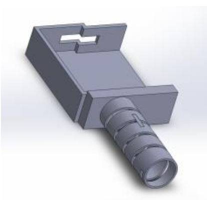
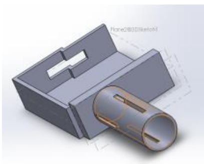
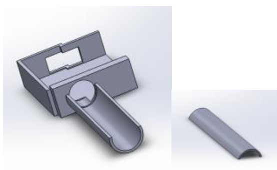


FIGURE 11 : LENS SYSTEM

Then three solutions to do that are designed, which are listed in Table 8:

TABLE 8 : FOUR SOLUTIONS CONSIDERED

Solutions	Advantages	Disadvantages	Chosen
Solution I 	▪ Extremely accurate ▪ Robust	▪ Hard to fabricate ▪ Easy to abrasion ▪ Hard to adjust	No
Solution II 	▪ High accuracy ▪ Easy to adjust	▪ Low strength ▪ Easy to broke	No
Solution III 	▪ Robust ▪ Easy to fabricate	▪ Relatively low accuracy ▪ Hard to adjust	No
Solution IV 	▪ Extremely easy to adjust ▪ Easy to fabricate	▪ Low accuracy	Yes

5. Design description

J-eye has mainly four parts as shown in the flow diagram in Figure 12. A projector is attached to the cell phone to project the image in the screen of the cellphone. The light emitted from the projector is gathered and converged to 1mm in diameter. The bunch of light then move through the fiber bundle to a convex lens, which enlarges the bunch of light to form images in the user's eye. Then the user will see the images or movies displayed by the cell phone.

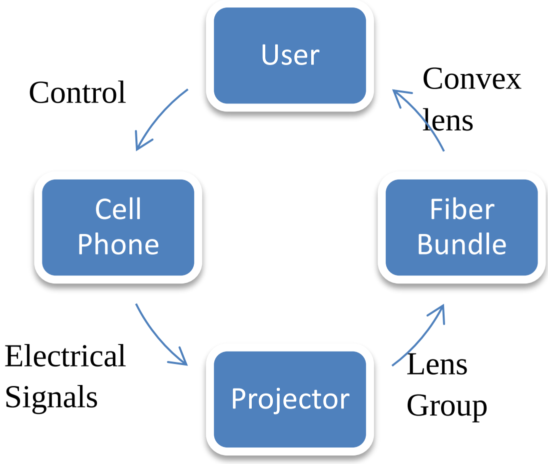


FIGURE 12 : GENERAL CONCEPT

5.1 Overall Structure

Figure 13 shows the overall structure of J-eye. As shown in the picture, J-eye has mainly four parts: projector, lens system, fiber bundle, and convex lens. The projector generates images which are originally displayed in the cell phone screen. The lens system shrinks the images and tapers them into the fiber bundle of 1 mm in radius. On the other end of the fiber bundle, the convex lens generates enlarged virtual images before the user's eye.

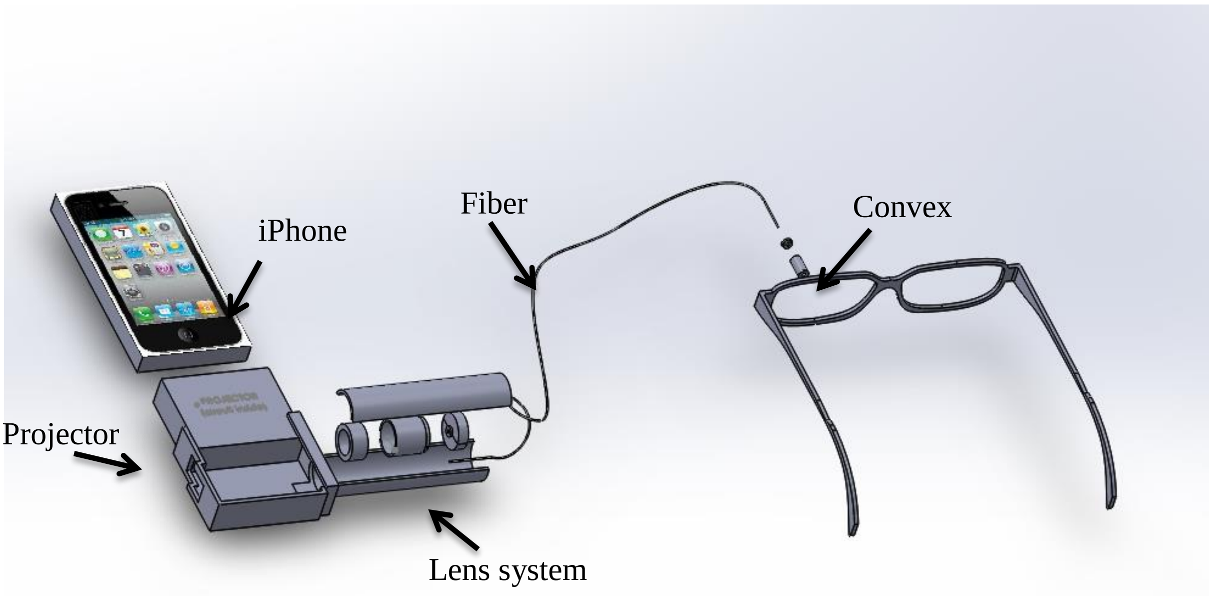


FIGURE 13 : OVERALL STRUCTURE

The picture of prototype is shown below. The prototype is exactly the same with the sketch above, except for the cell phone is replaced by a media player.

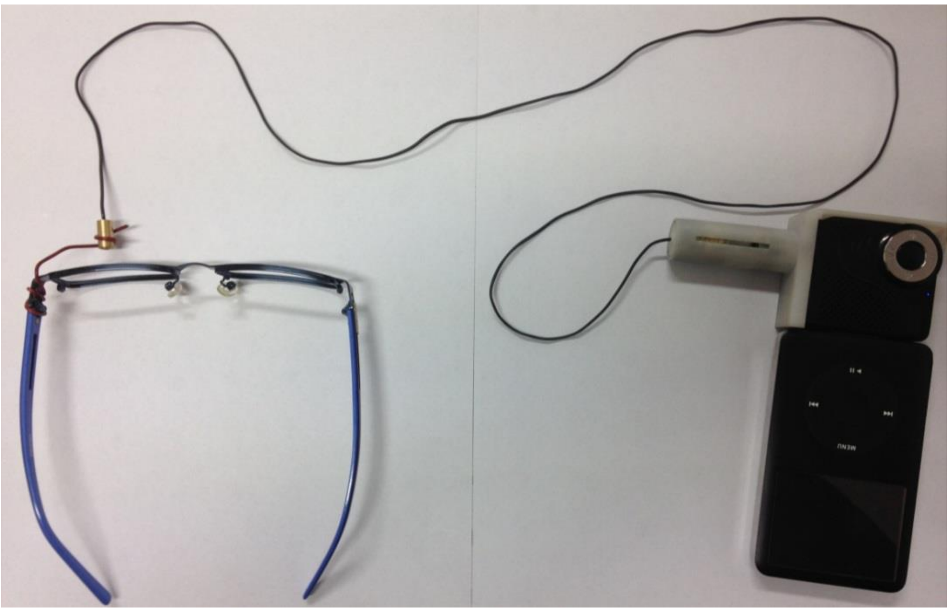


FIGURE 14 : PROTOTYPE

5.2 Projector

Figure 15 is the projector used in J-eye. It is connected to iPhone and generates exactly what is displayed in the screen of the cell phone. It is pretty small, the size is about $57.5\text{mm} \times 48.0\text{mm} \times 16.0\text{mm}$ $(\text{L} \times \text{W} \times \text{H})$, and the weight is about 32 grams. The resolution of this projector is 320 times 240 pixels. (More detailed information attached in appendix D)

FIGURE 15 : PROJECTOR

5.3 Lens System

The lens system is used to shrink the image from the projector and taper it into the fiber bundle. There are two lenses in this system, and the distance between the lenses and the distance between the lens and the projector are required to be very accurate. The structure to fix the lenses is designed by Solidworks and 3D printed to ensure the accuracy. The schematics of the whole system and separated components are shown in Figure 16.

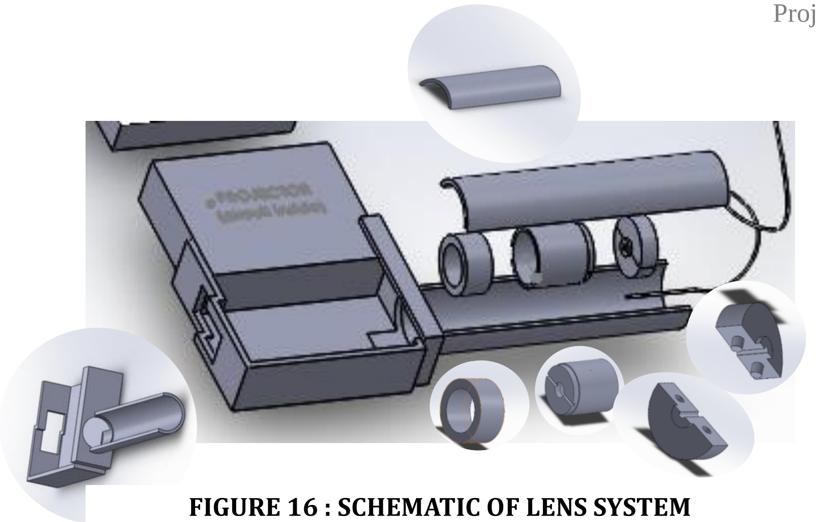


FIGURE 16 : SCHEMATIC OF LENS SYSTEM

FIGURE 17 : LENS SYSTEM

Figure 17 is the lens system part of the prototype of J-eye.
The system is uncovered so that the structure of the lenses can be seen

FIGURE 18 : TWO LENSES IN LENS SYSTEM

5.4 Fiber Bundle

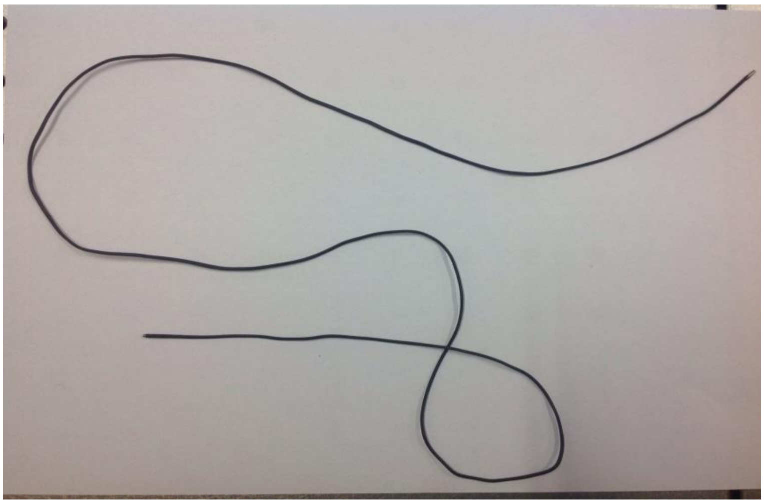


FIGURE 19 : FIBER BUNDLE

Figure 19 shows the picture of the fiber bundle used in J-eye.
Its function is to transmit the image from the lens system to the convex lens.
The radius of the fiber is 0.50mm, and adding the cladding of the fiber the radius becomes 0.60mm.
The detailed information is attached in the Appendix E.

5.5 Convex Lens

Figure 20 is the convex lens which is located on the end of the fiber bundle near the glasses. It generates enlarged virtual images before the user's eye. The fiber bundle is fixed in the outer shield of the lens by plastic steel glue.

FIGURE 20 : CONVEX LENS

6. Manufacturing plan

Manufacturing plan helps the project turning into the real products. All the manufacturing time, and the cost of the project depends on the manufacturing plane. A good manufacturing plan can make the fabricate progress more organized, and the cost of the entire project can be hence reduced. For this reason, an optimized solution for the manufacturing should be found, which is the manufacturing plan.

In this project, manufacturing plan is mainly for mechanical structure.

6.1 Manufacturing plan for mechanical structure

As the manufacture of the mechanical part of the projects requires lots of adjustment, then the traditional mechanical method is not an good choice. Using 3D printer is a better and cheaper way to fabricate the complicate part.

Not like the traditional method, 3D printer doesn't need the annotated design drawing; one 3D model file will provide everything its need. Then the 3D printer has a better tolerance in everywhere than the traditional method. The software used to build the model is Solidworks, which can provide all the functions including simulation, analyzing and assembling.

For choosing the 3D printer, the SLA (Stereo lithography) rapid prototyping becomes the first choice. Not like the FDM (Fused deposition modeling) technology, SLA is much more accuracy and hard. However, the cost of this is relatively higher, 7.5 RMB per gram.

Figure 21 is the manufacture flow for the structure part:

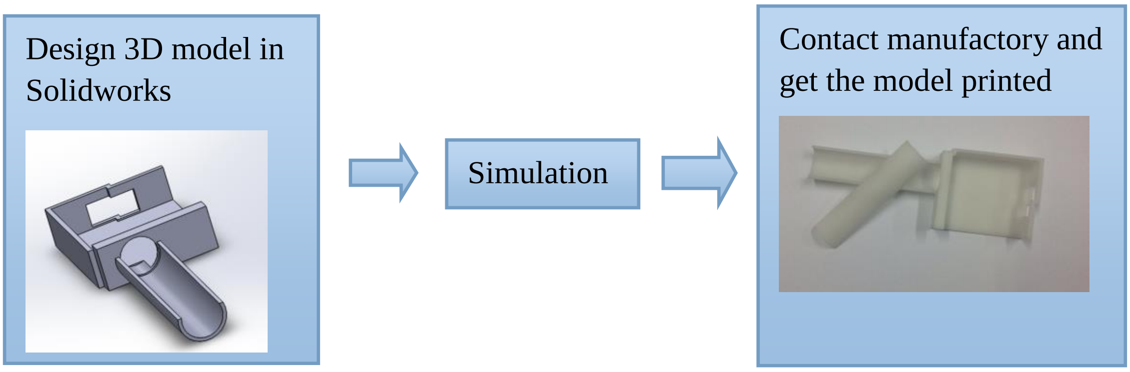


FIGURE 21 : MANUFACTURING FLOW

Table 9 is the list for all the materials used in the project:

TABLE 9 : MATERIALS USED IN J-EYE

Term	Notes	Number
Mobile phone	iPhone 4s	1
Projector	Ruiqi micro projector for iPhone	1
Lens system	objective lens x10	1
	Ball lens φ6	1
Fiber bundle	300x300	1

7. Validation Result

7.1 Field of View

This test is to figure out the field of field of image generated by J-eye to see if it is big enough for users.

The equation to calculate field of view is the width of the image divided by the distance from it to the eye. The method of measuring the width of the image is locating the ruler where it can be most clearly seen when the eye is focusing on the image generated by J-eye, and then read the ruler to get the result. By maintain the ruler, the distance between it and the eye is measured. Then the field of view can be calculated by the equation.

The outcomes are 0.1, which is big enough for the user to catch the image. In fact, it would be better if the field of view is larger. However, as the budget and the quality of the components are limited, 0.1 is almost the limitation that can be achieved.

7.2 Weight

This test is to measure the weight of the components on the glasses to check out if the product reaches the goals set in previous report to make sure it would not be uncomfortable to wear.

A balance is used to measure the weight, which is the weight of the components fixed on the glasses. As for the total weight of J-eye, it is not considered necessary since the total weight is the weight of the glasses part added by the projector, which is in close attach to the cell phone and does not add to the weight of the glasses.

The weight of the glasses part is 23.5 grams as determined in the design review 2. 23.5 grams is not too large to make the glasses very heavy to wear while it enables J-eye to have adequate components to achieve its fundamental functions.

7.3 Radiation

This test is to whether J-eye produces noticeable electrical radiation nearby. If not, it is considered to do no radiative harm to users.

Since the approach to the equipment of measuring the radiation is hard and the accurate measurement is not necessary. A simple method is selected to finish the measurement. It is locating a radio near J-eye (around ten centimeters in distance) in a room isolated from electrical radiation and set the waveband of the radio to AM, and if the radio does not produce obvious noise, it is believed that J-eye is non-radioactive.

The result is that the radio does not detect any obvious noise when located 10 centimeters beside J-eye's glasses part. The definition of obvious is hearable when standing just nearby the radio.

7.4 Comfort Level

This test is to figure out whether J-eye is comfortable for long-term use.

A tester will wear J-eye for a whole day to check out whether wearing J-eye brings any tiredness, discomfort in eyes or impact on the user's view.

The comforting levels are shown in the diagrams in Table 10 in the next page:

TABLE 10 : COMFORTING LEVELS

Score	Tiredness	Discomfort in eyes	Impact on view
4	> 24 hours	> 24 hours	Not apparent at all
3	> 12 hours	> 12 hours	No apparent impact on daily life
2	> 2 hours	> 2 hours	No impact on the way to work or school
1	> 1 hours	> 1 hours	Able to walk
0	< 1 hours	< 1 hours	Not able to walk

The evaluation is made from the total score, as shown in Table 11:

TABLE 11 : EVALUATION OF COMFORT

Total Score	0 - 4	5 - 8	9 - 12	13 - 16
Evaluation	Suffering	Uncomfortable	Normal	Comfortable

The expected score is 7, which means wearing J-eye is acceptable, but ucomfortable in daily life, maybe it is not comfortable to wear it all day long.

7.5 Robustness

This test is to figure out the robustness of J-eye.

Several tests should be made for figuring out the robustness. However, since the manufacture of the design is not available by now, it is not possible for us to reach the bound of robustness of J-eye. The tests mainly focus on whether J-eye is robust in some fundamental levels.

The tests are shown in the diagram in Table 12 in the next page:

TABLE 12 : ROBUSTNESS

Score	Safe falling height	Duration	Adaption in different circumstance
4	> 1.7m	> 2 weeks	In all conditions
3	> 1.4m	/	Except for shaking
2	> 0.9m	/	Added that wetness breaks it
1	> 20cm	> 1 week	Added that bad weather breaks it
0	< 20cm	< 1 week	All above breaks it

Since the time for long-term use testing was limited, the longest period is only about 2 weeks. If the long-term use score is below 4, it is count as 1.

TABLE 13 : EVALUATION OF ROBUSTNESS

Total Score	0 - 4	5 - 8	9 - 12	13 - 16
Evaluation	Caution	Weak	Normal	Robust

The score is 6, which means it is not very durable with bad conditions.

7.6 Adjustability

This test is to figure out whether J-eye is able to be adjusted to fit users with different physical features, such as pupil distances, distance of distinct vision, relative position of eyes and glasses.

Testers of different physical features will be invited to test the adjustability of the design. If J-eye is able to be perfectly adjusted to fit one tester, one test is passed. The rate of pass will be calculated to check out whether J-eye is suitable for all the users.

The outcome is 100%, which means J-eye can be adjusted for all the testers.

8. Project Timeline and Plan

The project has eleven tasks. All the tasks have been separated equally to the five team numbers. A Gantt chart and several tasks are used to show the detailed time plan, as shown in Figure 22 below.

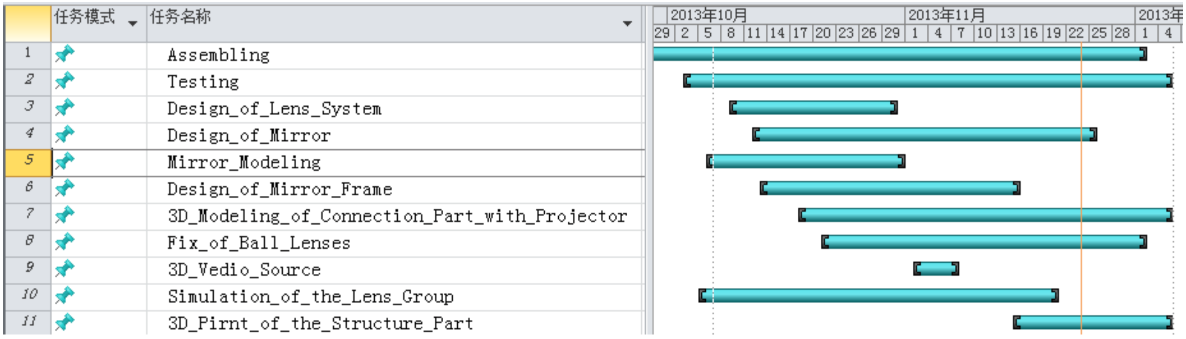


FIGURE 22 : GANTT CHART

A table of deadlines (Table 14) is used to show the completion of work.

TABLE 14 : DEADLINE TABLE

Task	Deadlines
Design of Lens System	Done
Design of Mirror	Done
Mirror Modeling	Done
Simulation of the Lens Group	Done
Design of Mirror Frame	Done
Assembling	12/1'
Testing	12/6'
3D Print of the Structure Part	12/1’
3D Modeling of Connection Part with Projector	12/6'
Fix of Ball Lenses	12/1'

9. Milestones

There are three milestones for the project. Milestone 1 is on October. 20th, Milestone 2 is on November 1st and Milestone 3 is on November 18th. Before Milestone 1, rough video transfers though the lens system with a large lens system. Before Milestone 2, clear video (150*120 pixels) transfers though the system. Before Milestone 3, the whole project can be taken off the lab table and the project is portable. Milestone 4, the project achieve 3D-image.

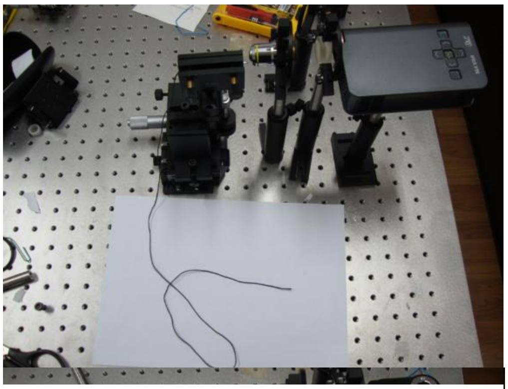


FIGURE 23 : MILESTONE 1

Milestone 1

Lager lens system
Large projector
Rough image

FIGURE 24 : MILESTONE 2

Milestone 2

Lager lens system
Small projector
Clear image

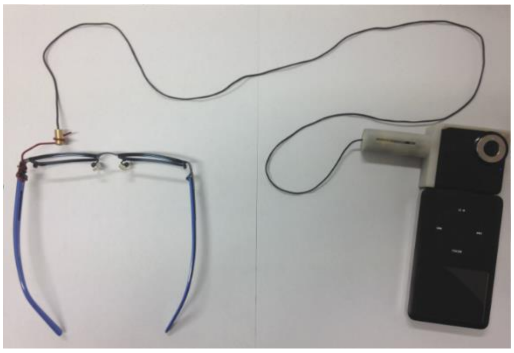


FIGURE 25 : MILESTONE 3

Milestone 3

The system is portable
Small lens system & Small projector are capsuled together.

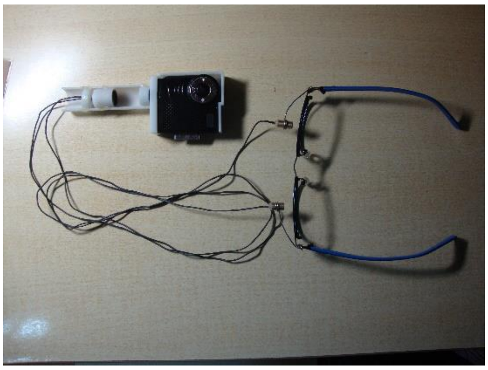


Figure 26: MILESTONE 4(1)

Milestone 4
Two eyes image
3D image

Figure 27: MILESTONE 4(2)

10. Budget

Since the 3D printing and projector are expensive. The budget needs to be well planned. Some of the lenses are from TAOBAO to reduce budget. A table is used to show all the components that might be needed in the project.

TABLE 15 : PRICES OF MATERIALS

Name	Projectors	3D Printing	Lenses	Fiber Bundles	Other objects	Total
Projectors (¥)	500	1200	30	1500	150	3380

11. Analysis of Remaining Problems

- **Problem**: Resolution not high enough for 3D movie

  Analysis: The resolution of the fiber bundle is 18600 (about 150*120). It is imposable for user to figure out the different between 3D-movie and 2D-movie.

  Possible Solution: Change the fiber bundle and adjust lens system. But higher resolution fiber bundle need high budget. Improving the quality of 2D-image will be the main task.

- **Problem**: Out of budget

  Analysis: Fiber bundles and projectors are all very expensive. It has been out of budget.

  Possible Solution: Get financial support from Sponsor.

- **Problem**: The accuracy of 3D print is not enough for the lens system

  Analysis: Because of limit budget, the 3D print is not accurate enough for the lens system. The accuracy of 3D print is often not suitable for the project.

Possible Solution: Files and rotors are used to fix the mistake.

- **Problem**: The drilling machine in the lab is not accurate enough for the project.

  Analysis: A small bin with a 1.8mm diameter hole is needed. But the drilling machine in the lab is not accurate enough for this.

  Possible Solution: Find another lab to drill the hole. It is also can be done with the DG-EAG.

12. Conclusions

The concept of J-eye comes from the recent trend of Head Mounted Display equipment. Tens of HMDs are present in the market. Google Glass, as is well known, showed us a fantastic way of phoning, taking photos, using SNS (Social Networking Services), and other functions which turn up in smart phones. While Google Glass seems to be impressive, it does not meet the most important ones of the the customer requirements. There are some shortages such as inadequacy of movie display function, radiation near head, and so on. J-eye is supposed to achieve the similar functions while getting rid of the weakness of present HMDs. J-eye goes through a different way from most HMDs, and by now it has almost achieved the goal.

In this report, six customer requirements are concluded, and two of them are the most essential ones that must be considered prior. Six corresponding engineering specifications are generated. In the design process, most engineering specifications are met, but there are still problems. The resolution of the product is reduced because of the aberration. This can be solved by better fiber bundles.

The lens system design goes smoothly after the structure of the project is changed. However, the lens in front of user's eyes undergoes big changes during the experiment. It changes from reflection method to directly project images into eyes. Because this part is the interface between the product and human's eye, it does need friendly connection and make sure the user feel comfortable. This part is supposed to be as user-friendly as possible. But due to the lack of related experience, the team only enhances a little bit. This is still the part which has the most refining space.

The mechanical structure changes along with the need for fixing the lens and the fiber. It undergoes several big changes. The most tedious part is to draw it in the Solidworks. Additionally it takes several days to print out. After 3 times feedback and resign, the final version works well.

As for the test and evaluation of the final result, it is easy to find the light weight (less than 30g), radiation-free (absolutely no radiation near head) and portable requirements are well satisfied. The resolution is not very high, which is around (200x200 dpi) due to the distortion in fiber and aberrations in lenses, but it is enough to distinguish people's faces on the screen. Overall, the project is regarded as successfully achieved.

13. References

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2. http://www.google.com/glass/
3. "Electromagnetic fields and public health: mobile phones". Fact sheet N°193. Wold Health Organization. June 2011. Retrieved 5 November 2013.
4. All pictures in table 1 comes from : http://www.beareyes.com.cn/2/lib/201204/25/20120425548_0.htm
5. http://item.taobao.com/item.htm?spm=a230r.1.14.180.Mwb3Ye&id=35355174068
6. http://item.taobao.com/item.htm?spm=a230r.1.14.10.zFBsb9&id=35908895501
7. http://item.taobao.com/item.htm?spm=a230r.1.14.77.Y6UHiQ&id=35481791242
8. All pictures in table 7 are from Taobao.com
9. Figure 3 from :http://www.funsci.com/fun3_en/tele/tele.htm
10. Figure 6 from Kevin K. Tsia's lecture note of MEDE 2009 in Hong Kong University
11. Figure 7 from Kevin K. Tsia's lecture note of MEDE 2009 in Hong Kong University
12. Figure 8 from Kevin K. Tsia's lecture note of MEDE 2009 in Hong Kong University

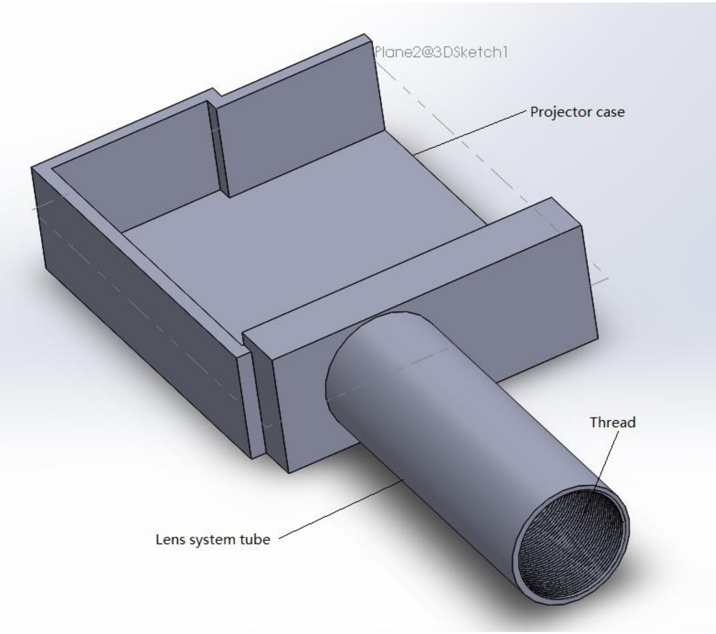
14. Appendices

A. QFD

	Weight (1-10)	Weight	Size	Connecting steps	Resolution	Structure material	Circuit around head	Cost	Our prototype	Benchmark 1	Benchmark 2
Convenient	9	9	9	9	1	3	1	1	4	3	2
Comfortable	10	9	9	9	3	1	1	1	5	4	1
Clear	2	1	1	1	9	1	1	3	3	4	5
Easy to use	4	3	3	9	1	1	1	1	5	4	2
Reasonable price	4	3	3	1	3	3	3	9	3	1	2
Low radiation	7	1	1	1	1	1	9	3	5	1	2
Measurement Unit		g	cm^3		px	g/cm^3		RMB			
Target Value		30	2x3x2	3	300x300	1.04	0	2000			
Total		204	204	220	80	62	100	86			
Normalized		0.21	0.21	0.23	0.08	0.06	0.10	0.09			

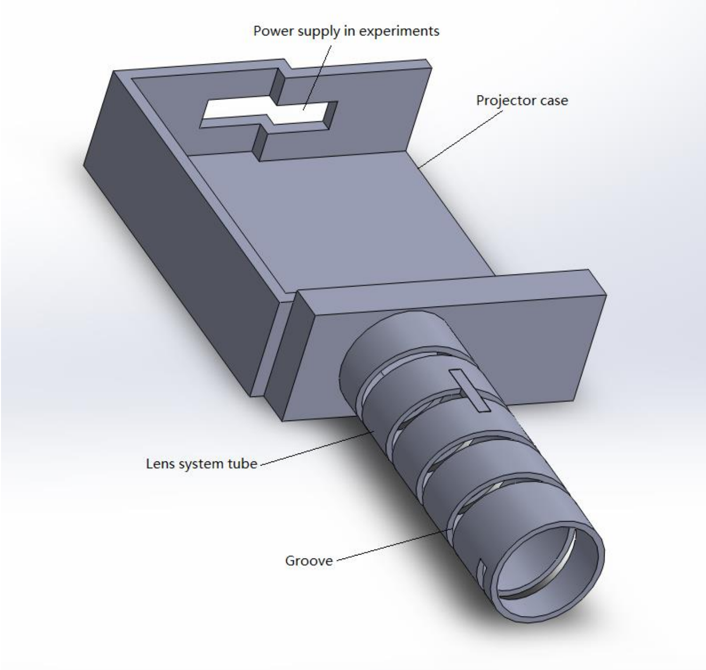
APPENDIX FIGURE 1 : QUALITY FUNCTION DEPLOYMENT

B. Mechanical Structure I



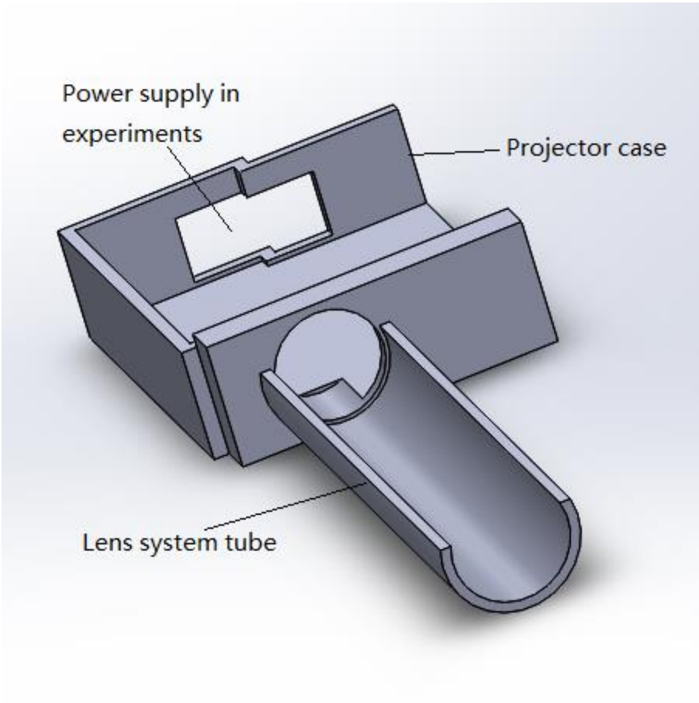
APPENDIX FIGURE 2 : CASE WITH A SIMPLE TUBE

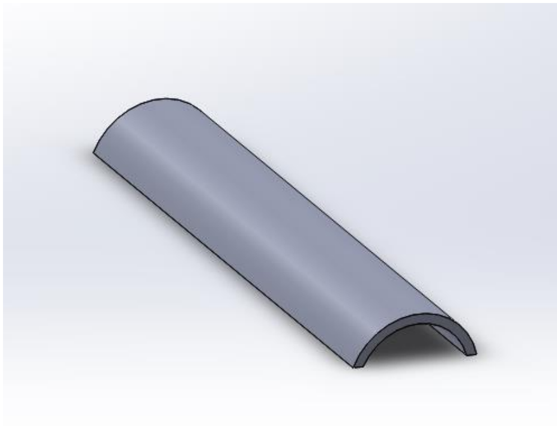
Appendix Figure 2 shows the first design of the image-generation part. It consists of two main components: one is the projector case, and the other is the lens system tube. The tube's inner wall is thread, and it fit the lens cases to adjust the distance between them. The major disadvantage in this design is that the thread is hard to fabricate. The 3D printer could not reach the accuracy it needed.



APPENDIX FIGURE 3 : CASE WITH GROOVE

Appendix Figure 3 is the second version of the image-generation part. Since in the experiments, the projector continues to project images, the power supply from the test iPhone could not last for a long time. In this design, additional power supply can be used with the power supply window on the projector case. The lens system tube's design is also changed. Groove is added and sticks which are attached on lens cases can be twisted in the groove to adjust the distance. However, the shape of the groove reduces the strength of the tube. As a consequence, lens cases could not perfectly put in the proper positions.



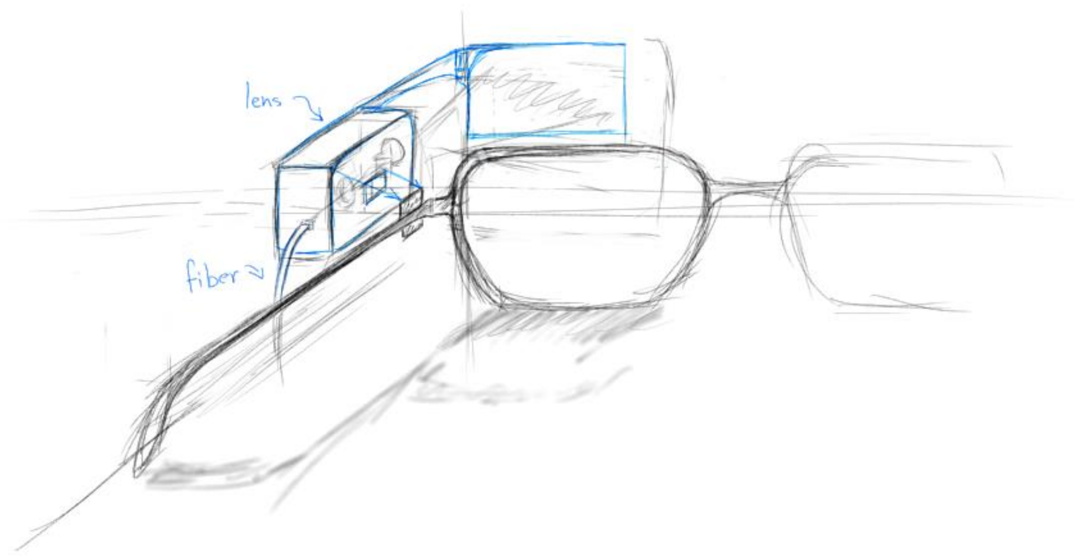


APPENDIX FIGURE 4 : THE CAP OF THE TUBE

APPENDIX FIGURE 5 : CASE WITH HALF OPEN CAP

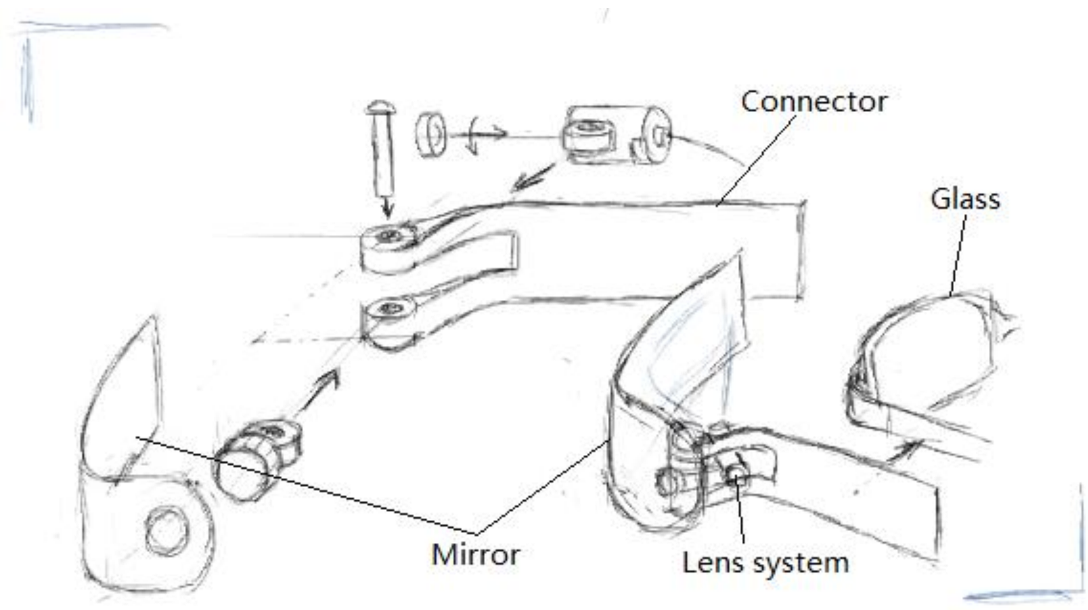
Appendix Figure 4 & 5 are the third version of the image-generation part. This design reduces the complexity of the structure. The lens system tube is cut into two components, and the cap is apart. Lens cases can be easily put in the tube and adjust the distance. Once the positions of lens cases are determined, the cap will cover them and connected by adhesive.

C. Mechanical Structure II



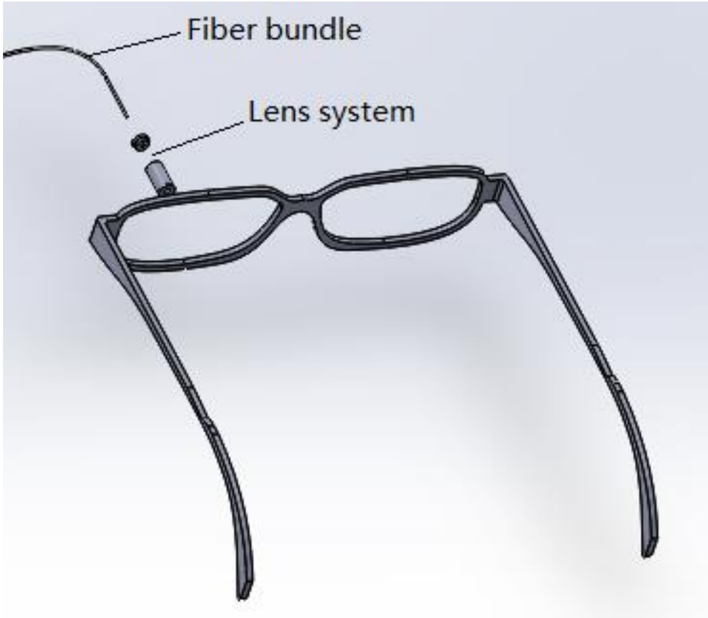
APPENDIX FIGURE 6 : HAND SKETCH 1

Appendix Figure 6 shows the first design of the image-receiving part. There is a big lens case to put then ball lens. A mirror is connected with the case. But it cannot be adjusted easily, so in experiments it is uneasy to test.



APPENDIX FIGURE 7 : HAND SKETCH 2

Appendix Figure 7 shows the assembling sketch of the second version of the image-receiving part. The mirror and the lens system can rotate to adjust the distances and the directions. The mirror even can rotate with two axises. However, this version is too heavy to wear.



Appendix Figure 8 shows the final version of this part. Lens system is simply attached to a glass with a component that can flip (which is not shown in the figure). There is no need to adjust the distance or direction, for the design changed.

APPENDIX FIGURE 8 : STRUCTURE TO FIX THE CONVEX LENS

D. Detailed Information of the Projector Used in J-eye

Description	Multifunctional projector for iPhone		
Dimensions	Color	–	Black，Whit
	Size	–	57.5mm *48.0mm*16mm（L*W*H）
	Weight	–	32 grams
Power	Working voltage，DC5V，supplied by iPhone or other product of APPLE Working current，300mA-450MA，work last for more than 4 hours without charging		
Optics dimensions	LCoS display technology		
	Light source	–	White LED
	Luminance	–	10 lm
	Projecting size	–	From0.3 to 3m 7.5''0.3m----25''1m
	Distortion	–	1.5%
	Resolution	–	320*240px
	Image ratio	–	1.33：1
	Contrast ratio	–	＞80：1
	Duration of lamp	–	＞50000 hours
	Angle of light	–	15 degree
	Color	–	＞40%NTSC

Information from: http://item.taobao.com/item.htm?spm=a230r.1.14.37.TKWpMr&id=13938168622&_u=d1ie1mrocd52&qq-pf-to=pcqq.c2c

E. Detailed Information of the Fiber Bundle Used in J-eye

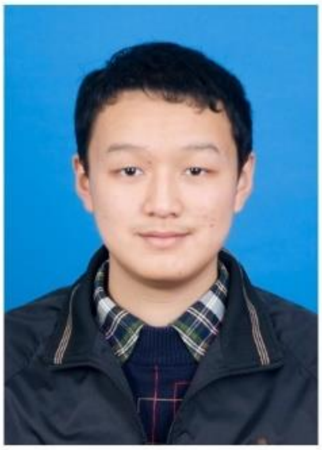
<table>
<tr><th colspan="2" rowspan="4">Type</th><th rowspan="4">Outer diameter (mm) (cladding)</th><th rowspan="4">Length (mm)</th><th rowspan="4">Effective area (diameter, mm)</th><th rowspan="4">Single fiber (pixel) size (u)</th><th rowspan="4">Amount of fiber (within effective area)</th><th colspan="5">Acceptable defect</th></tr>
<tr><th colspan="2">Super</th><th colspan="2">A level</th><th>B level</th></tr>
<tr><th colspan="2">Single*</th><th colspan="2">Single*</th><th rowspan="2">Nearby**</th></tr>
<tr><th>Total</th><th>Black</th><th>Total</th><th>Black</th></tr>
<tr><td rowspan="2">I</td><td>Ia</td><td>0.57 (0.75)</td><td>840</td><td>0.49</td><td>6.4</td><td rowspan="2">5400</td><td rowspan="2">3(0)</td><td rowspan="2">1(0)</td><td rowspan="2">4(2)</td><td rowspan="2">2(1)</td><td rowspan="2">2</td></tr>
<tr><td>Ib</td><td>0.66(0.85)</td><td>840</td><td>0.57</td><td>7.4</td></tr>
<tr><td colspan="2">II</td><td>1.00 (1.20)</td><td>840</td><td>0.92</td><td>7.4</td><td>14000</td><td>4(0)</td><td>2(0)</td><td>8(3)</td><td>3(1)</td><td>4</td></tr>
<tr><td colspan="2">III</td><td>1.75 (2.00)</td><td>1350,1650</td><td>1.60</td><td>10.0</td><td>23500</td><td>6(0)</td><td>3(0)</td><td>12(4)</td><td>5(2)</td><td>6</td></tr>
</table>

15. Bios

Zhang Bo is a senior student in Shanghai Jiao Tong University Joint Institute, majoring in Electrical and Computer Engineering. Outstanding in academics, he worked as teacher assistant four times and won scholarships every year. Fascinated in optics and physics, he has positively participated in several optics related research projects in his previous undergraduate study. Through these experience, he accumulates solid understanding of principles of optics and the ability of high-efficiency teamwork.

He so dedicated to the proposition that benefiting human being is the both primitive motivation and ultimate goal of doing research. He also deeply believes optics technologies, which develops so quickly in recent years, still has strong potential benefit to be exploited to serve for humans. The digital technology is pretty mature and once it combined with optics, brilliant products might be invented. He admires Steve Jobs and has the ambition to make a difference, and he wants to design something can really cool and revolutionarily change people's life.

Motivated by this idea, he decides to practice what he preach and devote himself to this project "J-eye: Head Mounted Display Device". He is an excellent leader, who is applauded for his easygoing and creative thinking. Whenever new difficulty appears, he can always stay in a cool mind, calmly analyze the problem, and finally come up with solutions.



Xu Daxiao is a senior student in Shanghai Jiao Tong University Joint Institute, majoring in Electrical and Computer Engineering, minor in Economics.

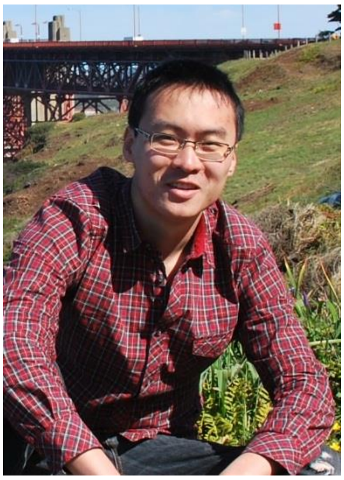
He was the candidate winner of the second price of Contemporary Undergraduate Mathematical Contest in modeling (6.5 teams out of 100 teams). He finished two SJTU's Participation in Research Program, which needs operational ability.

He joined the J-eye project because of his good operational ability and originalities. He want to make people's life better. He believes J-eye will become a product in the market J-eye could improve living quality by making people enjoy watching 3D-miove.

Zhang Haiyue is a senior student in Shanghai Jiao Tong University Joint Institute, majoring in Electrical and Computer Engineering. He was from Shandong Province, planned to be an electronic engineer or software engineer when graduated from SJTU.

He finished several projects during previous academic life and showed great interest in designing and making product. A most enjoyable one for him was a coin saving machine in freshman year that had the counting function and could push out certain amount of money according to the number typed in by the user.

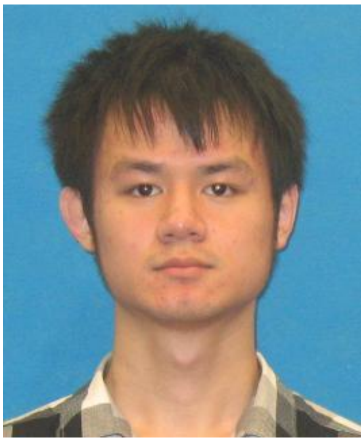
He was very interested in the J-eye project since it was really popular at the moment and even more popular in the future. He thought the project was to try to build a product that only appeared in fictions fifteen years ago and that was really amazing. He would pay great effort in J-eye project.



Zheng GONG is a senior student in Shanghai Jiao Tong University Joint Institute, majoring in Electrical and Computer Engineering. He always has great passion in all kind of researches and competitions. He is also the winner of the 2013 national intelligent car race.

He considers the ultimate goal of studying and doing research is to benefit human beings. He also deeply believes knowledge becomes powerful only when it is related to the real world. He cares about the people and world around him, and he wants to design something that can really change people's life.

Motivated by this idea, he decides to devote himself to this project "J-eye". He is an excellent member in this team. When the team is facing difficulties, he can always stay calm and find ways to overcome all the problems.



Peng Xuesong is a senior student in Shanghai Jiao Tong University UM-SJTU Joint Institute, majoring in Electrical and Computer Engineering. Always being top in his class, he won scholarships every year. He has been involved in several research projects in his undergraduate study. The experience helps him to gain self-study abilities and cooperation abilities.

He think engineering is the field in that he can learn brand new knowledge, he can fully take advantage of what he has learned, and he can make a positive effect on people's lives. Especially, engineering can convert a shining idea to reality very soon and benefit people's lives, which he deeply believes in.

Motivated by this faith, he decides to devote himself to this project "J-eye: Head Mounted Display Device", that can benefit people in visual experience. He is a nice team member. He can always work well with other members.