Safe Method to Teach Fluoroscopy During Surgical Simulation

Design Description Document

Customer: Dr. Ahmed Ghazi

Faculty Advisor: Dr. Greg Schmidt

Katie Armstrong (Project Coordinator)
Nora Lane (Customer Liaison)
Chih-Hsuan Tsao (Document Handler)
Joseph Kelly (Scribe)

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Authentication Block

REVISION HISTORY

Rev	Description	Date	Authorization
A	Initial DDD	1-20-2018	KA
B	Second DDD Review	2-7-18	KA
C	Third DDD Review	2-21-18	KA
D	Midterm Review DDD	3-2-2018	KA
E	Fifth Midterm Review	4-9-2018	KA
F	Sixth Midterm Review	4-25-2018	KA
G	Final DDD	5-6-2018	KA

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TIMELINE

Before Spring Semester	• Learn LightTools • Research new sample materials
January	• Test new and researched materials • Begin working with mechanical engineering senior design team
February	• Finalize sample material for “tissue” • Finalize design specifications
March	• Finalize cost • Begin building • Begin testing • IA presentation
April	• Finish building • Finish testing
May	• Present at design day • Have final customer meeting • Return all materials borrowed or purchased by the customer • Submit all documentation for this project

VISION

The product is a near infrared (NIR) imaging system prototype that can be used in surgical simulations to accurately replicate the current technology of fluoroscopy using NIR light in place of X-Rays. The design includes an optical illumination and imaging system that must image through DMSO or other customer approved material and a display to show real time results. A Mechanical Engineering Senior Design Team will simultaneously work on a mechanical C-arm prototype that houses the optical components. Performing these practice surgeries gives the surgeons a much higher rate of success, and this project will allow them to perform these practice surgeries in a safer environment. This design is intended to be reproducible and cost efficient.

PROJECT SCOPE

Our responsibilities include: designing and testing the optical system, working with our customers to select the best materials, and constructing a functioning optical prototype of the system.

We are not responsible for: making the sample material, creating a functional mechanical prototype.

SYSTEM DESIGN

Optical Design Specifications

Required Specifications	
Parameter	**Requirement**
Diameter of Sample Illuminated (cm)	10-15
Minimum Depth of Sample (cm)	10
Maximum Depth of Sample (cm)	$\geq$ 25
Source	
Wavelength (nm)	850
Camera	
Frame Rate	$\geq$ 30 fps
Minimum Feature Size	~ 1 mm
Camera Lens	
Focal Length	25 mm
F/#	1.4
Angular FFOV	24.3 degrees

Note: The Sample mentioned above is the block of material that is used to mimic the human body

Mechanical Design Specifications

Distance between light source and table	45cm
Size	Tabletop

Arm Rotation	30 degrees roll ± 15 degrees pitch
Power Source	Outlet Power

Current Layout

Illumination Design

Listed in the table below are the components being used in the illumination system and their specifications. An important note is that the NIR LED Array chosen for this illumination system had a diffuser built into it. As a result, the final design does not include a diffuser. If a different LED Array is ever chosen, a diffuser may be necessary.

Component	Parameter	Value
Fresnel Lens	Size	11’’ x 11’’
	Material	Acrylic
	Focal Length	18’’
	Weight	0.886lbs
LED Array #1	Diameter	6 cm
	# of LEDs	4
	Power	~4 mW
	Full Angular Spread	24 °
	Weight	6.4 ounces
	Wavelength	850 nm

As this design needs to be cost efficient and easily reproducible, we have decided that the test illumination design should consist of one fresnel lens in order to minimize the cost and number of parts of the design. The diffuser built into the NIR LED Array spreads the light from out so that it illuminates a wider area, which the fresnel lens then focus onto the camera sensor.

In order for the illumination to match with the imaging design, the angular spread after the sample needs to be converging in order to image properly. A 6.18 degree angle to match the acceptance angle of the camera detector was used. This was then traced back through the sample and it was determined that the lens needs to have a diameter of at least 26cm. This is why a fresnel lens was chosen, as it provides a cheaper lighter option than a traditional lens for the size and focal length needed.

The illumination design was done by treating the image as an object and imaging it through the system. So the "image plane" is referencing where the lens images the built-in diffuser. The illumination by design overfills our system so there is an even illumination. The design constraints are an illumination diameter of 15cm maximum and 10cm minimum on the rear surface of the sample, our design used 15cm diameter.

Fold mirrors will be added in the final mechanical design to make it more compatible with the mechanical engineering prototype.

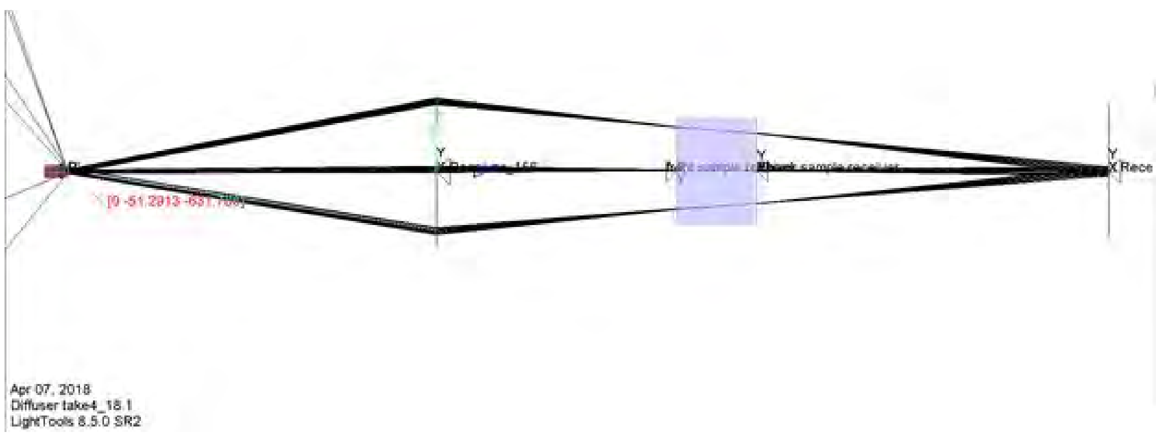


***Figure 1**: The design consists of an LED array, a diffuser, a fresnel lens, and a sample under test.*

Parameter	**Length**
Diffuser to Fresnel Lens	43.93 cm
Focal Length of Fresnel Lens	34.5 cm
Fresnel Lens to Sample	45 cm
Sample Length	15 cm
Index of Sample	1.4
Image Half Field of View	6.18 degrees
Sample to Image Plane	69.2 cm

***Note**: Dimension inputted into Light Tools in the simulation shown. The math to determine the lengths and the chosen lengths are described in Appendix D.*

The rays traced in this image are backtraced through the design to make sure that the aperture of the camera will accept the light coming from the LED. The ray bundles must match for each point of the sample in order to make sure that points from all areas of the sample that are being illuminated will reach the detector. According to the simulation, the light that will be accepted by the camera comes from a very small area of the LED, but all areas of the sample will be seen by the detector. This shows that the design is losing light, but this problem can be solved by decreasing the size of the LED and diffuser.

Object	Specification (As Modeled)	
Fresnel lens	Length x Width	11” x 11”
	Focal Length	18” = 45cm
	Material	Acrylic-PMMA
Diffuser	Elliptical Gaussian	80% Gaussian, 20% Diffuse
	Gaussian Spread Half Angle	50 Degree

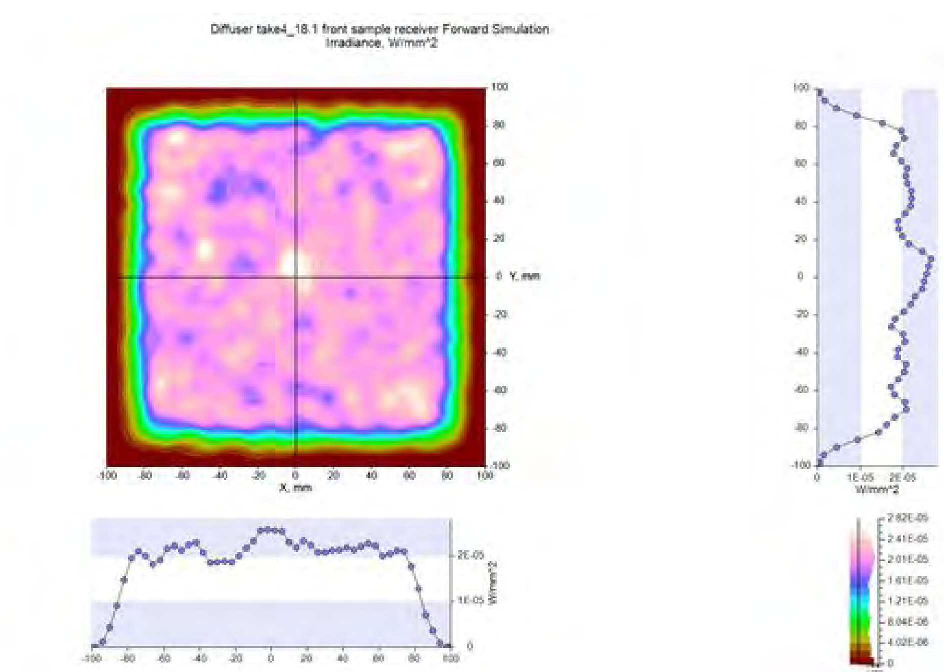


Figure 2*: Shows the Irradiance at the top of the sample. The illumination is even across the sample. The total power incident on the detector is 2.876W. This image shows a 20cm by 20cm sample range, when the area illuminated only has to be even within a height and width of 14cm.*

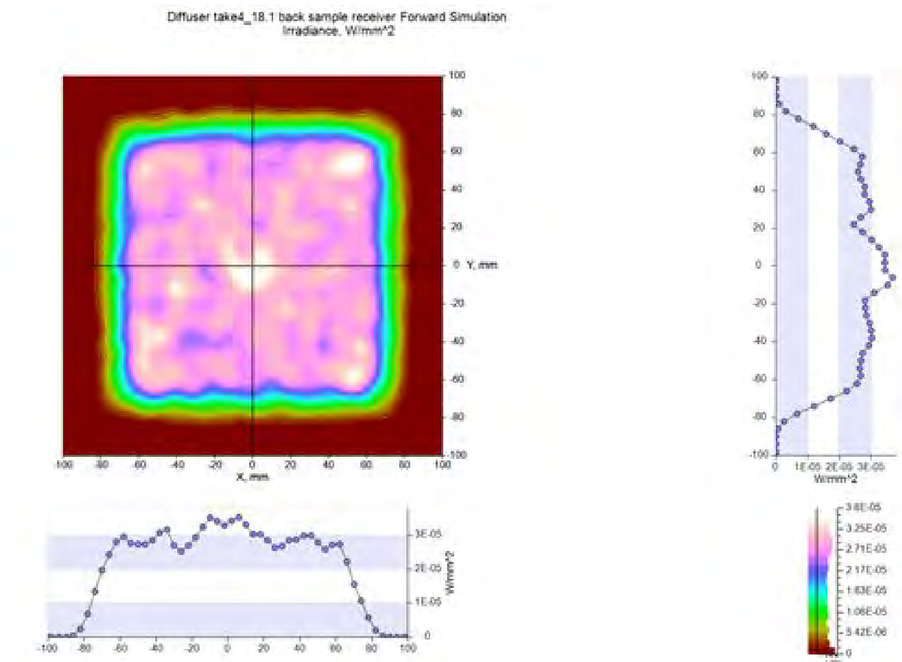


***Figure 3**: Shows the Irradiance at the bottom of the sample. The illumination is even across the sample, and shows how the sample will cause the light to converge. The total power incident on the detector is 3.017W. This image shows a 20cm by 20cm sample range, when the area illuminated only has to be even within a height and width of 10cm.*

Surface	**Power Received on Detector Surface**
Emitting from LED	17.7 W
Front Surface of sample	2.9 W
Rear Surface	3.0 W
Image Plane	3.37 W

***Note**: The power looks to increase as it goes throughout the system. We think this is because the detectors built into our Light Tools program are not big enough. The light is converging, so the light that did not hit the detectors may converge so they are the proper height to be measured into the power.*

Potential Future Plans in Illumination Design:

1. Introduce camera into LightTools simulation
2. Introduce optical properties of sample in LightTools
    a. How to obtain these coefficients discussed in the material testing section.
3. Introduce new materials to be embedded in the sample.
4. Propose future designs, such as expanding on the lens array mentioned in Appendix E.

Imaging Layout

The specifications for the imaging lens being used were presented in the main "Current Layout" section. To summarize: the lens being used is the Navitar NMV-25M23, which is part of the company's Machine Vision - 2/3" Format Lenses Line. It has a focal length of 25 mm, FFOV of 24.3°, and an F/# of 1.4. This lens was originally purchased by Dr. Ahmed Ghazi's group from ThorLabs before the senior design group was assigned.

It was decided that the performance of the lens was satisfactory enough to be used during this project. Given that price is a major concern, having to re-purchase another lens would have also been undesirable. ThorLabs only provided a basic closed system diagram and lens transmission diagram.

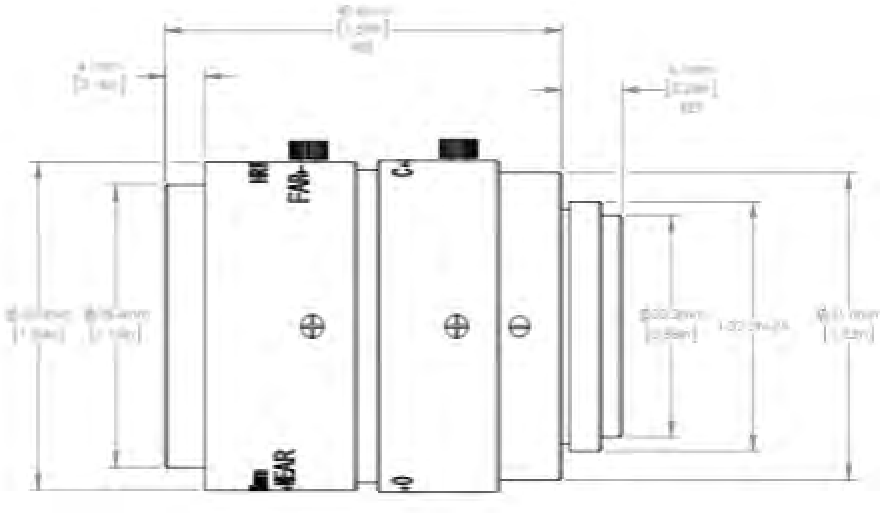


Figure 4*: Shows diagram of the lens provided by the ThorLabs website.*

While the lens itself was designed for the visible light range, at 850 nm (the wavelength needed for this project) the data lists the lens at 70-80% transmission.

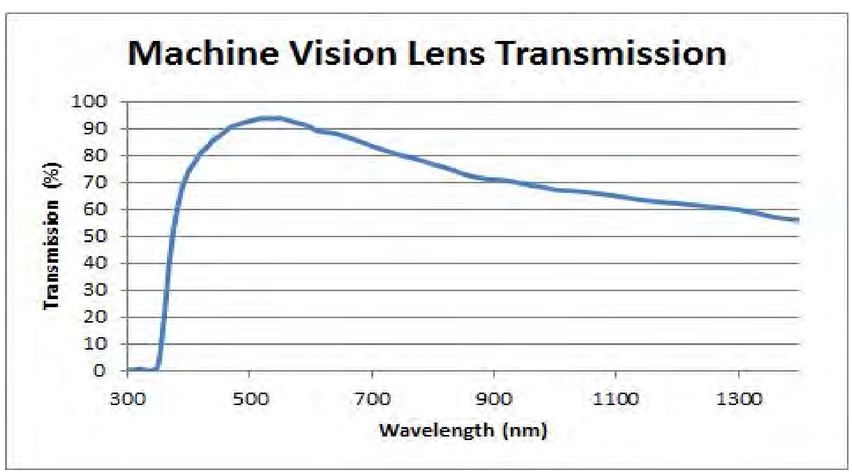


Figure 5*: Shows the transmission of the lens being used. For our wavelength (around 850 nm), there is about 75%-80% transmission.*

To obtain more data on performance metrics, we contacted Navitar: the original designers and manufacturers of the lens. They sent a “Black Box” Zemax file. Some of the more useful optical data is provided below.

The diagram illustrates the Ray Aberration curves for the fields. Astigmatism and distortion are the two primary aberrations. Please note that data is only provided for Configuration #1. Configuration #2 and #3 came with the “Black Box” file, but provide data for the ⅓” and ½” version of this lens. As mentioned, we are using the ⅔” configuration.

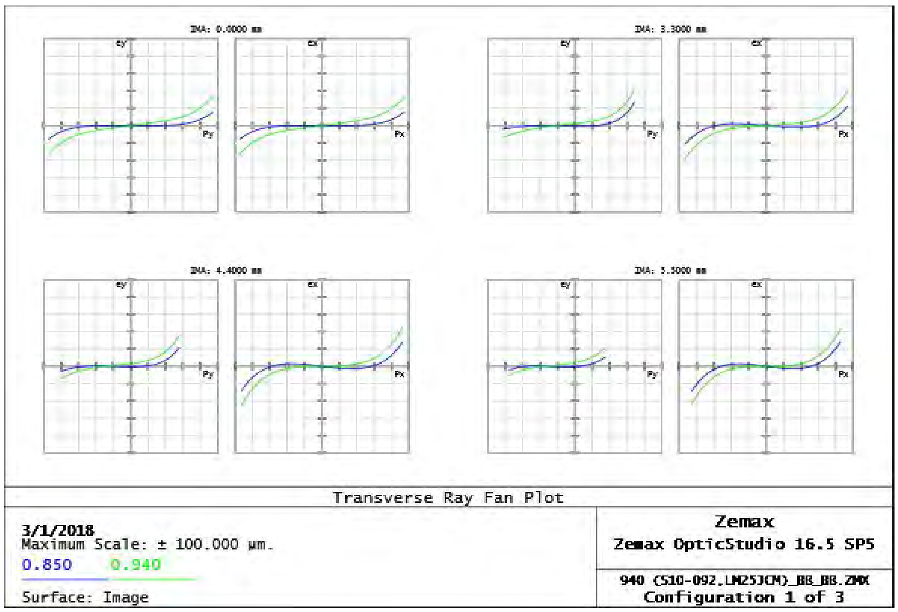


Figure 6: *Shows the Ray Aberration Curves for 4 different field points.*

The smallest resolvable feature size is 0.5 mm, which, on the MTF graph, corresponds to 1 cycle per mm, so the MTF requirement for this project is low. The MTF graph is shown below.

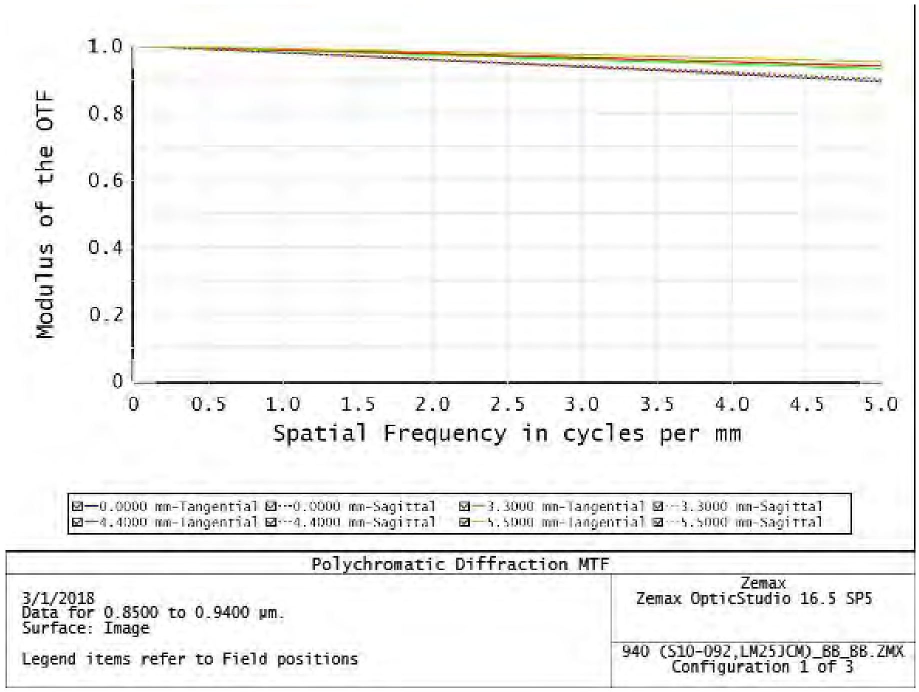


***Figure 7**: MTF data up to 5.0 cycles/mm (the smallest feature size is 0.5 mm).*

In the spot diagrams for the lens we see that the further off-axis the image gets, the worse the spot is. When paired with the illumination design, however, this is not as much of a concern. A relatively low input angle is being used, and the device itself will be able to rotate across the field in order to image different points/

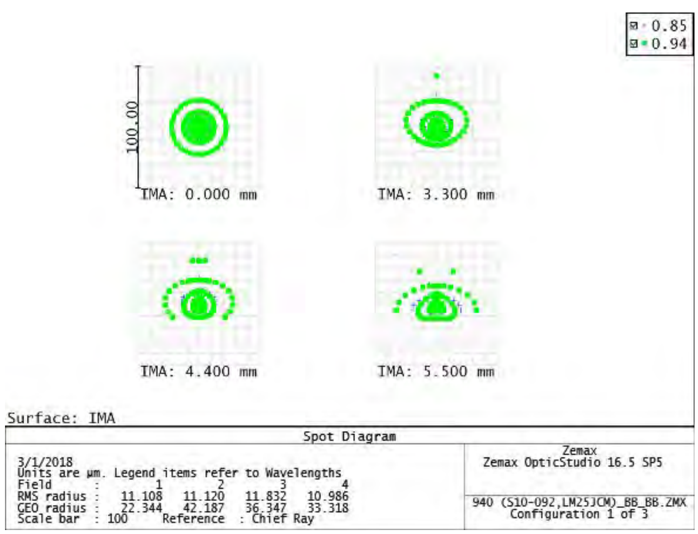


***Figure 8**: The spot diagram for 4 different field points. The spot is rather large, but mostly for off-axis field points.*

More detailed specification data from the Zemax file are listed below. Note that these specifications differ from the ones listed on the ThorLabs website, and may further differ if any manufacturing errors exist.

Lens	**Specification**	
Navitar NMV-25M23 2/3" Format Machine Vision Lens	Effective Focal Length	25.4959 mm
	Image Space F/#	1.46
	Entrance Pupil Diameter	17.46293 mm
	Angular Magnification	0.331074
	Length	55.0080 mm
	Weight	0.23 lbs

Camera	**Specification**	
Blackfly 1.3 MP Mono USB3 Vision (Sony ICX445)	Pixel Size	3.75 µm x 3.75 µm
	Sensor Size	4.86 mm (H) x 3.623 mm (W)
	Frame Rate	30 FPS
	Lens Mount	CS-mount
	Weight	~0.08 lbs

Mechanical Layout

A team consisting of members Devin Marino, Ariana Cervantes, Ryan McEvoy, and Gina Bolanos will complete the design for the mechanical C-arm.

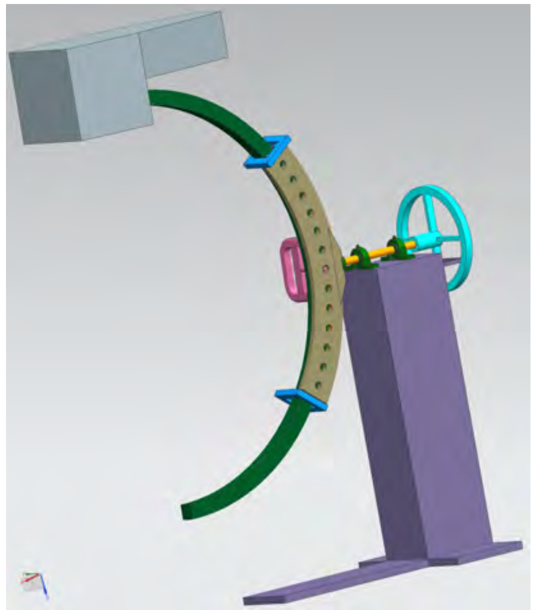


Figure 9: *Current CAD design of the c-arm.*

The design in **Figure 9** includes a roller and sleeve with spring support mechanism and spring-loaded pins in the handles. The design shows a "track" design to hold the C-arm in place. The green inner member can move within the yellow outer member to rotate the optical system at 5 degree increments. Further design information is included in the Mechanical Engineering Preliminary Design Review.

Figure 10: *The above pictures show the parts for the mechanical engineering team's prototype c-arm design, before assembly.*

SAMPLE MATERIAL STUDY

***Note:** Materials chosen can be tested for scattering and absorption by shining a laser with the correct wavelength used and measuring the power before and after the sample. This is mentioned in the Illumination section. This was not done for our design because we changed materials often, and it was more important for us to find a material that worked than to perform an in depth study of a material. This can be done in the future if the material is finalized.*

SAFETY OF DMSO

According to Dr. Ghazi's team, DMSO absorbs very quickly into the skin when not handled with protective gloves. While this is not harmful by itself, it also absorbs any harmful materials into the body with it that the epidermis may normally block. As such, one should always use protective gloves whenever handling the DMSO. Further material on the safety of DMSO in Appendix B.

DMSO (Dimethyl sulfoxide)

All testing has been done with 940-nm light, as this was the wavelength of the source provided by the customer.

DMSO has been chosen since it is optically clear, provides high image quality, and also gives a skin-like texture when mixed with water and PVA. After the material is chosen, different concentrations of DMSO samples are tested to compare the image quality and how well it replicates the feeling of human skin. The three concentrations that were tested are 25%, 50%, and 75% DMSO (x% DMSO, (100-x)% water, and extra 5% PVA).

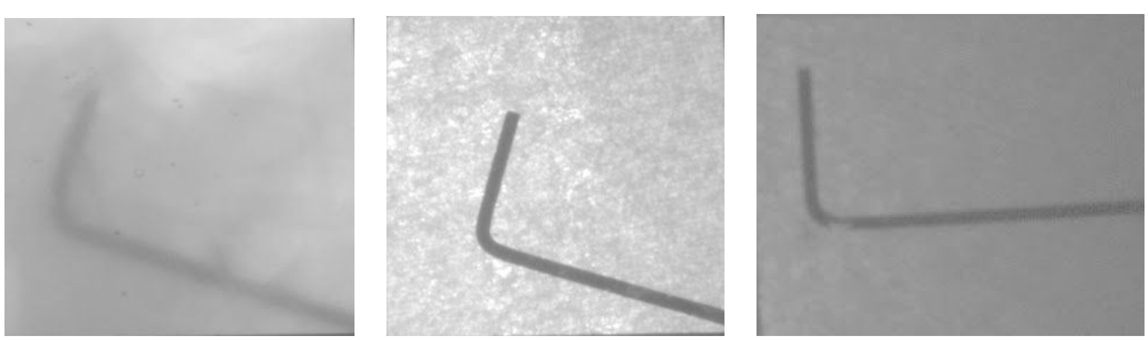


***Figure 11:** Left to right: 25%, 50%, and 75%. The samples are approximately 1cm thick and the object being imaged is 1mm thick. Sample imaged with paper towel over to decrease the saturation of the image.*

As one can see, low concentration DMSO sample produced poor image quality. However, the texture of low concentration sample is closest to human skin. After discussing with our customer, the decision was to use 40% sample since it feels the most skin-like while maintaining the optical properties necessary .

Another issue with DMSO is that it will fog when in contact with water. However, this has minor effects on image quality and the problem was solved by storing the samples in DMSO solutions. The sample also shrank significantly over time when stored in DMSO solution. This is a problem, but can be minimized since the samples made will be used in a timely manner.

Thicker Samples

When the thickness is increased, the image quality was not affected much and our customer was satisfied.

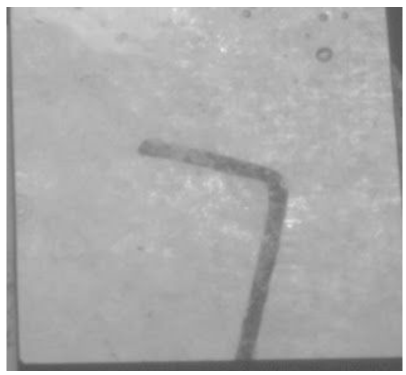


Figure 12: *10x 1 cm slices of 75% DMSO. The item being imaged is 1mm thick and placed on top. A sheet of paper towel was placed over the sample to decrease the saturation of the image.*

Dyed Samples

Another problem with DMSO is that since it is clear even under visible light, the surgeon will be able to see through the sample with naked eye . To prevent this, food coloring or dye is added to the samples. NIR wavelengths can still penetrate the dyed samples, but visible wavelengths cannot. The red and purple dyes tested are used in the current simulations.

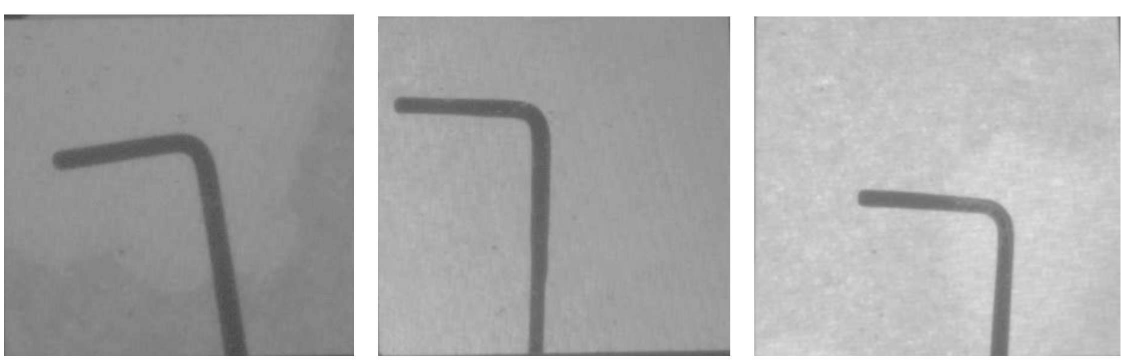


Figure 13: *Left to right: purple dye, red dye, and green food coloring. 75% DMSO sample is approximately 1cm thick and the item being imaged is 1mm thick. Sample imaged with paper towel over to decrease the saturation in the image. Red and purple dye are currently being used by our customer.*

All three colored samples were near opaque under visible light and maintained good image quality under NIR. However, the green food coloring started to come off over time. Thus, the dyes are a better way of obscuring the sample than the food coloring. Another solution would be to add a "skin layer" on top of the samples. Currently Dr. Ghazi's group is using a "cotton layer" and they also suggest using bed sheet. Both samples showed promising results and we decided to stay with cotton since it has been what Dr. Ghazi's group is using.

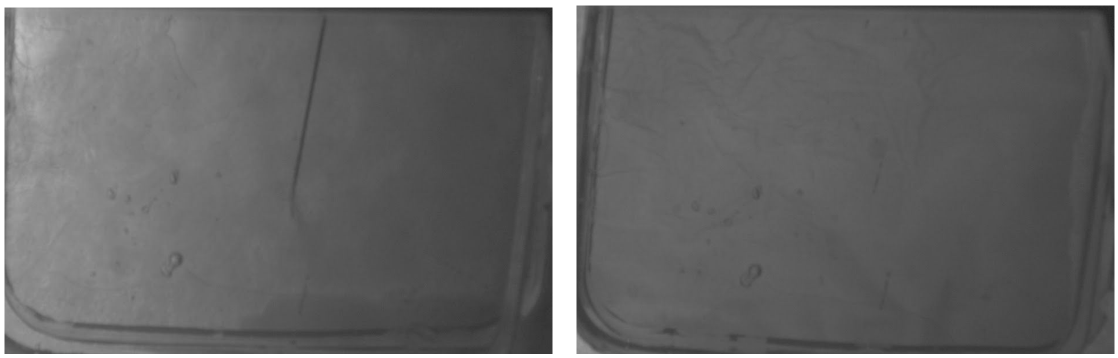
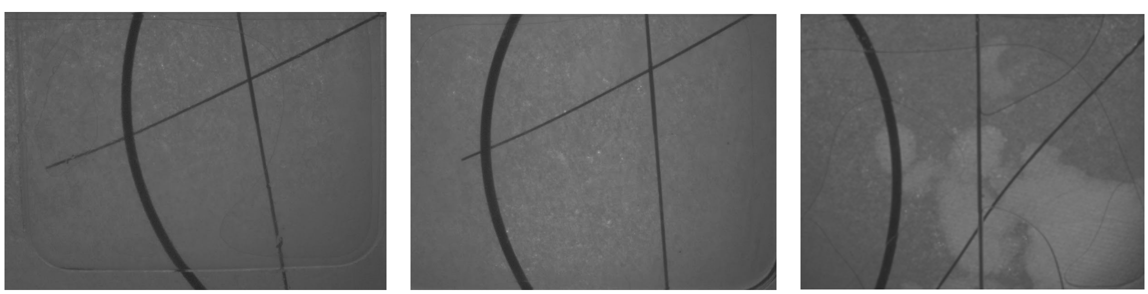


Figure 14: *Left: cotton with needle. Right: bed sheet. Both are optically clear under NIR and can be used as the skin layer.*

Other Materials: Needle and Kidney Stone Material

In this section, the tools that will be used during the surgical training and material that will be used to 3D print the kidney stones are imaged. For each image in Figure 14, the needle is the thin line placed vertically through the center of the sample; the wire is the thin line at an angle across each image, and thicker black strip is a sample of the material used to simulate the kidney stones.



1 cm purple dye **1cm red dye** **3 layers of 1 cm, no dye**

Figure 15: *All samples are 75% DMSO. In the 3 layer sample, we placed the needle underneath the first layer, while the other two samples were placed on top, so we could perform a preliminary test for objects at varying depths. All three objects appeared very clear when imaged under various conditions.*

Current Testing Setup

Besides the c-arm that will hopefully be delivered by the mechanical team at the end of the semester, we designed a basic test setup that can hold all the parts in place but will not rotate. Special thanks to John Miller from the machine shop who helped us built the setup. This set-up and any future testing uses the 4 LED Array with 850nm mentioned in Illumination Design section.

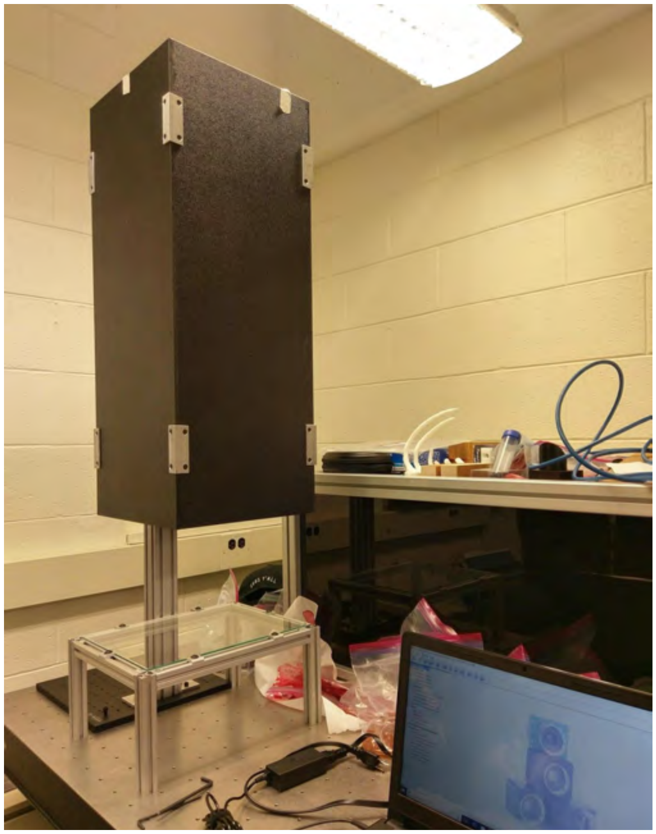


Figure 16: *Current testing setup. The black box holds the light source, diffuser, and the fresnel lens. The height is adjustable.*

With this setup, an image is taken and shows promising results as expected.

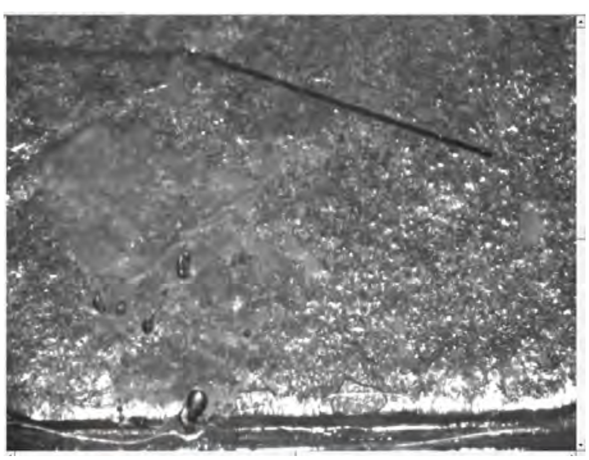


Figure 17: *The image on the left is of the 50% DMSO Sample, the 40% Sample and the cotton skin layer, stabbed through with a needle, taken with the 48-LED Source and no diffuser. The image on the right is of the same set-up but with a 60/10 diffuser in place.*

Figure 18: *The left image shows the 50%, 40% and cotton layer, stabbed with the needle, taken with the 4-LED Source and no diffuser, the middle image is the same but with the 5 degree diffuser, and the right image with the 0.2 x 10 degree diffuser.*

Figure 19: *These images all feature the same set-up as* ***Figure 18****; the left image has the 0.5 x 10 degree diffuser, the middle image has the 2 x 10 degree diffuser, and the right image has the 10 degree diffuser.*

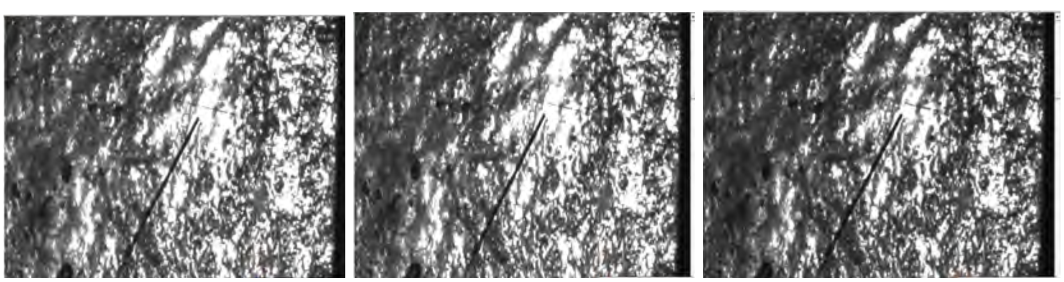


Figure 20: *The left image has the 0.4 x 20 degree diffuser, the middle image has the 20 x 5 degree diffuser, and the right image has the 5 x 30 degree diffuser.*

Figure 21: *The image on the left has the 10 x 60 degree diffuser, the middle image has a piece of paper placed over the light source, and the right image features a paper towel placed over the sample.*

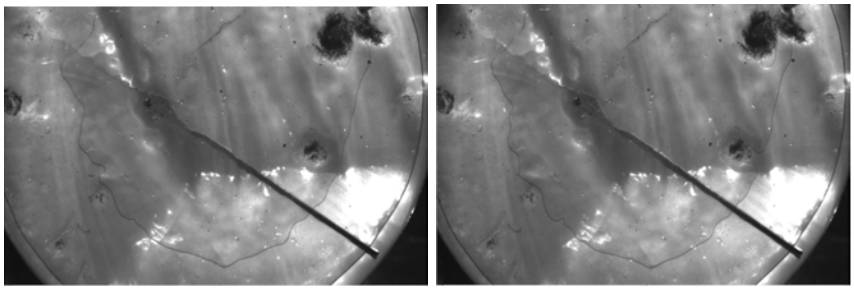


Figure 22: *The image on the left is a sample of ballistic gel with the needle stuck through it, taken with the LED array at 9 Volts. The image on the right is the same set up with the LED array at 12 volts.*

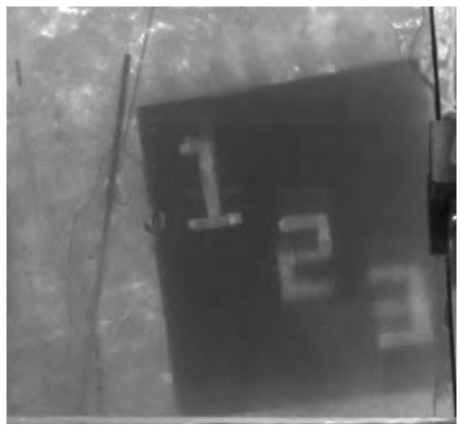


Figure 23: *Bar target and needle in between two layers of 40% DMSO sample with skin layer on top.*

Possible Future Testing

- Correct order for opacity- from most transparent to least:
  - Tissue (samples that we have been testing)
  - Contrast liquid dye that are injected in the organs when simulating surgery.
  - “Kidney Stone”.
  - Needle, wire, and spine.
- Test full size model.
- Determine a contrast liquid.

Note: *A full size model was not tested because our customers provided the models and they wanted to work out problems in the creations of the samples before testing a full model with our design.*

COST ANALYSIS

Item	Cost	Link
JC 4pcs High Power LED	$ 11.99	https://www.amazon.com/Power-Array-Illuminator-Vision-Camera/dp/B01D

IR Array Illuminator		73XM24/ref=sr_1_6?ie=UTF8&qid=1521471135&sr=8-6&keywords=infrared+spotlight
Phenas Home 48-LED CCTV Infrared Night-Vision Illuminator	$ 12.49	https://www.amazon.com/Phenas-48-led-Infrared-Vision-Illuminator/dp/B00GFDAJEI/ref=pd_sbs_421_6?_encoding=UTF8&pd_rd_i=B00GFDAJEI&pd_rd_r=43AS2R8RFXNDEMJ8X92S&pd_rd_w=CsGPT&pd_rd_wg=Hzt9m&psc=1&refRID=43AS2R8RFXNDEMJ8X92S
Blackfly 1.3 MP Mono USB3 Vision	Provided by Customer	https://www.ptgrey.com/blackfly-13-mp-mono-usb3-vision-sony-icx445
MVL25M23 - 25 mm EFL, f/1.4, for 2.3’’ C-mount Format Cameras	Provided by Customer	https://www.thorlabs.com/thorproduct.cfm?partnumber=MVL25M23
8 Inch Round Mirror: ¼ inch Thick, Flat Polished Edge (10 in each box)	$ 29.95	https://www.amazon.com/Inch-Round-Mirror-Thick-Polish/dp/B00J8NN3Q8
11.0’’ x 11.0’’, 18’’ Focal Length, Fresnel Lens	$ 110.00	https://www.edmundoptics.com/optics/optical-lenses/fresnel-lenses/11.0quot-x-11.0quot-18quot-focal-length-fresnel-lens/
Total Cost	**$164.43**	

This leads to a tentative total cost of $164.43. This does not include any projected costs for the material for the structure holding the optics. This will be done by the Mechanical Engineering Senior Design Group and will be added later. Dr. Ghazi’s group has also offered to help pay for materials, if necessary, and has given us a tentative budget of $5000 for the entire prototype.

FUTURE PLANS

For the future, there are several areas that must still be covered before this can become a finished product.

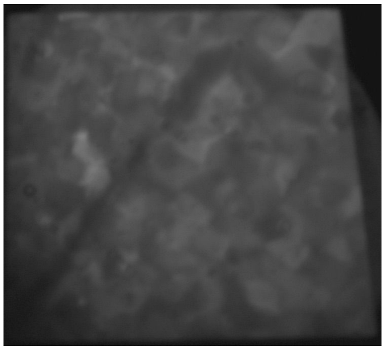
These include:

- Fully integrate the optical and mechanical designs into one cohesive design.
- Finding a fluid that can be used in the fluoroscopy procedure, which is semi-transparent under near infrared light.
- Designing a switch and developing an attached program that will allow the surgeons to take images whenever he/she wants.

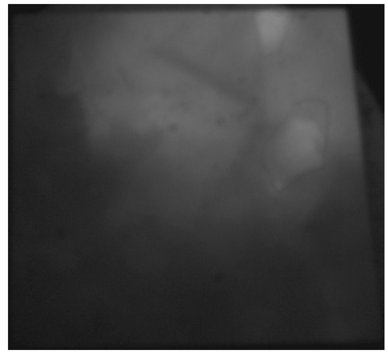
- Continue to test different materials to make it more lifelike and that will not shrink.
- Possibly designing an illumination system that uses a lens array rather than a diffuser.
- Future teams may want to try to shrink the design to make it more portable.

APPENDIX A: Other Materials Considered

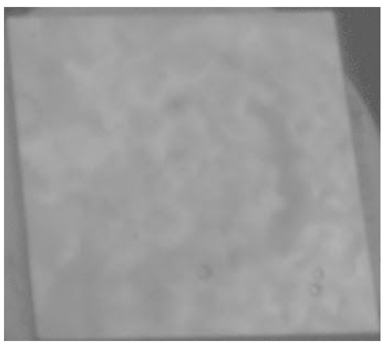
PVA(All samples are around 1.5 cm thick and the object is 1 mm thick).



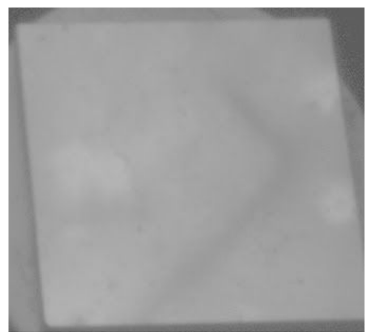
7% PVA 850-nm



10% PVA 850-nm



7% PVA 940-nm



10% PVA 940-nm

After testing, one can see that both samples have a large scattering effect on both light sources. The reason for this, and the marbled patterns on the samples, is due to cross-linking during the freezing process that solidifies the sample. It creates crystals in the material that form areas of differing refractive indices, contributing to the large amount of scattering.

APPENDIX B: MSDS of DMSO

ScienceLab.com
Chemicals & Laboratory Equipment

Health	1
Fire	2
Reactivity	0
Personal Protection	F

Material Safety Data Sheet
Dimethyl sulfoxide MSDS

Section 1: Chemical Product and Company Identification

Product Name: Dimethyl sulfoxide

Catalog Codes: SLD3139, SLD1015

CAS#: 67-68-5

RTECS: PV6210000

TSCA: TSCA 8(b) inventory: Dimethyl sulfoxide

CI#: Not applicable.

Synonym: Methyl Sulfoxide; DMSO

Chemical Name: Dimethyl Sulfoxide

Chemical Formula: (CH3)2SO

Contact Information:

Sciencelab.com, Inc.
14025 Smith Rd.
Houston, Texas 77396

US Sales: **1-800-901-7247**
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Section 2: Composition and Information on Ingredients

Composition:

Name	CAS #	% by Weight
Dimethyl sulfoxide	67-68-5	100

Toxicological Data on Ingredients: Dimethyl sulfoxide: ORAL (LD50): Acute: 14500 mg/kg [Rat]. 7920 mg/kg [Mouse]. DERMAL (LD50): Acute: 40000 mg/kg [Rat].

Section 3: Hazards Identification

Potential Acute Health Effects:
Slightly hazardous in case of inhalation (lung irritant). Slightly hazardous in case of skin contact (irritant, permeator), of eye contact (irritant), of ingestion, .

Potential Chronic Health Effects:
Slightly hazardous in case of skin contact (irritant, sensitizer, permeator), of ingestion. CARCINOGENIC EFFECTS: Not available. MUTAGENIC EFFECTS: Mutagenic for mammalian somatic cells. Mutagenic for bacteria and/or yeast. TERATOGENIC EFFECTS: Not available. DEVELOPMENTAL TOXICITY: Not available. The substance may be toxic to blood, kidneys, liver, mucous membranes, skin, eyes. Repeated or prolonged exposure to the substance can produce target organs damage.

Section 4: First Aid Measures

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Eye Contact:
Check for and remove any contact lenses. Immediately flush eyes with running water for at least 15 minutes, keeping eyelids open. Cold water may be used. Get medical attention if irritation occurs.

Skin Contact:
Wash with soap and water. Cover the irritated skin with an emollient. Get medical attention if irritation develops. Cold water may be used.

Serious Skin Contact: Not available.

Inhalation:
If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention.

Serious Inhalation: Not available.

Ingestion:
Do NOT induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. Loosen tight clothing such as a collar, tie, belt or waistband. Get medical attention if symptoms appear.

Serious Ingestion: Not available.

Section 5: Fire and Explosion Data

Flammability of the Product: Combustible.

Auto-Ignition Temperature: 215°C (419°F)

Flash Points: CLOSED CUP: 89°C (192.2°F). OPEN CUP: 95°C (203°F).

Flammable Limits: LOWER: 2.6% UPPER: 28.5% (Lewis), 42% (NFPA)

Products of Combustion: These products are carbon oxides (CO, CO_2), sulfur oxides (SO_2, SO_3...).

Fire Hazards in Presence of Various Substances:
Flammable in presence of open flames and sparks, of heat. Non-flammable in presence of shocks.

Explosion Hazards in Presence of Various Substances:
Risks of explosion of the product in presence of mechanical impact: Not available. Risks of explosion of the product in presence of static discharge: Not available.

Fire Fighting Media and Instructions:
SMALL FIRE: Use DRY chemical powder. LARGE FIRE: Use water spray, fog or foam. Do not use water jet.

Special Remarks on Fire Hazards:
When heated above its boiling point, dimethyl sulfoxide degrades giving off formaldehyde, methyl mercaptan, and sulfur dioxide

Special Remarks on Explosion Hazards: Not available.

Section 6: Accidental Release Measures

Small Spill:
Dilute with water and mop up, or absorb with an inert dry material and place in an appropriate waste disposal container. Finish cleaning by spreading water on the contaminated surface and dispose of according to local and regional authority requirements.

Large Spill:
Combustible material. Keep away from heat. Keep away from sources of ignition. Stop leak if without risk. If the product is in its solid form: Use a shovel to put the material into a convenient waste disposal container. If the product is in its liquid form: Absorb with an inert material and put the spilled material in an appropriate waste disposal. Finish cleaning by spreading water on the contaminated surface and allow to evacuate through the sanitary system.

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Section 7: Handling and Storage

Precautions:
Keep away from heat. Keep away from sources of ignition. Ground all equipment containing material. Do not ingest. Do not breathe gas/fumes/ vapor/spray. Wear suitable protective clothing. In case of insufficient ventilation, wear suitable respiratory equipment. If ingested, seek medical advice immediately and show the container or the label. Keep away from incompatibles such as oxidizing agents.

Storage:
Keep container in a cool, well-ventilated area. Keep container tightly closed and sealed until ready for use. Avoid all possible sources of ignition (spark or flame). Hygroscopic. Sensitive to light. Store in light-resistant containers.

Section 8: Exposure Controls/Personal Protection

Engineering Controls:
Provide exhaust ventilation or other engineering controls to keep the airborne concentrations of vapors below their respective threshold limit value. Ensure that eyewash stations and safety showers are proximal to the work-station location.

Personal Protection:
Safety glasses. Synthetic apron. Dust respirator. Be sure to use an approved/certified respirator or equivalent. Gloves (impervious).

Personal Protection in Case of a Large Spill:
Splash goggles. Full suit. Dust respirator. Boots. Gloves. A self contained breathing apparatus should be used to avoid inhalation of the product. Suggested protective clothing might not be sufficient; consult a specialist BEFORE handling this product.

Exposure Limits: Not available.

Section 9: Physical and Chemical Properties

Physical state and appearance: Liquid.

Odor: Sulfurous. (Slight.)

Taste: Bitter with sweet after-taste (Slight.)

Molecular Weight: 78.13 g/mole

Color: Clear Colorless.

pH (1% soln/water): Not available.

Boiling Point: 189°C (372.2°F)

Melting Point: 18.45°C (65.2°F)

Critical Temperature: Not available.

Specific Gravity: 1.1008 (Water = 1)

Vapor Pressure: 0.1 kPa (@ 20°C)

Vapor Density: 2.71 (Air = 1)

Volatility: Not available.

Odor Threshold: Not available.

Water/Oil Dist. Coeff.: The product is more soluble in water; log(oil/water) = -2

Ionicity (in Water): Not available.

Dispersion Properties: See solubility in water, diethyl ether, acetone.

Solubility:
Soluble in cold water, hot water, diethyl ether, acetone. Soluble in chloroform, ethanol, and benzene.

Section 10: Stability and Reactivity Data

Stability: The product is stable.

Instability Temperature: Not available.

Conditions of Instability: Heat, ignition sources, flames, incompatibles

Incompatibility with various substances: Reactive with oxidizing agents, reducing agents, acids, alkalis.

Corrosivity: Non-corrosive in presence of glass.

Special Remarks on Reactivity:
Hygroscopic. It has a strong water affinity, and if left exposed it will become rapidly diluted. Incompatible with strong oxidants, arylhalides, bromobenzoyl acetanilide, magnesium perchlorate, perchloric acid, and sodium hydroxide, alkali metals, hydrobromic acid, acidic solutions of alkali bromides, organic and inorganic acid chlorides, acid halides, cyanuric chloride, silver fluoride, methyl bromide, sodium hydride, periodic acid, diborane, iodine pentafluoride, silicon tetrachloride, phosphorous halides (phosphorous trichloride), trichloroacetic acid + copper wool, phosphorous trioxide, thionyl chloride, plastics

Special Remarks on Corrosivity: Not available.

Polymerization: Will not occur.

Section 11: Toxicological Information

Routes of Entry: Absorbed through skin. Eye contact. Inhalation.

Toxicity to Animals:
Acute oral toxicity (LD50): 7920 mg/kg [Mouse]. Acute dermal toxicity (LD50): 40000 mg/kg [Rat].

Chronic Effects on Humans:
MUTAGENIC EFFECTS: Mutagenic for mammalian somatic cells. Mutagenic for bacteria and/or yeast. May cause damage to the following organs: blood, kidneys, liver, mucous membranes, skin, eyes.

Other Toxic Effects on Humans:
Slightly hazardous in case of inhalation (lung irritant). Slightly hazardous in case of skin contact (irritant, permeator), of ingestion, .

Special Remarks on Toxicity to Animals: Not available.

Special Remarks on Chronic Effects on Humans:
May cause adverse reproductive effects (female fertility and fetotoxicity - post implantation mortality) and birth defects based on animal data. May cause cancer (tumorigenic) based on animal data. May affect genetic material (mutagenic).

Special Remarks on other Toxic Effects on Humans:
Acute Potential Health Effects: Skin: Causes skin irritation. May cause urticaria(hives), skin rashes, and dermatitis. Dimethyl Sulfoxide is readily absorbed through skin and may carry other dissolved chemicals into the body. An unusual garlic-onion-oyster odor may develop on breath and body/skin. Absorption through skin may also cause diarrhea, and affect respiration(dyspnea, cyanosis), blood, behavior (fatigue, dizziness, sedation, headaches), vision (transient photophobia, and disturbances of color vision), urinary system (hematuria). Eyes: Causes eye irritation. May cause blurred vision, corneal opacity, chemical conjunctivitis. Inhalation: Causes respiratory tract irritation. Symptoms from exposure to high vapor concentrations may include coughing, shortness of breath, headache, dizziness and sedation. Ingestion: Causes gastrointestinal tract irritation, and an usual garlic-onion-oyster may develop on breath, and body/skin. May affect behavior/ central nervous system, respiration (dyspnea). Symptoms may include nausea, vomiting, and diarrhea, abdominal pain, drowsiness, confusion, lethargy, agitation, disorientation, tremor, muscle weakness, chills, chest pains. May also affect liver (elevated liver enzymes, jaundice), cardiovascular system, and urinary system (hematuria, hemoglobinuria, renal tubular injury), eyes (transient photophobia and disturbances of color vision, conjunctive irritation) Chronic Potential Health Effects: Skin: Chronic absorption may cause effects similar to that of acute skin absorption. Chronic skin contact may cause scaling

dermatitis. Ingestion: Repeated oral doses may affect the kidneys (hematuria), blood (normocytic anemia, changes in red blood cell count), and metabolism (weight loss/anorexia), liver (jaundice).

Section 12: Ecological Information

Ecotoxicity: Not available.

BOD5 and COD: Not available.

Products of Biodegradation:
Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.

Toxicity of the Products of Biodegradation: The product itself and its products of degradation are not toxic.

Special Remarks on the Products of Biodegradation: Not available.

Section 13: Disposal Considerations

Waste Disposal:
Waste must be disposed of in accordance with federal, state and local environmental control regulations.

Section 14: Transport Information

DOT Classification: Not a DOT controlled material (United States).

Identification: Not applicable.

Special Provisions for Transport: Not applicable.

Section 15: Other Regulatory Information

Federal and State Regulations: TSCA 8(b) inventory: Dimethyl sulfoxide

Other Regulations:
OSHA: Hazardous by definition of Hazard Communication Standard (29 CFR 1910.1200). EINECS: This product is on the European Inventory of Existing Commercial Chemical Substances. National Inventory Lists of China, Japan, Korea, and Philippines.

Other Classifications:

WHMIS (Canada):
CLASS B-3: Combustible liquid with a flash point between 37.8°C (100°F) and 93.3°C (200°F).

DSCL (EEC):
R36/37/38- Irritating to eyes, respiratory system and skin. S26- In case of contact with eyes, rinse immediately with plenty of water and seek medical advice. S36/37/39- Wear suitable protective clothing, gloves and eye/face protection.

HMIS (U.S.A.):

- **Health Hazard:** 1
- **Fire Hazard:** 2
- **Reactivity:** 0
- **Personal Protection:** F

National Fire Protection Association (U.S.A.):

- **Health:** 2

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Flammability: 2

Reactivity: 0

Specific hazard:

Protective Equipment:
Gloves (impervious). Synthetic apron. Dust respirator. Be sure to use an approved/certified respirator or equivalent. Wear appropriate respirator when ventilation is inadequate. Safety glasses.

Section 16: Other Information

References: Not available.

Other Special Considerations: Not available.

Created: 10/10/2005 08:37 PM

Last Updated: 05/21/2013 12:00 PM

Appendix C: Additional Lens Specifications, Data, and Performance

GENERAL LENS DATA

Configuration 1 of 3

Stop :	4
System Aperture :	Image Space F/# = 1.46
Reference OPD :	Exit Pupil
Temperature (C) :	2.00000E+01
Pressure (ATM) :	1.00000E+00
Adjust Index Data To Environment :	Off
Effective Focal Length :	25.58398 (in air at system temperature and pressure)
Effective Focal Length :	25.58398 (in image space)
Back Focal Length :	0.7028125
Total Track :	55.09281
Image Space F/# :	1.46
Paraxial Working F/# :	10000
Working F/# :	10000
Image Space NA :	0
Object Space NA :	8.761636e-10
Stop Radius :	6.008408
Paraxial Image Height :	5.5
Paraxial Magnification :	0
Entrance Pupil Diameter :	17.52327
Entrance Pupil Position :	16.17913
Exit Pupil Diameter :	51.95971
Exit Pupil Position :	-75.86118
Field Type :	Real Image height in Millimeters
Maximum Radial Field :	5.5
Primary Wavelength [µm] :	0.85
Angular Magnification :	0.3372474
Lens Units :	Millimeters
Source Units :	Watts
Analysis Units :	Watts/cm^2
Afocal Mode Units :	milliradians
MTF Units :	cycles/millimeter
Include Calculated Data in Session File :	On

Fields : 4

Field Type : Real Image height in Millimeters

#	X-Value	Y-Value	Weight
1	0.000000	0.000000	1.000000
2	0.000000	3.300000	1.000000
3	0.000000	4.400000	1.000000
4	0.000000	5.500000	1.000000

Vignetting Factors

#	VDX	VDY	VCX	VCY	VAN
1	0.000000	0.000000	0.000000	0.000000	0.000000
2	0.000000	-0.157256	0.012360	0.157271	0.000000
3	0.000000	-0.218501	0.023712	0.218522	0.000000
4	0.000000	-0.305716	0.043520	0.305746	0.000000

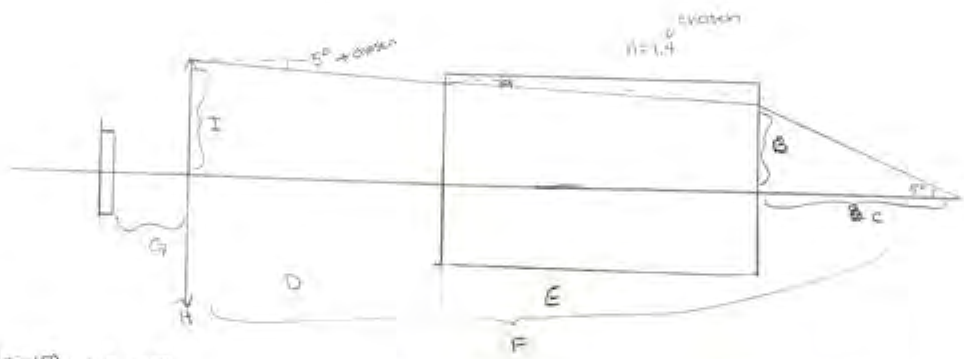
Wavelengths : 2

Units: µm

#	Value	Weight
1	0.850000	1.000000
2	0.940000	1.000000

Total Seidel Aberration Coefficients							
Configuration	**SPHA S1**	**COMA S2**	**ASTI S3**	**FCUR S4**	**DIST S5**	**CLA (CL)**	**CTR (CT)**
1	0.022193	-0.060365	0.191327	0.000000	-0.388222	0.000041	-0.000011

Appendix D: Illumination Math



A. $1\sin(5°) = 1.4\sin\theta$
$\theta \approx 3.5°$

B = 7.5cm → chosen to overfill desired area

C = $\tan(5°) = \frac{B}{C}$
$C = \frac{B}{\tan(5°)}$

D = 45 cm
chosen for working space

E = 20 cm max
max size of sample as determined by customer

F = D + E + C

Back path length ≈ 1'
= 161 cm

G = $\frac{1}{5'} = \frac{1}{5} + \frac{1}{3}$
= 3

H = f ≈ 43 cm
chosen based on given lenses w/ correct size
= 34.5 cm

I = size of lens
= B + tan(A) E + tan(5°) D
≈ 13 cm

J = size of diffuser to give correct image size

$\frac{B}{D+E} = \frac{J}{G}$
J ≈ 4.3 cm

Degrees of Incoming Cone Angle	6.18
Radians	0.107861257
B. Height on rear of sample (cm)	7.5
C. Distance from rear of sample to focus point	69.26390922
Index of material	1.4
E. Length of sample (cm)	15
A. Angle in sample (rad)	0.076970432
Height on front of sample (cm)	8.65684193

D. Distance between lens and front of sample (cm)	45
I. Height on lens (cm)	13.52950944
F. Total image working distance (cm)	129.2639092

Thin lens formula	
H. Focal length (cm)	45
F. Image distance (cm)	129.2639092
D. Object distance (cm)	-69.03164082

The yellow font indicates an inputted property. The rest of the properties have been calculated using the formulas on the image above and solved using an excel file.

Appendix E: Other Illumination Design

Lens Array

The lens array design can be more customizable and should give a greater amount of power for the illumination. It is not being used due to difficulty in finding and and cost of a lens array with a size of 13cm. The information listed below are the results from when this design was first explored.

With the lens array design there needs to be a focusing lens before the lens array. Two fresnel lenses were used to focus the expanded beam of light onto the sensor. The hope is that this design will allow for less light loss while still scattering. However, based on existing commercial optics, the existing lens arrays are too small in dimension and not collecting enough light from the source. A solution will be to order a custom made larger lens array. This design is eliminated since customized parts will take a long time to be made and this project is time sensitive.

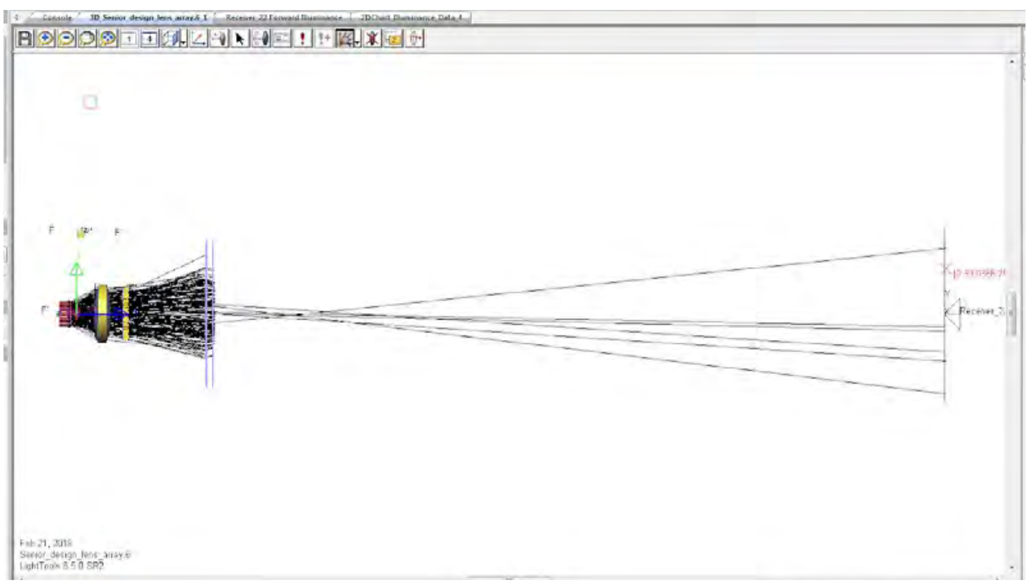


Figure A: *Shows LED array, focusing lens, lens array, and two fresnel lenses. It shows that very little light is reaching the detector plane.*

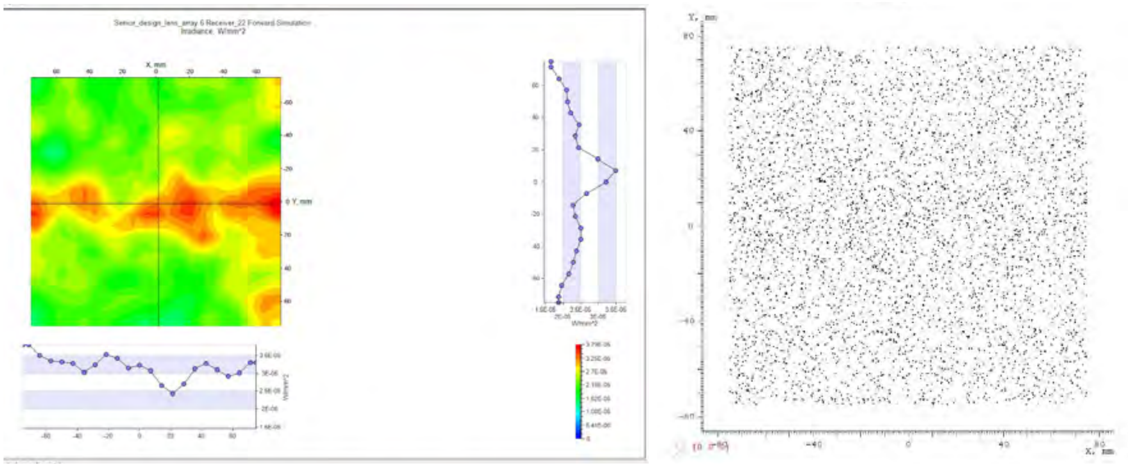


Figure B: *Left: The irradiance plot at the detector, approximately 600mm away from the final lens. Right: scatter plot of the receiver. Not many rays are reaching the receiver.*

Kohler Illumination

The Kohler Illumination was researched and we decided that the model would have too large of a path length to be effective in this design and was not further analyzed.

Appendix F: Senior Design Day Plan

- Will have a prototype of our product
- It does not have to rotate like our final product does. It is only meant to take a single picture at one angle
- We will demonstrate how the product images a provided sample.
- There will also be a poster meant to showcase our product in more detail.
- A sketch of what our prototype will look like can be seen below.
- This may not be used if the Mechanical engineering prototype is completed and used in design day.

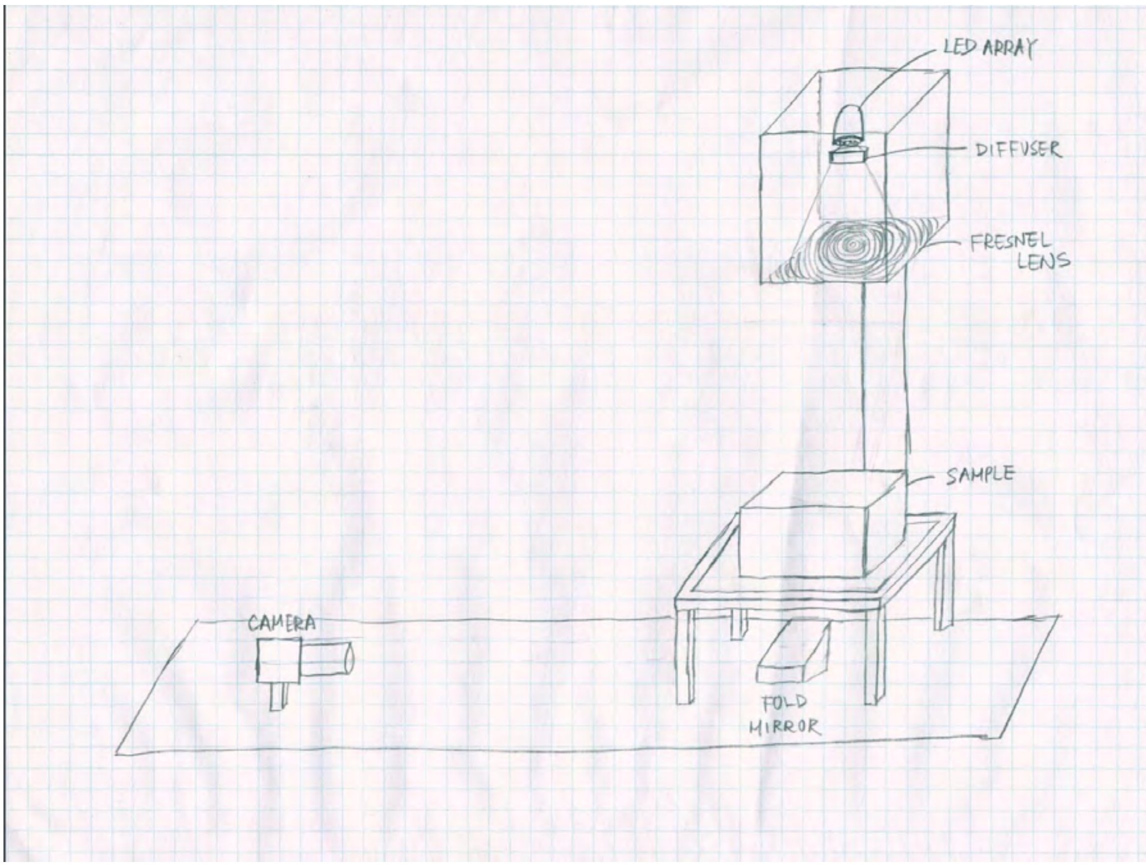


Figure C: *Shows a sketch of the proposed set-up for Design Day*

During Design day we used the 4 LED light source at 9V instead of the recommended 12V. This was to save power and for safety.

Figure D: Design Day 2018.

Figure E: Design Day set-up and image of sample. (2018)