

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 #2

Quarter from 01/01/2013 to 3/31/2013

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GLOSSARY

CDOT	The Colorado Department of Transportation
CU	University of Colorado
DG	DigitalGlobe Inc.
DN	Digital Number
IRI	International Roughness Index
MPO	Municipal Planning Office
PPACG	Pikes Peak Area Council of Government
QB	QuickBird
WV2	WorldView-2

EXECUTIVE SUMMARY

We continue to struggle with the automated assessment of road surface parameters from satellite and aerial data to make it fit what is known from in-situ measurements made by our MPO and CDOT partners in this project. To verify the ability of this imagery to depict important road condition information, we looked at the wavenumber spectra of cracking (fatigue), rutting, and IRI. We found that cracking was the most responsive to a paving event. We then turned to aerial imagery of a road and we could clearly see the cracking that led to the high fatigue values. We found that wavenumber spectra of rutting and IRI did not respond to the same paving event and have decided to focus our study on cracking which is clearly a variable that influences decision support systems. To demonstrate whether or not satellite data can also reveal cracks, we carried out a subsample exercise to show that the cracks in the 30 cm resolution aerial image could also be seen in a resampled 50 cm resolution image typical of the WV2 satellite. Finally we just recently acquired the in-situ data collected by our partners in Colorado Springs that covered a ground survey consisting of both high-resolution video and road distress maps. DigitalGlobe was able to collect a cloud-free WV2 image of this area just a week before this in-situ data collection. These data were collected specifically for this project and we believe they will be a big asset in finally developing the automated image analysis system that we are working on to give us the road surface conditions which will assist MPO and CDOT decision in the care and maintenance of their roads and highways.

I — TECHNICAL STATUS

We visually examined aerial images associated with fatigue values measured by CDOT and confirmed that changes in the appearance of cracks are consistent with changes in in-situ measured fatigue values. A resampling study was also conducted to confirm the capability of WV2 imagery to detect cracking in addition to what was demonstrated in the higher resolution aerial data. The results show that WV2 imagery is useful for automated detection of severely distressed road surfaces where in-situ fatigue values are high. In more lightly distressed areas it may be necessary to use aerial imagery with its higher spatial resolution (30 cm for aerial versus 50 cm for WV2).

Pikes Peak Area Council of Government (PPACG) performed a ground survey over a section in Colorado Springs, CO, in early December 2012. A week before this data collection, DigitalGlobe was able to collect a cloud-free WV2 image over the area where the in-situ data were collected. We obtained the road distress data and photographs and they will be utilized with the corresponding WV2 imagery for further investigation. A contract is finally in place with DigitalGlobe that will allow for the delivery of the WV2 image just before the new PPACG survey is delivered to this project. We believe that this new dataset will be a big asset to this project. The PPACG agreed to collect these data with the specific purpose of developing a satellite/aerial image analysis that could be used and validated over other areas of PPACG jurisdiction.

An important difference in this new dataset is that both high-resolution video and radar roughness were collected from the van over this area. Thus, it will be possible to generate objective measures of the in-situ parameters that can be compared with the truck video and the satellite image. This is a big difference from the CDOT in-situ data, which is video only and must be visually and manually interpreted to develop measures of fatigue, rutting, and IRI.

We will continue exploring remote sensing and in-situ data to establish a new automated analysis algorithm using the workflow process discussed in our last report. At this point, the visual confirmation of cracking (corresponding to the fatigue parameter in the in-situ data) has confirmed fatigue as the primary variable for the repaving operations of the Colorado DOT (CDOT) that will help us to focus our development of automated procedures to assess road surface conditions from the satellite and aerial data.

Road Surface Fatigue Observations in Aerial Imagery

In order to investigate spatial variability of remote sensing imagery associated with road surface conditions, wavenumber spectra analysis was performed using CDOT distress data. Fatigue power spectra analysis showed temporal dependency. CDOT annually measures road fatiguing, also known as cracking,

all over the state's highways using video data. Fatigue values range from 0 to 7000 and the measurement unit is ft^2 . Figure 1 shows the fatigue power spectra of segment 3 of CDOT Highway Stretch #002A over several years. We confirmed segment 3 of #002A was repaved in 2010. While the fatigue wavenumber power in 2011 shows small continuous magnitude over the entire cycles, the power magnitude in 2012 is somewhat higher suggesting that cracking has again increased. The results confirmed that fatigue is responsive to repaving and we can measure the variation using remote sensing imagery.

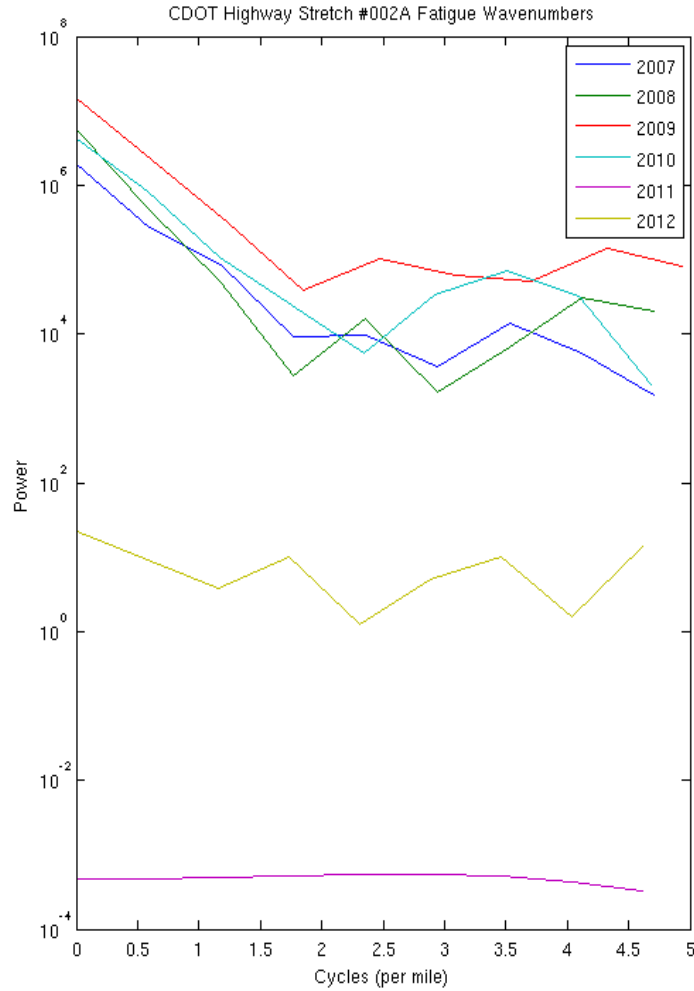


Figure 1. Fatigue power spectra Highway Stretch #002A

In Figures 2 and 3, we present IRI and rutting wavenumber spectra respectively for the same road segment and surprisingly there is no sharp response to the known paving event that caused the low fatigue values in Figure 1 for 2011. In Figures 2 and 3, all of the IRI and rutting wavenumber spectra are essentially similar over the same set of years. All of them have very high values at low wavenumbers (long wavelengths) and oscillatory behavior between 1 cycle/mile (wavelength of 0.5 miles) and 6 cycles/mile (0.17 mile wavelength). In 2011, the IRI and rutting values are very similar to those in 2009 and 2010 and give no obvious indication that a paving event took place in 2010.

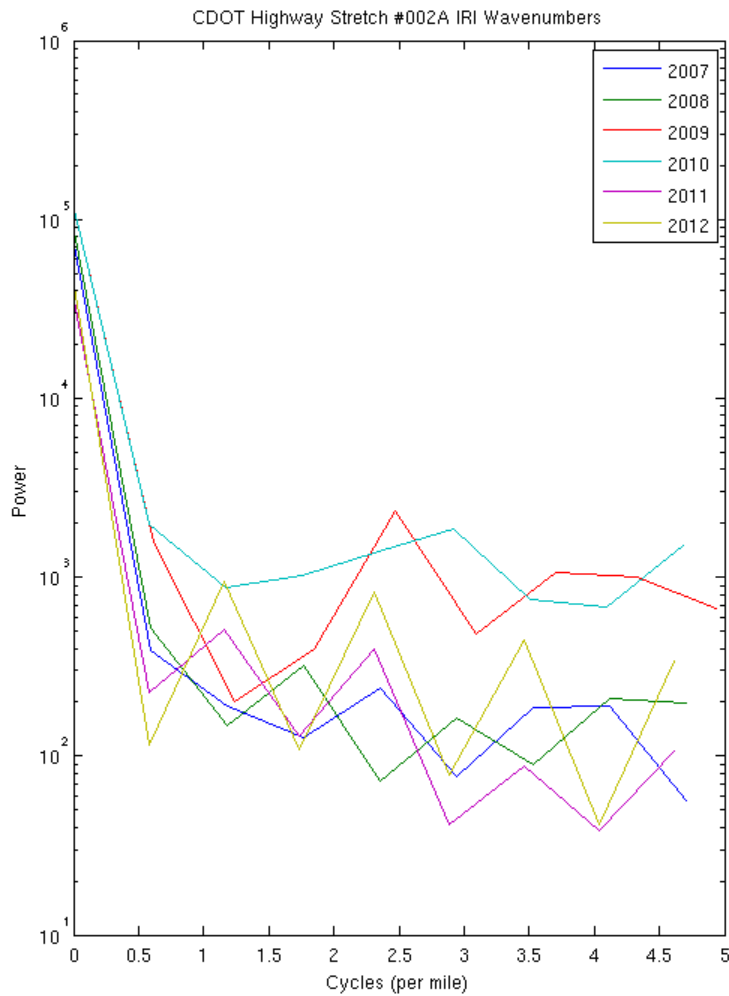


Figure 2. IRI power spectra Highway Stretch #002A

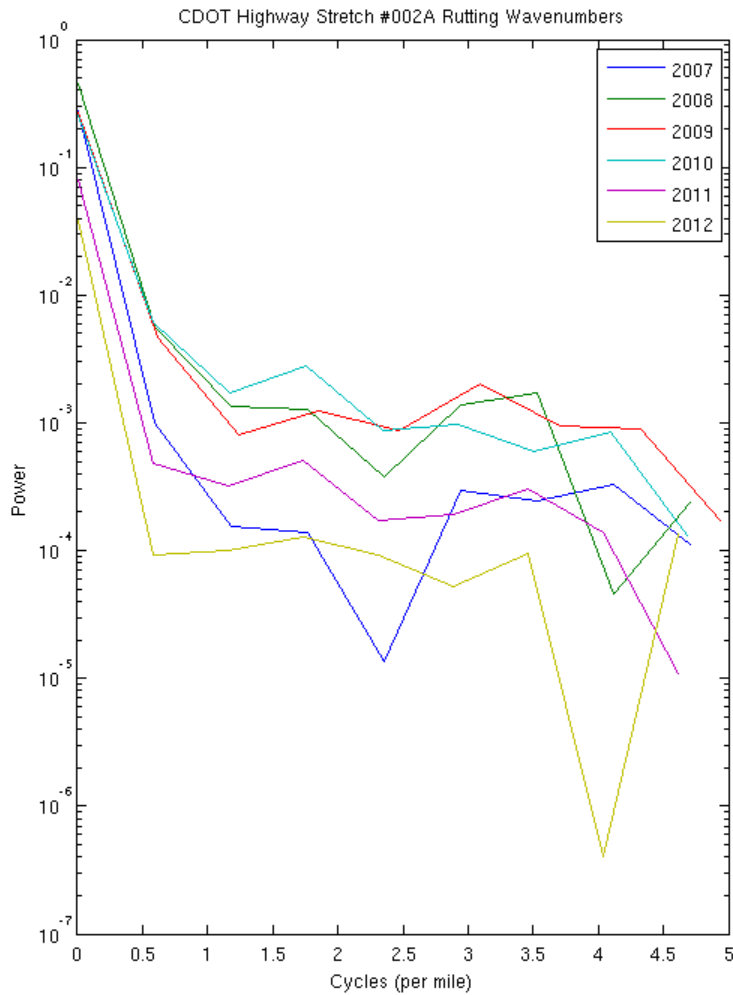


Figure 3. Rutting power spectra Highway Stretch #002A

Aerial imagery was examined with the intent of establishing automated detection of road surfaces with high fatigue values. Road surfaces in aerial imagery along Highway Stretch #34A in eastern Greeley, CO were visually examined and compared with fatigue values measured by CDOT. The aerial imagery and in-situ CDOT collection dates were 4/22/2011 and 2/18/2011, respectively.

Figures 4 and 5 show road pieces in aerial imagery with low fatigue values of 171 and 414 ft², respectively. The road surfaces look consistently dark and smooth.

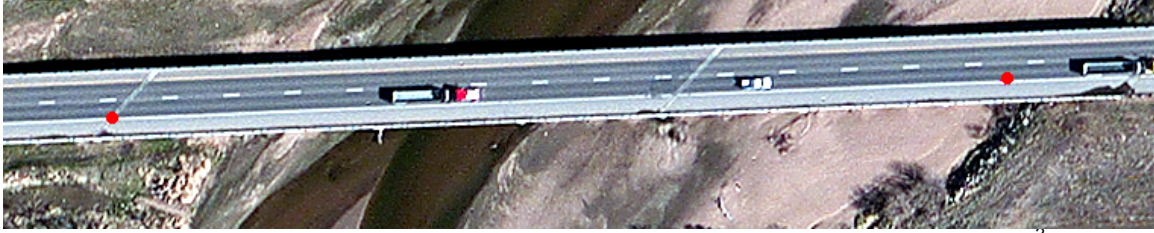


Figure 4. Aerial imagery Mile 114.6-114.7 (between red circles), Fatigue 171 ft²



Figure 5. Aerial imagery Mile 114.1-114.2, Fatigue 414 ft²

Figures 6 and 7 show road pieces with moderately high fatigue values of 5760 and 5014 ft² respectively. The road surfaces look brighter with higher fatigue values and thin perpendicular stripes are visually recognized. They are categorized as transverse cracking.



Figure 6. Aerial imagery Mile 115.0-115.1, Fatigue 5760 ft²



Figure 7. Mile 115.1-115.2, Fatigue 5014 ft²

Figures 8 and 9 show road pieces with high fatigue values of 6567 and 6225 ft² respectively. The road surfaces also look bright and many cracks are clearly exhibited on the imagery.



Figure 8. Mile 114.8-114.9, Fatigue 6567 ft²



Figure 9. Mile 114.9-115.0, Fatigue 6225 ft²

Overall, changes in the appearance of cracks are consistent with changes in fatigue values on aerial imagery.

We will continue to explore the in-situ analysis of the CDOT data with aerial and WV2 imagery. There are many other areas where we have both the in-situ and satellite data that have severe fatigue conditions which we can explore. The challenge now is that since we know the cracks are visible, we must come up with an automated analysis that yields the same information that the decision makers need for their paving planning.

A successful automated satellite image analysis will initially compliment the vehicle mounted video data collection and manual analysis routinely conducted by CDOT for their decision support system. This vehicle based and manual analysis system is quite expensive as it depends on many man-hours of effort. While the satellite data analysis is not likely to completely replace the in-situ data collection, it will strongly compliment the present in-situ system and make repaving decision easier and quicker to make. This is a very important capability as we hope to transition to a more automated method for making these financially important decisions.

Resampling Study

Since we confirmed that cracks are detectable on aerial imagery, the capability of WV2 imagery to detect cracking was explored. Synthetic WV2 panchromatic imagery was generated from aerial imagery and visually examined to determine if the slightly lower spatial resolution of WV2 would be able to detect the cracks of the fatigue parameter.

The aerial imagery observed on 4/22/2011 was also used for this study. The region of interest is an extended area of Figure 8, which is along Highway Stretch #34A in eastern Greeley, CO. This segment showed a high fatigue value of 6567 ft² in 2011 CDOT data as described in the previous section. Given that the spatial resolutions of aerial and WV2 imagery are 30 cm and 50 cm, respectively, resampling was performed to generate a synthetic WV2 image from the aerial image. While the original aerial image chip size was 1212 x 493 pixels, the synthetic WV2 panchromatic image size needs to be 726 x 295 pixels. Among several resampling algorithms, the Lanczos method was adopted in this study. The Luminosity method was adopted for the color conversion from RGB to gray scale, and the formula is $0.21*(red) + 0.71*(green) + 0.07*(blue)$. The color conversion was performed after image resampling.

Figures 10, 11, and 12 show aerial, resampled RGB, and synthetic WV2 panchromatic images, respectively. Transverse cracking is visible in both aerial and synthetic WV2 images as shown in Figure 13. These results indicate that WV2 imagery can be utilized for automated detection of severely distressed road surfaces where in-situ fatigue values are high.



Figure 10. Aerial image (original), 1212 x 493 pixels



Figure 11. Resampled RGB image, 726 x 295 pixels



Figure 12. Synthetic WV2 (resampled gray scale) image, 726 x 295 pixels

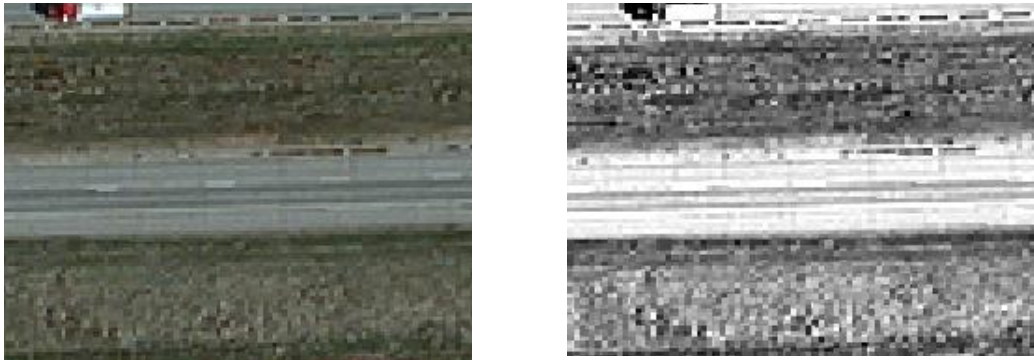


Figure 13. Transverse cracking on aerial (left) and synthetic WV2 panchromatic (right) images

New Data Acquisition

One of our MPO partners, the Pikes Peak Area Council of Government (PPACG) conducted a ground survey between 12/02/2012 and 12/07/2012. The target area is a rectangular region bound by $(38.890^\circ, -104.771^\circ)$ in the upper left, $(38.890^\circ, -104.713^\circ)$ in the upper right, $(38.833^\circ, -104.771^\circ)$ in the lower left, and $(38.833^\circ, -104.713^\circ)$ in the lower right. It is highlighted in lavender in Figure 14.

The acquired dataset includes shapefiles showing where the distresses are located and photographs from the van used for the survey. Figure 15 shows a map of a specific intersection, Constitution Ave. and Wynkoop Dr., in Colorado Springs. Figure 16 shows a photograph of the corresponding intersection as a sample data.

Fortunately our partner DigitalGlobe Inc. was able to collect a cloud-free WV2 image over this region only a week before this data collection took place. It has taken a while to get a contract in place with DG, but that has now been accomplished. We will get the digital data for this image to analyze in conjunction with the excellent new set of in-situ data. This will be an important part of this project and we have rather high expectations for this analysis. Unlike

the CDOT data this data set has both video and radar measurements of the road surface conditions.

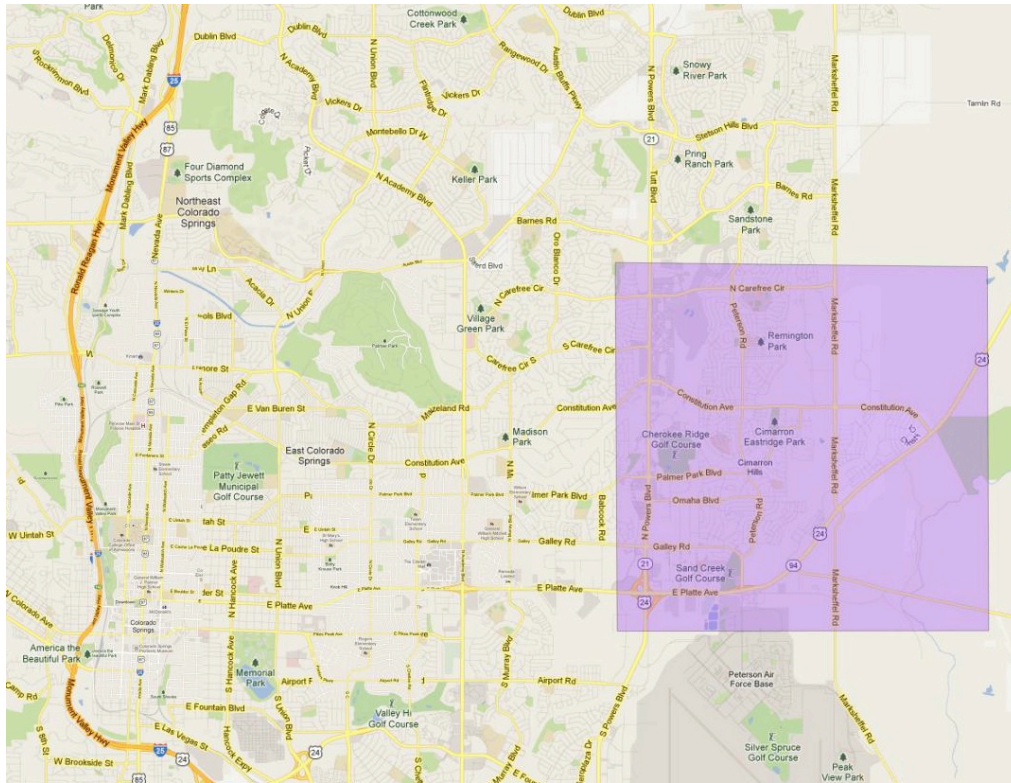


Figure 14. Ground survey area in Colorado Springs

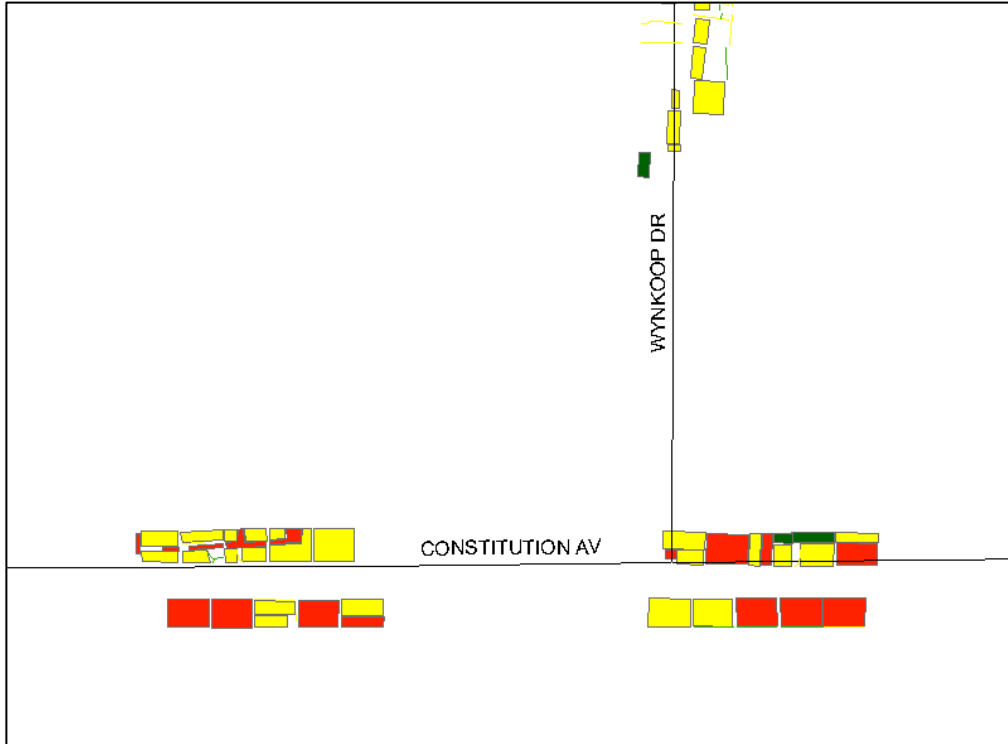


Figure 15. Intersection of Constitution Ave. and Wynkoop Dr. in Colorado Springs. Green, yellow, and red indicate distress severity as low, moderate, and high, respectively.



Figure 16. A photograph of Constitution Ave. and Wynkoop Dr. in Colorado Springs. Obvious road fatiguing can be recognized.

Web reporting

As part of our reporting requirements, we plan to submit project description information to TRB's Research in Progress (RiP) Database. Ashwin Yerasi and Tomoko Koyama attended a webinar conducted on February 13, 2013, titled "Learning About and Using the Updated Research in Progress (RiP) Database Interface". The webinar provided information about RiP's updated search interface and new search functionality.

A "reports" page will be added to the project website (<http://ccar.colorado.edu/dot/>) during this quarter and this report will be added to the previous quarterly reports.

Future Plans

We will continue to explore the remotely sensed and in-situ data to develop a new automated algorithm to generate satellite-based estimates of paved surface quality. It is confirmed that we can detect cracks in aerial imagery and WV2 panchromatic images can be utilized for automated detection of pavement distress where in-situ fatigue values are high. However, further investigation is necessary to fully examine the WV2 imagery's capability, considering the difference of spatial resolutions between aerial and WV2 imagery and severity degree of pavement distress. We will compare aerial and WV2 images on a larger area with respect to in-situ distress parameters.

It should be acknowledged here that the problem of using satellite data to assess road surface conditions is a very difficult one and has eluded a lot of investigators in the past. We feel that our access to high-resolution satellite and aerial data offers us a higher probability of success. Our difficulty at the present is finding an automated procedure that can be applied to the great many roads for which we have in-situ data and corresponding satellite images. For now we have to do manual analyses, which is very time consuming. Nathan Longbotham on our time continues to refine his workflow to achieve this automated analysis. The important result in this report is the realization that cracking (known as fatigue in the in-situ parameters) is the important quantity for paving decisions. We have made similar comparisons for IRI and rutting as that seen in Figures 2 and 3 for fatigue and have not found a similar response to repaving. Thus, we can now focus our automated tool on cracking (fatigue) as the most important parameter to be able to assess from satellite and aerial images. We won't forget rutting and IRI but they will not be the primary focus of this investigation.

Recently acquired data from PPACG includes detailed pavement distress information and continuous high-resolution video. We will study this dataset with the corresponding WV2 observation and explore the linkage between the satellite data and the optical and radar in-situ data. As stated above, this dataset was uniquely collected for this project and we think it will play a significant role in the

development of the automated analysis portion of this project. We plan to apply the resultant analysis scheme to all of the other roads of the PPACG and they will they carry out another independent data collection to validate and verify the analysis.

II — BUSINESS STATUS

Please see Appendix.

FEDERAL FINANCIAL REPORT

(Follow form instructions)

1. Federal Agency and Organizational Element to Which Report is Submitted <p style="text-align: center; font-size: 1.2em;">Department of Transportation</p>	2. Federal Grant or Other Identifying Number Assigned by Federal Agency (To report multiple grants, use FFR Attachment) <p style="text-align: center; font-size: 1.2em;">RITARS-12-H-CUB</p>	Page 1 of 1 pages
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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 00-743-1515	4b. EIN 1846000555A	5. Recipient Account Number or Identifying Number (To report multiple grants, use FFR Attachment) 1549569 & 1549570	6. Report Type <input checked="" type="checkbox"/> Quarterly <input type="checkbox"/> Semi-Annual <input type="checkbox"/> Annual <input type="checkbox"/> Final	7. Basis of Accounting <input checked="" type="checkbox"/> Cash <input type="checkbox"/> Accrual
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8. Project/Grant Period From: (Month, Day, Year) 08/15/2012	To: (Month, Day, Year) 08/14/2014	9. Reporting Period End Date (Month, Day, Year) 03/31/2013
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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	59,918.05
b. Cash Disbursements	88,631.02
c. Cash on Hand (line a minus b)	-28,712.97

(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	88,631.02
f. Federal share of unliquidated obligations	
g. Total Federal share (sum of lines e and f)	88,631.02
h. Unobligated balance of Federal funds (line d minus g)	420,658.98
Recipient Share:	
i. Total recipient share required	509,290.00
j. Recipient share of expenditures	109,095.51
k. Remaining recipient share to be provided (line i minus j)	400,194.49
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
	Pre-determined	52.50%	8/15/12	3/31/13	51817.71	27204.31	27204.31
		0.00%					
	g. Totals:				51,817.71	27,204.31	27,204.31

12. *Remarks: Attach any explanations deemed necessary or information required by Federal sponsoring agency in compliance with governing legislation:*
 Tuition charges is exempt from F & A base.

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 penalties. (U.S. Code, Title 18, Section 1001)

a. Typed or Printed Name and Title of Authorized Certifying Official <p style="font-size: 1.2em;">Andy Wang, Grant Accountant</p>	c. Telephone (Area code, number and extension) <p style="font-size: 1.2em;">303-492-8925</p>
b. Signature of Authorized Certifying Official <p style="font-size: 1.2em;">Andy Wang</p>	d. Email address <p style="font-size: 1.2em;">xingji.a.wang@colorado.edu</p>
e. Date Report Submitted (Month, Day, Year) <p style="font-size: 1.2em;">04/15/2013</p>	14. Agency use only: Standard Form 425 OMB Approval Number: 0348-0061 Expiration Date: 10/31/2011

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 19:09:37 -0600

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