Michigan Technological University

Characterization of Unpaved Road Condition Through the Use of Remote Sensing

Deliverable 4-A: Sensor Selection for use in Remote Sensing the Phenomena of Unpaved Road Conditions

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Purpose of this document

This document describes the process of selecting the sensor(s) that will be needed to measure the relevant parameters required to estimate unpaved road condition and includes details on the candidate sensors that were evaluated as part of this process.

Motivation

Unpaved road condition can be assessed visually: the texture, color, shapes, surface imperfections, and other characteristics allow us to identify and classify various problems with the road. The things that we can measure are produced by the interaction of light with the road surface. These are the phenomena that are important. These combine to form textures, patterns, and other features that we would recognize as a "distress". The sensor needs to measure these distresses at a resolution and rate that will meet the system requirements (detailed in Deliverable 1-A, the "Requirements for Remote Sensing Assessments of Unpaved Road Conditions, available at http://geodjango.mtri.org/unpaved/media/doc/deliverable_Del1-A_RequirementsDocument_MichiganTechUnpavedRoadsr1.pdf). In this document, we will be discussing the process of sensor selection, and the sensor(s) that have been identified as candidates for our subsequent system design.

Summary of sensor requirements from Deliverable 1-A

Field-of-View

The field-of-view (FOV) of the sensor depends on the range to the road and the focal length of the lens. From our requirements, we see that the FOV needs to be twice the width of a typical road (plus drainage), or about 72'.

Focal Length

Given the nominal altitude of the collection (~100' - 400'), that corresponds to a focal length of 61mm – 244mm, which is in the range of standard telephoto lenses.

Resolution

From the requirements on the various distresses, the smallest size needed is ~1". For a 61mm lens with a FOV of 72', and applying the Nyquist Sampling criterion [1] one would need a sensor with 1728 pixels across the road to measure +/-1" [2]. This would be about the size of a 4Mp (megapixel) camera. Since typical COTS (commercial off-the-shelf) digital cameras with resolution of 16Mp are widely available, this should not be a problem (i.e. almost any camera would provide sufficient resolution). Alternatively, if we use a camera with a larger sensor (i.e. more pixels) then the focal length of the lens can be reduced and still maintain the required ground sample distance (1”). The advantage of using a lens with a shorter focal length is that it is lighter, gathers more light (making exposures faster, for less motion-blur), and has better depth-of-field (making focus less of an issue). This argues that we should try to obtain the sensor with the largest number of pixels, so that we can relax the optical requirements.

Frame-Rate

The fastest frame rate needed would be for a sensor mounted on a manned, fixed-wing, aircraft, flying just above stall-speed (~60 mph). For an along-track FOV (field of view) of 94’, and a 50% overlap in consecutive images, this corresponds to collecting images at 2.3 frames per second. If the overlap is larger (which may be needed for full 3D reconstruction, say 75% overlap, the frame rate becomes 3.5 fps (frames per second).

Additional Requirements

There are several other requirements on the camera:

1. It must have a remote trigger to allow software control of the image collection
2. All possible collection scenarios should be possible with a single lens

Sensor Types

All optical sensors must convert photons of visible light into electrons. These electrons accumulate in each cell (pixel) of the sensor and are counted, producing the intensity values of the image.

There are two main types of sensors commonly available: charge-coupled devices (CCD) and complimentary metal-oxide semiconductor (CMOS). In a CCD array, which is an analog device, the accumulated charges in each cell are shifted from one cell to the next (in a sort of “bucket brigade”) to the edge of the sensor array where the charge is measure and converted to a digital count; in CMOS sensors, each cell has circuitry around it that measure the voltage induced by the photons, and can be read individually. Because of the very different ways the charges are sensed, these sensor types have very different characteristics. We should understand how these characteristics might affect our ability to measure road conditions.

The most important differences [3] between the sensors are:

- CCD arrays can produce high-quality, low-noise images; CMOS arrays tend to be more susceptible to noise.
- CMOS sensors tend to be less sensitive to light, since each pixel has several components near it, which photons strike but are not measured.
- CCDs typically consume much more power (100x) than CMOS sensors.
- CMOS can be fabricated more easily, and tend to be cheaper than CCD sensors.
- CCD have been around longer, and are a more mature product, tending to possess higher quality than CMOS sensors.

- CCDs tend to be susceptible to smear from bright light sources.
- CMOS tends to be affected by "rolling shutter" artifacts (a process that is often used to increase the sensitivity).
- CCDs have about 2x better dynamic range than CMOS.
- CMOS can be faster, because all camera functions can be placed on-chip.

Neither sensor type has a clear advantage. CMOS imagers offer better integration, lower power consumption, and smaller size (and weight). CCD imagers have superior quality at the expense of system size and power consumption. Total cost is approximately equal. The question is: for our application, will this make any difference?

Consider the typical collection of data for rural road condition assessment. Data will be collected during the day, in good weather (no rain, light winds). This means sensor noise should not be an issue, since noise contributions are less (signal-to-noise ratio (SNR) is higher) under typical daylight illumination [4]. Further, many CMOS sensors have adopted a technique (back-illumination) which improves the sensitivity at low light levels. Exposure times can be adjusted to eliminate motion blur and still provide sufficient SNR, by appropriate choice of forward speed and lens characteristics. The conditions under which the data will be collected do not extend to those areas where sensor differences manifest themselves.

In summary it appears that while there are significant differences in sensor technology, for the purposes of this program they are not important differences. We will not be using this as an exclusionary factor in choosing an imager.

Candidate Sensors with Recommendation

Table 1 below contains a subset of the information which we used to indicate which sensors might be appropriate. Many of the cameras have very similar features. The first requirement, though, is that they be able to be controlled remotely. The cells that are shaded grey are those cameras that while very capable in other respects, lack this remote control feature. These are excluded from consideration, as are cameras that have reached the end of their production life (and will no longer be supported), shown in red. All cameras that are shaded green (a total of 22 models) are possible candidates. They range in price from $600 - $35,000, with the more expensive cameras generally having one (or more) exceptional capabilities (e.g. RED Epic can collect full-resolution images at 120fps. This is much faster than most of the others, and its price reflects this).

In order to evaluate the sensor, we will choose one that is more capable than some, and less capable than others. That is, one that lies somewhere in the middle in capability. Then, once data are collected, we can evaluate whether more, or less, capability is desirable.

The sensor that we have chosen for initial testing is the Nikon D800, the first line in Table 1. This camera has a full-sized (FX) sensor with 36.3Mp and a full-speed frame rate of 4fps. It more than meets all our requirements as known at this time. It is one of the heavier cameras (1kg), and with a prime lens, the total camera should weigh less than 1.5kg. Detailed specifications for this recommended sensor are shown in Appendix A.

Table 1: Comparison of Candidate Sensors

No single lens will fit our requirements		No Remote Trigger Option	
		Discontinued	

Manufacturer	Model	Mp	Price (USD)	Max FPS (at fu	Max FPS (full r	Sensor Width	Sensor Heigh	Remote Trig
Nikon	D800	36.3	$2,999.95	4	4	7360	4912	Yes
Nikon	D3X	24.5	$7,999.95	5	5	6048	4032	Yes
Canon	EOS 5D Mark III	23.4	$3,499.00	6	6	5760	3840	Yes
Canon	EOS-1Ds Mark III	21.1	$6,999.00	5	5	5616	3744	Yes
Canon	EOS 60Da	19	$1,499.00	5.3	5.3	5200	3462	Yes
Canon	EOS-1DX	18.1	$6,800.00	12	12	5184	3456	Yes
Canon	EOS 7D	18	$1,699.99	8	8	5184	3456	Yes
Canon	EOS 60D	18	$999.99	5.3	5.3	5184	3456	Yes
Canon	EOS Rebel T2i EF-S	18	$699.99	3.7	3.7	5184	3456	Yes
Canon	Eos Rebel T3i EF-S	18	$849.99	3.7	3.7	5184	3456	Yes
RED	Epic	14.3	$34,500.00	120	120	5120	2700	Yes
RED	Scarlet-X	14.3	$9,700.00	30	30	5120	2700	Yes
Nikon	D4	16.2	$5,999.95	10	10	4928	4280	Yes
Nikon	D7000	16.2	$1,199.95	6	6	4928	3264	Yes
Nikon	D5100	16.3	$849.95	4	4	4928	3264	Yes
Canon	EOS-1D Mark IV	16.1	$4,999.00	10	10	4896	3264	Yes
Nikon	D300s	12.3	$1,699.95	7	7	4288	2848	Yes
Nikon	D90	12.3	$899.95	4.5	4.5	4288	2848	Yes
Nikon	D5000	12.3	$629.95	4	4	4288	2848	Yes
Canon	EOS Rebel T3	12.2	$549.99	3	3	4272	2848	Yes
Nikon	D700	12.1	$2,699.95	5	8	4256	2832	Yes
Nikon	D3S	12.1	$5,199.95	9	9	4256	2832	Yes
Pentax	645D	40	$9,995.95	1.1	1.1	7264	5440	No
Sony	NEX-7	24.3	$1,349.99	10	10	6000	4000	No
Sony	a77	24.7	$1,399.99	8	8	6000	4000	No
Sony	a65	24.3	$998.00	8	8	6000	4000	No
Canon	EOS 5D Mark II	21.1	$2,499.00	3.9	3.9	5616	3744	No
Pentax	K-5 Black	16.3	$1,099.00	7	7	4928	3264	No
Pentax	K-01	16.49	$899.00			4928	3264	No
Sony	NEX-5N	16.1	$699.99	10	10	4912	3164	No
Sony	TX66	18.2	$349.99			4896	3672	No
Sony	TX200V	18.2	$499.99			4896	3672	No
Nikon	D3100	14.2	$646.95	3	3	4608	3072	No
Sony	TX55	16.8	$289.99			4608	3456	No
Nikon	P510	16.1	$429.95			4608	3456	No
Nikon	P310	16.1	$319.00			4608	3456	No
Nikon	S9300	16	$346.95			4608	3456	No
Pentax	Optio WG-2 GPS	16	$399.00	1	1	4608	3456	No
Pentax	Optio VS20	16	$184.95	1	1	4608	3456	No
Sony	TX20	16.2	$329.99			4608	3456	No
Pentax	Q	12.4	$749.95	5	5	4000	3000	No
Nikon	1 V1	10.1	$896.95	5	5	3872	2592	No
Nikon	1 J1	10.1	$649.95	5	5	3872	2592	No
Nikon	D3000	10.2	$499.95					
Sigma	SD1	46	$2,299.00	6	6	14400	9600	Yes
Olympus	E-5	12.3	$1,699.99			4032	3042	Yes

Candidate Lenses with Recommendation

The choice of lenses depends on the exposure characteristics (i.e., we want the fastest practical shutter speeds to minimize motion blur), the focal length and sensor resolution (we need to have sufficient ground-sample spacing at the collection standoff to meet the measurement requirements).

For a flight altitude on 400', and a ground-sample spacing of 0.5", that is a scene-size (FOV) of 200', which corresponds to a lens focal length of 90mm. At a standoff of 100', with about that FOV, that would be a 44mm lens. If we needed a single lens with a range of say, 40mm-90mm, there are several practical choices, shown in Table 2.

Table 2: Lens Comparison

Nikon	Nikkor	18-200mm	f/3.5-5.6G	$846.95
Nikon	Nikkor	28-300mm	f/3.5-5.6G	$949.95
Canon		28-300mm	f/3.5-5.6L	$2,689
Canon		18-200mm	f/3.5-5.6 IS	$629
Tamron		18-200mm	f/3.5-6.3 XR Di-II	$299.00
Tamron		18-270mm	f/3.5-6.3 Di II VC PZD AF	$649
Sigma		18-250mm	f/3.5-6.3 DC OS HSM	$479
Tamron		28-300mm	f/3.5-6.3 XR Di LD	$419
Sigma		18-200mm	f/3.5-6.3 II DC OS HSM	$499
Tamron		28-300mm		$629
Tamron		AF18-270mm	f/3.5-6.3 Ei-II VC LD Asph. AF (IF)	$449.95
Sony		18-200mm	f/3.5-6.3	$898
Tamron		18-200mm	f/3.5-6.3 Di III VC	$739
Sony		DT 18-250mm	f/3.5-6.3	$648.00
Sony		SAL-18200 18-200mm	f/3.5-6.3	$548.00

If we want a "faster" lens (i.e. a lens with a larger aperture, capable of capturing more light), then there are no single lenses that span the desired focal lengths. However, two lenses would be a possible compromise:

- Nikon AF-S 50mm f/1.4 (or f/1.8) $480
- Nikon AF-S 85mm f/1.4 (or f/1.8) $1229

These lenses have at least 8x the light-gathering capacity, which means that, for a given illumination, they can maintain quality at 1/8th the exposure time (further reducing motion blur).

For test purposes, we will be recommending and using the 50mm f/1.4 lens, based on these specifications.

Figure 1: Nikkor AF-S 50mm f/1.4

Appendix A: Detailed Sensor Characteristics

The Nikon D800 has the following details specification [5].

Body type	
Body type	Mid-size SLR
Body material	Magnesium alloy
Sensor	
Max resolution (px)	7360 x 4912
Effective pixels	36.3 megapixels
Sensor photo detectors	36.8 megapixels
Other resolutions	6144 x 4912, 6144 x 4080, 5520 x 3680, 4800 x 3200, 4608 x 3680, 4608 x 3056, 3680 x 2456, 3600 x 2400, 3072 x 2456, 3072 x 2040, 2400 x 1600
Image ratio w:h	5:4, 3:2
Sensor size	Full frame (35.9 x 24 mm)
Sensor type	CMOS
Processor	Expeed 3
Color space	sRGB, Adobe RGB
Color filter array	Primary Color Filter
Image	

ISO	100 - 6400 in 1, 1/2 or 1/3 EV steps (50 - 25600 with boost)
White balance presets	12
Custom white balance	Yes (5)
Image stabilization	No
Uncompressed format	.NEF (RAW)
JPEG quality levels	Fine, Normal, Basic
File format	• NEF (RAW): 12 or 14 bit, lossless compressed, compressed or uncompressed • TIFF (RGB) • JPEG
Optics & Focus	
Autofocus	• Phase Detect • Multi-area • Selective single-point • Tracking • Single • Continuous • Face Detection • Live View
Autofocus assist lamp	Yes
Digital zoom	No
Manual focus	Yes
Number of focus points	51
Lens mount	Nikon F mount
Focal length multiplier	1×
Screen / viewfinder	
Articulated LCD	Fixed
Screen size	3.2"
Screen dots	921,000
Touch screen	No
Screen type	TFT Color LCD with 170 degrees wide-viewing angle
Live view	Yes
Viewfinder type	Optical (pentaprism)
Viewfinder coverage	100 %
Viewfinder magnification	0.7×
Photography features	

Minimum shutter speed	30 sec
Maximum shutter speed	1/8000 sec
Exposure modes	• Programmed auto with flexible program (P) • Shutter-priority (S) • Aperture priority (A) • Manual (M)
Built-in flash	Yes (pop-up)
Flash range	12 m (at ISO 100)
External flash	Yes (Hot-shoe, Wireless plus sync connector)
Flash modes	Auto, On, Off, Red-eye, Slow sync, Rear curtain, High-speed sync
Flash X sync speed	1/250 sec
Drive modes	• S (single frame) • CL (continuous low speed) • CH (continuous high speed) • Q (quiet shutter-release) • MUP (mirror up) • Self-timer
Continuous drive	Yes (4 fps in FX format, max 6fps in DX)
Self-timer	Yes (2 to 20 sec, 1 to 9 exposures at intervals of 0.5, 1, 2 or 3 sec)
Metering modes	• Multi • Center-weighted • Average • Spot
Exposure compensation	±5 EV (at 1/3 EV, 1/2 EV, 1 EV steps)
AE Bracketing	(2, 3, 5, 7 frames at 1/3 EV, 1/2 EV, 2/3 EV, 1 EV steps)
WB Bracketing	Yes (2 to 9 frames in steps of 1, 2 or 3)
Videography features	
Format	• MPEG-4 • H.264
Microphone	Mono
Speaker	Mono
Resolutions	1920 x 1080 (30, 25, 24 fps), 1280 x 720 (60, 50, 30, 25 fps), 640 x 424 (24 fps)
Storage	
Storage types	Compact Flash (Type I), SD/SDHC/SDXC UHS-I compliant
Storage included	None
Connectivity	
USB	USB 3.0 (5 GBit/sec)
HDMI	Yes (Mini Type C)
Wireless	None

Remote control	Yes (Optional, wired or wireless)
Physical	
Environmentally sealed	Yes (Water and dust resistant)
Battery	Battery Pack
Battery description	Lithium-Ion EN-EL15 rechargeable battery & charger
Weight (inc. batteries)	900 g (1.98 lb / 31.75 oz)
Dimensions	146 x 123 x 82 mm (5.75 x 4.84 x 3.23")
Other features	
Orientation sensor	Yes
Timelapse recording	Yes
GPS	Optional
GPS notes	GP-1

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