Automated U-Bolt Inspection System

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Consolidated Metal Products has a unique cold-forming process to create U-bolts that makes them the industry leader in U-bolt production. This process has a tendency to create cracks due to high residual stresses. The senior design team researched several methods of crack detection including ultrasonic, dye penetrant, and visual camera inspection. The conventional ultrasonic method was tested by NDT systems in house and was shown to work with the curvature of the U-bolt. Fluorescent dye penetrant was tested by applying the dye to the bolts with, and without cracks in them and then observed the difference in light values in and out of the cracks. Camera inspection was tested statistically by comparing light intensity values inside and out of crack areas on gathered images without the application of dye. After testing these methods, camera inspection was chosen through the use of a selection matrix. In The senior design, the team began with construction of a controlled lighting environment box for taking photographs of U-bolts. A Matlab code was formed to compare light intensity values of bolt images and to work in unison with an Arduino to output separate signals for normal and defective U-Bolts. The Matlab code also automatically analyzed images taken by the camera. The Matlab code was then tested with sample bolts. Threshold light values were obtained to optimize the system's ability to detect cracks.

I. Introduction

Consolidated Metal Products (CMP) is the industry leader in the production of steel U-bolts. These bolts are used in light and heavy duty truck suspensions and are a critical component of these vehicles. CMP utilizes a cold forming process to give the bolts their U-shape and high strength. This cold working leaves high stresses in the material which can lead to cracks. These cracks can lead to failure of the U-bolt and thus the vehicle's suspension system. This could cause serious accidents and leave CMP liable. Another risk is less dramatic, but poses equally dire consequences for CMP - if their customer finds cracked bolts they will take their business elsewhere, potentially costing CMP millions in lost sales. This project focuses on designing an automatic system to inspect every U-bolt after the cold forming process to check for cracks. Initially the senior design team was also asked to check the bolts for dimensional accuracy and proper threading, but these issues were found to lead to different solutions and the topic was narrowed to only checking for cracks. Cracks were determined to be the most serious problem, since a U-bolt with incorrect dimensions or missing threads can't be installed in the truck, but one with a small crack could easily be missed and put in a vehicle and later fail.

Currently, CMP visually inspects all of their U-bolts. With a single production line able to produce up to 300 parts per hour, it is easy for the inspector to miss a small crack. The overarching goal of the project is to develop a system that will automatically detect cracked bolts and signal an operator to remove them from the line. To meet this requirement, many possible design solutions were researched and evaluated. Literature and patent searches were completed in areas related to flaw detection and automatic inspection systems.

In Fluorescent Penetrant Inspection (FPI), fluorescent die is applied to the U-bolt. The dye collects inside cracks and is visible under ultraviolet light after applying a developer agent [1]. Research has shown that through the use of FPI, cracks that are 0.06" in length or larger have a near 100% detection rate [2]. Cameras could easily be used to detect the concentrations of the brightly colored dye. The major downside to this method is cost. The cost of dye per bolt is $0.10 based off the cost of a bulk dye kit [3]. Also, the bolts must be cleaned before the dye is applied, and then dried after the developer is applied. This adds processing steps and equipment which further increases costs above acceptable amounts..

. In laser ultrasonic testing, a high frequency wave is induced on the part by a pulsed laser [4]. A second laser measures that wave at the opposite end of the part. Any defects in the material surface will alter the wave, and thus can be detected by comparing the test signal to a database of known good parts. While this technology can detect even the smallest cracks, it costs over $100,000 which put it out of reach of the $50,000 budget restraint.

Conventional Ultrasonic Inspection uses the same principle but instead of using a laser, the waves are generated by a transducer and are transmitted to the part through a liquid medium, often oil [5]. Such a scanner could be purchased for around $4,000 and NDT Systems, Inc. performed a validation test on a U-bolt. The wave passed through the bolt but it was unclear how accurate the method would be with the threads disrupting the signal from the surface of the bolt where cracks are most dangerous.

X-Ray Topography was briefly considered as a possible solution. The physical basis for this X-Ray imaging system for inspecting items is the diffraction contrast in the image between different regions of the specimen [6]. X-rays are generated from a source extending around an imaging volume. This contrast is formed as a result of the differences in the intensities and directions of the rays from different points of the part. An X-ray detector array also extends around the imaging volume and is arranged to detect X-rays from the source points which have passed through the imaging volume, and to produce output signals dependent on the detected X-rays [7]. Such a system would require expensive new machinery and also add a radiation hazard to the plant, causing it to be the first idea eliminated.

Resonant Frequency Testing is a method based on the concept that as a crack is introduced to a part, the overall stiffness of the part is decreased leading to a lowering of the natural frequency of that part [8]. This concept can be applied to the testing of cracks in bolts by comparing the natural frequency of an ideal part, to that of the parts that are being tested. The requirements for a system using this method would include using a solid object to ping each U-bolt, one or multiple accelerometers to record data on the response of the bolt, and a computer system to analyze the response over time and determine the resulting frequency of each tested bolt. This would be an inexpensive system to build and could test a bolt in just a few seconds. Unfortunately lab testing found no clear difference between the resonant frequencies of good and cracked U-bolts.

Camera inspection is similar to the human testing currently used, but a computer would be programmed to recognize cracks in a camera image of the bolts. Such a system could be inexpensive, needing only a camera and computer with analysis software. There are many ways to have the computer recognize a crack. This method was ultimately selected for the project due to the low cost and design flexibility.

II. Main Body

The goal of the inspection system is to find cracks in U-bolts faster and more accurately than manual inspection. By using the system, the goal is to fully automate the crack inspection process, thus allowing CMP workers to focus on other areas of their plant. The specifications of this system include a well-tested working prototype that can be easily integrated into an automated (PLC controlled) system by the specialists at CMP. The final working prototype is expected to be able to visually test several consecutive Ubolts without the presence of type 1 or type 2 errors during testing, and should demonstrate high potential for easy user interface as well as adaptability for use with different bolt types.

The first step in the design process was to perform experimentation and analysis on the several viable testing methods available for crack detection. After extensive research and discussion, the possible options were reduced to camera, conventional ultrasonic inspection and vibration inspection. Vibration inspection testing was completed by suspending both normal and cracked U-bolts from a test frame. An accelerometer was fixed on one leg of the bolt and the other side was struck with an impact hammer as shown in Fig. 1.

Figure 1. The resonant frequency test setup.

The impact hammer returned data on the impact force to the computer and the accelerometer measured the acceleration caused by the wave generated by the impact. Data was input through Labview SignalExpress. The data was converted and input into MATLAB where a Fast Fourier Transform was performed to examine the frequency response. Three good bolts and three bad bolts were each tested three times to ensure consistent data. Below is the MATLAB code used to perform the FFT, which was created by Dr. Singh [9].

```
function [ NatFreq ] = FFTnatfreqfind( t, Ft, xt )
dt=t(2,1)-t(1,1);
Fs=1/dt;
N=2^(nextpow2(length(t))-1);
t=[0:dt:((N-1)*dt)]';
df=1/t(N);
f=[0:df:(N-1)*df]';
w=2*pi*f;
Fs=fft(Ft(1:N,1));
Xs=fft(xt(1:N,1));
Hs=Xs./Fs;
A=abs(Hs)/(N/2);
nn=round(N/2);
figure;
plot(f(1:nn),A(1:nn))
```

```
xlabel('Frequency in Hz.')
ylabel('Normalized Amplitude')
title('Frequency Response Using FFT')
NatFreq=f(A==max(A(1:nn)));
end
```

Figure 2. The FFT Matlab code.

For comparison purposes, the natural frequency that had the highest amplitude was recorded at the end of the Matlab code. While this frequency can vary depending on how the bolt is struck by the hammer, in almost every test the same frequency range was produced. This was because of special care taken to strike the bolt in the same place at the same angle each time. This natural frequency was compared between the different bolts to see if there was a noticeable difference for the cracked and un-cracked bolts. The frequency response plot below shows the natural frequencies highlighted from noise. The labeled point is the natural frequency used for comparison. A graph like this was formed for each test and Matlab calculated the precise frequency where resonance occurred.

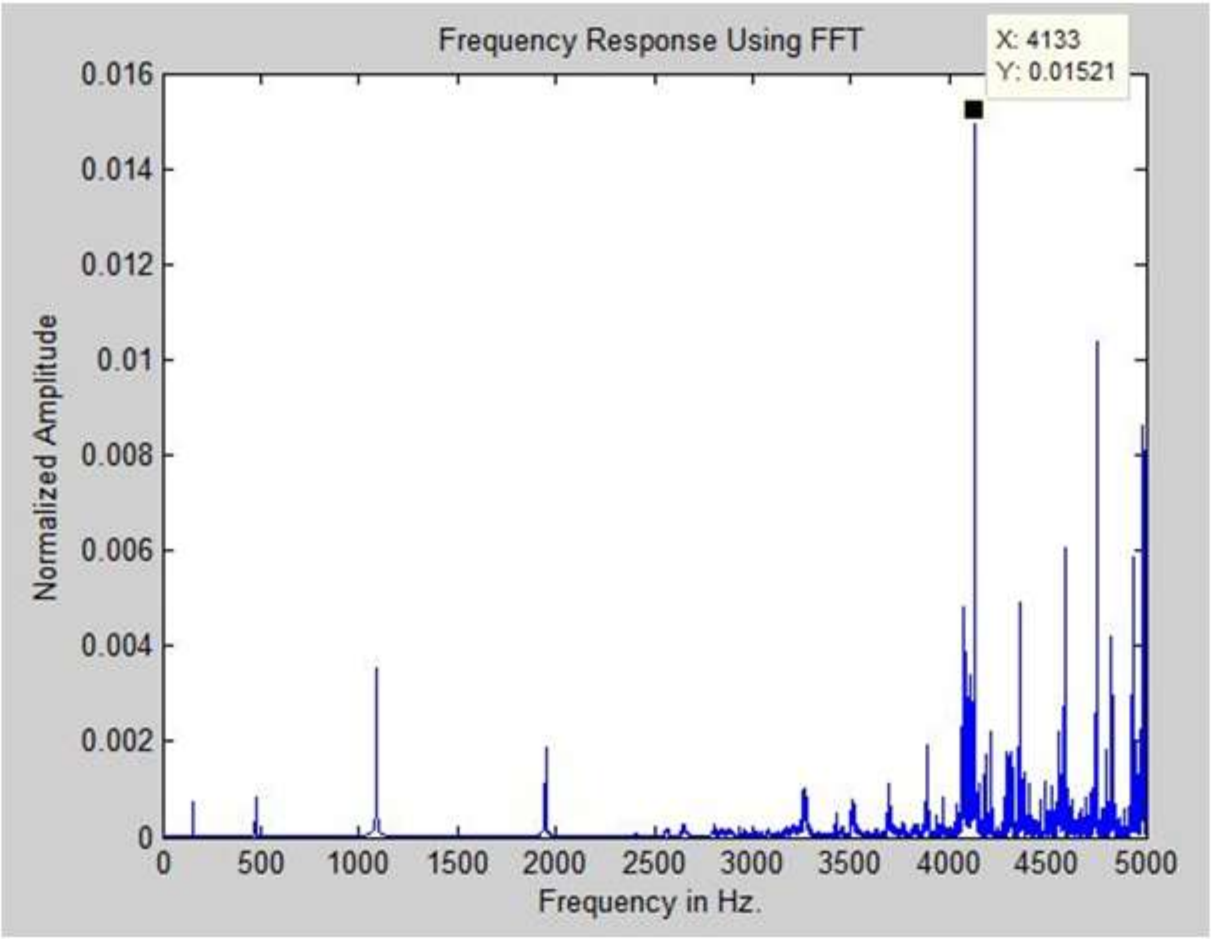


Figure 3. Output plot for bad U-bolt #3, test run #1 showing the natural frequencies after FFT.

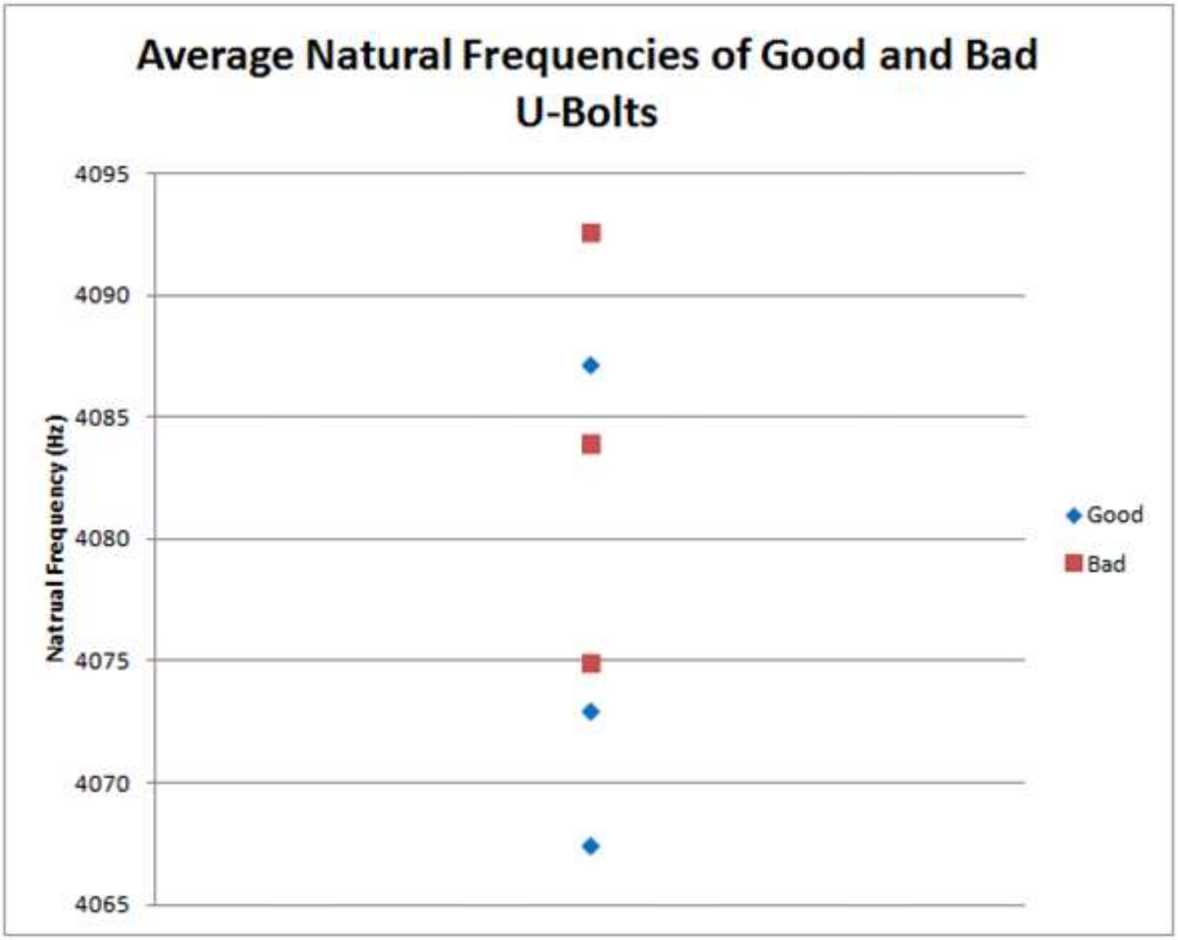


Figure 4. Natural frequency plot from vibration analysis.

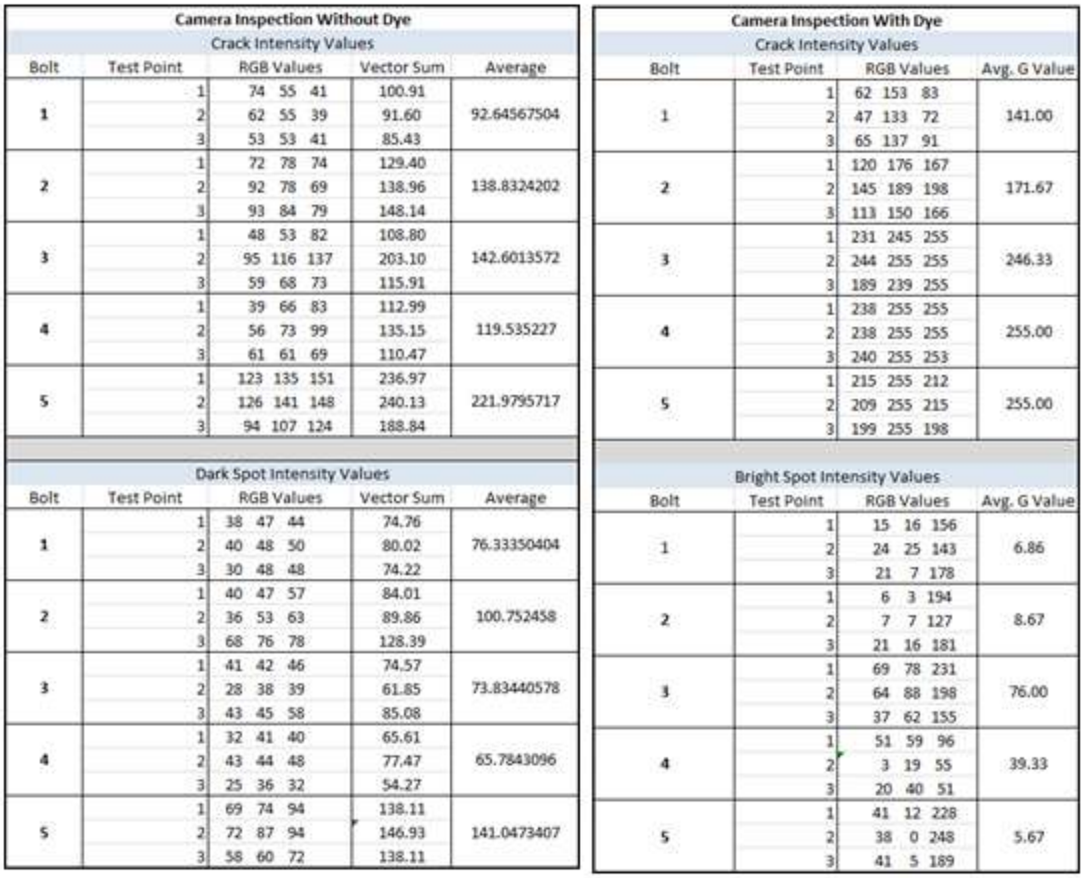
From the plot in Fig. 4 and data in Appendix 1, it was clear there was no significant correlation between the natural frequency and whether or not the bolt was cracked.. Natural frequency is the square root of the stiffness divided by mass. Ideally, a crack would lower the stiffness of the U-bolt so that the natural frequency would be shifted downward. It appears that the small cracks are not enough to make a noticeable difference compared to other variables.

Conventional ultrasonic was the next method to be tested. The first concept validation testing performed by NDT Systems gave mixed results [5]. They transmitted ultrasonic waves through a U-bolt and were able to measure the response. This proved that the signal could successfully pass through the geometry of a U-bolt. There was an unexpected change in the sound wave velocity. Ultrasonic could still be effective but a correction factor may need to be used when calculating the crack/obstruction size. The change in sound wave velocity verified the conventional ultrasonic proposal as feasible and worth presenting to the leaders at CMP. The technology would easily detect cracks but could not check the threading due to the noise caused by the many threads. Surface cracks could also be obscured by the interference from the threads.

The study of how ultrasonic inspection was used in a power plant to examine curved steam pipes for cracks provided mixed results. It clearly demonstrated ultrasonic's ability to detect and measure even the tiniest of cracks. At the same time it showed that the scanner probe would have to move across the entire profile of the U-bolt. It was previously expected the ultrasonic wave could be transmitted from one end of the bolt through to a receiver at the other end. This was discovered to be ineffective. In order to avoid interference from unavoidable surface irregularities and the threads, the ultrasonic wave would need to be transmitted perpendicular to the cross section and the scanner would have to move along the profile of the bolt to perform a full scan. This would take more time than anticipated and require very controlled movement of the scanner around the U-bolt.

To determine how accurate ultrasonic testing could be, the wavelength was calculated. Frequencies used for ultrasonic testing can be over 50 MHz. For this situation a frequency of 20 MHz was chosen arbitrarily. Wavelength = speed of sound / frequency. Based on the speed of sound in steel being 6,100 m/s the wavelength would be 0.0003 m. Ultrasonic systems can detect a crack down to half the wavelength size, which would be 0.00015 m. This was certainly an impressive range [10].

The last method considered was camera inspection both with and without the use of fluorescent dye penetrant. This was completed by using an 8 Megapixel camera to upload images of six bolts into Matlab. These were then used to obtain the data presented in Fig. 6 below by computing the average vector sum of the RGB values at three points on each bolt.



Camera Inspection Without Dye

Crack Intensity Values

Bolt	Test Point	RGB Values	Vector Sum	Average
1	1	74 55 41	100.91	92.64567504
	2	62 55 39	91.60	
	3	53 53 41	85.43	
2	1	72 78 74	129.40	138.8324202
	2	92 78 69	138.96	
	3	93 84 79	148.14	
3	1	48 53 82	108.80	142.6013572
	2	95 116 137	203.10	
	3	59 68 73	115.91	
4	1	39 66 83	112.99	119.535227
	2	56 73 99	135.15	
	3	61 61 69	110.47	
5	1	123 135 151	236.97	221.9795717
	2	126 141 148	240.13	
	3	94 107 124	188.84	

Dark Spot Intensity Values

Bolt	Test Point	RGB Values	Vector Sum	Average
1	1	38 47 44	74.76	76.33350404
	2	40 48 50	80.02	
	3	30 48 48	74.22	
2	1	40 47 57	84.01	100.752458
	2	36 53 63	89.86	
	3	68 76 78	128.39	
3	1	41 42 46	74.57	73.83440578
	2	28 38 39	61.85	
	3	43 45 58	85.08	
4	1	32 41 40	65.61	65.7843096
	2	43 44 48	77.47	
	3	25 36 32	54.27	
5	1	69 74 94	138.11	141.0473407
	2	72 87 94	146.93	
	3	58 60 72	138.11	

Camera Inspection With Dye

Crack Intensity Values

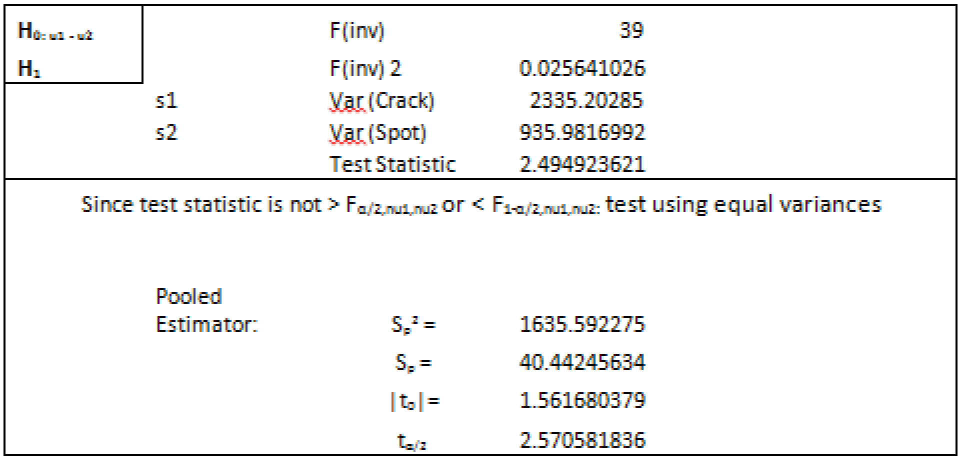
Bolt	Test Point	RGB Values	Avg. G Value
1	1	62 153 83	141.00
	2	47 133 72	
	3	65 137 91	
2	1	120 176 167	171.67
	2	145 189 198	
	3	113 150 166	
3	1	231 245 255	246.33
	2	244 255 255	
	3	189 239 255	
4	1	238 255 255	255.00
	2	238 255 255	
	3	240 255 253	
5	1	215 255 212	255.00
	2	209 255 215	
	3	199 255 198	

Bright Spot Intensity Values

Bolt	Test Point	RGB Values	Avg. G Value
1	1	15 16 156	6.86
	2	24 25 143	
	3	21 7 178	
2	1	6 3 194	8.67
	2	7 7 127	
	3	21 16 181	
3	1	69 78 231	76.00
	2	64 88 198	
	3	37 62 155	
4	1	51 59 96	39.33
	2	3 19 55	
	3	20 40 51	
5	1	41 12 228	5.67
	2	38 0 248	
	3	41 5 189	

Figure 5. **Camera inspection data used for hypothesis testing.**

This data was used to statistically observe the contrast of image points inside and outside of the cracks. This was quantitatively observed by using a hypothesis test that effectively analyzed these values as summarized in Fig. 6.



$H_{0: u1 - u2}$		F(inv)	39
H_1		F(inv) 2	0.025641026
	s1	Var (Crack)	2335.20285
	s2	Var (Spot)	935.9816992
		Test Statistic	2.494923621

Since test statistic is not > $F_{\alpha/2,nu1,nu2}$ or < $F_{1-\alpha/2,nu1,nu2:}$ test using equal variances

Pooled Estimator:	S_p^2 =	1635.592275
	S_p =	40.44245634
	$\lvert t_0 \rvert$ =	1.561680379
	$t_{\alpha/2}$	2.570581836

Figure 6. The camera inspection hypothesis test.

Since the square root of our test statistic is less than $t_{\alpha/2}$ we could not conclude that the means were statistically different, meaning type II error was highly probable.

After in depth comparison of these results, the camera inspection system was selected as the best design solution due to the low cost, ease of use, speed and flexibility for use with various parts. After much discussion and observation of the variables that came into play during the data collection for the camera inspection technique, it was concluded that the system would not work consistently without a highly controlled lighting environment. By controlling the lighting environment, the light values inside and outside of the crack should be statistically significant in their differences. To create the controlled lighting environment, a photo-booth-like wooden box was constructed as displayed below.

Figure 7. The controlled lighting environment.

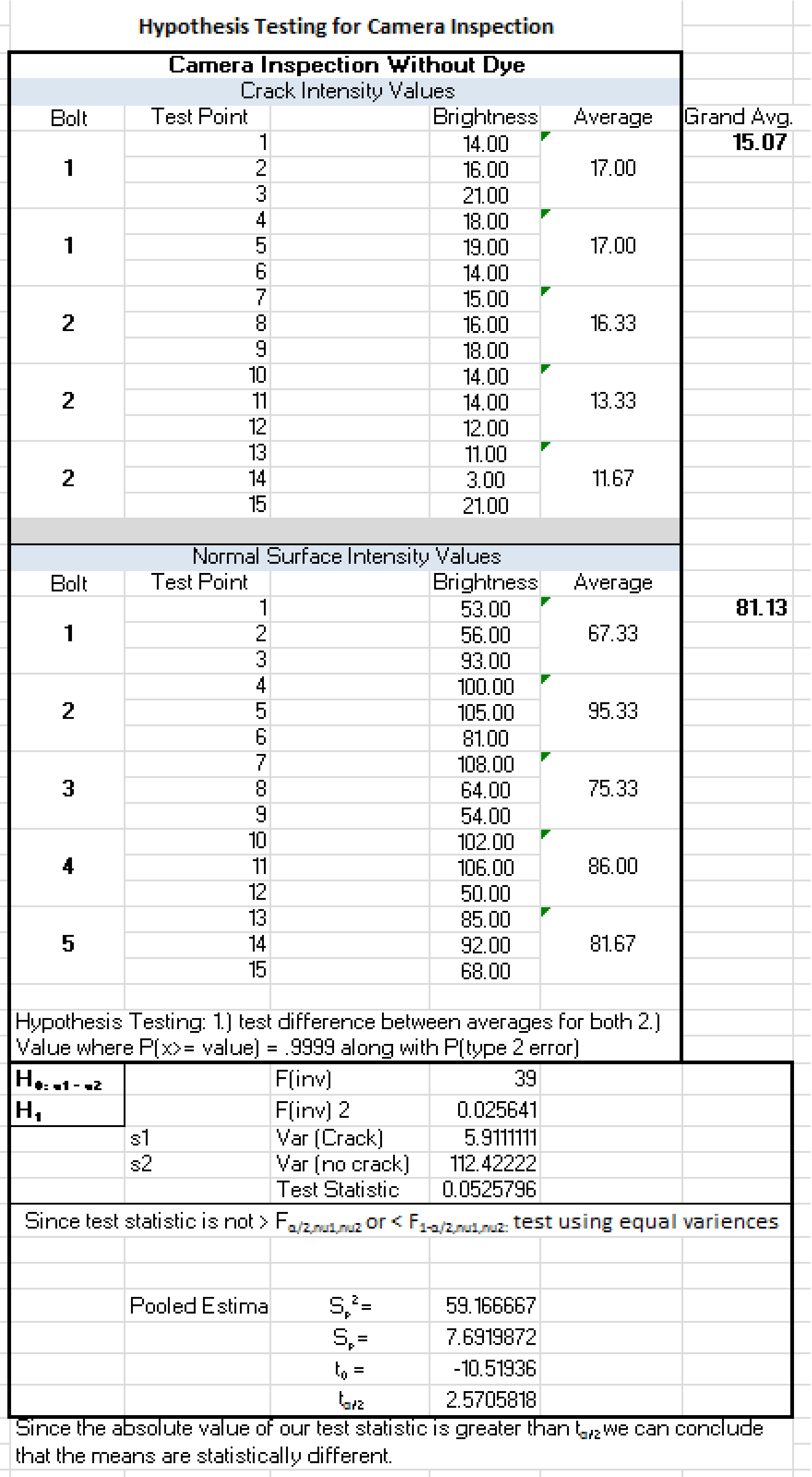
The dimensions of the box were created to allow the bolt, as well as any fixture that may be created later to hold the bolt, to fit inside without being too close to a light source which could skew the imaging results. The 2x2x3 ft. box was created of 1/2’’ thick birch veneer plywood which met the minimal structural requirements while providing a clean appearance. A door was created for access by mounting two standard door hinges to the front face of the box. This could easily be modified to accommodate an automatic opening system such as a pneumatic cylinder. On the inside of the box, a reflective white board was installed to line the inner surfaces of the box to ensure an even light distribution as shown in Fig. 7. At the top of the box are four bright white fluorescent light bulbs which are mounted to freely adjustable fixtures allowing for optimal orientation. Inside the box is an 8 megapixel web camera that is used to take pictures of the U-bolts and export them to a computer. Matlab constantly monitors the folder which the camera saves to [11]. When a new image is detected it automatically runs an analysis by examining a 100x100 sub-matrix of the image pixels and counting the number of pixels that fall under a certain threshold light intensity value. If there is a concentration of dark pixels in one small 100x100 section of the photo, the Matlab code reports the bolt as “bad.” This is currently accomplished by running a signal to an Arduino microcontroller commanding it to activate a red light [12]. If it is “good” a green light is activated. In the future, these signals could be used to trigger robots to remove the part from the assembly line to be dealt with later. Both the brightness value for a pixel to be considered “dark” and the number of “dark” pixels in the sub-matrix needed to be considered a crack are adjustable. If a sub-matrix passes the check, the code moves on to the next 100x100 section of pixels in the photo. The Matlab code can be viewed in Appendix 3.

Figure 8. The U-bolt and camera mounts.

After construction of the box, mounting systems were created for the U-bolt and the camera as shown in Fig. 8. The U-bolt simply slides into tubes which hold it upright. The white tubes were made from scrap PVC pipe and 2x4" lumber, painted white so it would not have any dark spots which could interfere with the scanning accuracy. The camera mount was made by inserting the web camera into a plastic shell. The shell then slides onto bolts protruding from the walls. The camera itself is simply an 8 megapixel web camera made by Logitech. 8 megapixels was chosen because in the initial testing, 8 MP cameras provided sufficient resolution to depict even small cracks.

Following the selection and installation of the box's analysis camera the senior design team had to determine the appropriate threshold for the brightness value of a crack. To do this, cracked bolts were loaded into the light controlled box and their photos were examined. Using Matlab's 'imread' and 'imshow' functions, the team was able to look at the image and see the brightness of each pixel. The team reviewed many pixel brightness values within cracks and settled on a brightness value of 15. Inside a crack a brightness value of 15 is typical, but outside of the crack on the smooth steel surface the brightness value is typically between 50 and 100. On the white background it generally exceeds 150. This data is from cameras viewing the front and rear faces of a U-bolt which is depicted in Fig. 8. More samples are needed to calibrate other camera angles, thus the rest of the analysis focuses on this camera arrangement. The minimum number of 'dark' pixels in a 100x100 sub-matrix needed to be considered a bad U-bolt was found by running the Matlab code and outputting the number of dark pixels in each sub-matrix of the entire image. With the dark threshold set at 15, it was found that sub-matrices that included a crack would contain between 15 and several hundred dark pixels while sub-matrices that covered just smooth, un-cracked would usually contain 0 and at most less than 5 dark pixels.

Following this a hypothesis test was completed to statistically verify the difference in brightness values inside and outside of cracks using the newly controlled lighting environment and consistent camera angles. The results are summarized in Fig. 9 below. Five un-cracked U-bolts were examined and three brightness values were taken from each. For the cracked brightness values, the team only had access to two U-bolts with cracks on the front or rear faces. This resulted in fifteen brightness values, but ideally the team would have access to more sample bolts to get crack brightness values from five different bolts.



Hypothesis Testing for Camera Inspection

Camera Inspection Without Dye

Crack Intensity Values

Bolt	Test Point	Brightness	Average	Grand Avg.
	1	14.00		**15.07**
1	2	16.00	17.00	
	3	21.00		
	4	18.00		
1	5	19.00	17.00	
	6	14.00		
	7	15.00		
2	8	16.00	16.33	
	9	18.00		
	10	14.00		
2	11	14.00	13.33	
	12	12.00		
	13	11.00		
2	14	3.00	11.67	
	15	21.00		

Normal Surface Intensity Values

Bolt	Test Point	Brightness	Average	
	1	53.00		**81.13**
1	2	56.00	67.33	
	3	93.00		
	4	100.00		
2	5	105.00	95.33	
	6	81.00		
	7	108.00		
3	8	64.00	75.33	
	9	54.00		
	10	102.00		
4	11	106.00	86.00	
	12	50.00		
	13	85.00		
5	14	92.00	81.67	
	15	68.00		

Hypothesis Testing: 1.) test difference between averages for both 2.) Value where P(x>= value) = .9999 along with P(type 2 error)

$H_{0:\ \mu1 - \mu2}$		F(inv)	39
H_1		F(inv) 2	0.025641
	s1	Var (Crack)	5.9111111
	s2	Var (no crack)	112.42222
		Test Statistic	0.0525796

Since test statistic is not > $F_{\alpha/2,nu1,nu2}$ or < $F_{1-\alpha/2,nu1,nu2:}$ test using equal variences

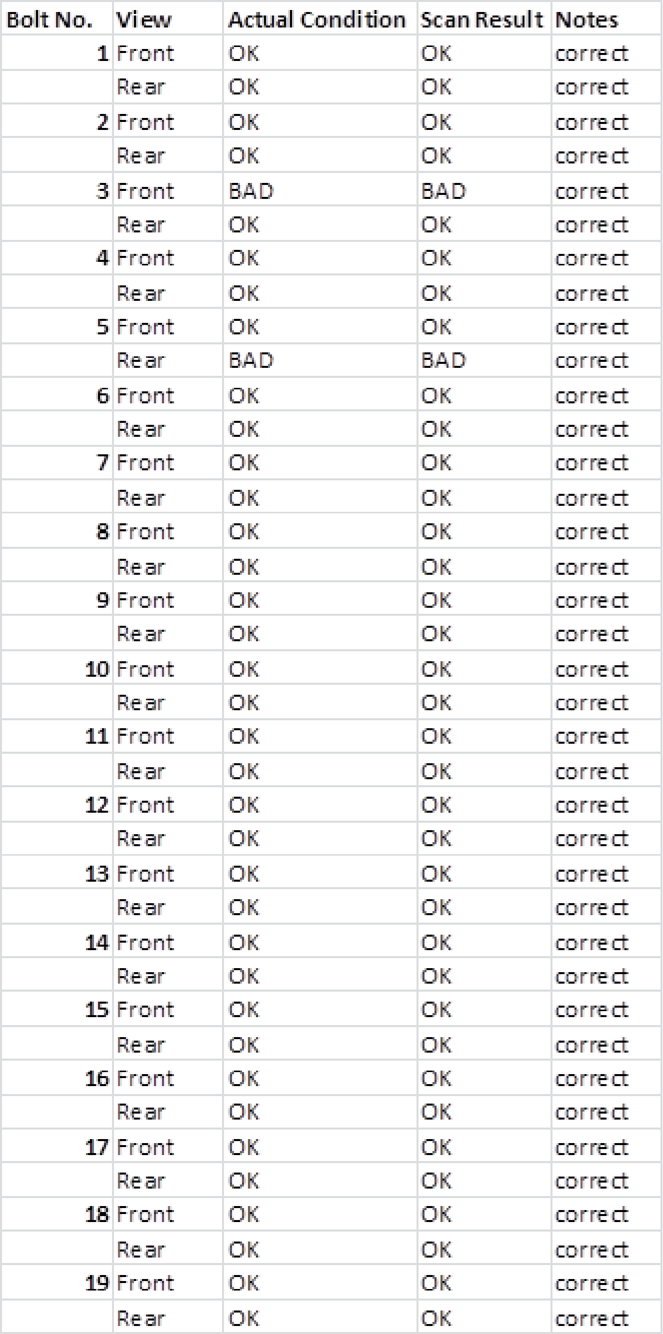
	Pooled Estima	$S_p^2 =$	59.166667
		$S_p =$	7.6919872
		$t_0 =$	-10.51936
		$t_{\alpha/2}$	2.5705818

Since the absolute value of our test statistic is greater than $t_{\alpha/2}$ we can conclude that the means are statistically different.

Figure 9. Hypothesis test of the camera system.

The hypothesis test was conducted. The brightness values were consistent for the five normal bolts and the two defective bolts with little noticeable variation. The hypothesis test confirmed that there was a statistical difference between the brightness value of cracked and un-cracked U-bolt surfaces.

The last project evaluation completed was the repetitive testing of 19 sample U-bolts for the presence of cracks. As in the analysis work above, the front and rear faces were examined by the camera. For this test, 38 images were analyzed.



Bolt No.	View	Actual Condition	Scan Result	Notes
1	Front	OK	OK	correct
	Rear	OK	OK	correct
2	Front	OK	OK	correct
	Rear	OK	OK	correct
3	Front	BAD	BAD	correct
	Rear	OK	OK	correct
4	Front	OK	OK	correct
	Rear	OK	OK	correct
5	Front	OK	OK	correct
	Rear	BAD	BAD	correct
6	Front	OK	OK	correct
	Rear	OK	OK	correct
7	Front	OK	OK	correct
	Rear	OK	OK	correct
8	Front	OK	OK	correct
	Rear	OK	OK	correct
9	Front	OK	OK	correct
	Rear	OK	OK	correct
10	Front	OK	OK	correct
	Rear	OK	OK	correct
11	Front	OK	OK	correct
	Rear	OK	OK	correct
12	Front	OK	OK	correct
	Rear	OK	OK	correct
13	Front	OK	OK	correct
	Rear	OK	OK	correct
14	Front	OK	OK	correct
	Rear	OK	OK	correct
15	Front	OK	OK	correct
	Rear	OK	OK	correct
16	Front	OK	OK	correct
	Rear	OK	OK	correct
17	Front	OK	OK	correct
	Rear	OK	OK	correct
18	Front	OK	OK	correct
	Rear	OK	OK	correct
19	Front	OK	OK	correct
	Rear	OK	OK	correct

Figure 10. System test results.

The results of this testing are shown in Fig. 10. Every image was correctly analyzed, supporting the hypothesis test previously mentioned. It must be noted that the senior design team only used one camera at a time due to budget concerns. Normally all six cameras would be calibrated and run at the same time, and if any one of them found the bolt to be defective it would be removed from the line. For the purposes of this project, only the front and rear were analyzed due to the inability to calibrate other camera angles with a limited number of sample bolts.

The Matlab analysis code takes approximately two seconds to run, while the camera takes an additional three seconds to take the photo and upload it. These times are well under the 300 parts per hour production speed that requires a scan every 12 seconds. The times could be reduced with a faster computer and an industrial camera.

III. Conclusion

Overall, the final design presented here is a highly functioning and aesthetically professional prototype that will be easily integrated and expanded by CMP staff. The final prototype meets all of the design requirements the senior design team has set.. The system can process several bolts with small probability of failing to reject defective bolts. This capability was demonstrated by both hypothesis testing and repetitive system runs with test bolts. Testing can be done with a process time well under the maximum required by CMP. The final system is well under the maximum allowed budget with a final cost of just over $3,000. This is especially appealing when comparing this number to the previously quoted visual inspection system at a hefty $50,000. The final solution will also require little to no maintenance since there are no dynamic mechanical components aside from the necessary automation parts, which will be added by CMP. When fully integrated into CMP, with the addition of automation for the loading and unloading of bolts and the calibration of the other camera angles, this design will completely eliminate the need for laborers during crack inspection. The money saved in labor costs is projected to quickly allow the system to pay for itself.

Acknowledgements

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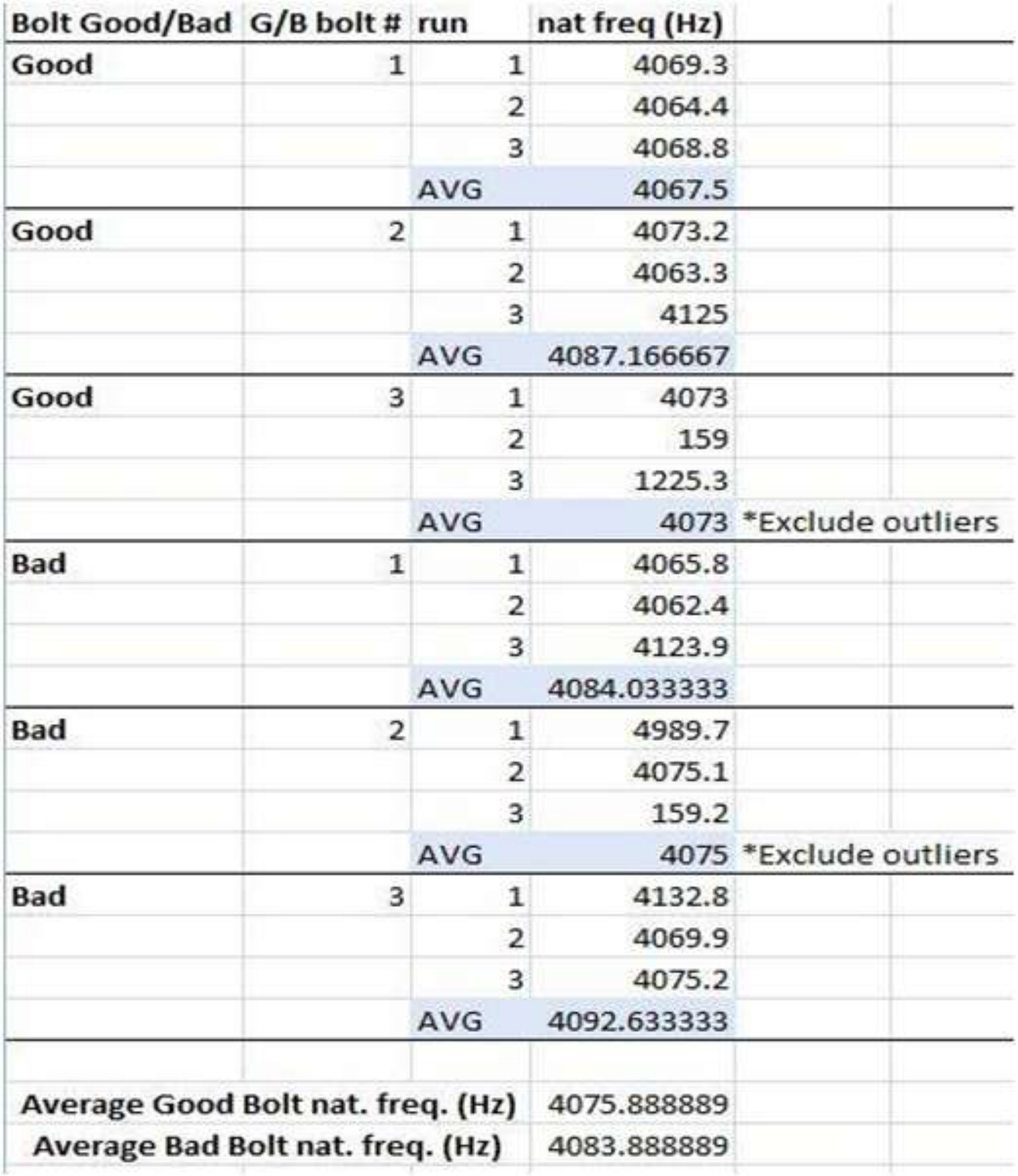
Appendix 1: Vibration Analysis Test Data



Bolt Good/Bad	G/B bolt #	run	nat freq (Hz)	
Good	1	1	4069.3	
		2	4064.4	
		3	4068.8	
		AVG	4067.5	
Good	2	1	4073.2	
		2	4063.3	
		3	4125	
		AVG	4087.166667	
Good	3	1	4073	
		2	159	
		3	1225.3	
		AVG	4073	*Exclude outliers
Bad	1	1	4065.8	
		2	4062.4	
		3	4123.9	
		AVG	4084.033333	
Bad	2	1	4989.7	
		2	4075.1	
		3	159.2	
		AVG	4075	*Exclude outliers
Bad	3	1	4132.8	
		2	4069.9	
		3	4075.2	
		AVG	4092.633333	
Average Good Bolt nat. freq. (Hz)			4075.888889	
Average Bad Bolt nat. freq. (Hz)			4083.888889	

Appendix 2: Budget

Item	Source	Quantity	Price	Item total	Notes
Camera	Amazon	1	$51.64	$51.64	8 Megapixel
Lamp Holder	Lowe's	4	$2.24	$8.96	
12' Power Cord	Lowe's	4	$6.14	$24.56	
Extension Cord	Lowe's	1	$3.44	$3.44	
Light Bulbs	Lowe's	1	$9.98	$9.98	6 pack, 60W equivalent CFL
MATLAB	MathWorks	1	$1,900.00	$1,900.00	
Plywood	Lowe's	2	$35.97	$71.94	0.75"x4'x8'
Screws	Lowe's	1	$5.58	$5.58	
Computer	TBD	1	$1,000.00	$1,000.00	UP TO CUSTOMER
Hinge Kit	Ace	1	$6.49	$6.49	
Hinge Chest	Ace	1	$8.99	$8.99	
Glue Spray	Ace	1	$11.99	$11.99	
10x2 Cabnet Screws	Ace	1	$9.29	$9.29	
10x1 Cabnet Screws	Ace	1	$8.79	$8.79	
Caulk	Ace	1	$2.49	$2.49	
Caulk Gun	Ace	1	$4.49	$4.49	
White Spray Paint	Ace	1	$2.99	$2.99	
Fasteners	Ace	27	$0.10	$2.83	
Wood Glue	Lowe's	1	$2.99	$2.99	
White Board	Lowe's	1	$12.98	$12.98	4"x8"x1/8'
TOTAL				$3,150.42	

Appendix 3: Final Matlab Analysis Code

```
% G is a grayscale image which we will scan - you must first import the
% image and convert it to grayscale using G=rgb2gray(picturefilename);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% LOOP WILL PERFORM FULL ANALYSIS EVERY TIME NEW PICTURE IS TAKEN
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
for i = 1:1000000000;

if length(dir(dirName)) > my_dirLength
disp('A new file is available')
my_dirLength = length(dir(dirName));

currentDir2 = dir(dirName);
NewFile2 = currentDir2(my_dirLength,1);
global FILENAME2
FILENAME2 = NewFile2.name;
disp(FILENAME2);

%X will load the current image into matlab for processing
%we can then set the monitor period just over the image analysis speed
directorySTR = 'C:\Users\gruberjw\Pictures\Logitech Webcam\';
fullFileName = strcat(directorySTR, FILENAME2)

X = imread(fullFileName); %image matrix
global G
G = rgb2gray(X);
%imshow(fullFileName); %just to check for correct image
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    %[INSERT: complete image analysis code with arduino output
    % G is a grayscale image which we will scan - you must first import the
% image and convert it to grayscale using G=rgb2gray(picturefilename);





    %]

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

if length(dir(dirName)) <= my_dirLength
%disp('No new files')
end

%imshow(fullFileName); %just to check for correct image
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    %[INSERT: complete image analysis code with arduino output
    % G is a grayscale image which we will scan - you must first import the
% image and convert it to grayscale using G=rgb2gray(picturefilename);


    %]
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

Result = 0;

[x,y]=size(G); % checks the size of pixel matrix so we know how many
submatrices to look at
rows=0; % initial row do not change
cols=0; % initial column do not change
iter=1; % counter
while (rows < (x-100)) % makes us stop at the last multiple of 100 of the
number of rows
    cols=0; % start at column 0
    while (cols < (y-100)) % makes us stop at the last multiple of 100 of the
number of columns
        examine=G((rows+1):(rows+100),(cols+1):(cols+100)); % define the
search area as 100x100 submatrix
        counts(iter)=sum(examine(:) < 15); % This counts the dark pixels in
the submatrix, the threshold to be "dark" is set here as 20
        cols=cols+100; % move horizontal to next submatrix to inspect
        iter=iter+1; % increment counter
    end
    rows=rows+100; % move down after scanning across a full layer of the
photo

end
counts % outputs the counted up dark pixels in each submatrix, depending on
photo size can be 750-800 numbers
if max(counts)>20
    Result=2; % bad bolt signal active
    disp('Bad Bolt')
else
    Result=1; % good bolt signal active
    disp('Good Bolt')
end

imshow(G)
%in future make if/then statement so it outputs just whether bolt is cracked
%or OK based on if any submatrix has too many dark pixels - will have to
%determine the threshold number of dark pixels

% possibly detect crack as a range of dark pixels, i.e. 70-1500 as more
% than that may mean just a big splotch of grease or something?

% OR just don't have the threads in the picture as those are basically
% cracks and have low light values!

%outside of crack on reflecting surface values are ~150 in original photo
%inside of crack value is around 30 or less
% white surface is around 210

%a = arduino('COM10') % specify port number
GoodLight = 2;
BadLight = 3;
%Result = 0;
LightDelay =4; % seconds to have light on for
```

```
  %a.pinMode(GoodLight, 'output'); %Good bolt indicator light
 % a.pinMode(BadLight, 'output'); %Bad bolt indicator Light

  if (Result > 0)

  if (Result == 1)

    a.digitalWrite(GoodLight, 1);
    pause(LightDelay) % good light on for length of lightdelay set above
    a.digitalWrite(GoodLight, 0);

  end
  if (Result == 2)
    a.digitalWrite(BadLight, 1);
    pause(LightDelay) % bad light on for length of lightdelay set above
    a.digitalWrite(BadLight, 0);

  end

  else


  end


end
pause(.25);


if length(dir(dirName)) <= my_dirLength
%disp('No new files')
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

end
```