Remote Sensing of Roads and Highways in Colorado

Large-Area Road-Surface Quality and Land-Cover Classification Using Very-High Spatial Resolution Aerial and Satellite Data

Contract No. **RITARS-12-H-CUB**

Quarterly Progress Report #4

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GLOSSARY

CDOT	Colorado Department of Transportation
CU	University of Colorado
DG	DigitalGlobe
DN	Digital Number
IRI	International Roughness Index
MPO	Municipal Planning Office
PPACG	Pikes Peak Area Council of Government
QB	QuickBird
WV-1	WorldView-1
WV-2	WorldView-2

EXECUTIVE SUMMARY

In the previous quarter, we have achieved a moderate amount of success with our study of the various statistical metrics that could possibly be used to detect road surface distress from satellite imagery. In this quarter, we aimed to build upon this success with further exploration of these metrics and their capabilities. We studied them with three different test cases. In each test case, the statistical calculations were applied to satellite images of good and bad roads. The resulting data from these roads were compared with each other. Because the uniformity of a road surface's appearance generally tends to decrease as its condition worsens, we hypothesized that there should noticeable differences between the good and bad roads in regards to how the statistical data of their images are distributed. Specifically, we believed that the data of the good roads should have relatively narrow distributions whereas the data of the bad roads should have relatively wider distributions. Our hypothesis was consistently confirmed in each of the test cases. The fact that we were able to see clear differences between the roads from nothing but satellite images shows that there is indeed great promise for the feasibility of assessing road surface quality through remote sensing techniques.

I — TECHNICAL STATUS

We initially thought that the way to success was to compare the satellite radiance values with the *in situ* measurements made by the Colorado Department of Transportation and our metropolitan planning organization partners. We carried out classification and regression studies with little success. From there, we turned to visual inspection of high-resolution aerial images compared to *in situ* measurements. In this comparison, we were able to demonstrate, as presented in Quarterly Progress Report #2, that we could actually locate and map conditions of a road before repavement would be necessary as indicated by the observed surface radiance.

Still, our complex methods were not very satisfactory because they did not return statistically significant results when applied to satellite data and *in situ* data. This was even true when the Pikes Peak Area Council of Governments collected a special *in situ* data set with high-density ground surveys for us to compare against. We have discovered working with this dataset that the surface measurements provided by the contractor hired by PPACG have some problems that we were not aware of initially. First of all, they are derived from laser data that we do not have access to and that these data are filtered with a running average that smooth's the data. We do not know the wavenumber character of this smoothing filter so we do not know just what the final spatial resolution of these data is. We are now trying to get a copy of the raw laser data so that we can make more direct comparisons.

Since these approaches did not yield any productive results, we decided instead to simply look at roads that we knew were either very bad or very good. The first area contained two northward oriented roads in Larimer County: Interstate 25, which was repaved recently, and US 287, which was repaved a number of years ago. We then also found a point on I-25 south of Colorado Springs where part of the road was paved much more recently than the other. Finally, from the CDOT paving schedule for 2014, we found an area to the west of Vail Pass where only the right lane of the eastbound lanes was scheduled for repaving. As will be shown below, all of these cases clearly demonstrated how well the DigitalGlobe satellite data could be used to indicate roads in need of repaving.

Satellite Data

The following studies will use the panchromatic (black and white) bands of the QuickBird, WorldView-1 and WorldView-2 satellites. We use these data to both depict conditions and to compute statistical co-occurrence texture parameters that reveal the details contained in these satellite images.

Case 1: Roads in Larimer County

The first case we examined consists of two north-south highways in Larimer County to the north of Boulder, CO. One is highway US 287 that travels from Boulder, CO north through Longmont, CO and on up to Fort Collins, CO. The segment of the highway analyzed was last paved in 1973 and was last maintained in 1998. The condition of the road is considered “Poor-0”, which is the worst rating that a highway can get from CDOT. We used this road because it was contained in the same WorldView-2 image from Aug. 8, 2012, which also contained the segment of Interstate 25 (I-25) that we analyzed. This interstate highway segment was last paved in 2011 and the condition is considered “Good” by CDOT.

We present images of both highway segments here in Fig. 1 with US 287 on the left and I-25 on the right.

Fig. 1: US 287 (left) and I-25 (right) from a WorldView-2 image collect on Aug. 8, 2012

In these coincident images, we can clearly see what we know to be better surface conditions of I-25 as indicated by the I-25 (paved in 2011) corresponding to the darker color of the road surface. Looking at the right northbound lanes, we can really sense the degraded condition of US 287 in this area by the apparent lighter colors of the road. Still, the highway condition appears to be better than the condition of the frontage road that parallels US 287 at this location.

To quantitatively assess the condition of these surfaces, we selected regions of interest indicated by the colors on the roads in question in Fig. 2.

Fig. 2: Regions of interest (ROIs) for the statistical calculations for US 287 (left) and I-25 (right)

An effort was made to keep the number of values used in the statistical computations somewhat similar. The first statistic examine was a simple mean computed over a pixel box passed over each image (Fig. 3).

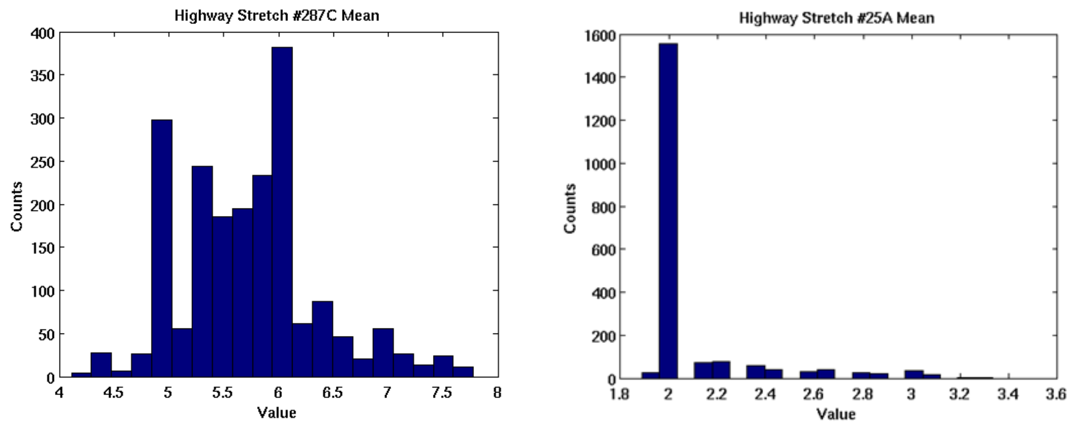

Fig. 3: Histograms of the mean value in a 2D pixel moving region for US 287 (left) and I-25 (right).

In these histograms, the recently repaved I-25 has a single peak at a relatively low value, which indicates a uniform dark reflectance of the highway surface. US 287, on the other hand, exhibits a wide range of values with the maximum number of points at a value of 6 which is below the maximum at about 7.8. This indicates a serious degradation of the highway surface leading to a wide range of increased reflectances and a lighter gray color of the highway.

Next, we looked at the variance computed in the same way as the mean. It also clearly showed the difference in these two road surfaces (Fig. 4).

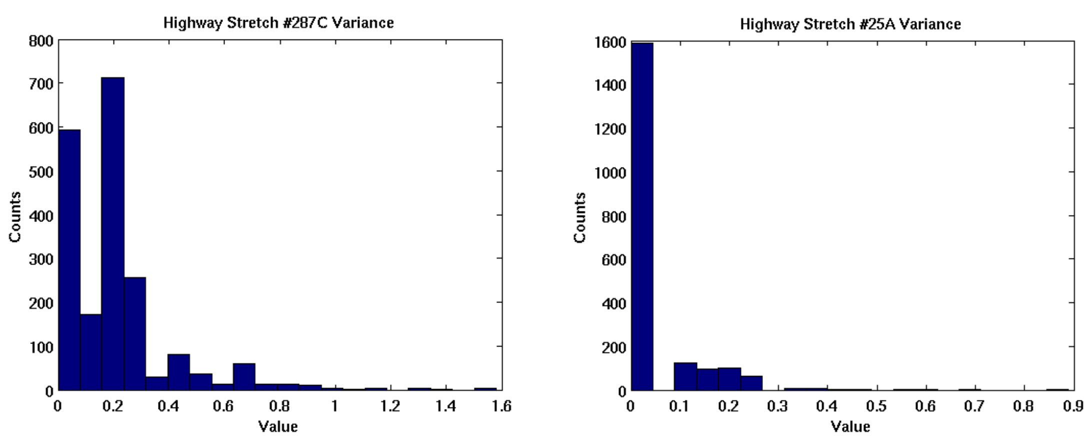

Fig. 4: Histogram of the variance in a 2D pixel moving region for US 287 (left) and I-25 (right).

Again, there is a marked difference in the variance of these two roads with I-25 having a very low and uniform variance as expected while the US 287 variance had larger values with a peak at about 0.25. An analysis of any highway would clearly show these differences indicating the quality of the road surface.

This effect is even more marked in a comparison of the contrast computed for this same moving area in Fig. 5.

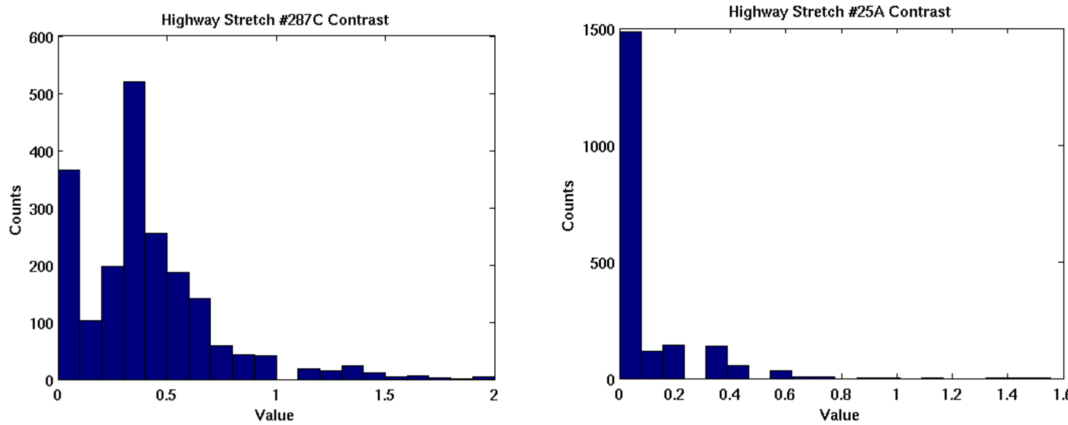

Fig. 5: Histograms of contrast computed over a 2D moving region for US 287 (left) and I-25 (right).

Here (Fig. 5) the spread for the US 287 contrast is even greater than it was in the variance, which is very different than the nearly uniform near zero values for I-25. There are a few values away from zero but these are likely due to the presence of white road markers, which were not specifically removed for this analysis. Still, the very wide spread for US 287 can't be all explained by the presence of white lane markers.

Moving on to homogeneity, we find (Fig. 6) that I-25 is extremely homogeneous (values mostly at 1) while US 287 has its contrast peak at about 0.85.

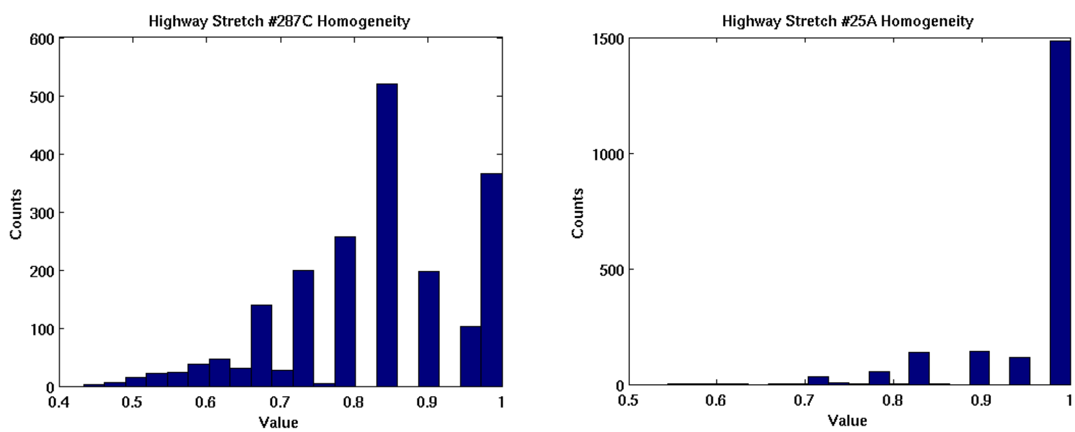

Fig. 6: Histograms of homogeneity over a moving 2D region for US 287 (left) and I-25 (right)

There is an interesting almost Gaussian series of histogram values surrounding this peak value. Again, the values away from 1 for I-25 are likely due to the presence of white lane markers.

Finally, we examine the entropy calculated from these two road segments in the satellite images (Fig. 7).

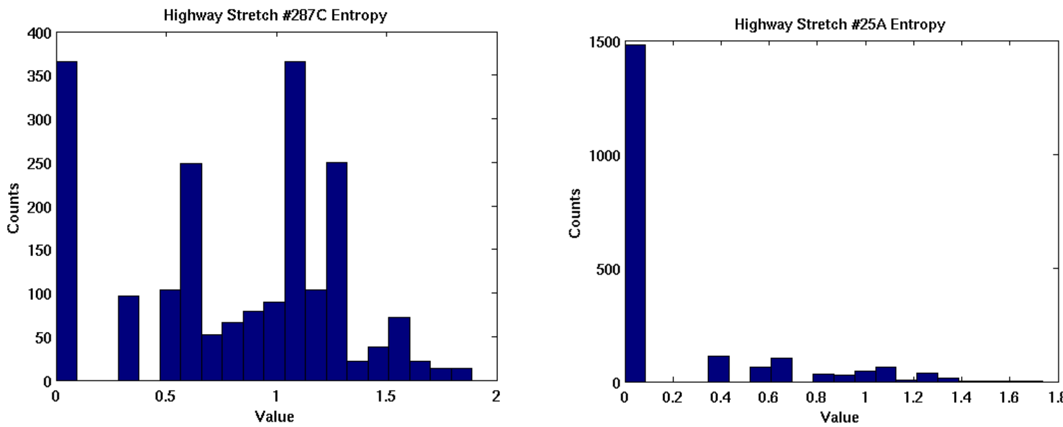

Fig. 7: Histograms of entropy computed for a moving 2D region for US 287 (left) and I-25 (right)

As a measure of disorder this parameter is particularly telling of the condition of the road surface. The left side of Fig. 7 shows a large spread again with a maximum about 1.2 in spite of values at zero. This variety of entropy values suggests that the surface is not at all uniform and that a great variety of conditions are present. However, the I-25 values are mostly at zero with again some off-zero values due to the presence of white lane markers in the analysis.

Discussion of Case 1

No matter what co-occurrence texture parameter we examine, there is a clear difference between these two roads. It is very likely with continued analysis of this type that we can develop a connection between the pavement age and the texture parameters of the corresponding panchromatic band image. Whether we look at coherency measures (mean, homogeneity) or variability measures (variance, contrast, entropy) the results are very consistent and the indication is that this type of analysis of the satellite data would clearly provide the information needed to make a future paving decision.

Case 2: I-25 South of Colorado Springs

In an effort to verify these initial results, we looked for other areas where we found similar results. We found an area of I-25 just to the south of Colorado Springs where the highway had been paved and then stopped very abruptly. We found that simply from appearance, the comparison of these road surfaces should be able to indicate a dramatic difference (Fig. 8). Note the large change in gray shade that takes place in the middle of this image on I-25. It should be noted that this image is from the older Quickbird satellite rather than from either of the WorldView satellites. The major change associated with this older satellite is a 60 cm resolution of the panchromatic rather than the 50 cm panchromatic resolution of the WorldView satellites.

Fig. 8: Quickbird 60 cm panchromatic image of I-25 south of Colorado Springs.

The dramatic change in appearance of these road surfaces is due to a six-year difference in paving. The darker homogeneous surface was repaved in 2007 while the lighter degraded surface was repaved in 2001. This is a relatively short period to have a major degradation in surface condition. We selected portions of this roadway for our statistical analysis as shown here in Fig. 9.

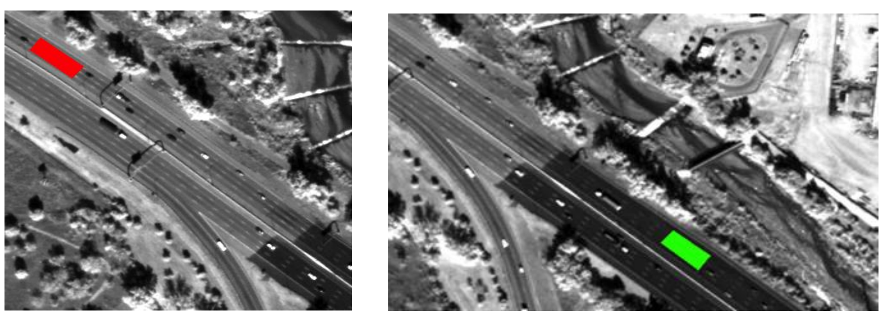

Fig. 9: Regions of interest selected for statistical comparisons of the textures of the road surfaces.

Looking at the same statistics that we looked at above, we present the mean values of the surface conditions of these two road segments in Fig. 10.

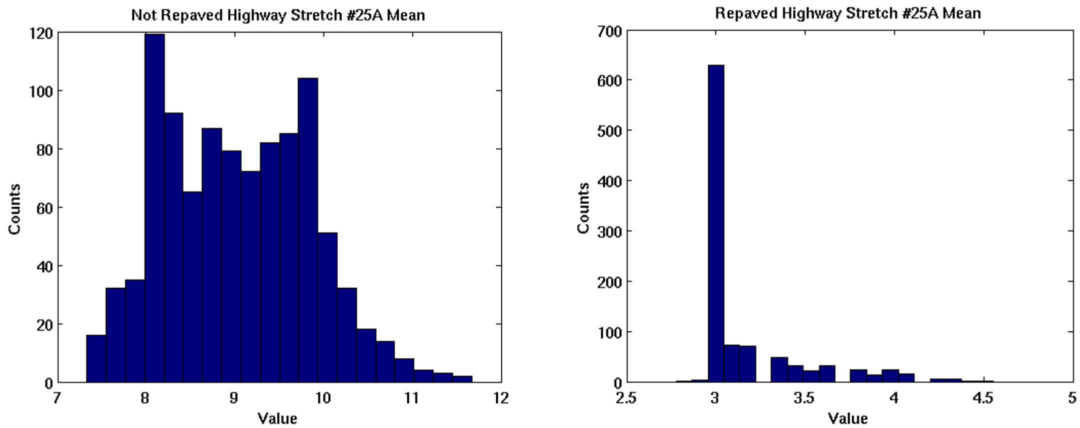

Fig. 10: Histograms of the mean reflectance from two segments of I-25 south of Colorado Springs. The 2001 paved surface is on the left while the 2007 paved surface is on the right.

Here the 2001 paved surface is on the left and the 2007 paved surface is on the right. The degraded surface histogram on the left has a wide range of values with peaks at 8.1 and 9.9 while the good surface has only one peak at 3. The really surprising thing here is that the histogram of the good surface of I-25 on the right is similar to the histogram on the right of Fig. 3, which is also from I-25 but much farther north. The main difference here is that the peak in Fig. 8 right is at 3 while the previous peak in Fig. 3 right is at 2. This might indicate that the better I-25 surface here has degraded slightly for the 2007 paved surface when compared with the 2011 farther north. At the same time, the histograms of the 2001 surface and the 1998 paved surface of US 287 (Fig. 3 left) are very different which suggests that roads degrade differently. However, both Fig. 3 and Fig. 10 left panels exhibit large ranges in values that demonstrate the degraded highways.

Looking at the variance for the road surfaces, we again have the 2001 surface on the left and the 2007 surface on the right (Fig. 11).

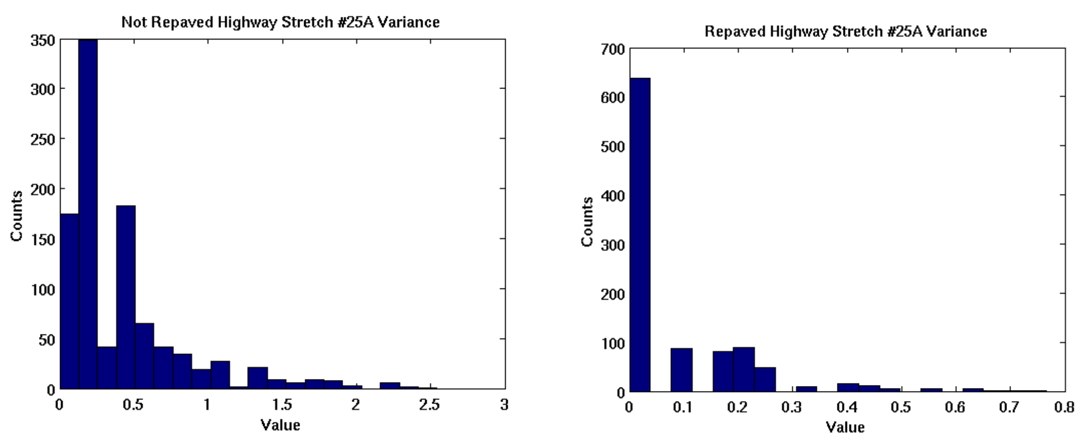

Fig. 11: Histograms of the variance of surface texture for the 2001 I-25 surface (left) and the 2007 I-25 surface (right).

The better-conditioned surface of I-25 on the right of Fig. 11 has a peak near zero as does the histogram of I-25 farther north on the right of Fig. 4. The primary difference in these two histograms is that the higher values peaks in Fig. 11 right are slightly larger than those for Fig. 4 right. This is likely because the I-25 represented by Fig. 11 on the right was paved in 2007 while that on the right of Fig. 4 was paved in 2011. So this degradation appears as slightly higher contributions to the variance. The 2001 paved surface by comparison has two large peaks at 0.2 and 0.5 and a wider range of values than in the right panel of Fig. 11.

The histograms of contrast for the road segment in Fig. 8 are presented here in Fig. 12.

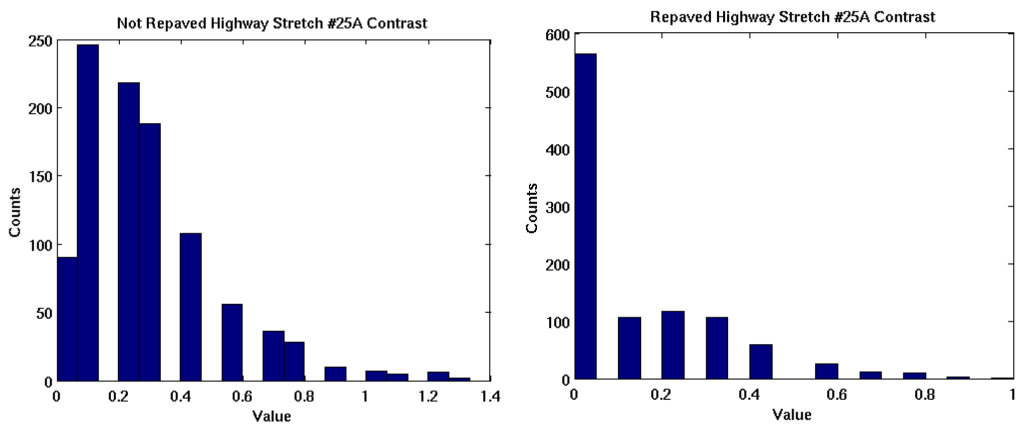

Fig. 12: Histograms of reflectance contrast for the 2001 paved segment of I-25 (left) and the 2007 paved segment of I-25 (right).

Here again, we see a very large peak near zero in the more recently paved portion of I-25 (Fig. 12 right) and a series of large peaks for the 2001 paved portion of the same highway (Fig. 12 left). In fact, the peak close to zero on the left is much smaller than that of four other peaks, which range up to 0.43. In addition, the histogram on the left of Fig. 12 ranges all the way up to 1.35. A comparison of the right panel of Fig. 12 with the right panel of Fig. 5 shows some very interesting differences. While the peak is again near zero there are a series of larger peaks strung across the x-axis up to about 0.6, which cannot be explained by the presence of white lane markers. These histogram peaks may indicate the degradation that must have occurred in the 2011paved surface of I-25 in Fig. 5 versus the 2007 paved surface of the same highway in Fig. 12.

There is again a very marked difference between the left and right panels with a number of higher histogram peaks in the left panel indicating the increased road surface deterioration in the segment of the road paved in 2001. More comparisons of this kind can likely develop in to an algorithm that could be used to indicate conditions leading up to a paving decision.

Turning to homogeneity, the histograms in Fig. 13 again show the difference between these two surfaces. As suspected, the right panel of Fig. 13 shows a very high homogeneity for the smooth appearing surface of I-25. However, this 2007 paved I-25 surface has many lower peaks when compared with the 2011 paved I-25 surface in the right panel of Fig. 6. This may indicate its condition.

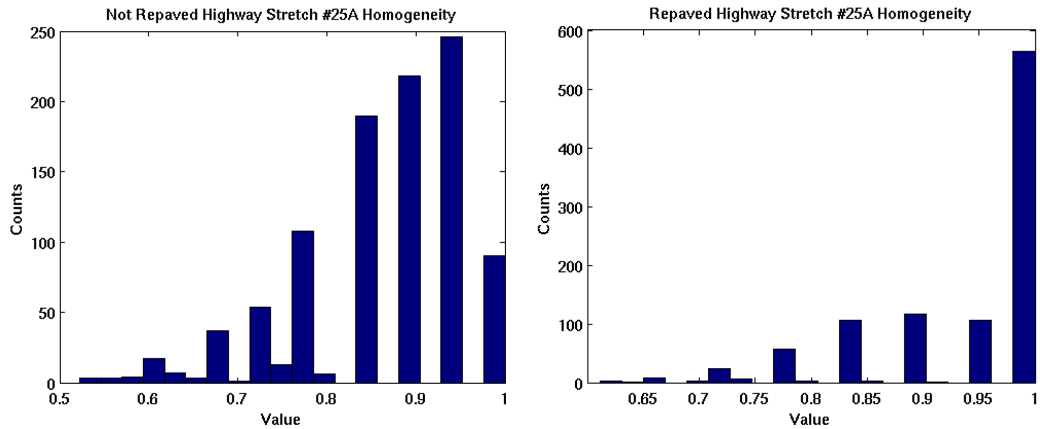

Fig. 13: Histograms of texture homogeneity for I-25 paved in 2001 (left) and paved in 2007 (right)

There are significant differences again between the right and left panels of Fig. 13 that are consistent with the degradation of the 2001 paved surface. A comparison of left panels in Fig. 13 and Fig. 6 do clearly suggest much worse surface conditions of the US 287 road consistent with its last maintenance in 1998 compared with the 2001 paving of the surface on the left of Fig. 13.

Finally we look at the statistical entropy for the road surface junction in Fig. 8 and present them in Fig. 14.

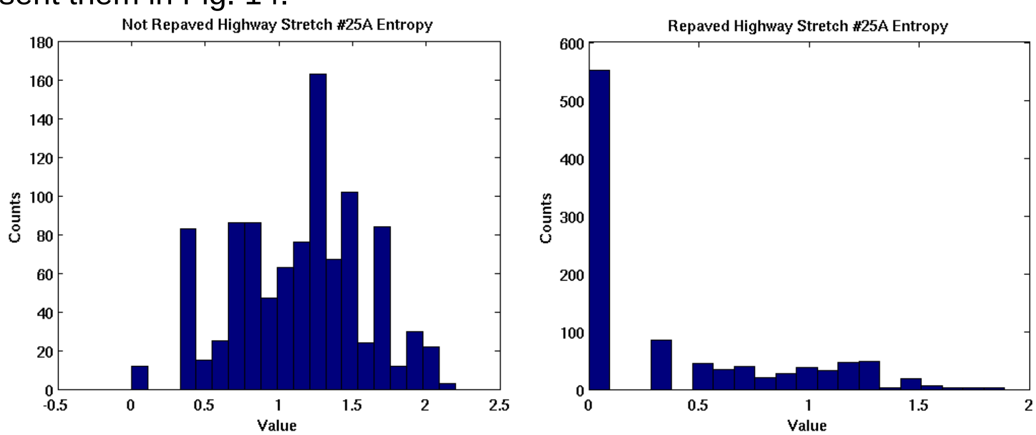

Fig. 14: Histograms of texture entropy for I-25 paved in 2001 (left) and paved in 2007 (right).

Here again, the entropy shows a dramatic difference between the more recently paved portion and that paved back in 2001. Since entropy is a measure of disorder, you want the value to be near zero, which is the case for the 2007 paved surface on the right of Fig. 14. A comparison with the right panel of Fig. 7 suggests the difference between the 2007 paved surface and the 2011 paved surface. Here the differences aren't as great as they were in other statistical parameters, but there are still some higher peaks at larger values in Fig. 14 when compared to Fig. 7. It is interesting that both of them show a range of very small peaks.

The entropy histogram of the 2001 paved surface in Fig. 14 has a peak at about 1.25 with other significant peaks at values stretching from 0.4 to 2. A comparison with the poor road surface conditions of the 1998 maintained US 287 in Fig. 7 show some surprising results. The older surface of US 287 still exhibits a large peak at 0 suggesting that in some ways this older surface is in better condition than that of the 2001 paved I-25 surface, which does not have very many values near zero. Again, there is a suggestion here that these texture statistics could be used to infer conditions of the road surface relevant to whether or not they need repaving.

Discussion of Case 2

Some of the most interesting results of Case 2 were comparisons with the I-25 portion of Case 1. Here we have I-25 paved in 2001, 2007, and 2011. While the 2007 and 2011 surfaces were similar there were differences that showed up on the texture measures. The question is whether or not these texture measures can be sorted into categories that assist CDOT in making decisions about their paving schedules for these highways.

All of the different statistics are supportive of the general conditions but there are subtle differences between statistics that suggest it may be possible to use a combination of these texture statistics to infer more specifics about the road surface that is apparent by looking only at a single statistic.

Case 3: I-70 West of Vail Pass

As a final test of these co-occurrence texture metrics comparisons, we got the 2014 paving schedule from CDOT and picked some roads that they were getting ready to pave. One ideal case is the right or slow lane of the two eastbound lanes of I-70 just to the west of Vail Pass. A WorldView-1 image was available for this area that was collected Aug. 17, 2011. Fortunately, WorldView-1 has the same 50 cm resolution panchromatic band as WorldView-2, which we used earlier for the Larimer County image.

As can be seen in the image of Fig. 15, the poor condition of this right eastbound lane visually differs from the left eastbound lane and both of the west bound lanes.


Fig. 15: Worldview 1 panchromatic image of I-70 just to the west of Vail Pass.

In fact the right eastbound lane is only slight darker than the shoulder of the highway. We selected the regions of interest for good and bad pavement as shown here in Fig. 16.

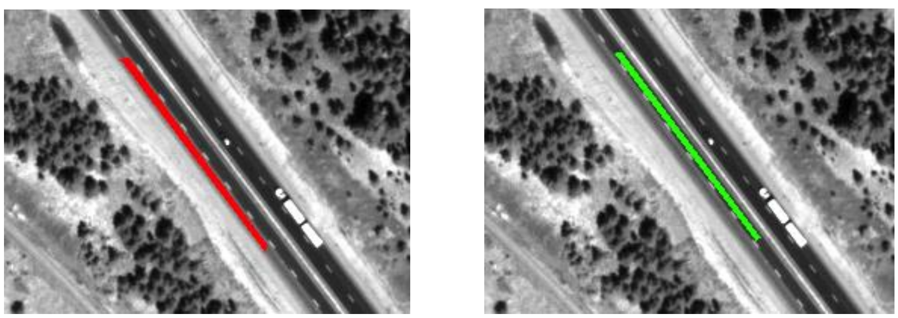
Fig. 16: Regions of interest for statistical computations of the poor road surface (red) on the left and the good road surface (green) on the right.

We have used the two eastbound lanes rather than mix between east and westbound lanes. We unfortunately do not know when the left eastbound lane was last paved nor when the right (poor condition) eastbound lane was paved. Hopefully upon receipt of this report, CDOT will provide us with those dates so that we can update the report.

As before, the first statistic that we will examine is the mean computed over a 2D moving area. The histograms of these means are presented here in Fig. 17 again with the poorer surface conditions on the left.

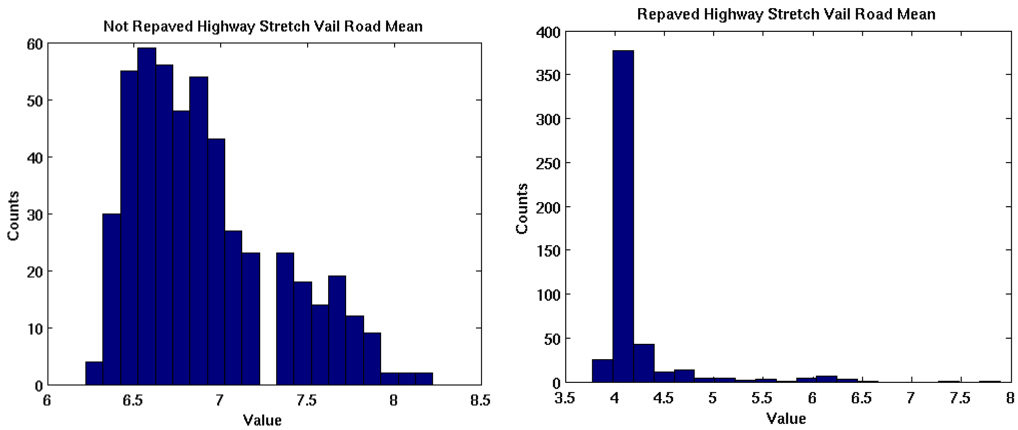

Fig. 17: Histograms of texture mean reflectance from the right eastbound lane of I-70 (left) and the left eastbound lane of I-70 (right).

Again there is a dramatic difference in these statistics. The "poor" surface values are all greater than the peak value of the "good" surface. In addition, the "poor" surface histogram has a very large range of values with peaks ranging from 3 to 8. It is this range of higher histogram values that seems to be very characteristic of poor road surfaces. The good surface has a single large histogram peak at about 4.1. Comparison between this good histogram with previous mean good histograms in Figs. 3 and 10 all show similar behavior with a single large peak but it is very interesting that the peak in Fig. 3 is at 2 for a road paved in 2011, in Fig. 10 is at 3 for road paved in 2007 and here in Fig. 17 is at 4 for a road that may have been paved prior to 2007. The mean histogram peak may suggest the progressive degradation of the road according to its age.

A similar comparison of the poor road surfaces is not as revealing. All of the histograms have a very large range but there is not a consistent shift of the histograms. If we compare with the I-25 condition of the 2001 paved surface on the left of Fig. 10 we find that its peaks range over larger values than does Fig. 17 but the peaks in Fig. 17 are larger. It may be once a highway has reached a poor condition, it is difficult to discern the exact condition from these metrics.

Turning now to variance, we present those in Fig. 18.

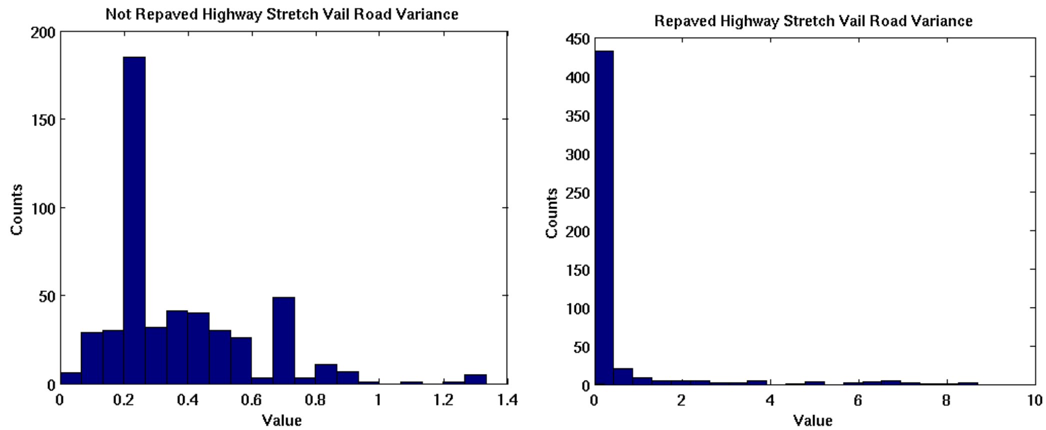

Fig. 18: Histograms of texture variance for the right eastbound lane of I-70 (left) and the left eastbound lane of I-70 (right).

As expected, the good surface condition on the right has a single large peak near zero. The poor lane has its largest peak at 0.2 but again the peaks are all spread over the range of values up to about 1. The right panel of Fig. 18 is very similar to the corresponding panels in Figs. 4 and 11 but the left panel is very different than the corresponding panels in Figs. 4 and 11.

We will not present all of the other statistics that were presented for the other cases and we will close this presentation with the entropies for this case in Fig. 19.

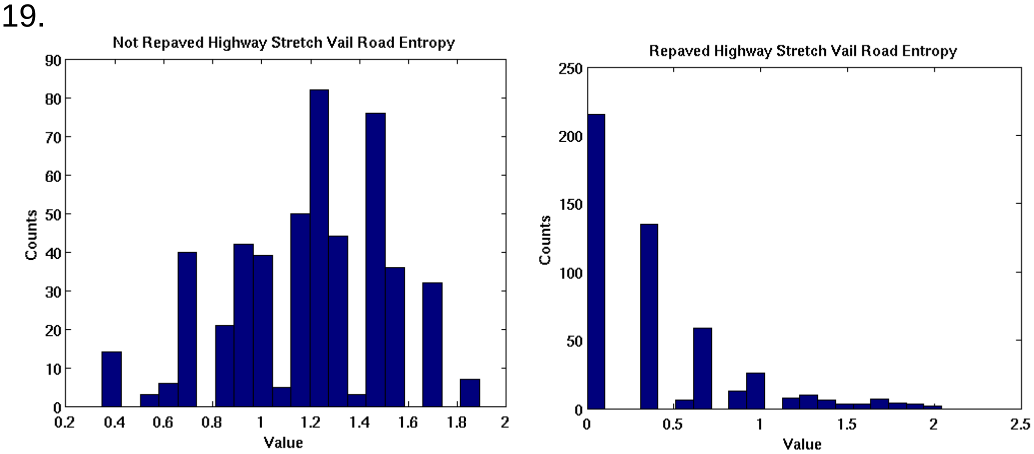

Fig. 19: Histograms of texture entropy for the right eastbound lane of I-70 (left) and the left eastbound lane of I-70 (right).

As before, the main entropy peak is near zero for the good surface (right) and is widely spread for the poor surface on the left. There are, however, a lot more peaks on the right at higher values than what appeared in any of the earlier entropies for good road condition. Since we do not know the date of repaving of the good lane, this might reflect that this date is not particularly recent. This was suggested by the earlier comparisons of the mean values that appear to be confirmed here by the entropy.

Discussion of Case 3

Unfortunately, we do not know the dates of previous paving of either the good or bad surfaces of the eastbound lanes of I-70. We do know, however, that the right eastbound lane is on the schedule to be paved in 2014 so we can easily infer that it was last repaved much earlier than the left lane. This is confirmed by the appearance of each lane in the satellite image and by the co-occurrence texture statistics computed from the satellite data. Looking at the mean value of the texture, there is a suggestion that the good surface might have been paved sometime before 2007 when compared with the I-25 road just south of Colorado Springs.

General Discussion of All Cases

The analysis of the images of these highways has clearly indicated that poor road surface conditions can be seen in high-resolution satellite images. More importantly, texture statistics computed from these images provide insight into the conditions of the roads that can hopefully be used in the future to decide when certain roads may be in need of repaving. These results are a lot more promising than our earlier studies of the satellite images relative to the *in situ* data collected by CDOT and the various MPOs that we are working with. Perhaps if we restrict our analysis to good, fair, poor road surface conditions we will be much more successful in being to estimate these conditions from the satellite data alone.

One might think that all we have achieved is a satellite measure of the age of the highway but a comparison of the statistics for US 287, paved in 1998, with those from the 2001 paved segment of I-25 south of Colorado Springs suggests that is not the case. For example the histogram of mean values for I-25 exhibits a wider range of values and a much broader histogram (Fig. 10 left) than that for US 287 (Fig. 3, left). Thus, a road paved in 1998 has a lower set of mean values than a road paved in 2001. Still this seems consistent in that I-25 sees a greater volume of traffic traveling at much higher speeds than does US 287. This is supported by the entropy values which in Fig. 14 (left) for I-25 (paved in 2001) that spread from 0.2 to 2.2 with a large mean peak at 1.2 and no values near zero while US 287 (paved in 1998) in Fig. 7 (left) has a peak near zero, a central peak at about 1 and maximum value of 1.8. Other statistics confirm that the older road actually exhibits texture statistics that suggest a better road surface condition for US 287 than for I-25 (paved in 2001).

Special Study of Colorado Springs

Since the beginning of this project, we have worked closely with the PPACG, the MPO of Colorado Springs. They provided us with their last sample dataset that was collected in 2007 and also arranged for a new collection of *in situ* data in 2012. For 2007, we have a QuickBird image and we arranged for a WorldView-2 image set to be collected during the 2012 survey. At present, we are limited to an analysis of the 2007 data since it was reported as polylines that follow the tracks of the vans that collected the *in situ* data. Unfortunately, the 2012 dataset was reported as point shapefiles and we can only extract the satellite data along the lines followed by the vans collecting the data. We are trying to get the contractor who collected these data to send us the polyline information along with some details about how their data are processed (smoothed, etc.).

We did, however, carry out an analysis of the 2007 data set. Once again, we were frustrated in trying to regress the extracted satellite measurements against the *in situ* dataset. Realizing that much of this problem was due to scatter in the *in situ* dataset, we decided to again look only at the satellite data. But now, it was extracted along the polylines that describe the tracks of the vans collecting data. Linear statistics along these lines were used to classify the conditions of the road surfaces. We basically had three classes: good condition (bright green), poor (red) and intermediate (olive drab). These classes were used to classify the roads in central Colorado Springs in Fig. 20. It can be seen that poor patches are juxtaposed to good and intermediate road conditions. This is typical of city streets, which are basically maintained according to citizen complaints about road conditions rather than by any predetermined maintenance schedule. Intersections are particularly susceptible to surface degradation as evidenced by the numerous red line segments at or around intersections.

It seems strange that the I-25 corridor has good, fair, and poor conditions but in light of the second case above, this is an expected condition depending on the road's paving history. It is very likely that these surface conditions can be directly linked to the past paving schedule. In Fig. 21, we present the same analysis for different parts of the satellite image that show similar features. Intersections are again the sites of poor surface conditions even when the road surface itself is in good condition. Here the I-25 surface exhibits largely poor (red) surface condition, but in the north of the image, the surface now appears to be in good (bright green) condition. Most of the rectangular crossing streets are in good condition with the caveat for the numerous intersections.

Fig. 20: Road surface conditions computed from a 60 cm resolution QuickBird image in 2007.

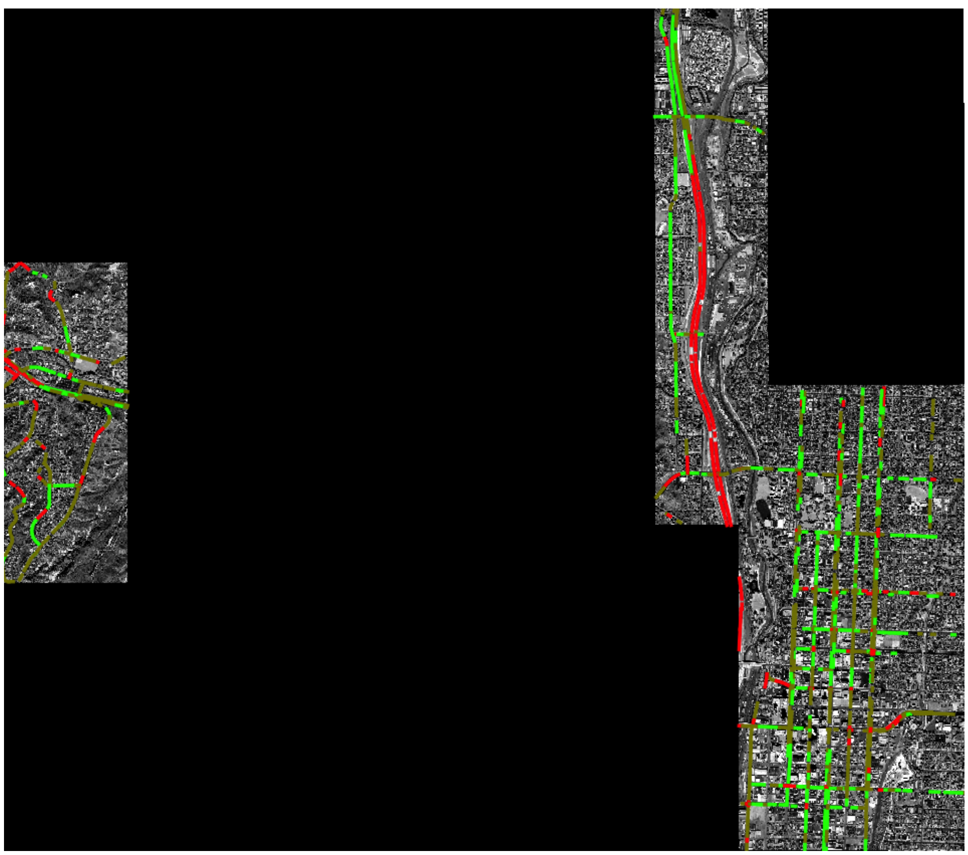

Fig. 21: As in Fig. 20, but for a slightly different area.

We are trying to find out how well this analysis compares with the PPACG's earlier analysis and paving decisions. Even though the *in situ* parameters (fatigue, rutting, IRI) are reported with high spatial resolution, we have learned that most paving decisions are made using a much rougher designations of "good", "fair", and "poor". Thus, we have elected to analyze the satellite images with a similar set of classifications. This appears to overcome the problems we had in comparing with the continuous *in situ* data.

Discussion of Colorado Springs Case Study

Once again, the real success appears to have come when we no longer attempted to regress the extracted satellite information against the *in situ* measurements. We want to now work with CDOT and our MPOs to determine if our satellite measurements could be used to assess future paving needs. If so, the satellite data represents a much simpler and more cost-effective method to determine when a road surface is in need of repaving or at least some form of maintenance. This can be done in a city or out on the open road wherever satellite data are available.

Future Plans

The analysis of these highway images has clearly indicated that good and poor road surface conditions can indeed be seen in high-resolution satellite images. More importantly, texture statistics computed from these images provide insight into the conditions of the roads that can hopefully be used in the future to decide when certain roads may be in need of repavement. We plan to continue this study in greater depth over the next few months. The most ideal outcome would be to perfect it so that it can be used to determine the unknown condition of a road surface. In order to do so, we would need to expand our investigation to many image sets so that we can account for variables such as solar incidence angle and satellite viewing angle. Also, we would need to analyze more intermediate road surface conditions rather than just extreme cases of good and poor. Only then can we truly consider satellite remote sensing to be a reliable road surveying technique. In any case, we plan to attend the Transportation Review Board conference on "Sensing Technologies for Transportation Applications" in Washington DC in January of 2014 to present our study.

In addition, we have independently begun another project that tangentially relates to this one. We have been taking photographs of road surfaces around Boulder, CO using a handheld digital camera. The road surfaces vary in quality from good to poor. We plan to convert these color photos into grayscale photos, reduce their resolution to that of WorldView-2, and artificially add noise characteristic to the sensors of WV-2. The idea is to simulate how visible road distresses, such as cracking, or lack thereof would appear in a WV-2 image. We shall also perform the same kind of texture calculations as explained in this report on our simulated WV-2 images. If we can get similar results, then we can reaffirm the fidelity of this method of analysis.

II — BUSINESS STATUS

Please see Appendix.

FEDERAL FINANCIAL REPORT

(Follow form instructions)

1. Federal Agency and Organizational Element to Which Report is Submitted Department of Transportation	2. Federal Grant or Other Identifying Number Assigned by Federal Agency (To report multiple grants, use FFR Attachment) RITARS-12-H-CUB	Page 1 of 1 pages

3. Recipient Organization (Name and complete address including Zip code)
THE REGENTS OF THE UNIVERSITY OF COLORADO, 572 UCB,3100 MARINE ST, BOULDER CO 80309

4a. DUNS Number	4b. EIN	5. Recipient Account Number or Identifying Number (To report multiple grants, use FFR Attachment)	6. Report Type	7. Basis of Accounting
00-743-1515	1846000555A	1549569 & 1549570	☑ Quarterly ☐ Semi-Annual ☐ Annual ☐ Final	☑ Cash ☐ Accrual

8. Project/Grant Period From: (Month, Day, Year)	To: (Month, Day, Year)	9. Reporting Period End Date (Month, Day, Year)
08/15/2012	08/14/2014	09/30/2013

10. **Transactions**	Cumulative
(Use lines a-c for single or multiple grant reporting)	
Federal Cash (To report multiple grants, also use FFR Attachment):	
a. Cash Receipts	174,694.40
b. Cash Disbursements	192,884.85
c. Cash on Hand (line a minus b)	-18,190.45
(Use lines d-o for single grant reporting)	
Federal Expenditures and Unobligated Balance:	
d. Total Federal funds authorized	509,290.00
e. Federal share of expenditures	192,884.85
f. Federal share of unliquidated obligations	0.00
g. Total Federal share (sum of lines e and f)	192,884.85
h. Unobligated balance of Federal funds (line d minus g)	316,405.15
Recipient Share:	
i. Total recipient share required	509,290.00
j. Recipient share of expenditures	171,918.34
k. Remaining recipient share to be provided (line i minus j)	337,371.66
Program Income:	
l. Total Federal program income earned	0.00
m. Program income expended in accordance with the deduction alternative	0.00
n. Program income expended in accordance with the addition alternative	0.00
o. Unexpended program income (line l minus line m or line n)	0.00

11. Indirect Expense	a. Type	b. Rate	c. Period From	Period To	d. Base	e. Amount Charged	f. Federal Share
	Predetermin	52.50%	8/15/12	9/30/13	115090.42	60422.47	60422.47
		0.00%					
[redacted]				g. Totals:	115,090.42	60,422.47	60,422.47

12. *Remarks: Attach any explanations deemed necessary or information required by Federal sponsoring agency in compliance with governing legislation:*
Tuition charges of $17,263.00 is exempt from F & A base. Only first $25K on sub-contract is charged with F&A.

13. Certification: By signing this report, I certify that it is true, complete, and accurate to the best of my knowledge. I am aware that any false, fictitious, or fraudulent information may subject me to criminal, civil, or administrative penalities. (U.S. Code, Title 18, Section 1001)

a. Typed or Printed Name and Title of Authorized Certifying Official Andy Wang, Grant Accountant	c. Telephone (Area code, number and extension) 303-492-8925 d. Email address xingji.a.wang@colorado.edu
b. Signature of Authorized Certifying Official Andy Wang Digitally signed by Andy Wang DN: cn=Andy Wang, o=Sponsored Project Accounting, ou=The University of Colorado at Boulder, email=xingji.a.wang@colorado.edu, c=US Date: 2012.05.24 19:08:37 -06'00'	e. Date Report Submitted (Month, Day, Year) 10/08/2013
	14. Agency use only:

Standard Form 425
OMB Approval Number: 0348-0061
Expiration Date: 10/31/2011