June 15, 2015
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MSEM 502 Final Project

Project Proposal: Head Mounted Gaze Tracker Using Embedded Computing

Company: Lightfield Studios, LLC Website: www.lightfieldstudios.io

Section 1: Executive Summary

This report proposes a potential first project to be carried out by Lightfield Studios, LLC which was formed in April of 2015. The mission of Lightfield Studios is to explore the cross-section creativity and technology. The technological focus is predominantly within the rapidly growing space of augmented an virtual reality (AR/ VR) hardware. The company is equally interested in the growing number of applications for immersive content and communication enabled by the technology. Lightfield Studios was co-founded by Kevin Lalli, Chief Technical Officer, and Nick Capezzera, Chief Creative Officer. Kevin is PI on this project, and will utilize his background in project management and optical engineering. Nick is a documentary filmmaker committed to staying on the bleeding edge of technologies that enhance his craft. The founding partnership is indicative of Lightfield Studios' overarching goals: we desire to invent and produce optical technologies based on demand in the AR/ VR space, as well as creating content and user experiences at the forefront of what is possible.

The proposed project carries forward the momentum of the Gaze Typer team, led by Kevin, who won Crowd Favorite at Startup Weekend Bozeman. Gaze Typer is an Augmentative and Alternative Communication (AAC) product for assistive computing that interprets eye movements and translates them to text input. The 48-hour delivery of a hardware and software prototype generated tremendous interest and support from local business innovators at the event. Since then the core team's, a mix of Montana State University students and graduates, has identified a related product with significant market potential. Subsequently, the team will continue to combine efforts to achieve the goal describe below. Dr. Frank Marchak, a local expert in gaze tracking applications, and Computer Engineering professor Ross Snider have also come aboard to offer their support, extensive skill sets, and industry expertise.

Over Startup Weekend (SUW), the team's focus was restricted to the AAC product for gaze-based typing. Both the application software and necessary hardware were prototyped based on an open source gaze tracking platform. While a useful application was prototyped, no such platforms are commercially available within a reasonable price point to run this software. Competitors offerings are upwards of $10,000 per unit, run on proprietary software via external servers, and lack truly wireless functionality. The applications for gaze tracking are widespread, spanning from security to human factors to data collection for neuroscience and other research. However, the market remains niche enough that there is not competitive pressure to drive high-value products.

The team is now in the research and development stages of creating an affordable, wireless, and highly capable head-mounted gaze tracking platform (HM-GT). This will likely be accomplished by leveraging Montana State University's expertise in disciplines including optics, engineering, and manufacturing. Throughout the design cycle, it would be of significant mutual benefit to put the gaze tracking hardware in the hands of capable researchers who can provide reviews of functionality and inform rapid iteration of the product. Active gaze-based research efforts in Bozeman include: psychology and visual perception (Veridical); driver habits and fatigue studies (Western Transportation Institute); and neurological research (Dr. Charles Gray).

While the proof-of-concept prototyping and early stage sales (i.e., traction) will be generated around a standalone device, the long term goal is integration with augmented and virtual reality hardware. The cumulative market value for all AR/ VR technology is projected to be $150B by 2020, according to one source[8]. Restricting projections to hardware AR/ VR systems puts the number around $45B. Another study estimates a 2018 market value of $18.4 for consumer VR hardware alone, ignoring augmented reality and enterprise products [9]. Providing OEM gaze tracking solutions in this space could be orders of magnitude more profitable than the niche market for standalone HM-GT's[5,8,9]. While the goals of a standalone unit and AR/ VR integration are in fact separate, there is considerable overlap in terms of the team background and technological development needed to fulfill either successfully - this overlap is highlighted in the figure below.

The first steps towards both independent goals will be to prove the feasibility of an HM-GT device that relies on embedded computing to execute image signal processing and wirelessly deliver a gaze vector via Bluetooth's Human Interface Device (HID) standards. Applying embedded computing to enable onboard gaze tracking will be a technical challenge versus relying a full-fledged computer, but provide a significant cost advantage at scale. Using Bluetooth HID will allow flexibility in the operating system or mobile platform chosen for interface. Shifting computational demands onboard means that there will be minimal requirements of the external device used, so smartphones or even "smart TV's" become an option as a target for interface. As new systems emerge for AR/ VR applications, the advantage of a low power and low computing bandwidth will become a paramount advantage [6].

This project is described in further detail in this report, including data summarized using the model of Discovery Driven Planning. This model is based on the reverse income statement, which defines a bottom line target at the outset of a venture. It is further informed by defining and tracking assumptions of project cost, sales potential, and market conditions. Below is the initial Reverse Income Statement, which simply dictates how much revenue must be generated, and at what Return on Assets, in order for a project or venture to be worth pursuing. Generally, this is done by stating a desired percentage increase on a companies existing returns. Since Lightfield Studios is very early existence, internally termed the "Potato Salad" phase, these goals have no historical precedent. Instead, the Reverse Income Statement for this project begins with an ad hoc target for revenue and ROA to be attained within five years.

5-year Reverse Income Statement

Current value of Lightfield Studios = $0 ($7k rounded down)

Target Revenue
Size of Standalone HM-GT Market: ~850 units per year
Percentage of Standalone HM-GT to Capture: 10-12%
Standalone units sold: 85-100/ year (Sales assumed to begin by 2017)
100 units * $1,800 per unit = $85k-$180k per year * (3 years) = $540k

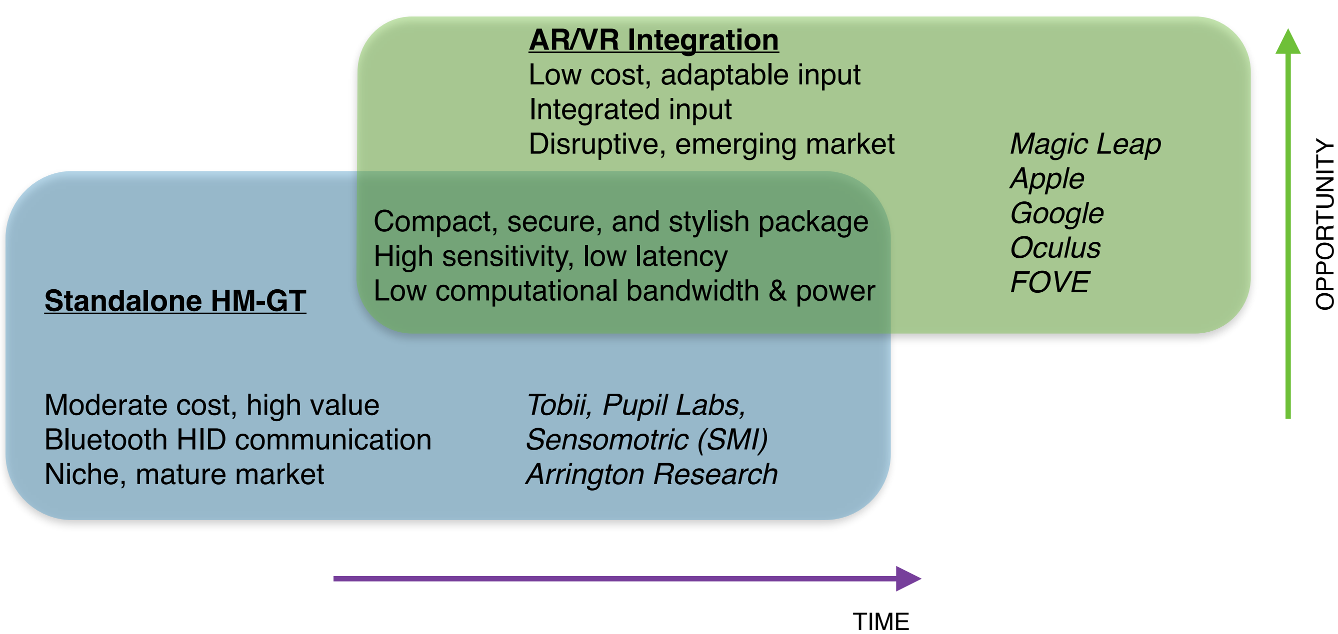
2020 Projected size of AR/ VR Hardware Market: $40 Billion
Percentage of Market to Capture (via Modular Device Sales, OEM & Consulting): 0.025%
$150B*0.01% = $1.5M

Total 2020 revenue generated by HM-GT Endeavors
Standalone + Consulting + OEM Sales = $2.04M

Target ROI: 25% [Source: VC RIO] (This should be maintained in both standalone and OEM operations)

Allowed Costs: $1.5M; with up to $405k going to standalone product development & unit costs

Customer Segment Ven Diagram



Section 2: Situation

2.1 Business & Team

Kevin's background in optical technologies was initially inspired by his undergraduate degree in Physics at Montana State University. Bozeman has been a hotbed of optical technologies for decades, and Kevin has been working in the local optics and photonics industry since graduating. He has experience in the production of complex optical instruments such as lasers, the research skills to quickly identify the potential of emerging technologies. Back at Montana State perusing a Professional Masters has greatly bolstered Kevin's ability to high-value ideas from a business and marketing perspective. His current term at AdvR, a Bozeman company specializing in non-linear optical components and integration, allows further practice in combining technical background with market identification.

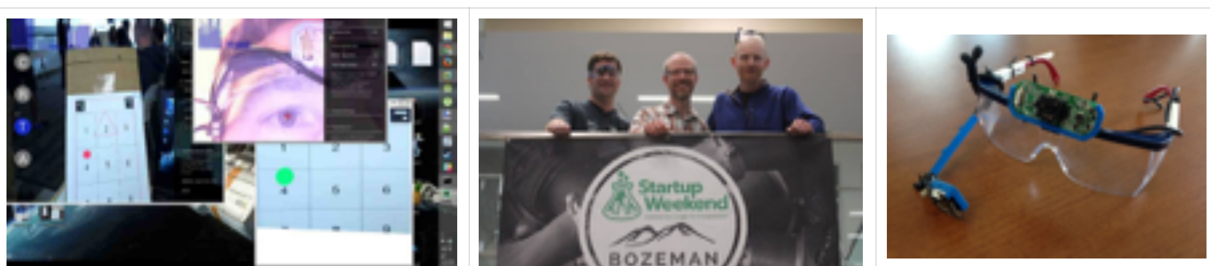
Kevin conceived the idea for Gaze Typer after months of research into AR/ VR hardware, and while considering a deliverable for SUW. A highly productive team of current and former MSU students was assembled, who worked quickly to deliver the hardware and software prototypes in parallel. This experience drew heavily on Kevin's professional experience optical assembly and testing, as well as impromptu leadership skills first established during MSU's pilot spectrograph competition in 2012.

Joe Wagner will lead software development as a full time asset during the project. Joe was a instrumental part of the SUW team, and also has extensive experience navigating the technical and funding challenges presented that early-stage startups must face. Joe is an expert in web applications, Python, Javascript and C, and has carried out testing and validation of embedded systems for LoadMan in Seattle. This experience will help guide the iterative and simultaneous processes of developing and testing the HM-GT at the embedded computing level.

Dr. Ross Snider will serve an advisory roll in guiding the embedded systems development needed to carry out the project. Embedded systems design presents unique challenges in upfront hardware design, coding, and testing. Dr. Snider has applied his skills to many complex projects, and revels in cross-disciplinary applications at the intersection of biology, signal processing, and computer engineering. Gaze tracking fits this description perfectly, and will aid in Dr. Snider's continued efforts to apply lessons learned from organic neural networks to inorganic ones via FPGA.

Dr. Frank Marchak is Professor of Industrial Engineering at MSU, as well as President and CEO of Veridical Research and Design. Dr. Marchak recently offered his encouragement and support to the project. He will provide invaluable feedback based on over twenty years of gaze research leading to concrete insight to offer on nearly all competitors. Dr. Marchak's interdisciplinary knowledge in human factors, visual perception, and cognitive science is backed by technical expertise in experimental design and analysis, and usability engineering. He has over twenty five years of experience in applied research, user interface design, and information visualization applied to interactive, human-machine systems. Besides serving as an experienced advisor, Dr. Marchak will test HM-GT platform throughout the design process and give feedback from the client perspective.

Outside of the core team, strong connections have been established in the Bozeman area and beyond. Blackstone Launchpad and Startup Bozeman have offered their continued support. Besides helping to fill in existing gaps in business and market strategy, they have helped make invaluable connections such as Dr. Marchak and Dr. Larry Johnson of the Montana Photonics Alliance, who is offering general guidance around the development of Lightfield Studios. Pupil Labs, a German based company run by two graduates of MIT's Computer Science department, has expressed interest in collaboration based on our success with the Gaze Typer application built on their open-source product. Additionally, Pupil Labs has kindly provided their own market data around the standalone HM-GT market.



*Left: Mosaic of Gaze Typer software prototype. Middle: Members of SUW Bozeman Team.
Right: Gaze Typer hardware prototype (and HM-GT "version 0")*

Section 2: Situation

2.2 Market Opportunities by Customer Segment

Standalone Gaze Trackers: Provide a high-value combination of low price and high functionality HM-GT, with standard wireless operation for use across multiple device platforms.

The demand for, and commercial production of, standalone gaze tracking devices has been present for decades. Early products to market were based on camera attachments to computer monitors, and similarly immobile technology. Demand for these products includes research oriented fields such as psychology [1], neurology [4]. A related commercial application would be data collection on user interest for advertising and marketing. Additionally, there is interest for security applications, market research including usability assessment, and most recently as an input for next-generation computing platforms [5,6].

Within the market for standalone gaze tracking systems, a number of companies have moved towards wireless, HM-GT products driven by general convenience. In the process, the already prohibitive costs have been further exacerbated. A Google patent [26] for pay-per-gaze pricing of online and physical advertising summarizes: "eye tracking systems have mostly been limited to research endeavors because of the intrusiveness, high cost, and reliability of these systems. A technique and system that can provide a reliable, low cost, and unobtrusive, eye tracking system could have a variety of useful everyday applications." This is exactly the solution we plan to create with our HM-GT platform. Competition starts pricing in the $10k-$15k range and cost escalates form there with features such as wireless or binocular tracking capabilities. As the SUW prototype was constructed for under $150, there is wide latitude to offer a much lower cost option with similar functionality and standard wireless communication.

The market for standalone HM-GT is niche, largely comprised of researchers and top-tier advertising and marketing firms. For that reason, projecting growth is difficult. For the purposes of this preliminary model, a reasonable assumption of 800 units/ year with 0% growth is made. In reality, there is potential for negative growth for the potentially disruptive technologies on the horizon described below. (As computing platforms develop with many including built in gaze tracking, there will be less demand for the described standalone devices.)

		
Pupil Lab's gaze tracking unit is the most affordable & open platform, but limited in functionality (e.g., wireless operation). Source: Pupil-Labs.com	*An immediate commercial application of gaze tracking is the generation of gaze fixation heat maps for advertising and marketing purposes. Source: tobii.com*	*Nokia perused an integrated gaze tracker and head mounted display, but has not released a commercial product. Providing functionality within a compact package is one of the primary challenges for AR/VR hardware. Source: Reference*

Virtual and Augmented Reality Integration: Provide design and execution of integrated gaze tracking for AR/ VR hardware, especially of the head-mounted variety. Use understanding gained through standalone product to create modular and OEM solutions the facilitate gaze-based input the next generation of computing.

In addition to standalone HM-GT products, a number of companies are currently pursuing head-mounted display technology for augmented and virtual reality (AR/VR) applications. Efforts in this field include Oculus, Magic Leap, Microsoft's HoloLens, and Google Glass. For all of the mentioned products, there exists great interest in gaze as input device, both for user interaction and display optimization[5,6,24,25]. To successfully integrated gaze tracking into these systems, considerations such as cost power consumption, computing speed, and package design become a top priority [6].

As one example, SMI offers a $14.9k gaze tracker upgrade [7] for the Oculus Rift, which is currently sold as a $400 developer kit and will soon be commercially available under $1,200. The upgrade requires an external server for interface, and requires significant mechanical modification to the stock Oculus optics. This is representative of the huge gap that must be bridged if gaze tracking is to be integrated into hardware at a price point attractive to the consumer.

The FOVE headset was just launched as the first VR headset to integrate gaze tracking in its stock configuration. Specifications confirm that FOVE will be a direct competitor to Oculus when launched, with integrated gaze tracking being the major technical distinction. So far, FOVE has raised $437k from over 1,200 backers two weeks into crowdfunding, a significant indication of the demand for integrated eye tracking in AR/ VR hardware. While the Kickstarter campaign is developing at a slower pace than the original Oculus campaign in 2012, this is as much a sign of the consumers learned rationality [12] as it is demand for eye tracking integration.

These two data points - the SMI add-on and FOVE headset - represent the wild variability of AR/ VR hardware space as it the market develops. The key to widespread customer adoption will not be the technology themselves, but innovative applications of the technology, be it film, games, or entirely new forms of augmentative applications. A noteworthy similarity of the Oculus and FOVE systems is that they both require an external computer, or server, to operate. Additionally, these platforms both create the impression of 3D experience using stereoscopic overlay of traditional display. This technology has the fundamental limitation of ignoring a number of visual cues that are naturally incorporated in 3D vision. While gaze tracking can enhance stereoscopic display to some degree, these systems should be seen more as a starting point to more convincing 3D display technology.

As display technologies develop, gaze tracking will become more critical to a given system's performance. Resolution will be hardware limited at the outset, which makes gaze-based optimization a needed solution. (This is technically known as "foveated rendering," and listed as a primary selling point of the FOVE system.) At the same time, the required computing will move towards onboard processing capabilities for software, input controls, and display rendering. Staying ahead of this curve is the major advantage of the embedded computing approach to HM-GT.

No companies within the Montana Optics Cluster are currently pursuing displays, inputs, or other hardware for augmented and virtual reality systems, nor are research efforts underway on campus. Lightfield Studios was formed to tackle the challenge of useful, cost-effective solutions in this space while leveraging the local expertise of Southwest Montana. The business objective of the HM-GT project would be to prove the company's engineering and manufacture capabilities, as well as generate capital for the internal funding of future projects.

SWOT Analysis

Strengths Willingness to act quickly to achieve a competitive advantage through embedded computing. Forward thinking, realize that standalone systems are merely a stepping stone to the more lucrative market of AR/ VR integration. Able to leverage Bozeman business community & university, with very capable professors ready to sponsor the project.	Weaknesses As the company's first project, lessons must be learned from on the fly. No significant funding, and a small team, means resources are spread thin. Need to secure funding in parallel to pushing the project forward. Need to prove traction quickly to be noticed for private sector support.
Opportunities Existing standalone HM-GT systems are exorbitantly overpriced, and a realistic approach to low-cost wireless functionality has been identified. Succeeding with the embedded computing platform will put the company at a significant advantage when integrating with AR/ VR systems. The display side of AR/ VR hardware is an enormous challenge in itself, with no clear leader existing yet. The ability to outsource system chunks like gaze tracking has high value.	Threats The market for standalone HM-GT is niche, and could potentially evaporate. Tobii, SMI, Arrington Research, and other longstanding players are moving towards AR/ VR solutions. New companies such as FOVE are constantly emerging in the AR/ VR space. Some percentage AR/ VR companies will prefer to work "in the shadows" and be reluctant to outsource any tech solutions.

Section 3: Project Scope

The scope of this project is development and production of a next-generation HM-GT integrated with onboard image signal processing and gaze tracking. The input will be a standard video rate imaging in the near infrared (NIR), while embedded computing will handle the image signal processing and wireless gaze vector output. The HM-GT will communicate with other devices based on the Bluetooth Human Interaction Device (HID) standards for the highest level of performance, power savings, and flexibility possible. The project will follow a three phase development plan, with Phase I including a proof of concept prototype.

The major goal of Phase I is to prove that embedded/ firmware-level algorithms can be constructed using a field programmable gate array (FPGA). FPGAs are the “supercomputers” of embedded computing, having much more flexibility and computing bandwidth than an operation-specific PCB. Embedded systems using FPGAs require the same approach to programming, and thus allow initial embedded algorithms to be defined. As computational requirements are defined and met with embedded algorithms, the minimal hardware requirements for custom PCBs are subsequently defined. Requirements of the optical layout and package will not be strict in Phase I, as proving the electronic feasibility is the primary goal.

If Phase I is completed successfully, Phase II will be carried out using a sample order of custom, application specific electronics (ASIC) to facilitate the embedded algorithms proven earlier on FPGA. Relationships will be established with a number of potential suppliers and cost analysis carried out for various key components. Layout and package iterations will be significant component of Phase II, as robust probability and styling is a significant competitive advantage for HM-GT devices. These first two phases are essentially an extended R&D period, with the first half focused on feasibility and the second half focused on cost analysis and manufacturability.

The commercialization of the product will be carried out during Phase III, which is represented only in rough preliminary numbers for this report. Phase III would involve scaling up manufacturing and establishing sales channels for the final product if Phases I and II are successful. In addition, further R&D would be carried out specific to AR/ VR integration while these markets are explored as a separate customer segment beyond standalone HM-GT. Fully assessing modularity of the hardware, better understanding OEM customer needs,

Assumptions to be Tracked

1. Dark pupil tracking algorithm can be reduced to an embedded computing platform (800MHz, 3MB Cache)
2. Proof-of-concept can be delivered on affordable FPGA boards ($500 max)
3. Custom PCB’s will not be cost-prohibitive (~$250 max for 2,500 units)
4. Latency goals will be achieved using embedded computing (minimum 60 Hz)
5. Sensitivity goals will be achieved using integrated optics and algorithms (minimum 0.5 degree)
6. Niche market for standalone HM-GT will hold until 2020 (~850 units/ yr)
7. Embedded computing will provide a long-term cost advantage (80-90% Savings over Tobii Glasses 2)
8. Cheaper, built-in wireless HM-GT will be immediately effective in capturing the standalone market (10-15%)
9. Bluetooth HID standards can be utilized for multi-platform usage (60 Hz @ 0.5 degree sensitivity)
10. Streamed gaze vector via Bluetooth HID will increase OS compatibility (Mac, Windows, iOS, Android,…)
11. Platform testing will be simplified by the Bluetooth HID interface (1 system test validates for any OS)
12. Application software must be tested on any system it is compiled for (Starting with Widows (10?) and iOS)
13. Minimum viable product application developed in parallel to platform (>1 With Gaze Typer at launch)
14. Application software will meet customer’s needs (>50 Customers for standalone product by yr 2)
15. Standalone HM-GT products will remain in use by researchers and private sector through 2020
16. Hardware components of the platform will be suitable for customer use (<100g package weight)
17. AR/ VR hardware products will integrate gaze tracking as a standard feature (4 companies and counting)
18. Hardware and embedded computer is adaptable for OEM use in HMD hardware (< power constraint TBD)
19. A significant portion of HMD manufacturers will prefer OEM HM-GT solutions over in-house (>2 by yr. 2)
20. No competing patents describing an embedded computer for gaze tracking (0 in June 2015)
21. Final patent search and patenting fees ($12,000)

Section 3: Project Scope

Milestones

Phase I

A. Current Market & Intellectual Property Analysis
- Scour the market for smaller but dangerous players in the HM-GT market
- Better understand offerings, especially the software features, of Tobii, SMI, Arrington, etc.

Assuptions to be tested:

B. Definition of Algorithms and Feasibility of Embedded Implementation
- Determine the robustness of dark pupil capture vs. bright pupil capture in various environmental lighting
- Confirm ability to run/ emulate Pupil Labs tracking software on Virtex 5 FPGA
- Seek less computationally intensive algorithms, such as employing fast Fourier transforms on image

Assuptions to be tested:

C. FPGA + Development Board Performance Analysis & Sourcing
- Must have an appropriate CMOS sensor or connectivity
- Computational bandwidth must be at or above minimum defined in B.
- Cost must be within prototyping budget (detailed in Data & Results)

Assuptions to be tested:

Phase II

D. Prototype 1.0 Construction
- Electronics equipment and workspace acquired
- Preliminary optical layout constructed for testing purposes. (Image quality and size are only constraints)
- Gauge efficiencies moving toward

Assuptions to be tested:

E. Prototype 1.0 Testing & Validation
- Discovery and remedy system bugs
- Begin working on data visualization software with hardware 1.0 as an input
- Gauge potential points of improvement for increased efficiency, decreased latency, etc.

Assuptions to be tested:

F. Prototype 2.0 Planning and Construction
- Reconfigure FPGA to work with tethered sensor
- Discover and remedy system bugs
- Validate

Assuptions to be tested:

G. Locally Coordinated Prototype 2.0 Beta
- Send units to Dr. Marchak, Dr. Grey, WTI, etc.
- Compile a usability survey to determine customer satisfaction and needed improvements
- Update software feature set to fulfill lacking features

Assuptions to be tested:

Phase III

H. Prototype 3.0 Refinement & Production Ramp-up
- Custom ASIC PCB's sourced, ordered and tested
- Determine cost for internal production lines, submit part RFQ's for analysis
- Cost analysis of internal production lines
- Reach out to Bolt, SKTA Innoparnters, and other hardware accelerators

Assuptions to be tested:

I. Phase III Sales & Marketing Outreach
- Reach out to existing users of HM-GT (Like those listed **here**)
- Survey basic needs, additional features desired, and customer support expected
- Asses typical battery life requirements in field to inform power supply

Assuptions to be tested:

J. Investigation of OEM & Modular AR/ VR Integration
- Determine if base system can provide computational bandwidth, or if ISP must remain separate
- External power constraints met with refinements to embedded computer
- Latency and sensitivity of standalone HM-GT will suffice for OEM solutions

Assuptions to be tested:

Section 3: Project Scope

Milestone Schedule (Gantt Chart)

	Phase I						Phase II										Phase III							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	X	X																						
B		X	X	X																				
C			X	X	X	X																		
D							X	X	X	X														
E										X	X	X	X											
F											X	X	X	X										
G														X	X	X	X							
H																X	X	X	X					
I																		X	X	X	X			
J																					X	X	X	X

To enable this plan, a seed funding source is required to facilitate the R&D phases. Following successful R&D, additional fixed costs will come into play in order to scale up manufacturing and deliver to customers by establishing sales channels. Below, the necessary budgetary requirements and possible funding avenues are explored, continuing with the Discovery Driven Planning Model. This model was selected due to its flexibility under uncertain conditions when entering a new market. “Learning the most important lessons, as quickly and cheaply as possible” is how MacMillan states the goal [14]. Also, the commitment to overturning embedded assumptions in a plan has provided valuable insights around the feasibility and commercialization opportunities of this project. As the first potential longterm project carried out by Lightfield Studios, the goal will be to learn as much as possible whether we succeed or pivot to the next project.

Section 4: Data & Results

This section of the project proposal outlines a flexible plan of attack towards the goals described. It is largely a cost estimate of the project through Phases I & II based on pro forma operational needs. It also includes preliminary estimate around the sale of the final product, which would tentatively take place during Phase III. The four-part template of Discovery Driven Planning is applied to data collected so far, and done so in a way that this project plan will continue to evolve as milestones are reach, assumptions are revisited, and new data is collected, such as a more accurate cost assessment of the final product.

Activities Needed

2015	Q1	Q2	Q3	Q4	Annual Total	2016 Q1	2016 Q2	18 Month Total
Advisory								
Frank Marchak	$2,000.00	$4,000.00	$4,000.00	$12,000.00	$22,000.00	$2,000.00	$4,000.00	$28,000.00
Ross Snider	$6,000.00	$6,000.00	$4,000.00	$4,000.00	$20,000.00	$6,000.00	$6,000.00	$32,000.00
Optical Eng								
Kevin Lalli	$4,000.00	$4,000.00	$4,000.00	$4,000.00	$16,000.00	$0.00	$0.00	$16,000.00
R.A. Funds (20 hr/wk)		$2,400.00	$2,400.00	$2,400.00	$7,200.00	$2,400.00	$2,400.00	$12,000.00
Software Dev								
Joe Wagner	$15,000.00	$15,000.00	$15,000.00	$15,000.00	$60,000.00	$15,000.00	$15,000.00	$90,000.00
Contracted Resources	$10,000.00	$10,000.00	$15,000.00	$15,000.00	$50,000.00	$15,000.00	$15,000.00	$80,000.00
Electrical Eng								
R.A. Funds (20 hr/wk)		$2,400.00	$2,400.00	$2,400.00	$7,200.00	$2,400.00	$2,400.00	$12,000.00
Bus/ Mktg.								
Intern					$0.00			$0.00
Marketing Consultant				$2,500.00	$2,500.00	$2,500.00	$2,500.00	$7,500.00
Other								
MSU Overhead	$0.00	$4,320.00	$4,320.00	$4,320.00	$12,960.00	$4,320.00	$4,320.00	$21,600.00
Legal Fees								
Patent Search	$800.00	$400.00	$800.00		$2,000.00			$2,000.00
Patenting						$20,000.00		$20,000.00
					$155,860.00			$299,100.00

Prototyping Strategy

It will be helpful to review the project's prototyping goals before expanding on equipment requirements. In the words of Ian MacMillan, the goal is to "learn as cheaply as you can, as quickly as possible." This applies to the business as a whole, but is especially applicable when developing a new product.

Electrical: Embedded systems programing presents short-term challenges, as embedded software or firmware is more difficult to code and test than in a compiled language. However, this tradeoff is repaid by a lower cost final product. The strategy will be to code an "overpowered" FPGA for validation and testing, and then move to ASIC design. For the SUW prototype, an algorithm known as dark-pupil tracking was utilized within the Pupil Labs platform. This algorithm offers high tracking sensitivity with a minimally complex routine, but may or may not be an appropriate choice when moving to embedded computing. This question will be approached early on in the feasibility study. For early feasibility tests and prototyping, a Virtex 5 series FPGA will be used to run dark pupil tracking and any other algorithms deemed feasible. This selection was made due to reasonably low price point ($500) and ability to fully emulate an Intel Atom processor [30], which is the minimum required hardware for the Pupil Labs software package.

Section 4: Data & Results

Optics: Two cameras will be used for the HM-GT system. One is the "eye cam", which acquires a video rate feed of the users eye to be sent to the image signal processing (ISP) unit. The other is the "world cam", which looks outward and takes in the user's field of view such that the processed gaze vector can be put in context. The world cam has the same functionality as a standard HD webcam; a de-cased webcam was in fact used for the SUW prototype. The eye cam utilizes a monochromatic sensor, which may be fixed or tethered to a camera PCB. Aspheric lenses provide the best image quality while maintaining camera compactness [30]. Two eye cams can be used for binocular, three-dimensional tracking in later versions.

Mechanical/ Package: The most critical aspect of the HM-GT package is stability under user movement (both head and body movement should be allowed). This was one of the biggest lessons learned form the SUW prototype; shaking of the headset with respect to the users eyes can render a calibration invalid. Quick-set silicon (Sugru) was used to aid stability, but better overall mechanics and a head strap would greatly improve the system's robustness. This might be achieved with a Boa Closure System, used in many performance sports products. Regardless, stability will be the utmost goal when iterating the package design.

Software: Following onboard ISP, the gaze vector output will be streamed via the Bluetooth HID protocol for a completely wireless gaze-based input. As a stepping stone to this goal, the v1.0 prototype relies on the full bandwidth and interface of a WiFi network. The HM-GT platform will interface modularly with nearly any desktop or mobile device given some basic system requirements (e.g., Bluetooth compatibility). This facilitates the goal of a lower price point than major competitors, meant not only to to attract a wider range of customers, but also to maintain viability as an "add-on" feature for consumer electronics within the AR/ VR space. Initial software offerings will be an updated Gaze Typer product, as well as software for visualizing gaze fixation data (e.g. heat maps).

Prototype Manufacturing Costs

		Prototype 1.0	Prototype 2.0	Prototype 3.0	
Bills of Materials (Costs per unit)	**Optical**				
	Lens Elements	$95.00	$95.00	$95.00	
	Filter	$25.00	$25.00	$25.00	
	Hot Mirror	$100.00			
	Board Cameras	$80.00			
	Electrical				
	FPGA (e.g. Vertix 5)	$500.00	$500.00		
	Tethered Sensor (e.g. NanEye)		$135.00	$135.00	
	Custom PCB			$250.00	
	i.MX6 GPU			$130.00	
	Mech. /Package				
	Initial Design (fixed)	$1,200.00	$1,200.00	$2,500.00	
	Iteration Costs	$45.00	$45.00	$55.00	
	3D Printing	$75.00	$75.00	$75.00	$5,270.00
	Quantity	12	12	25	
	Run Totals	$11,460.00	$12,780.00	$17,375.00	$41,615.00
	Unit Cost	$955.00	$1065.00	$695.00	

Section 4: Data & Results

Additional Assumed Costs for Phase III

Bozeman-based Headquarters & Final-stage Manufacturing: $8,000 per month
Full-time Test & Service Technician (beginning of Phase III): $3,500 per month
Full-time Sales & Marketing Team: $12,000/ month minimum
Shipping: Less $75-$100 profits per order
Legal Fees: Incorporation and Advising ~$2,500, Final Patent Search $5,000

Revised Reverse Income Statement

As mentioned at the outset, the requirement for 25% ROA should be upheld for the independent customer segments of standalone HM-GT and AR/ VR solutions. The initial R&D to

Fixed Costs Phases I-II (Salaries, MSU Overhead, & Prototyping)	$340,715
Projected Cost per Standalone Unit (Prototype 3.0 cost)*0.7	$487
Unit Price for Standalone Device	$1,800
REQUIRED STANDALONE UNITS SOLD FOR %25 ROI	**1,401**

The AR/ VR hardware space has existed for decades (e.g. Nintendo Virtual Boy), yet still in its infancy. Oculus is the first consumer product in years to gain any traction, and is still only available as a developer kit. This will change. Riding on the coattails of the smartphone revolution, the turning point is near and many platforms will be hitting the market in the coming decade. This is all to say that the details of this market have yet to solidify. The numbers presented for this market segment are preliminary. They reflect the overall strategic approach to competing in this space, but will no doubt change as the market evolves.

Fixed Costs Phase III (2 Year Runway including Add'l Salaries & Internal Overhead)	$375,000
R&D Contract per OEM Customer	$60,000
Average number of Units per OEM Customer	1,200
Projected Cost per OEM Unit	$250
Per Unit Markup	15%
Per Unit OEM Price	$288
Average Profit Per Contract	$105,000
REQUIRED OEM CONTRACTS FOR %25 ROI	**4**

Section 5: Funding Strategy

This section explores some possible paths going forward in terms of funding opportunities. As the Data & Results section suggests, the HM-GT project has high potential for profit, but requires a heavy investment upfront to enable a competitive advantage. Seed funding will be necessary to cover costs of the R&D phase, and business loans or substantial private funding from venture capital firms will require proven customer traction.

SBIR/ STTR: Small Business Innovative Research (SBIR) Small Business Technology Transfer (STTR) programs are federal grant opportunities geared towards technologically innovative small businesses. Every government agency that receives more than $1B of federal funding must host an SBIR program, and most of these agencies participate in STTR. Requests for proposals vary from agency to agency depending on their needs, some are contracts to fulfill very specific objectives and others are more open-ended grant submissions. There is also quite a bit of variation in how these agencies field applications. Calls for submissions can be annual or up to three times a year, and submission topics change either a great deal or very little between calls depending on agency. Submission topics relevant to the HM-GT project have so far been identified in calls from the National Institute of Health and National Science Foundation.

The primary distinguishing factor is the STTR requirement of research institution partnership, and an associated extension of the timeframe. SBIR is generally a six month Phase I while STTR have a twelve month Phase I run. The extended period of STTR is due in part to the slower movement inherent in an academic environment versus an independent startup. Another consideration when pursuing these funding avenues is intellectual property rights. Montana State has potentially attractive options for licensing university patents, but the ultimate value of licensing depends on how much research-level development must be carried out to realize a particular goal. While Lightfield Studios plans to leverage the capabilities of Montana State University on a contract basis, for this project it makes much more sense to peruse an SBIR Phase I as the For more complex projects, such as those related to holographic or diffractive optical elements for new display technology, STTR might be a more valuable option.

Additional Grants: Recently, the Montana State Legislature approved $15M in funding to be distributed on Montana University System campuses. This was the first time funds were offered, via the potentially ongoing Montana Research Initiative. The stated goal of the Initiative was to support new and innovative technologies to support the local business environment. While public announcements were kept to a minimum, Kevin was quick to submit a letter of interest for the HM-GT project after it was mentioned at a meeting of the Montana Photonics Alliance. The timeframe was not conducive to a competitive application being submitted, but this was a lesson in staying as informed and current as possible on *all* state and federal level grant opportunities.

There are a number of resources to navigate the grant funding landscape, with TechLink and Proposal Services being the best local options discovered. Research oriented grants are much more competitive, but still a possibility given the interest generated from to Dr. Marchak and Dr. Snider. As one example, CogNeuro initiative from National Science Foundation embraces interdisciplinary approaches to understanding the human brain. The initiative has already funded projects utilizing gaze tracking, including [Name of Micheal Paradiso project at Brown]. There is a huge span of opportunities for state and federally funded grants outside of SBIR & STTR, which presents the major challenge of keeping up to date on all relevant options.

Private Funding: If traction (i.e., a satisfied preliminary customer base) is shown, venture capital funding might be secured for a reasonable trade of equity. New Frontier Capital was recently announced as Southwest Montana's first venture capital firm, and has a special interest in technologies based on software or optics. This firm has a high probability of being the first stop for advising around the goals of a VC fund, which could lead to a formal pitch if interest is generated. Kevin has already established contact with New Frontier Capital advisor, and MSU's Vice President of Economic Development and Research, Dr. Rennee Reijo Pera for funding advice related to this project.

A potentially more attractive option than standalone VC funding might be to utilize a incubator/ accelerator specializing in hardware technologies. The incubator role is one that varies widely in both funding opportunity and capabilities to support product development. Companies like Bolt.io, SKTA Innopartners, and others would be on the list of potential companies from which Lightfield Studios could secure funding enabling this or similar projects. Bolt highlights its primary collaborators as "early state startups at the intersection of hardware and software." SKTA mentions areas of interest including smart devices with ultra-low power and interfaces for multi-modal input; the proposed HM-GT fits both of these descriptions.

In conclusion, grant funding would facilitate the R&D phases. This would defuse a great deal of the related risk and expense during the company's infancy. Soon thereafter, a shift in focus toward private funding would be appropriate as Lightfield Studios attains scale and shift focus to additional projects of value in the AR/ VR space are identified.

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