Seed Squirter Verification System

BAE 4023: SENIOR DESIGN II

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Contents

Mission Statement 3
Background 3
Problem Description 3
Statement of Work 4
Scope 4
Location of Work 4
Product Requirements and Deliverables 4
Resources Needed 5
Acceptance Criterion 5
Client Resources and Suppliers 5
Capstan Ag Systems 5
Great Plains Manufacturing, Inc. 6
Targeted Customer 6
Competitive Product Evaluation 6
Technical Development 6
Industry Analysis 7
Regulations and Standards 7
Publications 7
Solutions 7
Ruled-Out Solution 7
Proposed Solution 8
Experimentation and Testing 8
Camera Testing 8
Camera Selection Criterion 8
Cameras Tested 8
Methods and Procedures 8
Data Handling 9
Results 9
Camera Conclusions 9
Component Selection 10

Camera 10
Borescope 10
Lens Attachment 10
Row Unit 10
Plumbing 11
VT Display 11
Software 12
Row Unit Testing 12
Camera and Laser Placement 13
Calibration 14
Software and Coding 15
Cost Analysis 17
Impact 17
Environmental 17
Industrial 17
Social 18
Conclusion 18
The Next Steps 18
Updating Camera and Software 18
Converting Program and Display output 18
Field Testing 19
Division of Labor 19
Bibliography 20
Appendices 22
Appendix A: Planning 22
Schedule of Work for Spring 2016 22
Work Breakdown Structure 24
Appendix B: Research 25
Patent Search 25
Appendix C: Supporting Diagrams 31

Mission Statement

ExactoSpray Technologies strives to provide innovative technology to delight the modern farmer through cutting edge research, inventive engineering, and extensive testing. ExactoSpray works diligently with a number of universities and agricultural companies to provide innovative verification systems to provide further product support for all customers.

Background

Seed Squirter is machinery design that combines planter and sprayer technologies to allow clients to plant crops while simultaneously spraying initial fertilizer on or in close proximity to the seed. Seed Squirter is an idea Capstan Ag Systems has been pursuing for around 15 years that has recently been revived in a partnership with Great Plains Manufacturing Company. Great Plains Manufacturing at the 2015 Agritechnica Farm Show in Hannover, Germany released the final product under the name Accushot.

When planting, particularly corn in twin or narrow rows, it is difficult to spray initial fertilizer while planting seeds. In the past, this has been done by walking behind the planter and using backpack sprayers to apply the initial fertilizer on quarter sections of the field. Agronomists have found that the survival rates and condition of the plants are significantly better if the initial fertilizer is applied in the furrow with the crop seed. Therefore, it would be beneficial for farmers to have the technology, such as Seed Squirter, which applies the initial fertilizer in the furrow while planting the seed. However, in order for it to be marketable to farmers, the system would need to include a method of verifying the machine's performance.

Problem Description

Mr. Troy Kolb and Mr. Adam Madison, of Capstan Ag Systems in Topeka, Kansas, are currently working on a planter that can spray initial fertilizer in the furrow while planting simultaneously. It is known as the Seed Squirter system. Specifically, Mr. Kolb is trying to verify that the spatial relationships between the seed and the spray the current system is outputting similar to the relationship specified by the user. Mr. Kolb will utilize the technical expertise of Cortney Bromenshenk, Austin McCarthy, Taylor Johnson, Meg Sheehan, and Oklahoma State University to meet the objectives identified in the above-mentioned study. The senior design team will investigate the system to determine a method that verifies that the

Capstan Seed Squirter system is correctly spraying the initial fertilizer within the given distance to the location of the seeds in a Great Plains Manufacturing corn planter system.

Statement of Work

Scope

The Oklahoma State Senior Design Team was tasked to design a verification system that found the distance between the squirt and the seed, and determine a percent difference compared to the values set in the VT Programming. Due to the time constraints and weather conditions, the setup was limited to a laboratory environment, and the results were outputted to an excel sheet for simplification.

Location of Work

The primary testing site was in Dr. Taylor's Lab at the OSU Biosystems Engineering Lab in Stillwater, Oklahoma. Other test sites included Great Plains Manufacturing in Salina, Kansas, as well as, Capstan Ag Systems in Topeka, Kansas.

Product Requirements and Deliverables

The inputs that the proposed solution system considered were the pixels streamed from the camera; the breaking of the laser plain by the seed and squirt; a timer; the ratio of camera pixels to actual distance (i.e. 1 pixel = x number of millimeters); and the necessary equations to calculate distance considering ratio. Other considerations included the user's input of the seed distances to the spray and the length of the spray to be able to compare the expected and the experimental values.

The outputs considered for the display included the calculated distance between the seed and the spray and the percent distance in the measured value compared to the VT setting.

Figure 1: Verification Methods prior to the verifications system (Manual Verification)

Resources Needed

The materials needed for the proposed solution were divided between Capstan, Great Plains, and Oklahoma State. The Following list is the materials loaned from Great Plains Manufacturing Co.:

- A Single row system to test
- An Ag Leader VT screen similar to the ones used on the Seed-Squirter System
- A copy of one of the Slow-motion videos from the Great Plains Lab
- Great Plains Seed tube with sensor
- Sprayer tube with nozzle
- Any CAD drawings that can be given of the seed tube, spray tube/nozzle, and the planting system of the single row unit, specifically, with measurements and dimensions shown

The following list is the materials loaned from Capstan Ag Systems:

- A Seed Squirter controller
- A liquid application system

The list below is the materials used from Oklahoma State University:

- Basler acA2000-340km High Speed Camera
- Fiberscope lens or a fiber optic cable camera lens
- Brightly colored corn seeds
- Bright Orange or White liquid dye or hydrostatic testing solution
- Matlab software and Microsoft Community Visual Studio C++ software

Acceptance Criterion

The customer has requested a planter that will fertilize and plant at the same time. However, along with this, they also asked for a verification system. There is a diagram on the monitor that displays distance of the seed to squirt, but the customer would like to see that the system is performing the way the settings are programmed. The verification system will make the distance between the seed and the squirt apparent, which will confirm that it is in close proximity to that of which it is programmed to.

Client Resources and Suppliers

The Biosystems and Agricultural Engineering Senior Design Students of Oklahoma State University produced this project for both Capstan Ag Systems and Great Plains Manufacturing Co. Ltd.

Capstan Ag Systems

Capstan Ag Systems is a technology company based out of Topeka, Kansas that concentrates on creating new electronic systems for agriculture applications. They proudly use a design process that involves research, engineering design, and both lab and field testing, while still working with other specified experts.

In 1992, Capstan licensed a patent for Pulse Width Modulation (PWM) spray technology, which improved spray processes. In 1994, the first PWM system, Synchro®, was introduced in California for commercial custom applications and three years later, Capstan signed their first large OEM agreement to allow the sale of Synchro®. Twenty years of service later, Capstan Ag

Systems has improved the quality of spraying through innovative technology, proven results, and a team that is motivated to support a farmer's demands for agricultural spray systems.

Great Plains Manufacturing, Inc.

Roy Applequist, the company founder, who has led Great Plains to become one of the largest privately held manufacturers of agricultural implements for tillage, seeding, and planting in the United States, established Great Plains Manufacturing, Inc. in 1976. They are also known as a leading producer of dirt working, turf-maintenance, and landscaping equipment between their five major divisions.

Salina, Kansas based division of Great Plains Manufacturing, Great Plains Ag remains a leader in seeding equipment since its 1976 founding. They are proud of their Midwestern roots and the work ethic gained by developing, testing, and manufacturing their products in smaller Kansas communities. They use the latest computer aided design technology to design their equipment and rigorous testing in both the field and lab to ensure high quality products. The design process coupled with the rural backgrounds of their employees has made them not only known as a leading producer of Grain Drills, but also recognized across North America as a leader in Planters, Vertical Tillage and Conventional Tillage Equipment, Fertilizer Applicators, Sprayers, and Compact Drills.

Targeted Customer

Seed Squirter is targeted for farmers planting twin row or narrow row corn. Capstan and Great Plains are currently exploring the idea of Seed Squirter possibly being applicable to pumpkin and other vegetable planting in the future.

Competitive Product Evaluation

The idea of fertilizer application while planting has been in use since the 1990s, including liquid fertilizer application through open nozzle streaming. However, since Seed Squirter is unique in its use of pulsating spraying for a dose per seed amount of initial fertilizer application, there are not many existing products to research. Because there is little competition or existing projects to focus on, our patent search focused on these existing spraying while planting methods and the evolution of the technology required for Seed Squirter to be developed. This can be found in Appendix B.

Technical Development

Seed Squirter contains parts that are produced and patented by companies outside of Capstan Ag Systems and Great Plains. Some of these parts include the VT monitor and the seed sensor. The process for planting corn and the scientific methods behind the application of fertilizer within the furrows, however, has been in existence. This method works by spraying initial fertilizer in an open furrow with the seed. Capstan's Seed Squirter system differs from previously developed methods by instead placing the starter-fertilizer in a specific amount and location relative to the seed being planted. This method reduces the death of plants due to improper placement of fertilizer. The concept of this project is to verify that the theoretical placement of the fertilizer corresponds to its actual placement. Proper functioning of the system could determine whether plant growth is enhanced or detrimentally harmed. Patents of similar products and their relevance are included in the section above.

Industry Analysis

Regulations and Standards

The design standards for sprayer/planter electronics and precision agriculture are from the American Society of Agricultural and Biological Engineering (ASABE), the Institute of Electrical and Electronics Engineers (IEEE), and the International Organization for Standards (ISO). The recommended operation standards and applications for Seed Squirter that will be used are provided in table 1 and can be found on the Great Plains Accushot webpage at https://www.accushotsystem.com/features.

Table 1: Specifications and Application Rate Chart for Seed Squirter

AccuShot™	Sample Specifications
Min Rate*	2.6 gpa (24 l/ha)
Max Rate*	9.0 gpa (84 l/ha)
Min squirt length*	1.5 in (38 mm)
Max squirt length*	4 in (102 mm)
Typical boom pressure	30 psi (2.07 bar)
Optional mounted liquid tanks	2-200 gal (2-757 l)
Optional semi-mount liquid tanks	Compatible with 500 gal (1893 l), 735 gal (2782 l), and 1000 gal (3785 l) tanks
*Example Given: 5.5mph (8.85kph), 30" (76cm) Twin-Row spacing, 35,000 seeds per acre (86,5000 seeds per hectare). See website for complete application chart. Specifications are subject to change without prior notification.	

Publications

Industrial Publications that were used include:

- Accushot User Manual
- Accushot Quickstart Guide
- www.accushotsystem.com

Solutions

Ruled-Out Solution

The initial idea to solve this problem was to use an analytical approach. Using the signal from the seed tube sensor and a reading from a sensor on the spray valve, distances could be calculated using equations and conversions. While this could be theoretically accurate, this solution was rejected. This method was already used for the VT screen settings, and the system needed to by outside of the mechanism and independent.

Proposed Solution

The proposed solution was to use a high-speed camera and fiber optic lens to view the site of interest. A laser was mounted to create a false ground. From there, a Matlab code identified and measured seed to squirt length based on the breaking of the laser plane. This is a combination of the experimental set up at Great Plains, and the analytical proposition above.

Experimentation and Testing

Camera Testing

Camera Selection Criterion

The camera selection was the project assigned to the freshmen team. The goal of their project was to research the cameras that were available to the Senior Design Team, which met the Seed Squirter verification system requirements. The cameras on the list were selected from their ability to work well with the fiberscope lens, shutter speed, and quality of picture. The camera needed to be a high speed that included a shutter speed no less than 120 frames per second to catch around 12 seeds falling per second. A list of the specifications are provided in the table below.

Table 2: Important Camera Specificaitons

	Basler	GoPro
Cost	$1,530.00	$400
Battery Life	Battery powered or it can be hooked up to wiring in machine	Around 1 Hour
Durability	3 year warranty to ensure durability	1 Year Warranty
Lighting	Performs in various lighting	Needs dark background to display lighting
Picture color	Black and White	Color
Shutter Speed	340 Frames per second	60-120 Frames per second

Cameras Tested

Basler acA2000
Go Pro Hero 4

Methods and Procedures

The first test setup was a preliminary test evaluating the speed of the camera to understand the settings needed in the row unit test. Each camera was used to film the seeds dropping from the seed tube at a set distance from the ground. Since the target speed for the Seed Squirter system is to drop approximately 12 seeds every second, seeds dropped at known time intervals and fell a known distance. The acquired images from these tests and the observed times were used to calculate the pixel to distance ratio which were needed as conversion factors in the primary testing. The results formed a better idea of the positioning the camera required in the main testing. This experimentation was conducted the final week of October and was observed by the project's freshmen team.

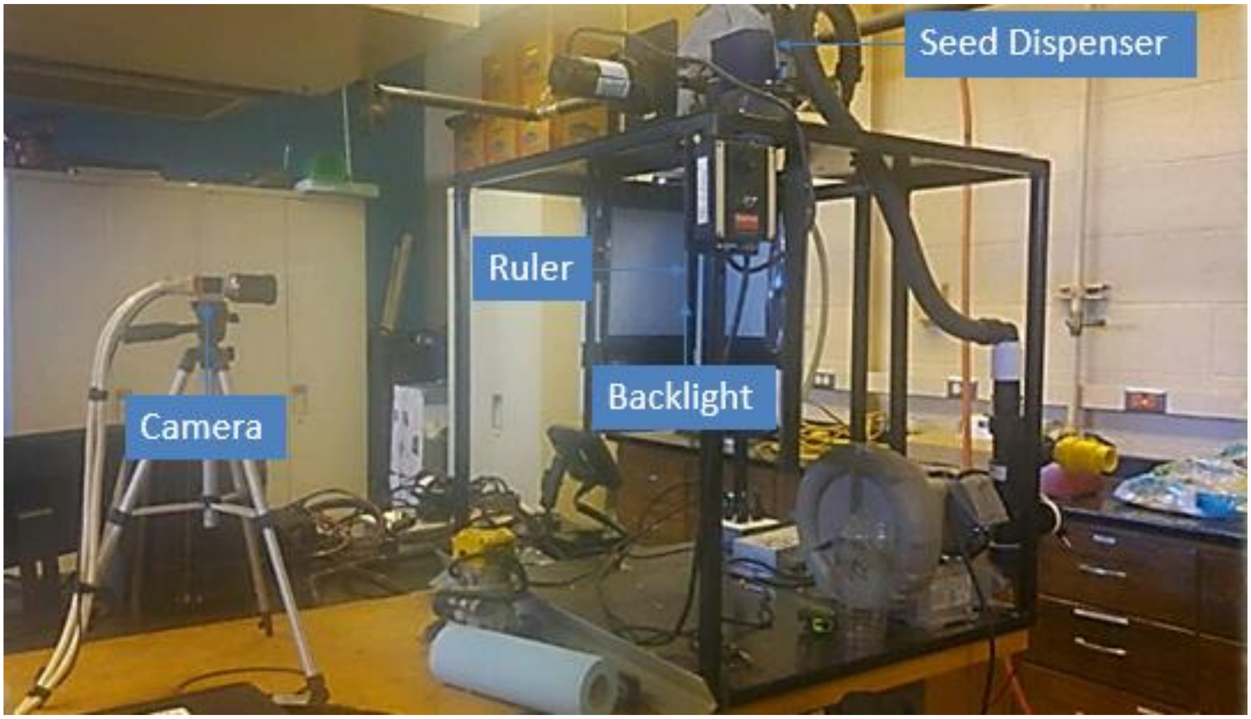

Figure 2: BAE 2012's Camera Project Setup

Data Handling

The data was analyzed by using the frame by frame function of VLC movie player software. The freshmen team, supervised by the senior team, went through the three tests from each camera, frame by frame, and counted the number of frames that the seed took to vertically fall a foot at a rate of 12 seeds per second. They then could verify each camera's frame per second rates to the frame rates they found in their research. In the end, they determined which camera was able to catch the most frames with clear pictures of the seeds falling, which would determine which camera system operated at a speed of no less than 120 frames per second, which should be fast enough to be effectively used in the Seed Squirter verification system.

Results

The research, done by the freshmen team, concluded that both the Go Pro and the Basler cameras were viable options to verify the Seed Squirter system. Both cameras promised a speed of 120 frames per second, however, the Go Pro was significantly cheaper than the Basler, thus, was a more economical choice. The Go Pro is a color camera, whereas, the Basler is a black and white camera.

Camera Conclusions

After analyzing the results of the camera testing, the freshmen team found that the Basler camera did provide more precise data due to its higher quality picture. This proved their initial hypothesize to be true. Therefore, the freshmen team recommends that the senior team use the Basler camera in their verification system. However, the initial research of the Basler camera indicated that its cost was outside the requested price range. If quality can be sacrificed, the freshmen team notes that the Go Pro will also work in the senior teams designed system and will provide a more economical option. The freshmen team also concluded that there is no applicable benefit of filming in color verses filming in black and white. They recommend the senior team film in black and white, as the speed of the camera is hindered by the camera trying to constantly compensate for the change in color and light between the background and the seed color.

Component Selection

Camera

The senior design team used a Basler acA2000. It was an economical choice that stayed within the recommended budget.

Borescope

The borescope selected was a flexible borescope kit from Imaging Products Group. The borescope kit contained a small light and a viewing eyepiece, where the lens attachment was placed to bring the image to the camera.

Lens Attachment

The lens attachment that was selected was a Luxxor® Video Coupler Lens with a 25 mm focal coupler length. A C-coupling lens attached to the eyepiece of the borescope. The attachment was used for live video inspection and documentation, which delivered a full field-of-view.

Row Unit

Seed Tube

The seed tube was a smooth flow seed tube provided by Great Plains, who requested its use. It was the same seed tube that will be used in the overall Seed Squirter system.

Seed Sensor

The Seed Sensor was a Dicky John seed sensor also provided by Great Plains.

Spray Pipe

The spray pipe was provided by Capstan and fits a size 5 tip.

Figure 3: The internal of a single row unit

Plumbing

Pump
Manual Release Nozzle
Nozzle Attachments

VT Display

An Ag Leader VT screen was provided by Capstan to manage and run the system.

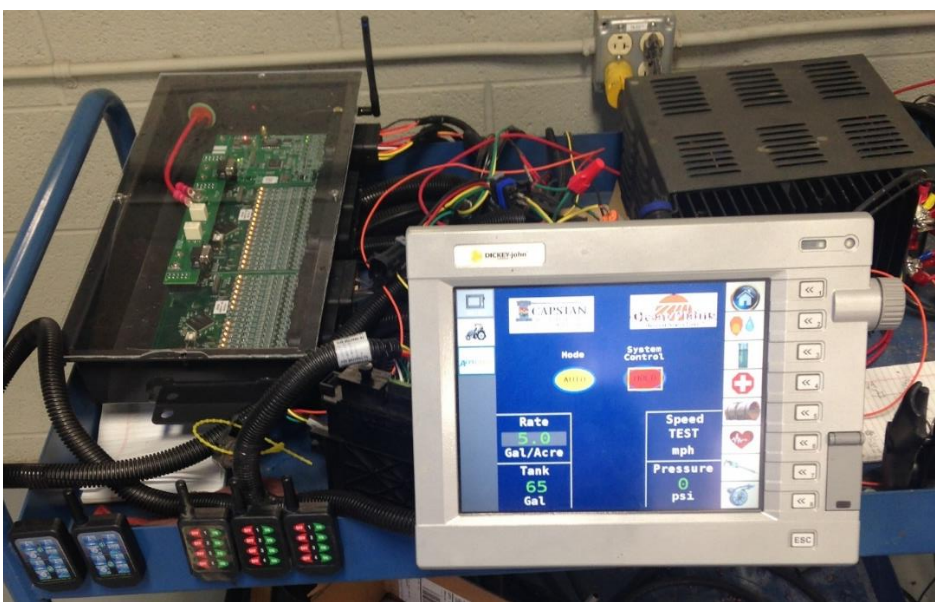

Figure 4: The display screen and its components for a single row unit at Great Plains Manufacturing

Software

An older system of Seed Squirter software was provided by Capstan, along with the display software for the VT screen. A free VLC media software was used to review the quality and calculate the actual speed of each camera system tested. A license of Matlab was provided by Oklahoma State University for the development of the verification system's display and data handling.

A Matlab program script, written by Dr. Cary Zhang of Oklahoma State University, was referenced which translates .vid files into Matlab using the Image Acquiring toolbox and counts the number of seeds falling. The senior design team used the image translating section of Dr. Zhang's code, then added the use of the Computer Vision Systems toolbox to track the location of both the seed and the squirt, using methods built into the toolbox and example code from the Computer Vision Systems toolbox documentation files provided by MathWorks

Row Unit Testing

The primary testing procedure was done with the camera system incorporated on a single row demo unit of the Seed-Squirter system. The electronics system for the row unit were mostly assembled by Capstan, and the planter system was mostly assembled by Great Plains. However, the senior design teams with parts and instructions provided by Capstan assembled the plumbing system in the row unit. Once assembled, the plumbing system was purged using the valve diagnostics tab on the VT screen to void the system of air pockets. The overall running of the system was first checked by manually dropping seeds down the seeding tube to trigger the squirt. A motor and vacuum were then attached to the seeding system to allow automating turning of the seed wheel, causing autonomous dropping of seeds. The system was then run completely automatically in manual mode and the results were filmed to assist in coding development.

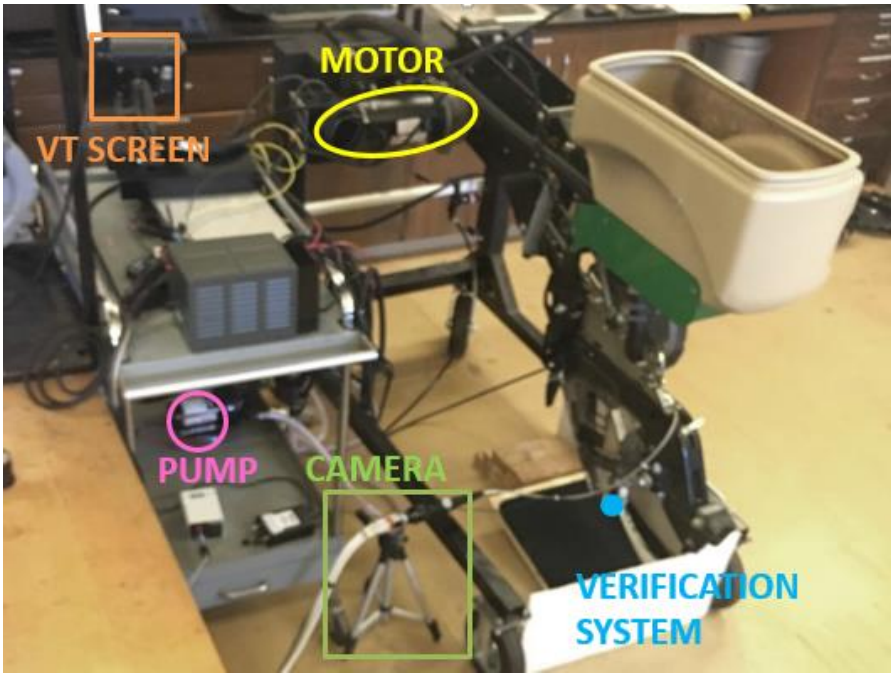

Figure 5: Primary Test Setup

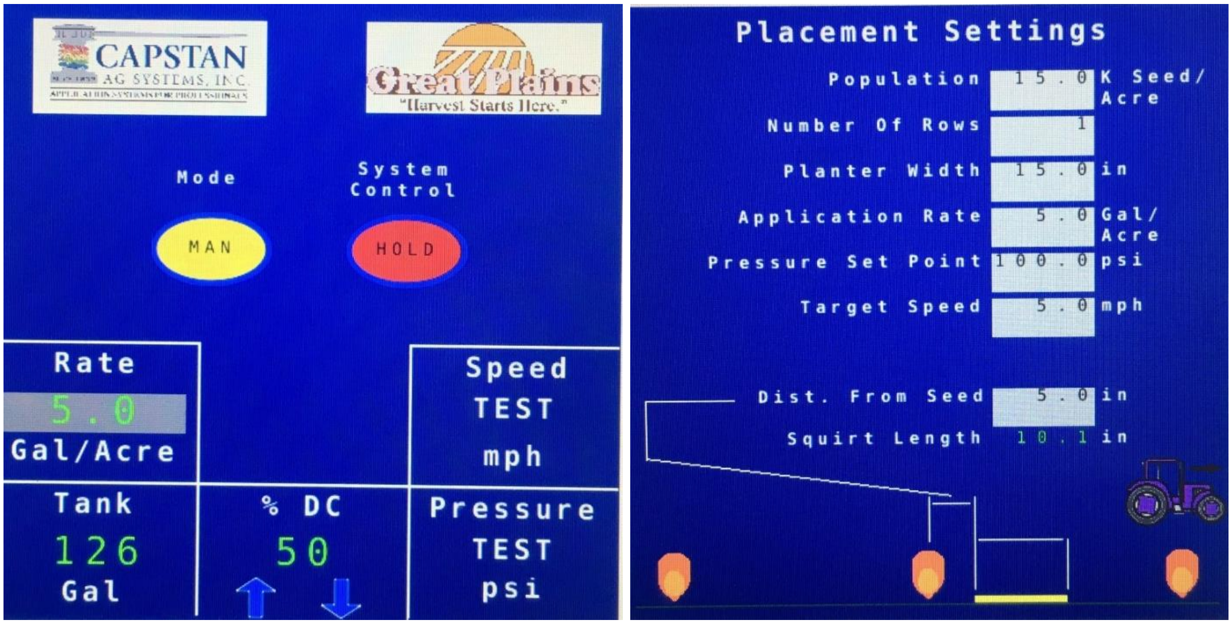

Figure 6: VT Setting used for testing

Camera and Laser Placement

The camera was fed images through a fiberscope lens that was situated close to the seed tube and the sprayer pipe. The exact location and position of the lens was determined by looking at the spacing constraints of the row unit and taking measurements. Figure 7 shows the design, which placed the fiberscope directly behind the seed firmer.

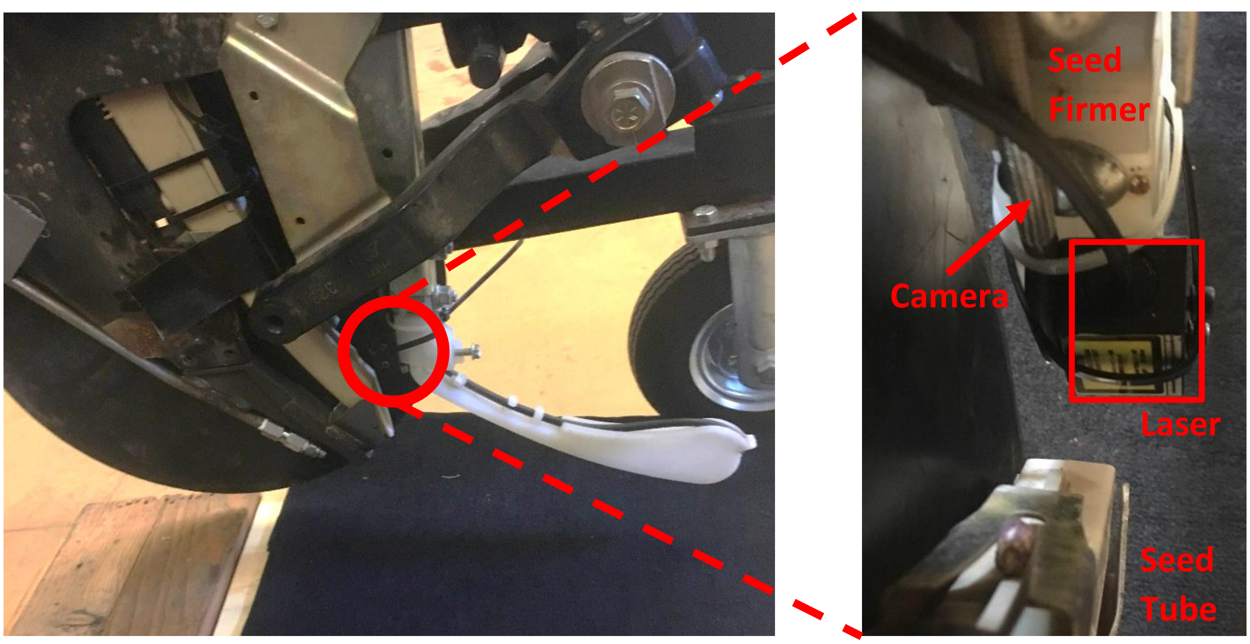

Figure 7: Camera and Laser Placement

Calibration

In order to calibrate the camera system, we used several methods. The first done by the suggested MatLab calibration. The specific coding identifies distortions in a checkered background and adjusts the picture accordingly. One major fix it makes corrects the fisheye view of the board due to the borescope's lens. The next step was establishing the pixel differences between the entrance position of the seed tube and the entrance position of the squirt. This is needed to adjust measurements based on pixel distortion in the 3D views. These two settings combined helped to adjust for biases in the data exported to the excel sheet.

Figure 8 shows the calibrated planes provided by the Camera Calibrator Application in Matlab. The first plane is where the seed is detected. The second plane is where the squirt occurs, and the third is the laser plane. These calibrations combined help to calculate an accurate ratio of pixels to millimeters.

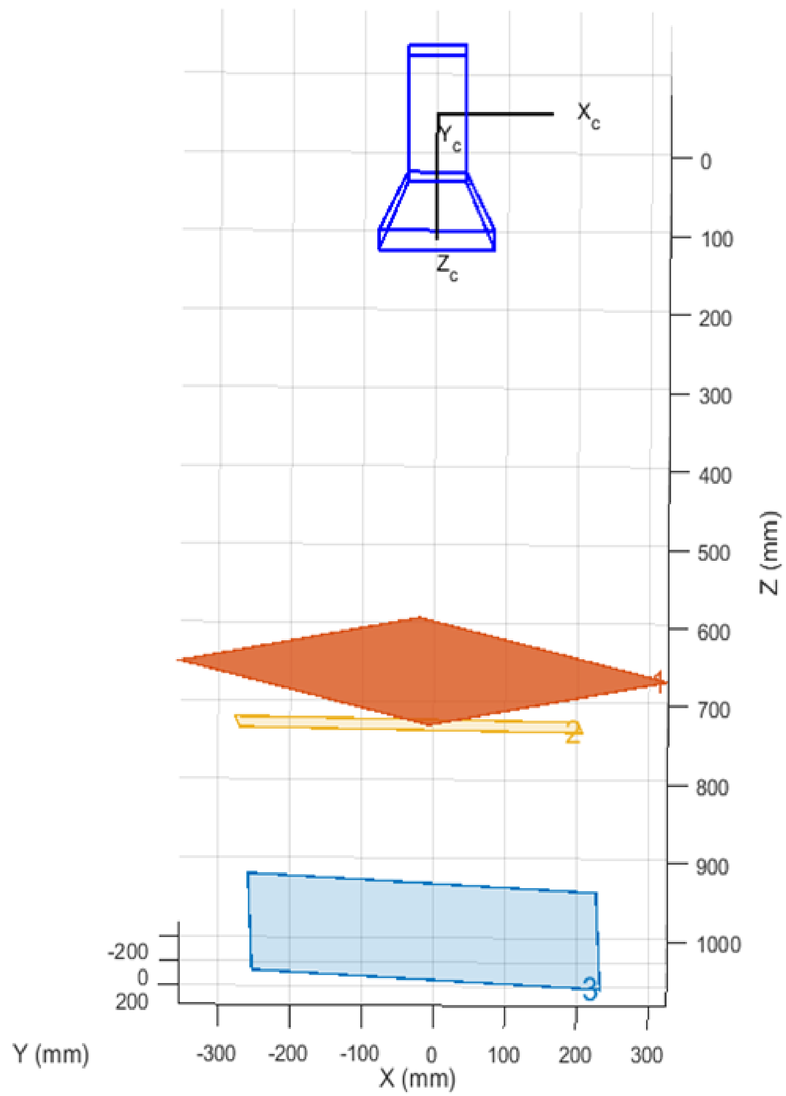

Figure 8: Calibration Layout from setup

Software and Coding

The early stages of testing used an integrated camera system to directly receive the video footage and run it through a Matlab program with the help of the Image Acquisitions and Computer Vision Systems Toolboxes provided by MathWorks. Due to the vertical nature of the footage obtained by the camera, a laser plane simulated a false ground. The Image Acquisition Toolbox moved the footage frame by frame. The program then applied the Computer Visions Systems Toolbox to track and predict the motion and positions of the seed and the squirts by using custom fitted trajectory equations and the visible change in light intensity of the objects passing through the laser plane. The Computer Vision Systems Toolbox, with the calibrated camera, then found the distance between the seed and the spray and the length of the spray, using pixel to distance relations. Finally, the Matlab program output the measured distances and the percent differences between VT settings and measurements to an excel spreadsheet. Two versions of the code were developed, one using footage provided in the row unit testing and one using live video, both with and without the borescope lens, to provide multiple test scenario support.

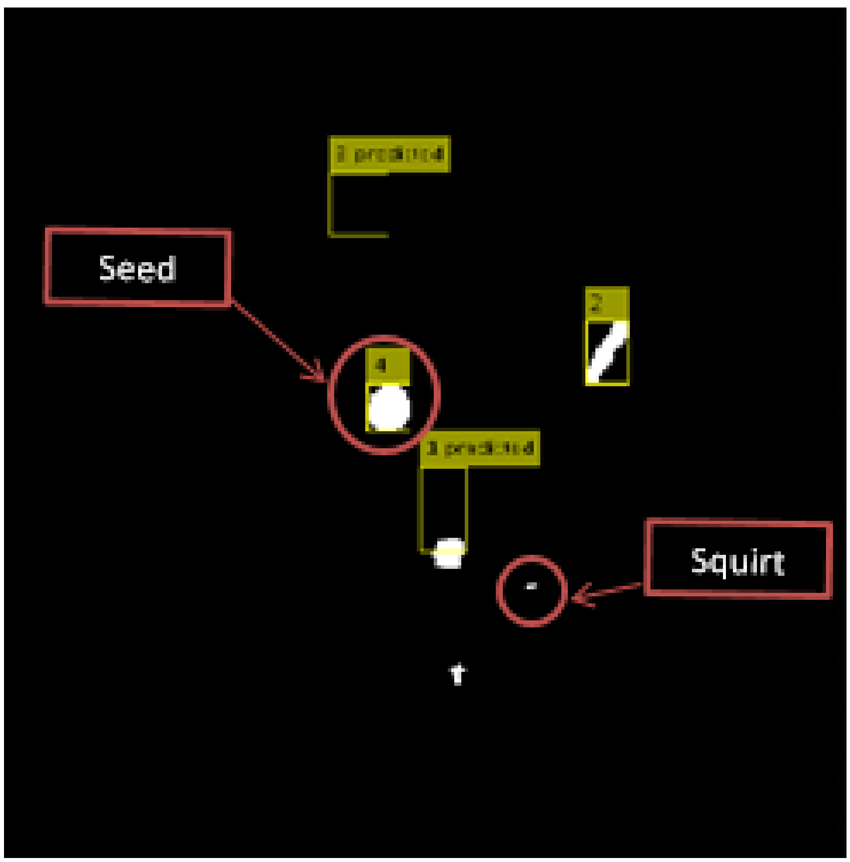

Figure 9: Annotated Screenshot of the code reading the locations from the video.

Table 3: Outputted Excel File from software

Inputted Distance	Measured Distance	Percent Difference
5	4.998300169	-0.033996627
5	4.998300169	-0.033996627
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Cost Analysis

All costs were based off the costs for single row equipment from a 32-row kit. The number of verification systems will be based on the cost of the final system. There will be as few as one on each side of the planter, or as many as one on each row.

Table 4: Cost Analysis Table

Part	Cost ($)	Covered By
Row Unit	2,675	Great Plains
Control Box	7,162.56	Capstan
VT Screen	727.95	Capstan
GPS Sensor	424.30	Capstan
Pressure Sensor	635	Capstan
Nozzle Valve Assembly	135	Capstan
Seed Tube w/ Sensor	68.79	Great Plains
Nozzle Tips	30	Great Plains
Pump Assembly	3,825	Capstan/Great Plains
PVC Piping	10	OSU
Camera	1000	OSU
Fiberscope	130	OSU
Lens Attachment	395	OSU
Software	150	Capstan/OSU
Key Fob	252	Capstan
Power Source	25	Capstan
Total	**17,645.60**	

Impact

Environmental

Seed Squirter limits the amount of extra initial fertilizer applied in corn planting. This limitation could possibly reduce the amount of nitrogen and phosphorus in the soil and groundwater. These are common chemicals associated with fertilizer that seep through the soil into the groundwater, which can affect the soil erosion and populations of aquatic life (Sharpley et al.1987).

Industrial

Application of starter fertilizer that includes phosphorus and potassium for corn products is highly recommended when planting, especially in late May, because the chemical compounds can help increase nutrient uptake in the plant, leading to larger stronger, and earlier growth (Bundy 1992). In addition, crops that are planted with a starter fertilizer show a larger yield due to its ability to lower moisture around the stalk (Bundy 1992). For all the yield benefits that come from planting with initial fertilizer, the application of the fertilizer is often tricky. Since most fertilizers include different balances of phosphorus, nitrogen, and potassium, the location in relation to the seed is important. If the fertilizer is too far from the seed, it is difficult for the plant's roots to reach the fertilizer so the plant does not ultimately reach the benefits of the fertilizer application. However, if the fertilizer is too close to the seed, the chemical balance can burn the roots of the plant, leading to plant death.

Since Seed Squirter is designed to allow the user to specify the dose amount and distance of the fertilizer application in relation the location of the seed, the fertilizer can be applied in the optimal position with higher precision. This allows almost every seed to benefit from the application of initial fertilizer, without risking overexposure to the fertilizer.

Social

The Seed Squirter System contributes to the reduction of the amount of labor required. The operator is able to plant a more prosperous crop with equal or lesser effort. The community also benefits from such technological advances. The more precise application of fertilizer will result in a lower amount of ground water contamination by phosphorous and nitrogen, which in turn, stabilizes water sanitation efforts.

Conclusion

After extensive research, ExactoSpray Technologies completed the laboratory design for a Seed Squirter Verification System given the time constraints and resources available. The team used a Basler acA2000 camera system with modifications to verify Capstan's system. Modifications included a fiber optic lens and software that verified the system's measurements. It was concluded that the average percent difference was minimal, or 0.033%. After calibration, the pixel to inches ratio was approximately 205 pixels to 1 inch. The team also determined that the calibration that adjusted this ratio +/-10% proved to be negligible when the measurements and percent differences were completed. Overall, the Seed Squirter system proved to dispense seeds and liquid fertilizer in the same specifications as displayed on VT screen based on the laboratory tests.

The Next Steps

Updating Camera and Software

Due to financial constraints and available technologies, the project used an older camera that was no longer manufactured. This caused several issues in processing data simultaneously while capturing video. The software used to film the video required an ExpressCard reader. These ports are only available on older laptops. The image processing code required the newest version of MatLab, which only works on newer laptops and desktop computers. This lead to unnecessary transfer of data between computers. The first step to finishing the verification equipment would be to update these constraints.

Converting Program and Display output

The next steps in getting this verification system on the market would be to convert the Matlab program to a C based language compatible with the VT screen. There would also need to be code inserted in order to output the data from the spreadsheet onto the VT. Figure 10 shows a possible solution to this. The picture of the seed and the squirt along with the measurement gives clear and apparent verification to the operator.

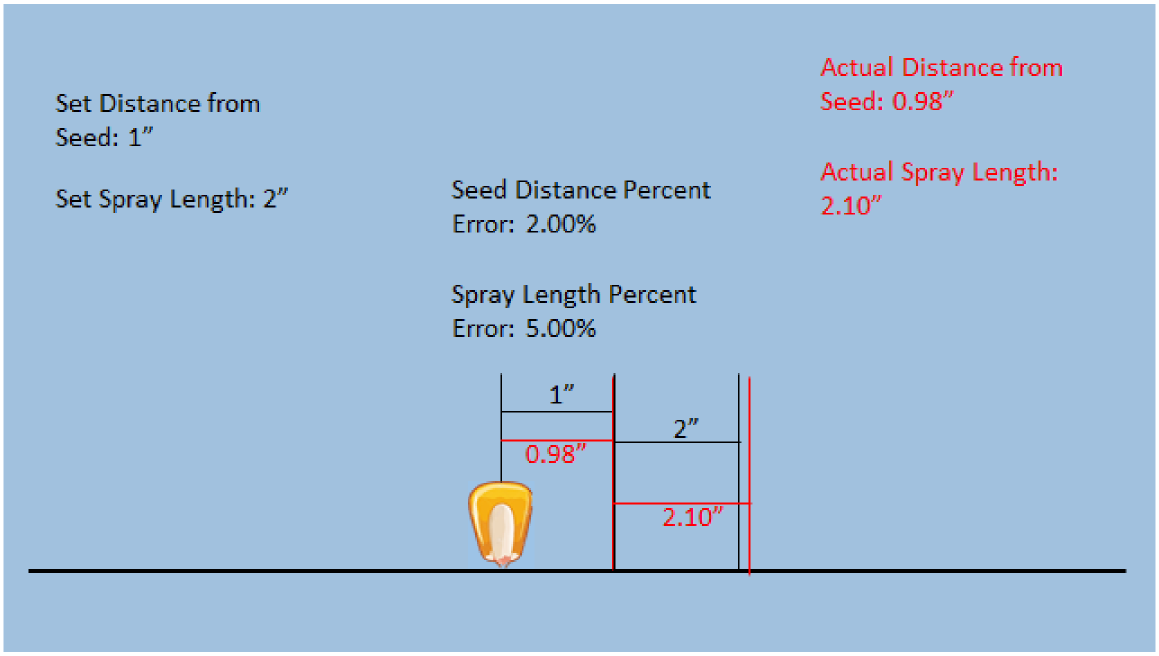

Figure 10: Possible VT Display Screen

Field Testing

The biggest challenge in getting the verification system on the market is introducing it to outside, operating conditions. Currently, the system is set up for laboratory use only based on time constraints. Most likely, the verification system will have issues in the field due to a number of variables. The next steps in moving forward would be to address lighting conditions, debris, and vibrations out in the equipment's working environment.

Spray Liquid Selection

One issue that may come with field-testing is squirt visibility. It was discussed that the selection of the test liquid to identify starter fertilizer in the verification system would be a strong possibility. This will possibly be an ingredient that can be added to the fertilizer so the camera will better recognize the squirt. Most starter fertilizers applied in the use of Seed Squirter are very difficult to be seen by the camera in the soil due to their transparent state. In previous attempts by Capstan to verify the Seed Squirter, radioactive material detection and camera detection of various dyes were tested. Conversely, the radioactive material was too hard to obtain and had too many legal restrictions to be a viable option. Therefore, the use of radioactive material detection was ruled out. Camera detection of dyes provided to be a problem in Capstan's testing because the various dyes were found to be absorbed too quickly by soil. Since the current system is limited to the laboratory, where light and soil types are controlled variables, thicker dyes or fluorescents may still be considered. In order to get the best results by camera detection, a test liquid that is either thick or consists of a bright matted color are ideal. The pump in the plumbing system is the limiting factor as far as the viscosity of the test liquid, so it must be able to be safely pumped through the provided system.

Division of Labor

Senior Team: Meg Sheehan, Cortney Bromenshank, Taylor Johnson, and Austin McCarthy

Freshmen Team: Katie Fedsor, Jonathan Cantwell, Patrick Vinson, and Jacob Jones

Dr. Marvin Stone and Mr. Jeff Grimm proposed this project. The Capstan advisors for this project are Mr. Troy Kolb and Mr. Adam Madison. The Oklahoma State advisor for this project is Dr. Paul Weckler with additional help from Dr. Randy Taylor, Dr. Tim Bowser, Dr. Ning Wang, and Mr. Andrew Slavens.

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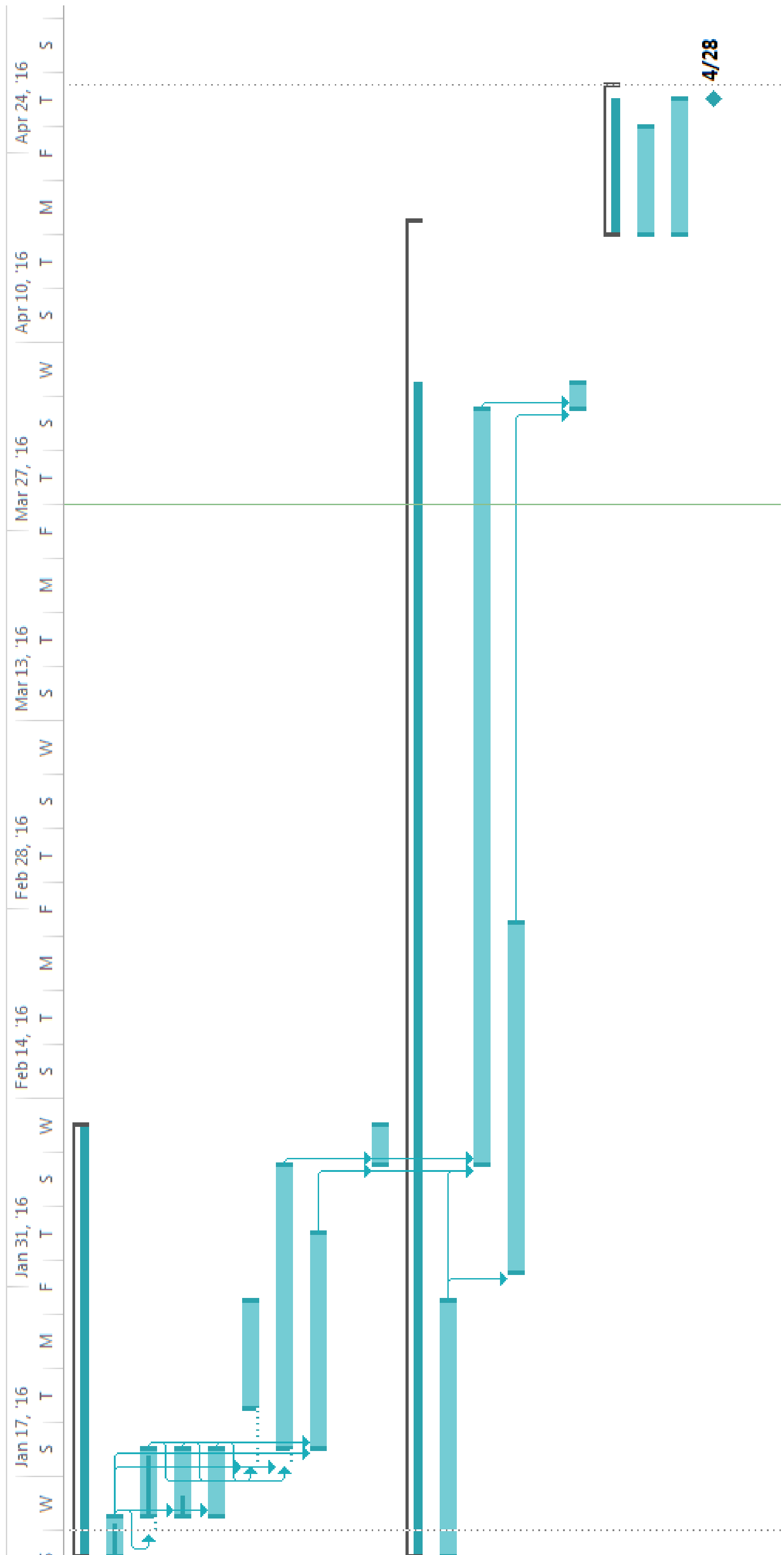
Upadhyaya, S. et al. 2005. Method and apparatus for ultra-precise GPS-based mapping of seeds or vegetation during planting. U.S. Patent number 6,941,225

Appendices

Appendix A: Planning

Schedule of Work for Spring 2016

Task Name	Duration	Start	Finish
Row Unit	**24 days**	**Mon 1/11/16**	**Thu 2/11/16**
Acquire Needed Parts	3 days	Mon 1/11/16	Wed 1/13/16
Assemble Row Unit	3 days	Wed 1/13/16	Mon 1/18/16
Install Plumbing	3 days	Thu 1/14/16	Mon 1/18/16
Install Electronics	3 days	Thu 1/14/16	Mon 1/18/16
Design System Test Setup	6 days	Mon 1/18/16	Fri 1/29/16
Test Row Unit and Electronics	3 wks	Mon 1/18/16	Mon 2/8/16
Determine Fiberscope Lens Position	12 days	Tue 1/19/16	Wed 2/3/16
Finalize Row Unit Test System	3 days	Tue 2/9/16	Thu 2/11/16
Software	**71 days**	**Mon 1/11/16**	**Mon 4/18/16**
Get Preliminary Matlab Program	15 days	Mon 1/11/16	Fri 1/29/16
Modify Matlab Code	40 days	Tue 2/9/16	Mon 4/4/16
Analyze System Test Data With Matlab Code	20 days	Mon 2/1/16	Fri 2/26/16
Finalize Matlab Code	2 days	Tue 4/5/16	Wed 4/6/16
Closeout	**9 days**	**Mon 4/18/16**	**Thu 4/28/16**
Final Report	6 days	Mon 4/18/16	Mon 4/25/16
Make Powerpoint	8 days	Mon 4/18/16	Wed 4/27/16
Final Presentation	0 days	Thu 4/28/16	Thu 4/28/16


Jan 17, '16
Jan 31, '16
Feb 14, '16
Feb 28, '16
Mar 13, '16
Mar 27, '16
Apr 10, '16
Apr 24, '16
4/28

Work Breakdown Structure

Level 1	Level 2		Level 3	
	WBS Code	Category	WBS Code	Task Name
1 Seed Squirter Verification System	1.1	Initiation	1.1.1	Review Customer Requirements
			1.1.2	Review Existing Technology
			1.1.3	List Possible Solutions
			1.1.4	Eliminate Unviable Solutions
	1.2	Planning	1.2.1	Create Project Objectives
			1.2.2	Define Project Deliverables
			1.2.3	Finalize Solution Plan
			1.2.4	Develop Solution Plan of attack
			1.2.5	Submit Project Plan to Customer
			1.2.6	Revise Project Plan according to Customer Reviews
			1.2.7	Create Parts & Supplies List
	1.3	Camera System	1.3.1	Acquire Needed Parts & Supplies
			1.3.2	Design Camera System Test setup
			1.3.3	Finalize Camera Testing Procedure
			1.3.4	Complete Camera Testing
			1.3.5	Analyze Camera Test Results
			1.3.6	Select Camera System
			1.3.7	Test Selected Camera With Fiberscope
			1.3.8	Verify Camera Selection Works With Fiberscope
	1.4	Row Unit Testing	1.4.1	Acquire Needed Parts & Supplies
			1.4.2	Assemble Row Unit & Electronics
			1.4.3	Test Row Unit & Electronics
			1.4.4	Design System Test setup
			1.4.5	Determine Possible Fiberscope Lens Position
			1.4.6	Test Possible Lens Location
			1.4.7	Select Ideal Lens Location
			1.4.8	Finalize Row Unit Testing System
			1.4.9	Complete Total System Testing
	1.5	Software	1.5.1	Get Preliminary Matlab Program From Dr. Taylor
			1.5.2	Modify Matlab Code to handle Total System Test Data
			1.5.3	Output to data to a spreadsheet
			1.5.4	Analyze Total System Test Data
			1.5.5	Finalize Matlab Code
	1.6	Closeout	1.6.1	Test Complete System
			1.6.2	Finalize Complete System
			1.6.3	Gather All Project Documentation
			1.6.4	Combine Complete Documentation for Project Report
			1.6.5	Format Project Report
			1.6.6	Complete Report Rough Draft
			1.6.7	Edit Report Rough Draft
			1.6.8	Complete Final Draft of Report
			1.6.9	Create Presentation Slides
			1.6.10	Practice Presentation
			1.6.11	Finalize Presentation
			1.6.12	Final Project Presentation

Appendix B: Research

Patent Search

System for spraying Plants and/or Plant Precursors
Company: Capstan Ag Systems Inc.
Date: 10/17/2013
Relevance: This is the base patent for Capstan systems. It involves replacing some components on existing sprayers to allow the Capstan system to control flow rate and pressure, which in turn allows for more precise spraying, which allows the user more control over where he or she sprays and the conditions of the spray.

Electrically Actuated Variable Control System
Company: Capstan Ag Systems, Inc.
Date: 12/7/2006
Relevance: This device measures pressure with a flow-controlled liquid application system. Pressure measurements could be a possible solution to determining a spray location. This is one of the key components to Capstan's systems, which adds the control system to monitor the pressure and flow controlling processes provided by Capstan's systems. The design of the connections, as far as power boxes and electrical attachments, could also be a benefit to this project.

High Speed Solenoid Valve Cartridge for Spraying an Agricultural Liquid in a Field
Company: Patchen, Inc.
Date: 12/7/2006
Relevance: This is a valve on the market that uses magnetized filters to control spraying. It also has a light emitting diode that senses when liquid is being released. These valves are a key component in Capstan's systems that allow the control of flow and pressure.

High Rate Seed Sensor
Company: DICKEY-john Corporation
Date: 11/26/1985
Relevance: This is a sensor that uses the breaking of an infrared plain to detect when the system drops the seed. It is located inside the seed tube and will be needed to give a better idea of the time it takes to drop a seed, which will allow calculations for the location of the seed at different times. The seed tube sensor is shown on the left in figure 4.

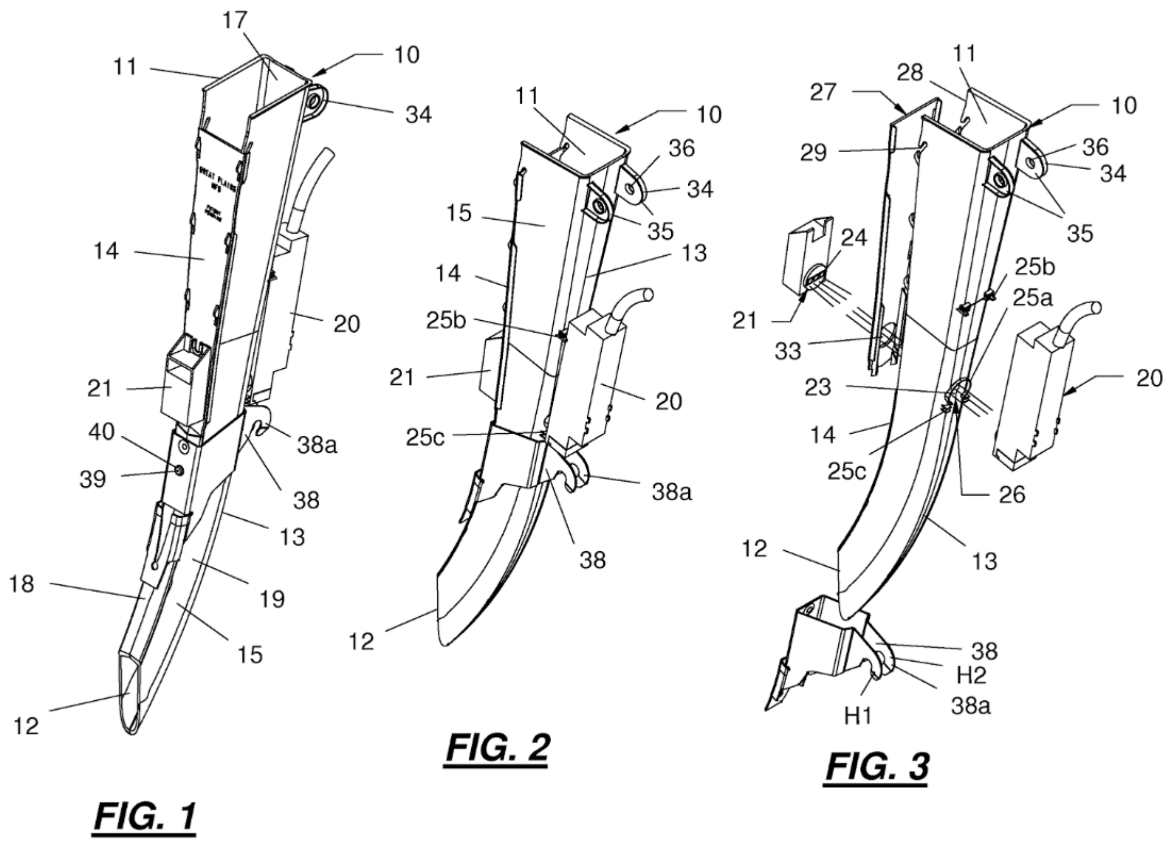


Figure 11 (above): The seed sensor in the smooth flow seed tube

Smooth Flow Seed Tube for Agricultural Planters
Company: Great Plains Manufacturing, Inc.
Date: 9/23/2008
Relevance: This was an improvement of the previous patent. The tube is now smoother to prevent significant amounts of deflection. Information on this may be helpful in order to better detect seed placement and better understand the detection methods. This part will need to be considered in both understanding the space we have to place our equipment and will need to be monitored by our verification system.

System and Method for Spraying Seeds Dispensed from a Planter
Company: Capstan Ag Systems, Inc.
Date: 2/20/2014
Relevance: This is the Seed Squirter patent. The overall system is shown in Figure 5. Since our goal is to verify the system (also shown in figures 6 and 7) is functioning correctly, it will be important to consider appropriate placement for the fiberscope and camera equipment that will need to be added, as well as consider the range of the camera system's picture required to capture both the seed drop and the squirt.

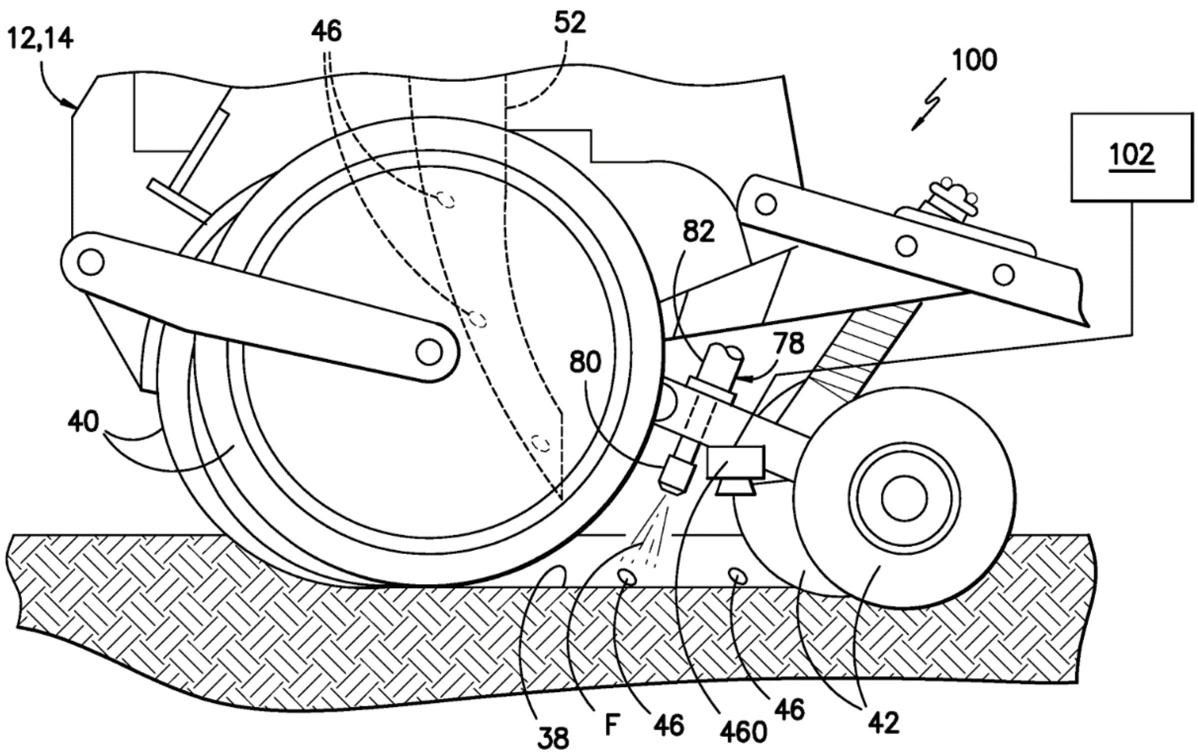


Figure 12 (above): Capstan's Seed Squirter System

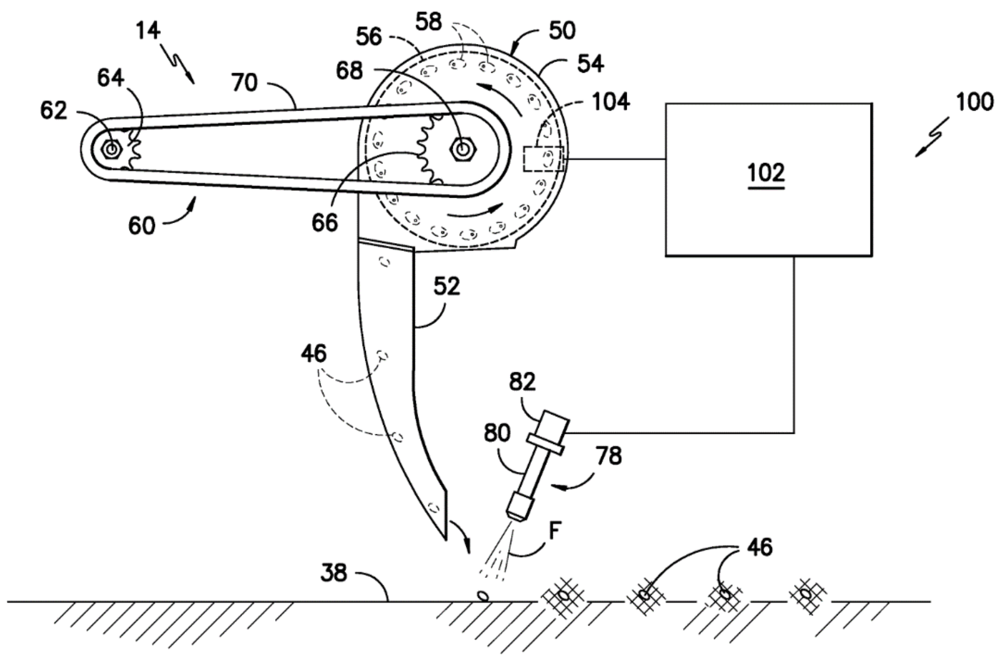


Figure 13 (above): The seed tube and sprayer layout of Capstan's Seed Squirter

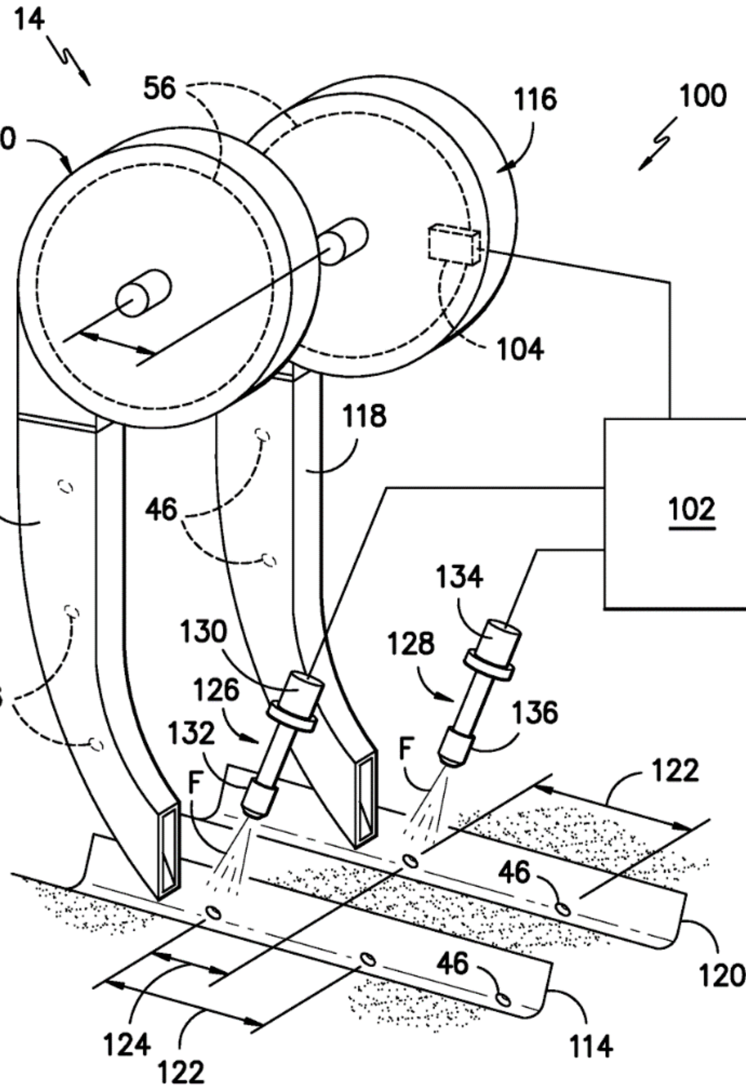


Figure 14 (above): A diagram of furrows planted by the Seed Squirter system

Seed spacing monitoring system for use in an agricultural seeder
Company: Deere & Company
Date: 8/20/2010
Relevance: This system detects seeds after they have been placed in the furrow to help ensure seed spacing. It may help in the process of developing technologies to detect the seed.

Auxiliary Fertilizer Applicator
Company: M & W Gear Co.
Date: 8/13/1968
Relevance: This system includes a shallow furrow fertilizer tube on a planter. It is shown in Figure 8, found in Appendix A, and was probably an early attempt at a similar concept to Seed Squirter.

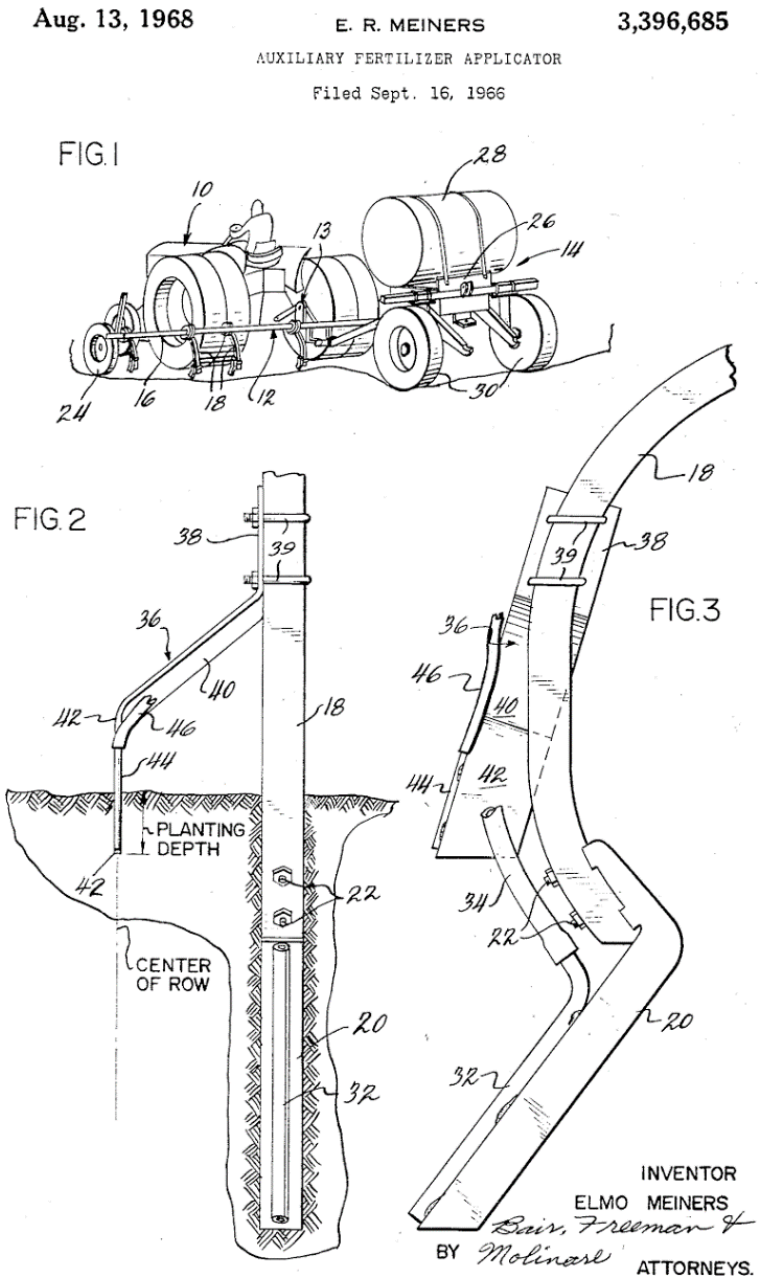


Figure 15: The design layout for an Axillary Fertilizer applicator

Method and apparatus for ultra-precise GPS-based mapping of seeds or vegetation during planting
Company: University of California
Date: 9/6/2005
Relevance: This apparatus consists of a GPS receiver, a data logger, and optical sensors to map the seeds being planted (as laid out in figure 9). This uses a similar machine vision and data logging system as planned, just for a different project. This could be a good reference of how to use data logging machine vision in the field.

Electrically Isolated Sterilizable Endoscope Video Camera Head
Company: Envision Medical Corporation
Date: 2/9/1999
Relevance: This system uses a similar fiber optic lens that need to be used to monitor the system. However, this system was designed to verify sterilization in food processing and medicine, whereas, this method will have to be modified to be more effective in the agricultural machinery industry. The connection in the head of the camera to the fiberscope that will need to be considered is shown in figures 10 and 11, which can be found in Appendix A.

Liquid Dispenser for Seed Planter
Company: Farmer Fabrications, Inc.
Date: 3/24/1998
Relevance: This is another system that applies liquid fertilizer to seeds during the planting process. Unlike Seed Squirter, which uses pulsating spraying, this system has an open nozzle attached to the seed firmer that follows the planting of the seeds (shown in figure 12).

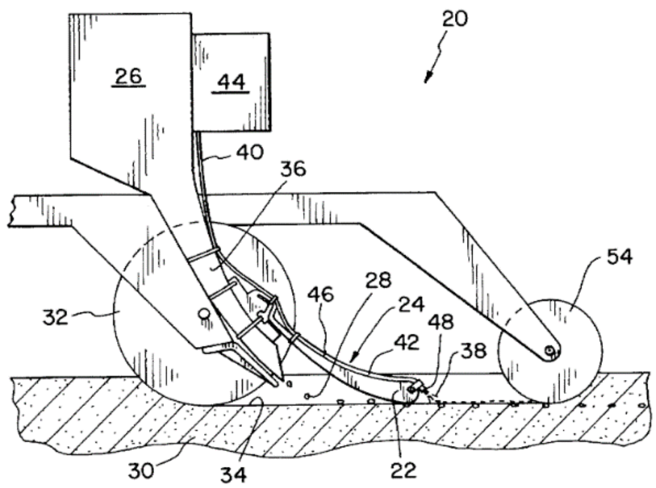


FIG. 1

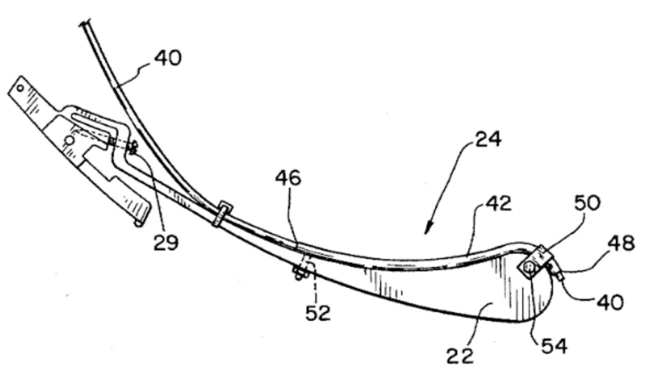


Figure 16 (above): An open nozzle liquid fertilizer applicator on a planter

Appendix C: Supporting Diagrams

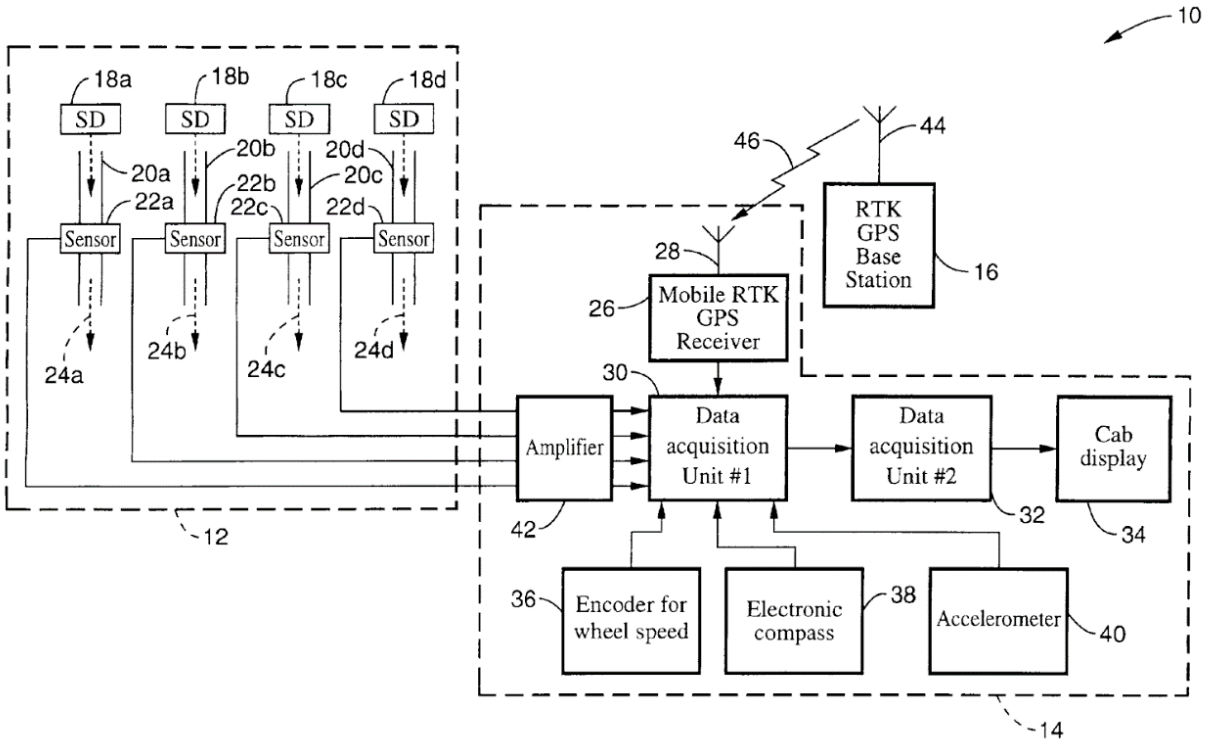


Figure 17 (above): The sensor and data logger layout of the GPS based seed mapping system

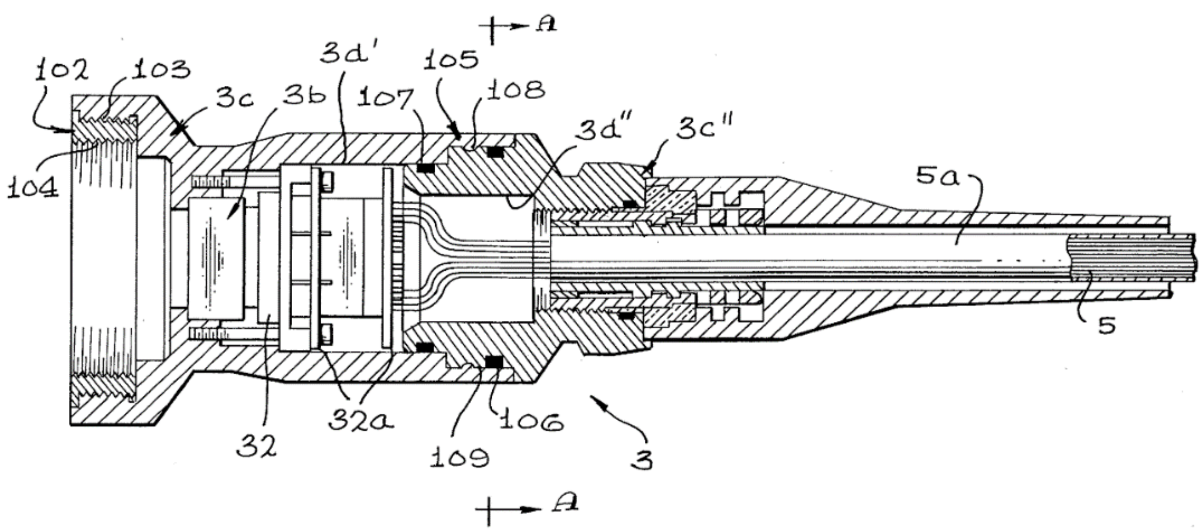


Figure 18 (above): The attachment of a fiberscope to camera head

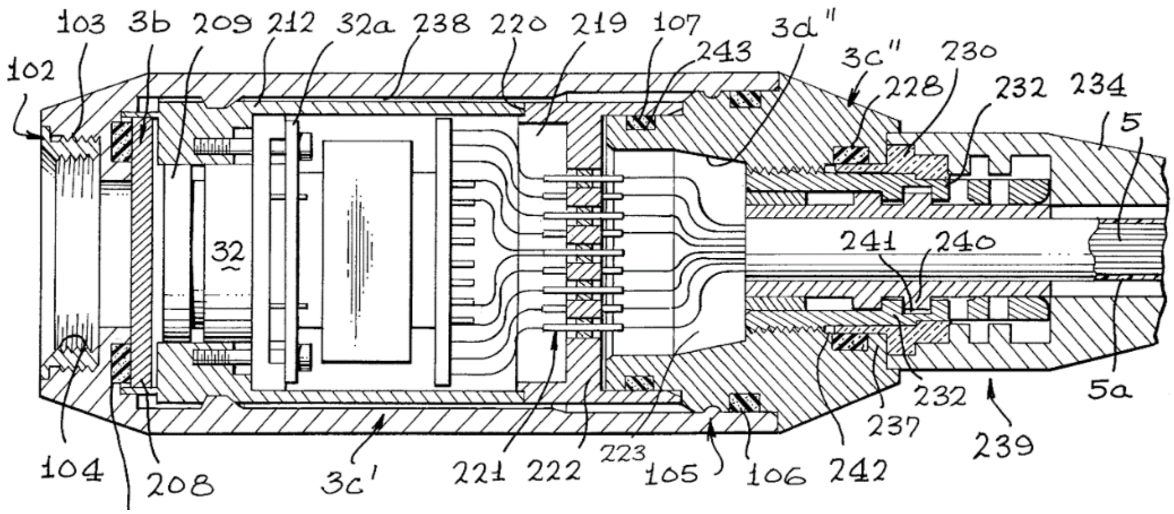


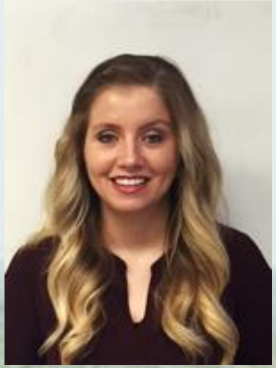
Figure 19 (above): The details associated with attaching a fiberscope to camera head

Capstan Ag System Seed Squirter Verification System

Meet the Team

Meg Sheehan

Option: Biomechanical



Cortney Bromenshenk

Option: Bioprocessing

Austin McCarthy

Option: Biomechanical

Taylor Johnson

Option: Environmental

ExactoSpray Technologies

Mission Statement

ExactoSpray Technologies strives to provide innovative technology to delight the modern farmer through cutting edge research, inventive engineering, and extensive testing. ExactoSpray works diligently with a number of universities and agricultural companies to provide innovative verification systems and further product support for all customers.

Clients

Capstan Ag System

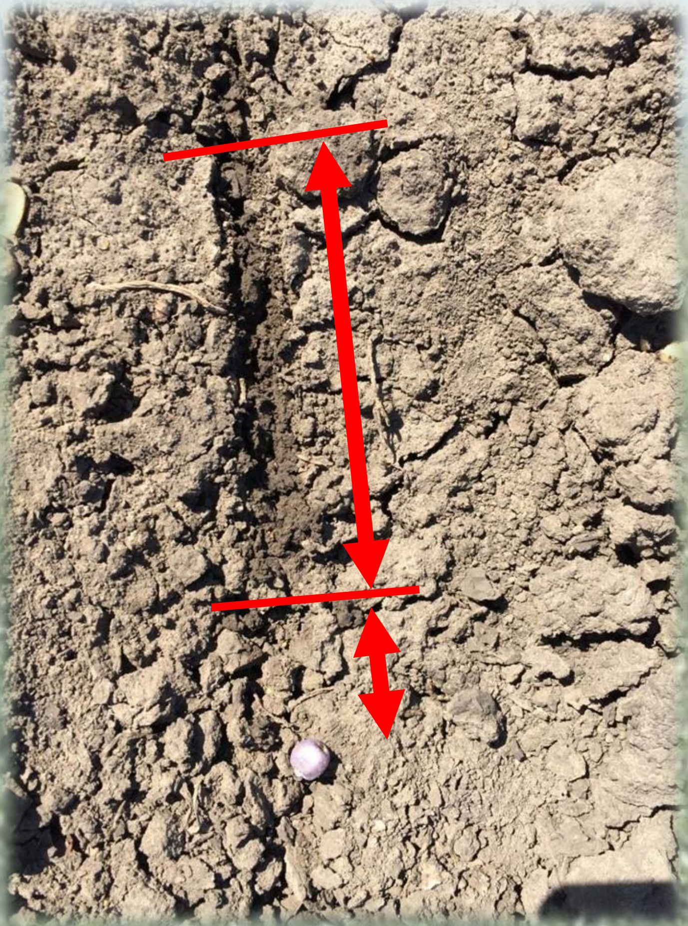
- Based out of Topeka, KS
- Designs electrical systems for ag applications
- Licensed a patent for Pulse Width Modulation (PWM) spray technology
- Aims to provide quality products and continuous customer support beyond expectations

Great Plains Manufacturing, Inc.

- Established in 1976 by Roy Applequist and based in Salina, KS
- Includes 5 major divisions
- Proud Midwestern company based largely from smaller Kansas Communities
- Leading producer of dirt-working, turf-maintenance, and landscaping equipment

What is Seed Squirter?

- Combines a Great Plains planter with a Capstan sprayer system
- Sprays initial liquid fertilizer in furrow with seed
- Length of spray and distance from seed are customizable
- Reduces death of plants due to improper placement of fertilizer



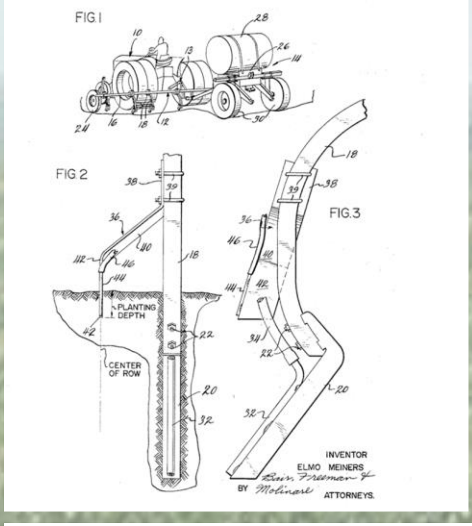
Primary Objectives

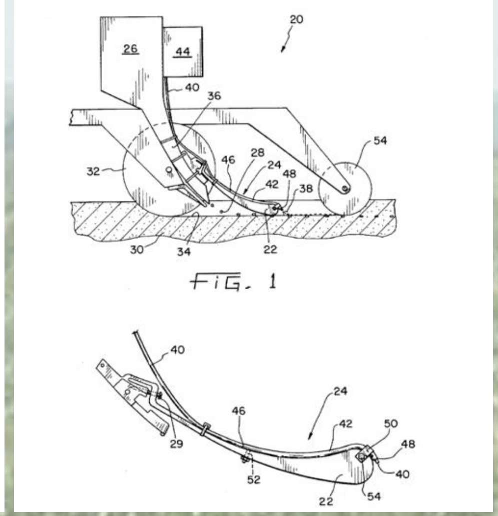
- Design a verification system to find the distance between the squirt and the seed, and determine a percent difference compared to the values set in the VT Programming.

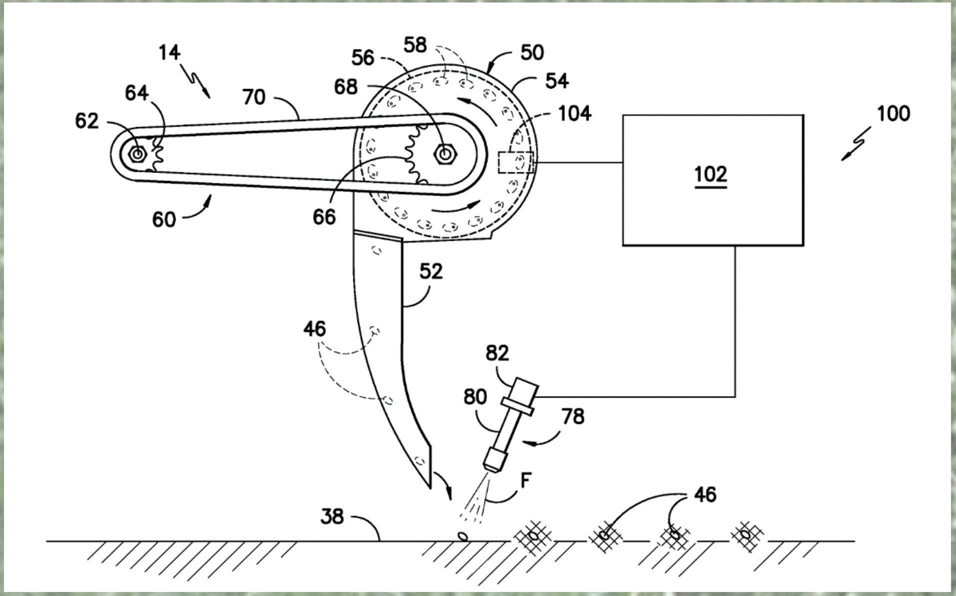
PLANNING

Technical Analysis & Research

- Started Seed Squirter in 1990s
- Patent search
  - existing spraying while planting methods
  - the evolution of technology required for Seed Squirter to be developed.







Visiting Clients




Ruled-Out Solutions: Analytical Approach

- Mathematical calculation of seed and fertilizer application
  - Pros: could be theoretically accurate
  - Cons: Possible oversimplification, potentially exist an infinite number of variables

Ruled-Out Solutions:
Experimental Approach

- Spraying with latex paint
  - Pros: Cheap, easy
  - Cons: lighting and soil conditions vary; possible damage to pump and sprayer
- Use radioactive materials
  - Pros: would be easy to detect, would be easy to apply
  - Cons: difficult to obtain, cannot cross state lines with it, large amount of handling requirements

Proposed Solution

- Use High-speed camera and fiber optic lens to view the site of interest.
- A plane from a laser will be mounted to identify locations of the seed and squirt.
- MatLab program will identify and measure seed to squirt distance and squirt length

Deliverables

- Camera system and set up designs for a single row unit
- Software for outputting an excel sheet of found distances, distances specified in the VT, and the percent difference between the two differences
- Laboratory methods and procedures for testing with the verification system

TESTING AND SIMULATIONS

Testing and Simulations: Camera Selection

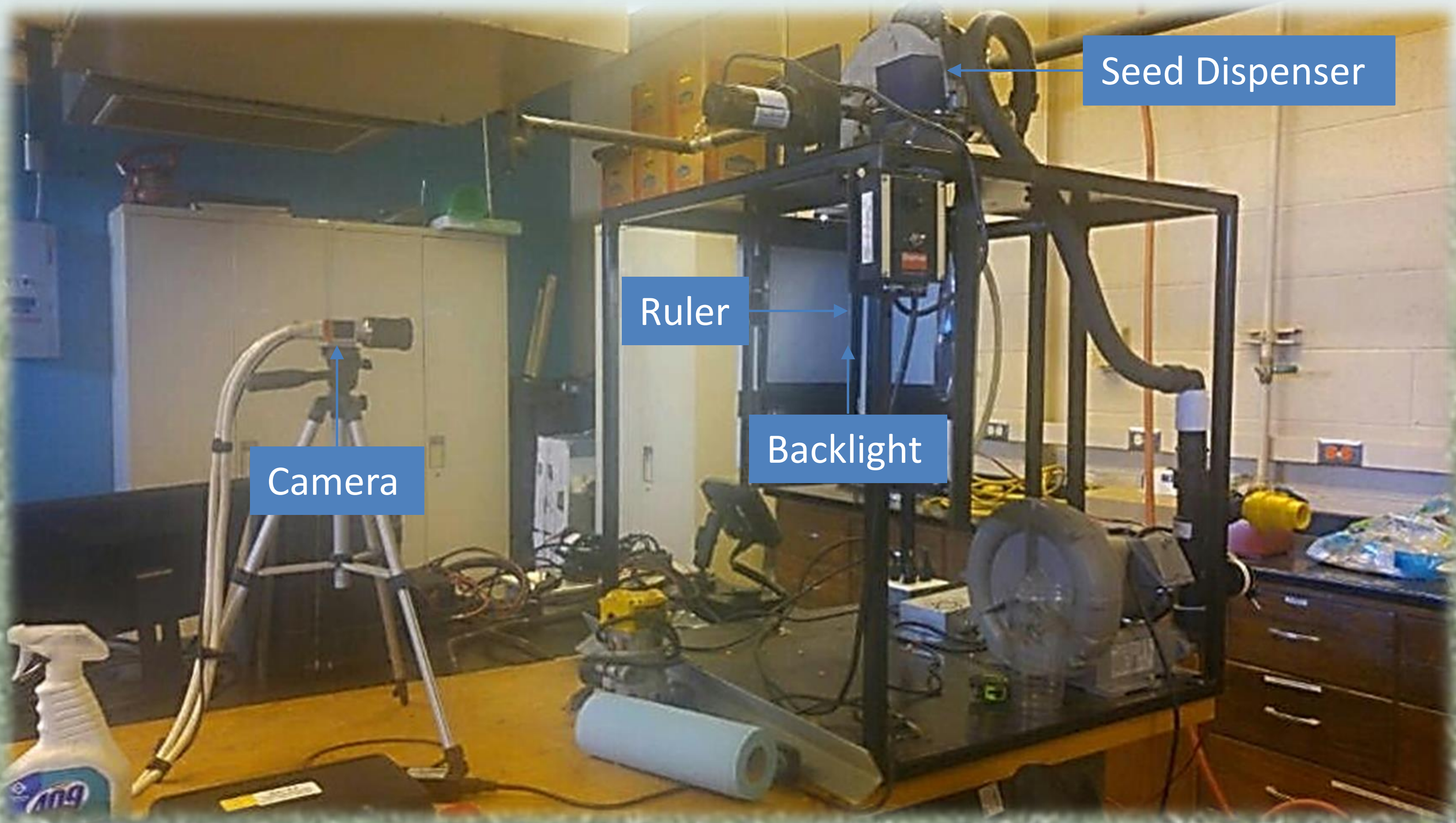
BAE 1012's Project: Camera Selection

- Requirements
  - Operate at > 120 fps
  - Operate with a fiberscope lens
- Models
  - Basler acA2000
  - Go Pro Hero 4

Camera Preliminary Research

	Basler	GoPro
Cost	$1,530.00	$400
Battery Life	Battery powered or it can be hooked up to wiring in machine	Around 1 Hour
Durability	3 year warranty to ensure durability	1 Year Warranty
Lighting	Performs in various lighting	Needs dark background to display lighting
Picture color	Black and White	Color
Shutter Speed	340 Frames per second	60-120 Frames per second

Camera Testing: Setup



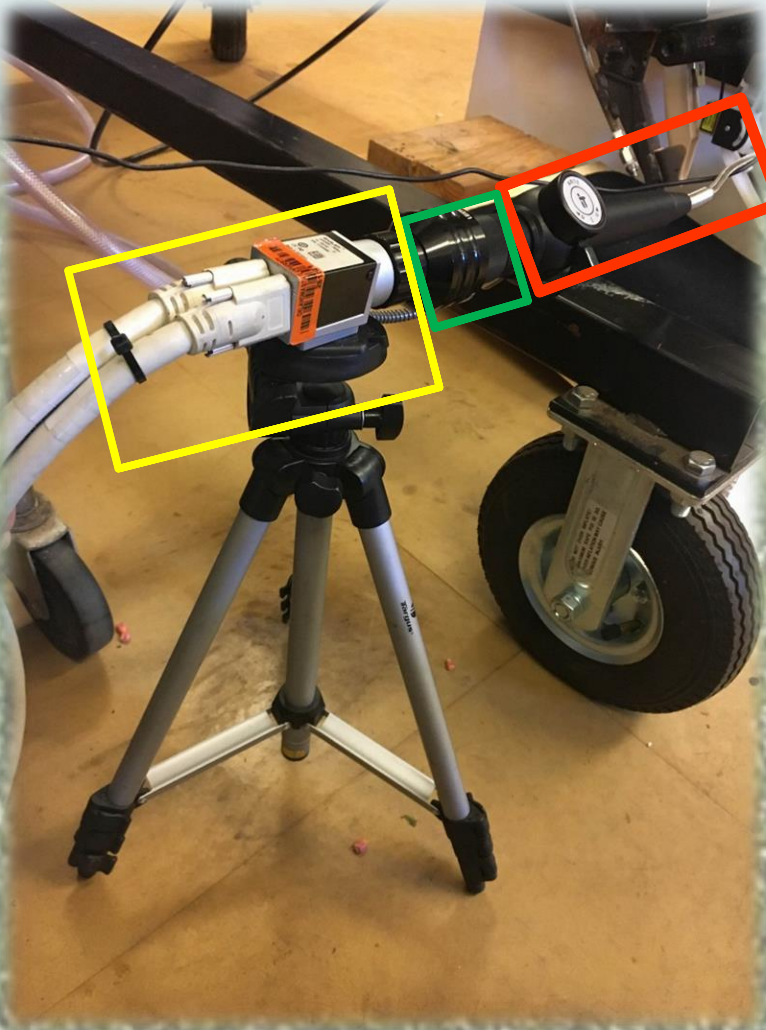
BAE 1012's Project: Results

Recommendation:

- Basler
  - Higher quality picture
  - Faster speed
  - Downside is cost
- Go pro is a cheaper alternative if quality is sacrificed

Final Camera Decision

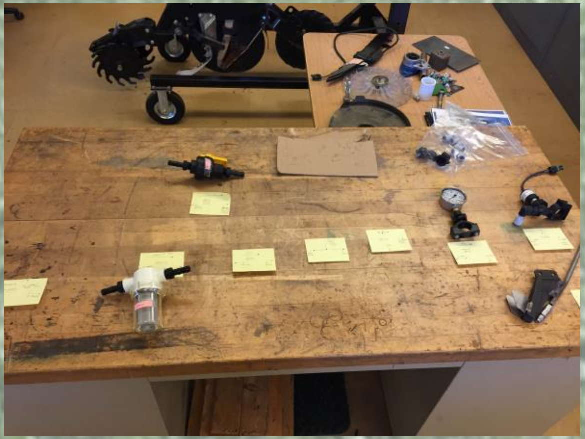
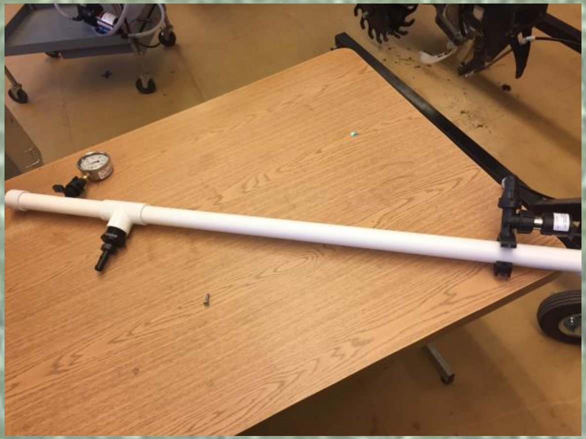
- Basler acA2000
- Boroscope
  - Includes small light
- Luxxor® Video Coupler Lens
  - 25 mm focal coupler length
  - C-coupling



Testing and Simulations: Row Unit Testing

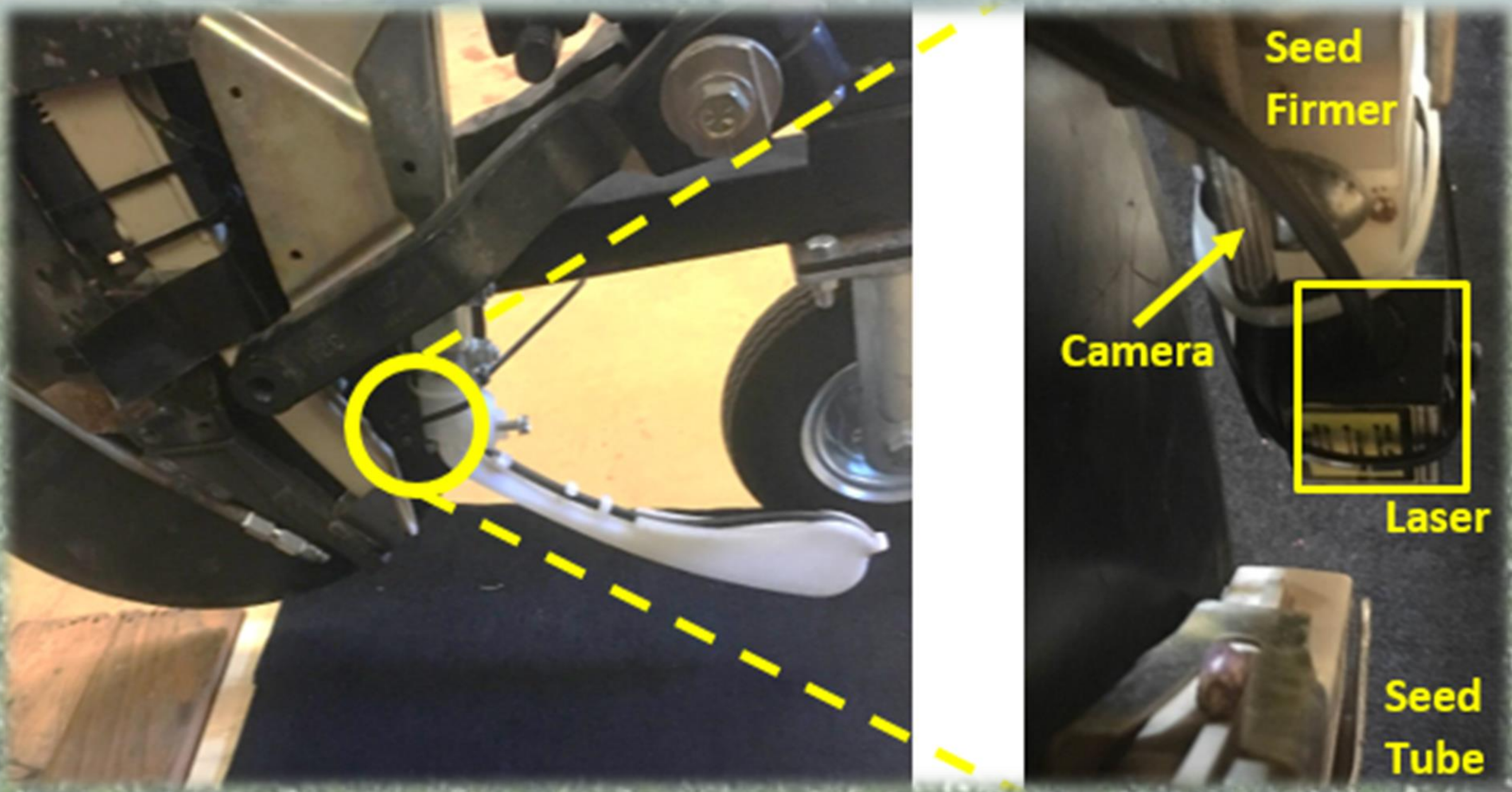
Row Unit Set-Up

- Assemble plumbing
- Test electronics
- Familiarize ourselves with
  - VT Display Settings
  - Setting distance relationships


Testing and Simulations: Camera System Testing

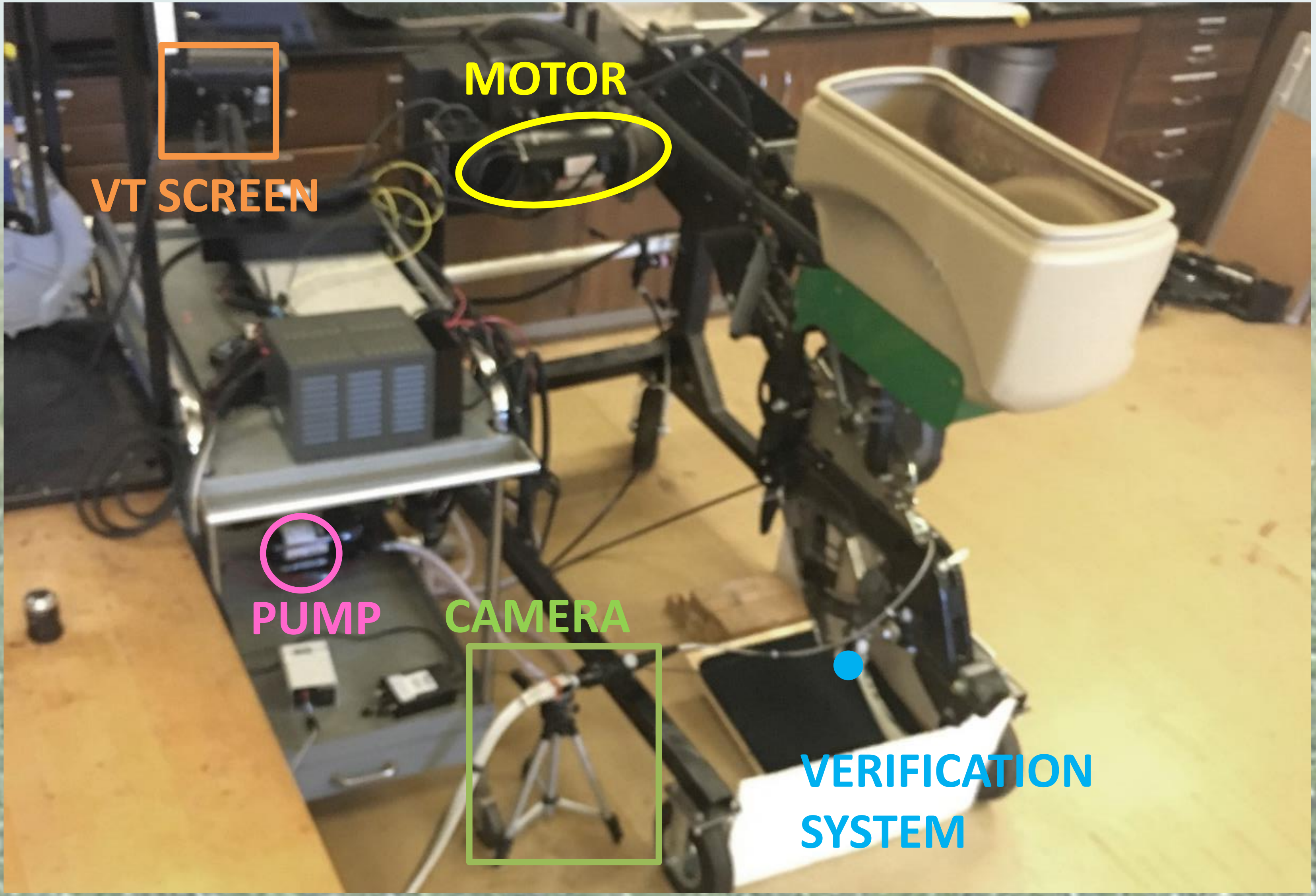
Integration Of Camera System into Row Unit



Taking Footage: Troubleshooting

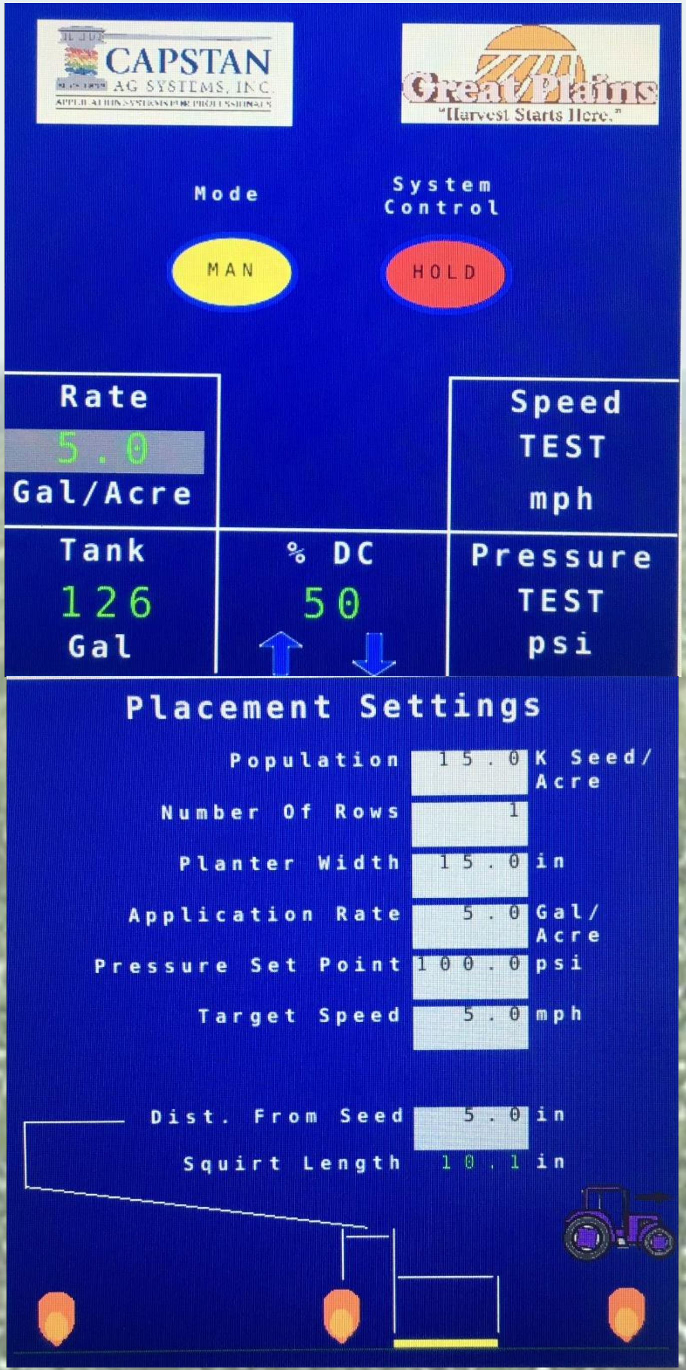
- Background
  - Solid (dark) color
  - Fast absorbing
  - Angled to remove seeds from camera vision
- Laser Placement
  - Mounted beside the camera

Final Test Setup



Final Test Setup (cont.)

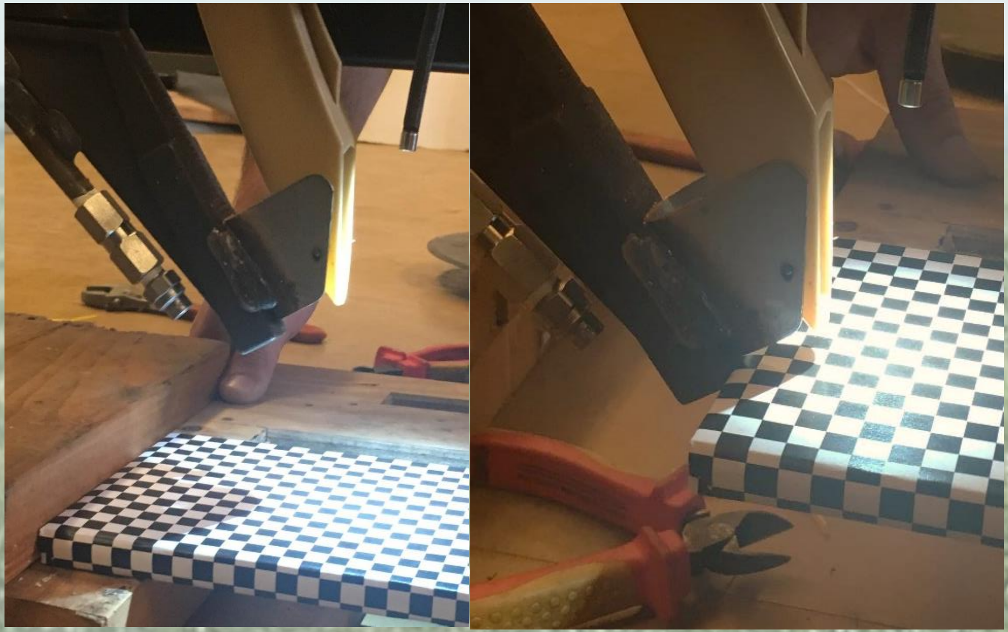
- Middle range values were used including:
  - Travel Speed: 5 mph
  - Population: 15,000 seeds/acre
  - Application rate: 5 gal/acre
  - Pressure set point: 100 psi
  - Seed-to-Squirt Distance: 5 in
  - Squirt Length: 10.1 in



Testing and Simulations: Software and Calibration

Camera Calibration

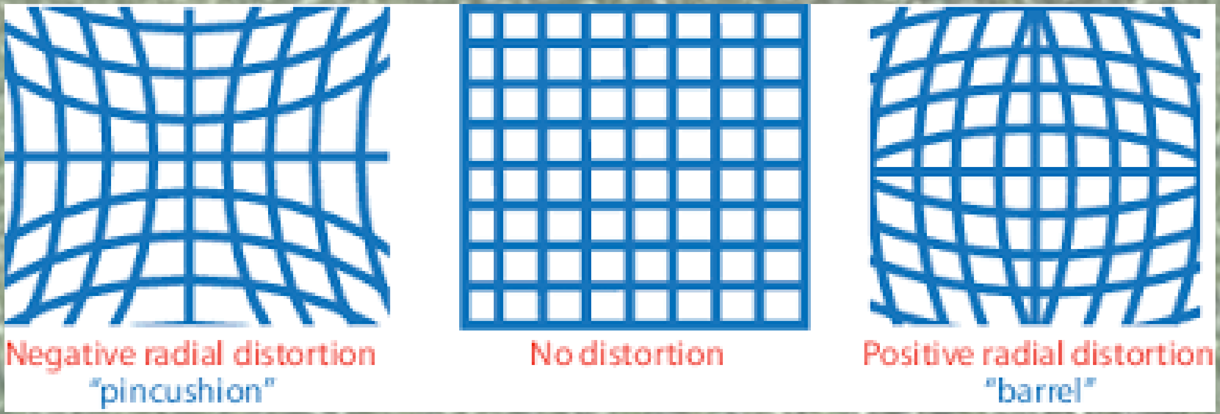
BELOW: correction for the z-axis



Above: Correction for pixel distortion between the entrance of the seed and Squirt

Adjusting View from Calibrations

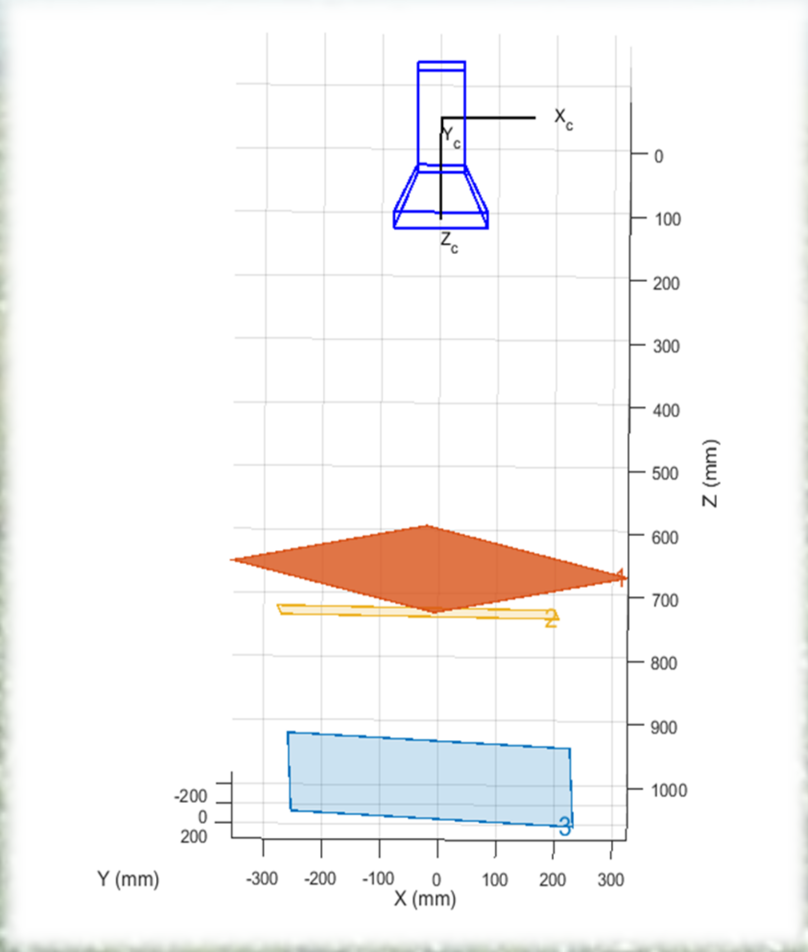
- Automatic detection and location of checkerboard calibration pattern
  - corner detection with subpixel accuracy
- Estimation of all intrinsic and extrinsic parameters including axis skew
- Calculation of radial and tangential lens distortion coefficients
- Correction of optical distortion
- Support for single camera and stereo calibration



Source: http://www.mathworks.com/videos/camera-calibration-with-matlab-81233.html?requestedDomain=www.mathworks.com

Adjusting View from Calibrations

- Using the Camera Calibrator App in Matlab
- Plane 1: plane where seed fall
- Plane 2: Plane where squirt occurs
- Plane 3: Laser plane
- Calculates the ratio of pixels to millimeters



Initial Footage Processing

- Uses Image Acquisition and Computer Vision Systems Toolboxes in Matlab
- Tracks locations of moving objects that pass the laser plane
- Generates a excel sheet with pixel coordinates for each seed and spray

Finding Distances from Footage

- Excel sheet of Coordinates are read back into matlab
- Pixel distance is calculated for each seed and squirt set
- Pixel distances are converted to measured distances using pixel to inch ratio

Final Processing

- Measured distance is compared to user inputted distance
- Percent difference is calculated
- Excel sheet is outputted with inputted distance, measured distance, and percent error

Outputted Product

Inputted Distance	Measured Distance	Percent Difference
5	4.998300169	-0.033996627
5	4.998300169	-0.033996627
5	4.998300169	-0.033996627
5	4.998300169	-0.033996627
5	4.998300169	-0.033996627
5	4.998300169	-0.033996627
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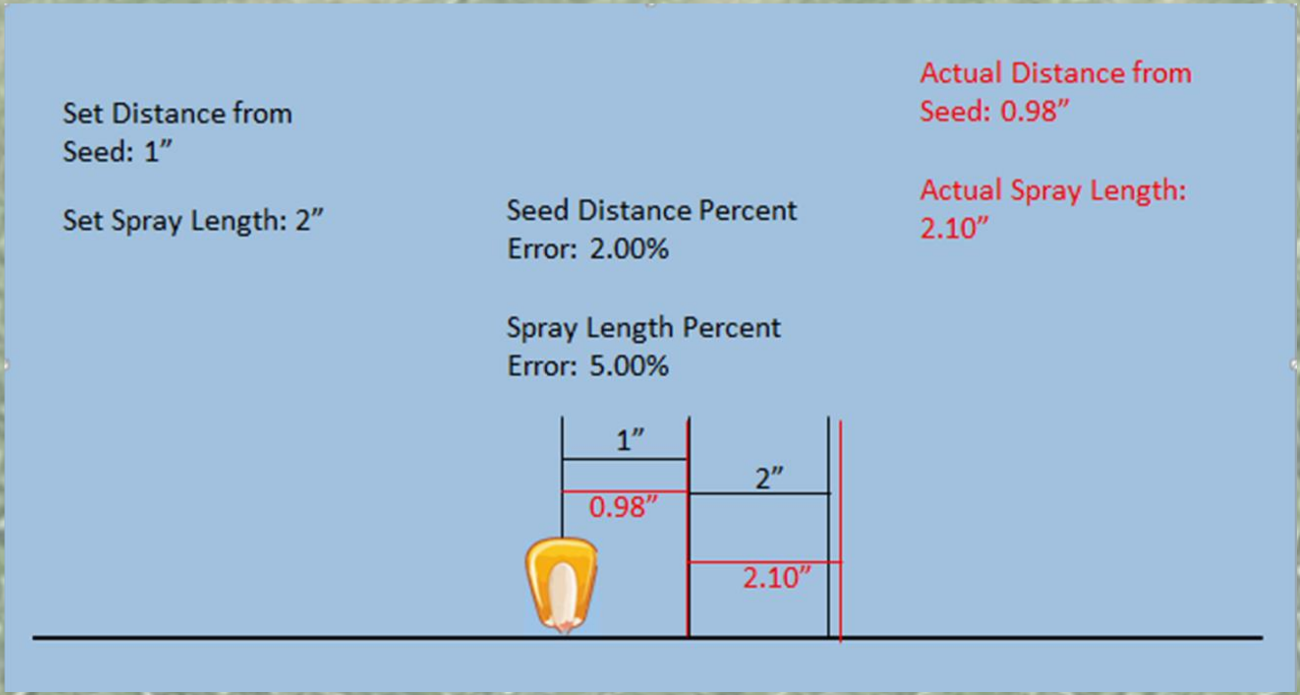
CONCLUSIONS

Accuracy

- The average percent difference was 0.033%
- The ratio for the laser plane was about 205 pixels = 1 inch
  - Errors caused by +/- 10% of the pixel ratio proved to be negligible

Suggestions for Further Studies

- Updating camera and software
- Higher Quality Laser (possibly infrared led or photodiode)
- Converting Program to Display Output
- Field Testing
  - Liquid Spray Selection



Acknowledgments

- Freshmen Team: Katie Fedsor, Jonathan Cantwell, Patrick Vinson, and Jacob Jones
- Capstan: Mr. Jeff Grimm, Mr. Troy Kolb, and Mr. Adam Madison.
- Great Plains: Mr. Brent Nelson, Mr. Paul Galle, and Mr. Matt Stewart
- Oklahoma State University: Dr. Paul Weckler, Dr. Randy Taylor, Dr. Tim Bowser, Dr. Ning Wang, and Mr. Andrew Slavens.

In Remembrance of Dr. Marvin Stone

without whom this project would not be possible

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Questions?