1 Executive Summary

3D scanning has a wide variety of applications, but the high cost of these scanners keeps the technology from being used in many potential applications. Bringing down the cost and complexity of accurate 3D scanning would enable the use of 3D scanning in many applications where it now is prohibitively expensive: research labs, hobbyist builders, 3D printing enthusiasts, artists, independent product designers, small manufacturers, etc.

We found that there is an academically popular method, structured light scanning, that maintains high scan accuracy, at lower costs. However, there is typically a large degree of complexity in setting up a structured light scanner; streamlining this service and packaging it into a plug-and-play device will enable us to sell the product to markets that currently cannot access or afford 3D scanning. Additionally, we have ways to make the product even less expensive than typical structured light scanners by substituting inexpensive components, such as smart phone cameras, in clever ways.

In short, we want to bring 3D scanning to a large group of users who cannot access it today. We will do this by building a low-cost, user-friendly, and high-accuracy, 3D scanner.

2 Market Overview

Digital 3D scanning is a large, established market, with an estimated market size of $530 million. Most of the products in this market are high-end and targeted at large corporations, costing tens of thousands of dollars. Reductions in component costs, advances in algorithmic efficiency, and increases in computing power now enable inexpensive 3D scanners that can achieve accuracy levels that are comparable to the expensive units.

Through building an accessible, affordable, desktop 3D scanner, we hope to expose a new, untapped market. The desktop 3D printing market has been experiencing rapid growth over the past few years, growing 240% each year from 2006 to 2011[2]. The primary customers for desktop 3D printers have been individuals: hobbyists, independent designers, artists, etc. We believe that this same market segment will buy an inexpensive desktop 3D scanner. In fact, we believe that 3D scanners will be the standard measurement tool used in shops, labs and studios. We believe that 3D scanners should be as common as a purchase as a cordless drill.

The 3D scanner that this market needs requires a set of qualities that we believe no other scanner on the market currently has:

- It must be painless to use. From opening the box, the user needs to be able to plug the scanner into his computer, put an object in the scanner, press scan, and then have a 3D model appear on his computer.
- It must be affordable. The scanner cannot cost so much that it is a luxury to the user. We judge that the scanner must be in the $300-$600 price range.
- It must be useful. The scanner needs to have an accuracy high enough to not be a constraint on most machining processes or 3D printing processes. It cannot take too long to scan. It must be able to scan all objects that can be 3D printed, and a significant percentage of objects that would be used in a design.

The market segment we are targeting be divided into individual consumers and small (¡ 10 people) enterprises.

The individual consumers we are targeting are hobbyists, enthusiasts, and artists. Many people have become excited about desktop 3D printing, and will be similarly excited by desktop 3D scanning. There is evidence for this recent successful crowd-sourced fundings for desktop 3D scanning projects, and excitement surrounding 3D scanning announcements. Though much of the popular focus has been on scanning objects in order to get a model to print, other uses of 3D scanners can be marketed. A sculptor may want to display his work online, or send an early version of a sculpture to a colleague; our scanner allows him to do so with ease. A garage tinkerer may need to get the dimensions of an object he wants to incorporate into a larger project.

The small enterprises we are focusing on include research labs, product designers, and small machine shops. In research labs, it is often important to have models and measurements of objects being tested; while the 3D scanners available today would be an unaffordable luxury, ours would be low-cost enough to have a practical purpose. Product designers can make initial designs with physical materials, which are nicer to work with, and then scan them to get a usable CAD model. Small manufacturers and machine shops can use them in the same fashion that large manufacturers do: for automated verification of manufactured parts, as well as for designing parts with unknown dimensions.

As 3D scanning technology has existed for a good deal of time, there are

Our competitors can be separated into 3 categories:

The current lowest-cost high-accuracy options: The major competitors in this range would be the NextEngine scanner or Artec's 3D scanners. Our price ($500) will be significantly lower than these products, and our scanner will be easier to use than the NextEnginer scanner. The NextEngine costs over $3,000 (once you've purchased all the necessary software), and the least expensive Artec scanner costs $12,000. Our scanner's accuracy will be in the same range as these products. Unlike these products, however, our scanner will only be able to scan objects that are under a certain size. While the Artec scanners make scanning large objects fairly simple, scanning large objects with the NextEngine is very inconvenient, which is also true for other products in the their range.

The very low-cost (free) options: There are some options on the market that come in at a price lower than ours. AutoDesk as an free app called 123D Catch–you take a series of images of an object and then it performs image reconstruction to generate a 3D model. Some products (like Scanect) allow a customer to use a Kinect to perform 3D scanning, and Microsoft recently released KinectFusion, which turns the Kinect into a 3D scanner for anyone with the Windows Kinect SDK. These technologies, though, do not provide the level of accuracy we are seeking, or the ease of access. They have more difficulty with highly specular objects than we will, and require user participation during the entire scanning process.

The emerging competitors: There are a couple competitors that have announced products but don't have anything for sale yet. CADScan successfully completed a Kickstarter project for a desktop 3D scanner that will be similar to ours in terms of target specifications and customers. From the Kickstarter funding levels, it seems that they plan on charging at least 650 ($1000) for the scanner, a price we are planning to come in significantly below. MakerBot also just announced at SXSW that they will be producing a desktop 3D scanner called the Digitizer. The announcement was very nebulous on details, but given their 3D printer costs and their description of the Digitizer, we surmise that they will be charging over $1500.

3 Innovation and Approach

Approach of our venture including its unique technology approaches/ideas:

There are already many well developed techniques for 3D scanning, so rather than reinvent the wheel the team spent a week researching 12 techniques and assessing each for their relevance and compatibility for our products goals. We concluded that structured light scanning, a basic triangulation method, would be the simplest and cheapest to execute.

From wikipedias article on Structured Light:

Structured light is the process of projecting a known pattern of pixels (often grids or horizontal bars) on to a scene. The way that these deform when striking surfaces allows vision systems to calculate the depth and surface information of the objects in the scene, as used in structured light 3D scanners.

There are tutorials online for how consumers can set up their own structured light scanners using a standard projector and a digital camera, but the amount of time required to calibrate the scanner and the hardware required makes the do-it-yourself approach both prohibitively difficult and expensive. Off-the-shelf already calibrated units are in the $3000 range and still dont boast the type of resolution that structured-light scanning techniques are accurate to.

What we require for our product (a pre-calibrated, affordable, high-resolution 3D scanner) is a [1] projection system, [2] an imaging system, and [3] the software to process the acquired data and generate a point cloud. The following discusses our development of the three subsystems so far.

[1] Projection:

In order to get around the requirement of having a standard projector (for which the cheapest units retail for $300 in the US, $75 from China) we instead looked into the cheapest way that we could project a static, high-contrast image on our object. We looked into doing this using the interference properties of coherent laser light but instead opted for projecting a high contrast silhouette of a grating onto the object. Using simple geometric arguments, the factor limiting the contrast of the projected silhouette is simply the size of the light source (as one can imagine, the projected image is simply the image created by a point light source convolved over the size of the light source). Our approach: to focus a well-collimated light source down to a single point - effectively creating a point light source and then allowing it to propagate through the focal point and diverge to cover an area large enough to cover our whole object. All that this requires is a single lens and a collimated light source, for which we used a laser and a 15mm focal length lens from Thorlabs, but from initial testing we believe we can improve on the existing setup substantially while still keeping costs low. Employing a well-collimated, incoherent, white light source and a system of lenses should allow us to get rid of unwanted interference patterns and project a large enough image from less than 2 feet away.

[2] Imaging:

The Smartphone industry has helped create a large demand for small, high resolution, inexpensive imaging sensor. These imaging sensors are the bare bones of digital cameras for only a fraction of the cost. The sensors are available for less than $10 ,even in small quantities, and can produce images in the 5-8 megapixel range. The imaging sensors allow us to maintain affordability while still provide high accuracy. Microcontrollers are also at a point where they are cheap, but easily powerful enough to utilize the full potential of the sensor. Craig is currently doing development using a Cypress PSoC (Programmable System on Chip), which allows for fast prototyping, without the need for peripheral chips, as they can be programmed into the PSoC. This minimizes downtime wiring chips or designing Printed Circuit Boards, and reduces cost.

[3] Software:

4 Lessons Learned

Imaging: Many of the issues that arose from prototyping have to do with the physical layout of the circuits. Many of the advanced sensors come in a format that is difficult to work with. The chips come in a Ball Grid Array package, which is not easily dealt with by prototyping. The grid consists of 56 balls of solder each spaced about 500-600μm apart, which are impossible to solder to directly; they must be reflowed onto a PCB. While this should not be a problem when dealing with the end product, it means that developmental tools are invaluable during initial phases.

5 Plan of Action

Following are the actions we will plan on completing, with more emphasis on tasks to complete over the summer.

5.1 Customer Milestones

Milestone	Date
Estimate consumer market demand via a Google Consumer Survey (or equivalent technique)	6/20
Choose product name and create logo as a reflection of desired brand image	8/1
Secure list of prototype testing partners	8/15

5.2 Product Milestones

Milestone	Date
Finalize the low-cost projection method that will be used in the system	7/1
Develop an IP strategy to protect crucial design components of the system, and file for provisional patents is appropriate	7/15
Complete alpha prototype of the system	9/1
Complete 2^{nd} alpha prototype of the system	10/1
Develop a list of components for a beta prototype, and select manufacturing partners to source parts from	11/1
Complete beta prototype	12/1

5.3 Team Milestones

Milestone	Date
Finalize team members' equity splits and vesting schedules, defining what will happen under different possible participation scenarios.	6/15
Bring in an additional team member with business experience to aid in business strategy, scaling, and marketing	9/1

Milestone	Date
Develop a high quality short and long pitch deck	7/1
1st order estimate of unit manufacturing costs at various build volumes using alpha prototype components	8/15
Secure funding in order to continue growing the business	9/1

5.4 Financial Milestones

6 Risk Factors

Risk Catergory	Risk	Probability of Risk Materializing	Risk Mitigation
Management Team	Having only technically oriented cofounders could leave us weak in terms of business strategy and entrepreneurial prowess	High	We must recruit another employee or cofounder who is business and marketing oriented
	Team unable to strategize operational plans to guide all steps of value chain	Medium	Proactively seek advice from experienced advisors and industry experts; implement monitoring and quality checks on a scheduled basis
Market	Over or under-estimated market size segmentation and location, such that operational and financial impact will be high	Medium	Target a statistically-rationalized need based audience. Perform a more thorough market analysis prior to product launch and design for operational flexibility to meet changes in demand
	Inability to capture targeted market, leading to lower sales than anticipated	Medium	Run an aggressive advertising campaign to attract new users. Verify that product aspects appeal to user-base by performing comprehensive usability tests
	Unexpected competition penetrates target market	Low	Focus on getting the product to market as quickly as possible. Track market trends and rising competition; design flexible and adaptable strategy to account for requirements to change aspects of product differentiation to stand apart
	Technical gap between po-	Dramatically	It is essential that the prod-

Finance	Unable to secure adequate funds for prototyping and scale-up	High	Apply for accelerators, VC's and Angels. A working prototype will dramatic help in this regard
	Lack of adequate funds to fairly compensate desired talent	Low	Ensure that realistic and competitive salaries and benefits are included in all financial models
	Unmet supply and demand projections will lead to unbalanced revenues with fixed and variable costs, such that unit price exceeds initial estimate. This will lower market absorption and increase time to break-even	Medium	Identify the largest sources of cost and strategize how to best mitigate. Alternatively, depending on the market, we might find that our current target price point can be increased without severely impacting sales
Delivery	Difficulties with shipping and packaging	Low	Connect with experienced mentors or consultants, and keep delivery channels in mind during design

7 Team

*Troy's Bio Troy is graduating this June with majors in 16-ENG (concentration in Robotics) and 8B (concentration in Computational Learning Systems), and a minor in 14. The majority of his experience is as a programmer, focusing on machine learning and web development. He plays tennis for MIT and is a Freshman Leadership Program counselor.

Craig is pursuing his degree in 2A-6, Mechanical Engineering with a concentration in Control, Instrumentation and Robotics. He has worked extensively with robotics and machine design since freshman year of high school. This past semester his team won the 2.12, Introduction to Robotics, term Robo-Gymnastics competition. The team won their division, the overall competition, and was awarded "Best Design Award". Additionally, Craig was awarded "Most Valuable Engineer" for his team. In addition to mechanical engineering, Craig is experienced with microcontrollers, software and embedded systems. Craig is currently president of his fraternity, captain of the varsity Waterpolo team, and a member of the national varsity swim team.

*Gus's Bio Gus is receiving his BS in physics from MIT this June. His focus has been on ultra-cold atomic physics, and he has worked in 5 different labs ranging from condensed matter physics to plasma physics. He sings with the Logarhythms, is a Freshman Leadership Program counselor, is a (half) Iron Man, and cooks a mean pork roulade.

* How long have you known each other, and what have you worked on in the past? (Include past work done on this project, if applicable.) We have been working on this project together since January, as part of 6.S078, Entrepreneurship Project. We have been working with another student as well, Turner Bohlen. Unfortunately Turner won't be able to join us for the summer as he has previous commitments.

Troy and Gus have known each other since their freshman year, and have been co-counselors in the Freshman Leadership Program for the past 2 years. Craig and Troy took the same robotics class, 2.12 Intro to Robotics, in the Fall of 2012 where they both placed in the top 5 out of 70 students.

8 Financial Plan

Annual Growth Rate(to year 3): 2.4
Quarterly: 0.3579
Initial Annual Sales :4000 units

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Revenue Projections
Years 1 to 5
($)

		Year 1	Year 2	Year 3	Year 4	Year 5
3D Scanner						
Number of Units		0	4,000	13,600	46,240	157,216
Price per unit	$	-	500	500	450	400
Total		0	2,000,000	6,800,000	20,808,000	62,886,400
3D Scanner with larger scan						
Number of Units	$	-	0	0	5,000	12,500
Price per unit		0	0	0	2,000	2,000
Total		0	0	0	10,000,000	25,000,000
Net Revenue		0	2,000,000	6,800,000	30,808,000	87,886,400

Revenues by Months & Quarters
($)

Months	Year 1	Year 2	Year 3	Year 4	Year 5
Month 1	0	100,000			
Month 2	0	100,000			
Month 3	0	140,000			
Total 1st Quarter	0	340,000	1,014,067	4,594,321	13,106,282
Month 4	0	120,000			
Month 5	0	140,000			
Month 6	0	140,000			
Total 2nd Quarter	0	400,000	1,377,008	6,238,656	17,797,099
Month 7	0	160,000			
Month 8	0	200,000			
Month 9	0	200,000			
Total 3rd Quarter	0	560,000	1,869,848	8,471,509	24,166,789
Month 10	0	220,000			
Month 11	0	240,000			
Month 12	0	240,000			
Total 4th Quarter	0	700,000	2,539,077	11,503,514	32,816,230
Total for year	0	2,000,000	6,800,000	30,808,000	87,886,400
Average Revenue					
by Month	0	166,667	566,667	2,567,333	7,323,867
by Quarter	0	500,000	1,700,000	7,702,000	21,971,600

DCBA

Cost Projections
Years 1 to 5
($)

	Year 1	Year 2	Year 3	Year 4	Year 5
Per Unit Costs (Scanner)	$ 150.00	$ 140.00	$ 120.00	$ 110.00	$ 100.00
Number of Units	0	4,000	13,600	46,240	157,216
Total Unit Costs	$ -	$ 560,000.00	$ 1,632,000.00	$ 5,086,400.00	$ 15,721,600.00
Per Unit Costs (Large Scanner	$ -	$ -	$ -	$ 300.00	$ 300.00
Number of Units	0	0	0	5,000	12,500
Total Unit Costs	$ -	$ -	$ -	$ 1,500,000.00	$ 3,750,000.00
Employees	5	10	20	30	35
Average Salary	$ 50,000.00	$ 100,000.00	$ 120,000.00	$ 150,000.00	$ 150,000.00
Total Labor Costs	$ 250,000.00	$ 1,000,000.00	$ 2,400,000.00	$ 4,500,000.00	$ 5,250,000.00
Facilities rate	$ 35.00	$ 35.00	$ 35.00	$ 35.00	$ 35.00
Square Footage per person	200	200	200	200	200
Total Facilities Cost	35,000	70,000	140,000	210,000	245,000
R&D Materials	100,000	200,000	100,000	2,000,000	5,000,000
Total Cost	$ 385,000.00	$ 1,830,000.00	$ 4,272,000.00	$ 13,296,400.00	$ 29,966,600.00
Net Income	(385,000)	170,000	2,528,000	17,511,600	57,919,800

References

[1] Gina Roos. *CMOS Image Sensors Continue to Advance*. 2013. URL: http://www.digikey.com/us/en/techzone/sensors/resources/articles/CMOS-Image-Sensors-Continue-to-Advance.html.

[2] T.T. Wohlers and Inc Wohlers Associates. *Wohlers Report 2012: Additive Manufacturing and Three Dimensional Printing State of the Industry Annual*. Wohlers Associates, 2012. ISBN: 9780975442975. URL: http://books.google.com/books?id=b1DrZwEACAAJ.