An Automated Digital Imaging System for Environmental Monitoring Applications

By Rian Bogle, Miguel Velasco, and John Vogel

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U.S. Department of the Interior
U.S. Geological Survey

COVER:
Right, a dust storm in the Mojave Desert captured by an automatic camera. Left, the automated camera system mounted on a tripod with an anemometer and solar panels. Photos by Rian Bogle.

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Introduction

Recent improvements in the affordability and availability of high-resolution digital cameras, data loggers, embedded computers, and radio/cellular modems have advanced the development of sophisticated automated systems for remote imaging. Researchers have successfully placed and operated automated digital cameras in remote locations and in extremes of temperature and humidity, ranging from the islands of the South Pacific to the Mojave Desert and the Grand Canyon. With the integration of environmental sensors, these automated systems are able to respond to local conditions and modify their imaging regimes as needed.

In this report we describe in detail the design of one type of automated imaging system developed by our group. It is easily replicated, low-cost, highly robust, and is a stand-alone automated camera designed to be placed in remote locations, without wireless connectivity.

System Requirements

The imaging system as described in this report is intended to be built from readily available, low-cost components, powered entirely by solar energy, highly flexible in scheduling and automation, and requires no remote communication, minimal maintenance, and only occasional visitation for data retrieval. The ultimate goal of the design of this system is that it be easily replicated by others who may have minimal technical or electronic experience.

System Overview

There are four basic subsystems or components that make up this imaging system: the data logger, the imager, the sensors, and the power subsystem. The data logger provides the basic functionality of the system; it maintains date and time, it collects, records, and analyzes data from environmental sensors, and it controls power to and triggers the imaging system as needed. In this system, images are stored on the camera itself, simplifying the connection and storage requirements for the controller. The imager is a stand-alone consumer-grade digital camera, which must have some means for non-mechanical remote triggering of the shutter (as in a wired remote, infrared signal, or serial port). The environmental sensors may include typical meteorological instruments for measuring wind, precipitation, temperature, humidity, solar radiation, leaf-wetness, soil-moisture, and so on. The power subsystem consists of a moderate-capacity sealed lead acid battery, solar panel, and customized circuitry to regulate and control power for the camera. Because each of these subsystems has certain requirements and limitations, careful consideration of subsystem component selection is necessary.

Data Logger and Software

The data logger component acts as the clock, programmatic controller, and environmental interface of the system. We desired to have a robust, highly configurable device which would be easily programmable. Important considerations for the data logger system were the power usage, data storage capacity, and clock accuracy, as well as a facility for interfacing multiple sensors and easy data retrieval. At the heart of the data logger system should be a flexible programmable software stack which allows collection, measurement, and analysis of data from environmental sensors, as well as control of accessories attached to the data logger.

Camera

Critical requirements for automated camera control are the ability to provide power to the camera without use of a proprietary battery, a mechanical power switch that can be left in the on position in order to control camera power by the flow of current, and a remote shutter-triggering facility. A camera with either a power input port or accessory to provide direct current (DC) voltage through the battery compartment is required for remote long-term operation. The typical proprietary batteries provided with cameras will not last between maintenance visits and are not usually robust enough to be charged directly via the solar power system. Cameras with momentary power switches, often found on point-and-shoot cameras, cannot be powered up remotely simply by providing current to the camera, and require more involved interfacing; thus they should be avoided. The most important feature of a camera for use in a monitoring system is the ability to trigger the shutter release or image-capture without mechanical means. Many cameras now provide an infrared remote interface, serial or USB port protocol, or electrical contact that is capable of initiating image capture.

An additional desirable feature is the presence of a battery-backed memory and clock in the camera. If the camera uses a lithium-coin-cell battery to maintain state and clock operation, the camera will keep reasonably accurate time and maintain its settings across power cycling. This allows for accurate time stamping of images as they are taken, and retention of critical focus, zoom, and flash settings after being powered down. Many consumer cameras, however, use a super-capacitor power backup for the camera memory and clock. These capacitors can maintain charge as long as the main battery or another power source is present; however, without a power source present the capacitor begins to discharge within hours or days, and eventually runs down completely, resulting in a reset of the camera settings and clock to default state. Because we must remove the camera's rechargeable battery and use a persistent power source that can be turned on by the controller, a 'super-cap' type camera requires periodic power cycling of the camera so that the capacitor can maintain charge and keep accurate time and settings. For this reason we have found that a camera with a coin-cell battery backup is superior to a capacitor backup.

Additionally, any camera used in an enclosure must have manual fixed focus (to avoid focusing on the enclosure window), as well as the option to disable any auto-flash mode. Having these features for the camera in question is important in order to avoid poor and inconsistent imaging.

Power

Important considerations for the power system are the component power budget, the cost to generate the power needed, and the ability to reduce the power used by the system as whole. For each installation location, it is necessary to calculate total power usage for a 24-hour period and then choose battery capacity and solar panel size to match the draw of the system, as well as the constraints of latitude and climate on potential power generation.

Sensors

Choices of environmental sensors depend almost entirely on the goals of the application, and whether the camera will be triggered based upon environmental inputs or by timed events. The most important considerations are the power consumption of the sensors, ease of programmability, and their total costs. While in many cases a regular timed image-capture interval is all that is required, in the case of dust storm studies, for example, we used the data collected from the sensors to control the capture of images. Calculated average wind speeds or averaged particulate concentrations were used to trigger the camera.

Mounting Hardware/Enclosure

To protect the electronic components of the system, it is necessary to have an environmental enclosure that seals the system from dust and moisture while minimizing exposure to temperature extremes. The enclosure should have a view port approximately 3-4 inches (in) in diameter for the camera lens. Additionally, the enclosure needs a secure mounting method for a vertical pole mount with adjustable orientations with multiple degrees of freedom, and the materials of the mounting hardware and the enclosure should be UV- and corrosion-resistant.

System Specifications

System Controller

Because it had the most features and flexibility for a reasonable cost, we chose the Campbell Scientific CR200-series data logger (fig. 1) as the controller for our imaging and data collection system. Notable features include a built-in 12-volt battery charge controller, five single-ended analog measurement channels, two pulse counting channels, a software-switchable battery-voltage output, two programmable excitation channels, two transistor logic level (TTL) control ports, a RS-232 serial port for communication, 512 kilobyte (KB) flash storage, and flexible programmability. These features provide the flexibility to add environmental sensors, simplify the power system, and control both the power and shutter to the camera, via both manual control and software programming. There is an additional cost for a software development kit which is needed for nonstandard sensors and devices, but this can be purchased at a one-time cost and used to program as many data loggers as needed.

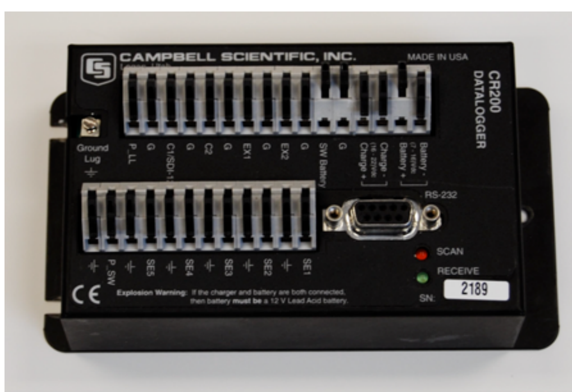

Figure 1. Campbell Scientific CR200-series data logger, which controls the power regulation, clock, sensors, data storage, and camera shutter release for the automatic imaging system.

Camera System

For this system, we chose to use the Canon EOS Digital Rebel™. The main advantage of the Digital Rebel™ over other brands and models is long-term stability in design and feature set. The Digital Rebel™ has a coin-cell backup battery for the clock and settings. The camera also supports a persistent controllable power source through a standard AC power adapter accessory, and a mechanical power switch that can be left in the on position. This allows a user to power the camera by controlling the flow of current to the camera via the data logger and an external power-regulation circuit. Most importantly, the camera also includes a wired shutter-control port, which permits electronic image triggering.

Power System

This system typically utilizes a 10-watt solar panel and a 7 amp-hour 12-volt battery to provide power generation and storage for this system, giving sufficient capacity to run the camera system while taking pictures as frequently as every 10 minutes during daylight hours. This system has been used in the desert southwest with many clear, full sun days; other regions and climates may require an increased capacity for storage and power generation.

Software System

The software for the system uses a script written in the CR-Basic language for the Campbell Scientific PakBus® operating system. Campbell Scientific's pc400 development software is fully capable of providing communication to the data logger over a serial port connection. It also provides the necessary compiler and development environment for writing the custom program required to control the camera.

Sensors

Environmental sensors utilized for this imaging system have included the Davis Instruments 7911 anemometer for measuring wind speed and direction, Decagon Devices Echo-20 soil moisture sensors, Campbell Scientific tipping buckets for measuring precipitation, and Campbell Scientific air temperature sensors. Each of these sensors requires minimal power for operation, and thus they are power-efficient for long-term deployment. Other considerations in choice of sensors were accuracy, reliability, and low cost. Selection of sensors was based upon feedback from colleagues and manufacturer specifications.

Image Storage

Images are stored on the camera's flash card storage, thus it is necessary to appropriately choose the size of the storage media in the camera to match the maximum number of potential images generated by the data-collection regimen. A typical high-resolution image might use from five to ten Megabytes (Mb) of storage depending upon the format chosen. For a 5 Mb image size each 1 Gigabyte (Gb) storage card could provide storage for 200 images. We find, in practice, an 8 Gb storage card provides enough storage for a few months of regular wind-triggered imaging. Images captured by the camera must be retrieved independently from the data collected by the logger.

System Assembly

Controller Programming

The principles of a Campbell Scientific CR-Basic script are fairly simple. The script is executed on a regular interval ranging from seconds to hours; in that loop you may specify commands to sample voltage values on various analog ports, count pulses on input ports, and activate various control ports. There are many supporting functions built into CR-Basic to allow calculation of date and time and the full range of typical mathematical functions. At any point during the data logger scan loop, you may request an update to any database table to store or update values. The database tables are configured at startup with parameters for how and when the data are aggregated and stored.

The typical program loop for a camera control program is as follows:

1) Get date and time
2) Sample sensor ports
3) Calculate sensor averages and (or) thresholds
4) If date/time and (or) sensor input meet thresholds, then
   a) Turn on power to camera
   b) Wait brief delay for camera to stabilize
   c) Toggle on camera shutter control port (take photo)
   d) Wait brief delay for camera to write to storage
   e) Turn off power to camera
5) Write data to database table

Testing of the timing and delay periods for camera stabilization and writing should be performed with the storage cards and camera being used, as different cameras, storage media, and card brands have different startup times and write speeds. A simple example of code written in CR-Basic to trigger a Canon Rebel™ camera can be found in appendix B.

Imager Connections and Configuration

On the Digital Rebel™ camera, the shutter control port is a standard mini 2.5 millimeter (mm) stereo female socket (fig. 2), which permits shutter control of the camera via a standard stereo headphone jack when both the left and right channels (red and white wires in fig. 2) are shorted to the ground plane of the port.

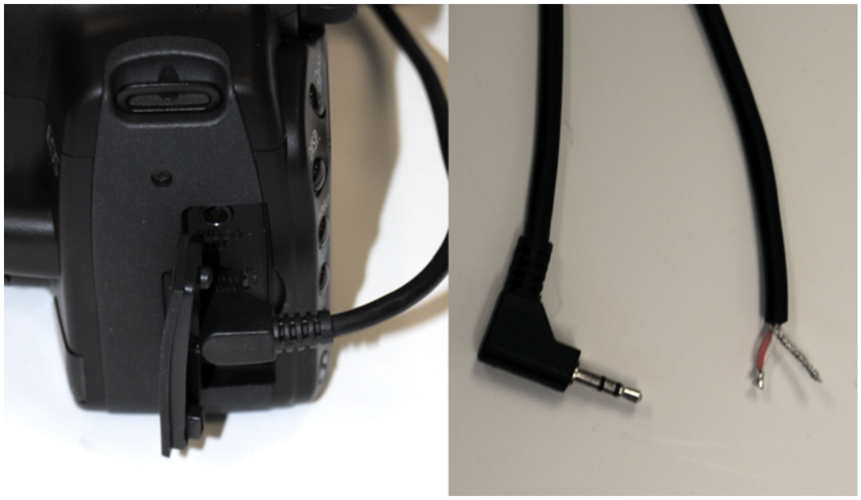

Figure 2. Shutter trigger port on the Canon Digital Rebel™ camera and 2.5 millimeter stereo cable, used for automatic control of shutter release.

To trigger the shutter via software, attach the left and right channels together and wire them to the C1 control port of the CR200. The ground wire is wired to any available GND port on the CR200 (fig. 3).

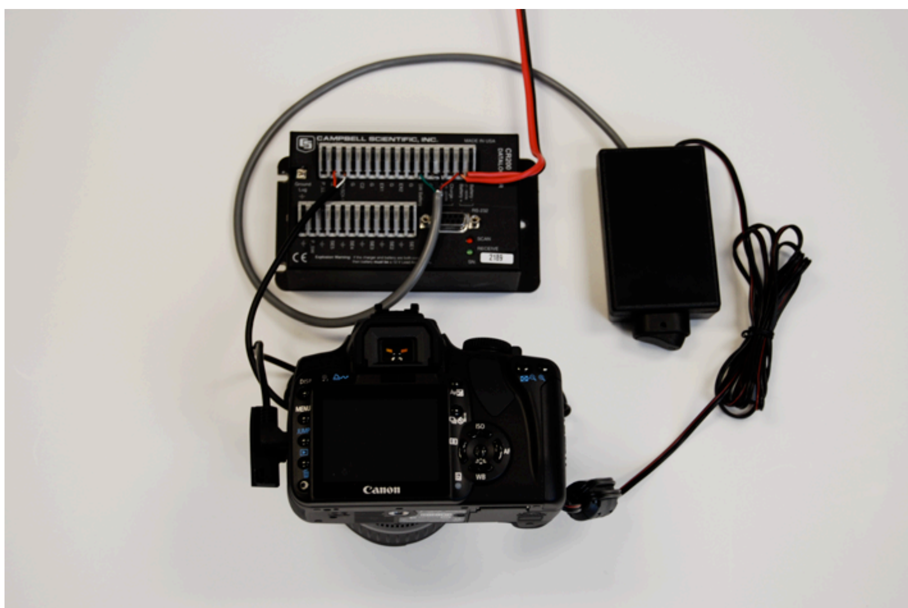

Figure 3. Wiring of shutter cable and camera to Campbell Scientific data logger.

In the data logger control software, you must ensure that the default state of the C1 port is set to high. In order to trigger the shutter, the program changes the state of the port from high to low for a brief period and subsequently returns the control port state to high. There is no measurable current draw on the C1 port when it is in the high condition and connected to the camera, so there is no waste of power in this setup.

To efficiently control the power state of the camera via software as well as manually, we developed a simple circuit to regulate the voltage provided by the battery or data logger and the 9 volts required by the camera. This circuit enables relay switching via the data logger "SW Batt" port as well as a single-pole, single-throw (SPST) mechanical switch (fig. 4).

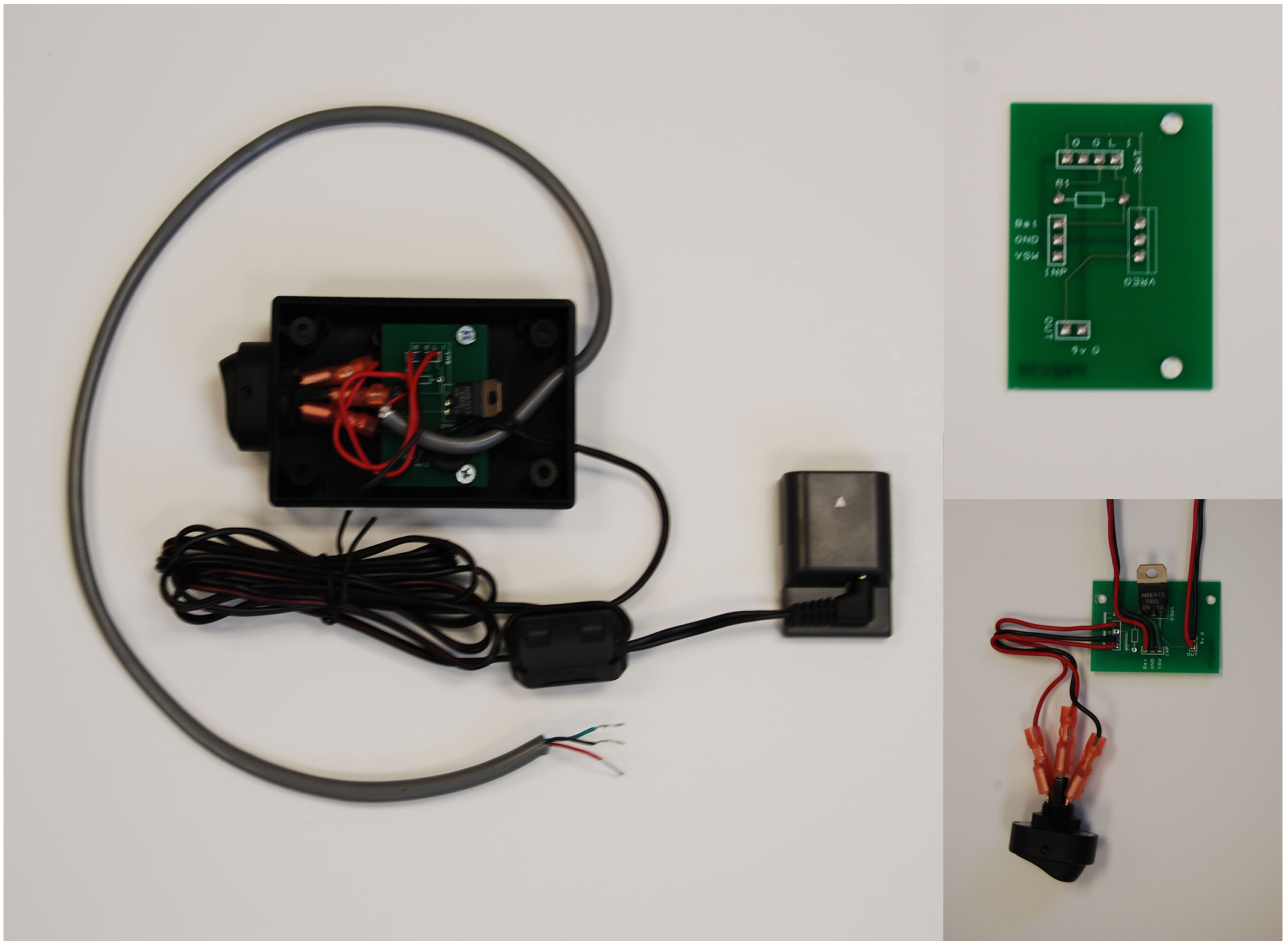

Figure 4. Power regulation circuitry for a Canon EOS Digital Rebel camera.

This circuit is used with a modification of the accessory AC power adapter that is available for the Digital Rebel. We use the "dummy" battery component with the DC voltage cord removed from the AC converter accessory to connect the 9-V and Ground (GND) outputs of the circuit to the camera. With this configuration, by setting the power switch of the camera in the on position and inserting the dummy battery into the camera battery compartment, we are able to control the camera power via a switch on the circuit board, or via a software command/condition in the data logger. The manual switch provides a means for field debugging and retrieval of images on the camera. A basic schematic for the regulation/switch board is shown in figure 5. Remote power control of the camera requires that the on/off switch on the camera is permanently left in the on position.

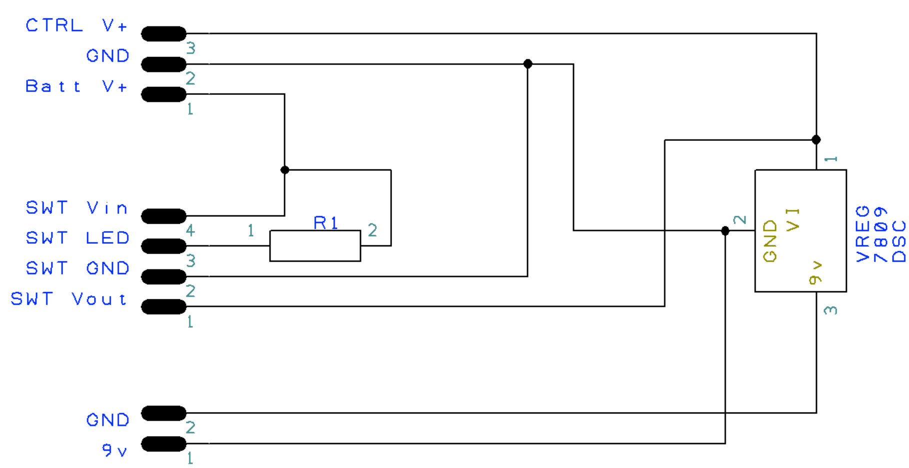

Figure 5. Circuit diagram for power regulation and on/off switch.

System Connections

The aforementioned components - data logger, camera, power regulator, battery, and solar panel—are wired together according to the wiring diagram in figure 6. Additional environmental sensors can be added to open ports on the data logger according to the needs of the project.

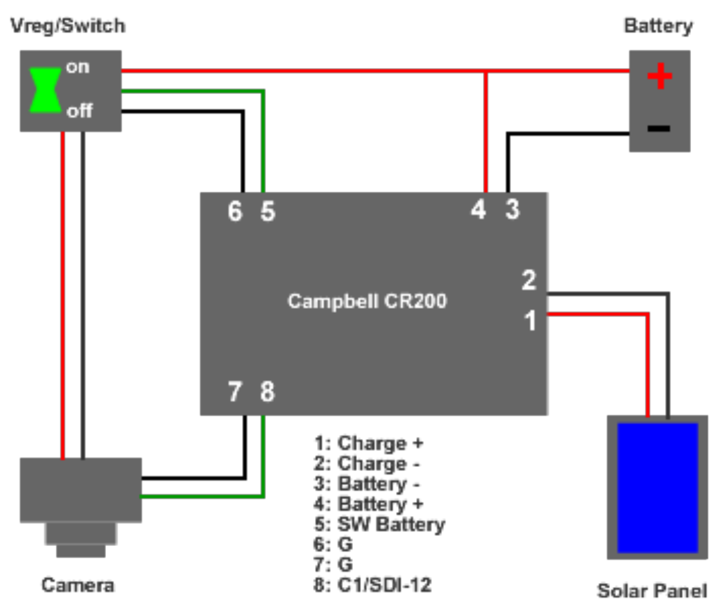

Figure 6. System wiring diagram for an automated imaging system.

Enclosure and Mounting Hardware

The system utilizes a latched, hinged-lid, fiberglass enclosure (see appendix A) that is rated for outdoor installations. The boxes are typically sized 12 x 10 x 6 in. These enclosures are then modified with a 4-in round hole. A 4-in ABS male threaded adapter is inserted into the hole to act as a lens hood, and a 4-in circular glass window is siliconed into the adapter to ensure weatherproofing and wide view angle while minimizing off-angle sun glare (fig. 7). Three-quarter-inch entry ports are drilled in the bottom of the box for the cables.

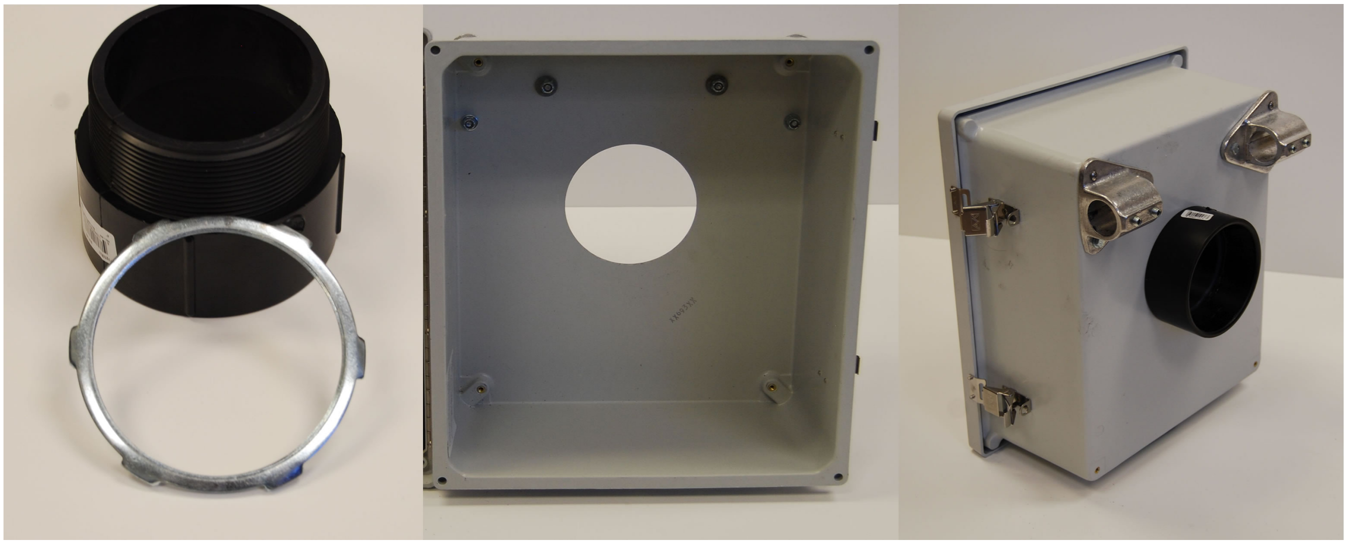

Figure 7. Lens hood components and enclosure window.

The cable entry holes are then fitted with three-quarter-inch watertight electrical conduit fittings, in order to encase the cables in flexible PVC electrical conduit. This protects the cables against damage from wind friction, sun, and animals. For mounting to a tripod or vertical pole, cast aluminum brackets (see appendix A) sized to fit 1-inch Nominal Pipe Size (NPS) pipe are attached to the view port side of the box at the top, such that a cross arm from an upright pole or tripod can slip through the brackets and suspend the box (see fig. 7, far right photo). Using these brackets allows two degrees of freedom in the adjustment of the view angle of the box: vertical angle (pointing the camera up and down) and compass direction (rotating the box around the pole). The utilized enclosure comes with an internal metal mounting plate that can be drilled and tapped to allow surface mounting of components to the plate, without adding extra holes through the exterior of the enclosure. Thus all components are mounted to this plate, which is then bolted to threaded mounts inside the box. A simple mounting mechanism is used for the camera: a one-quarter-inch threaded rod or carriage bolt is attached to the mounting plate just below the view port, then a small right-angle bracket is threaded onto the rod. This provides a horizontal mounting surface to which the camera can be attached via the tripod mount hole on the bottom of the camera (fig. 8). This installation allows adjustment of the camera’s position forward and back to compensate for the length of the lens. The position of the rod with respect to the mounting plate must be measured and placed so that after mounting the camera, the camera lens is centered in the viewport. The fully wired and mounted system of components can be seen in figure 9.

Figure 8. Camera mounted to back plate inside the enclosure.

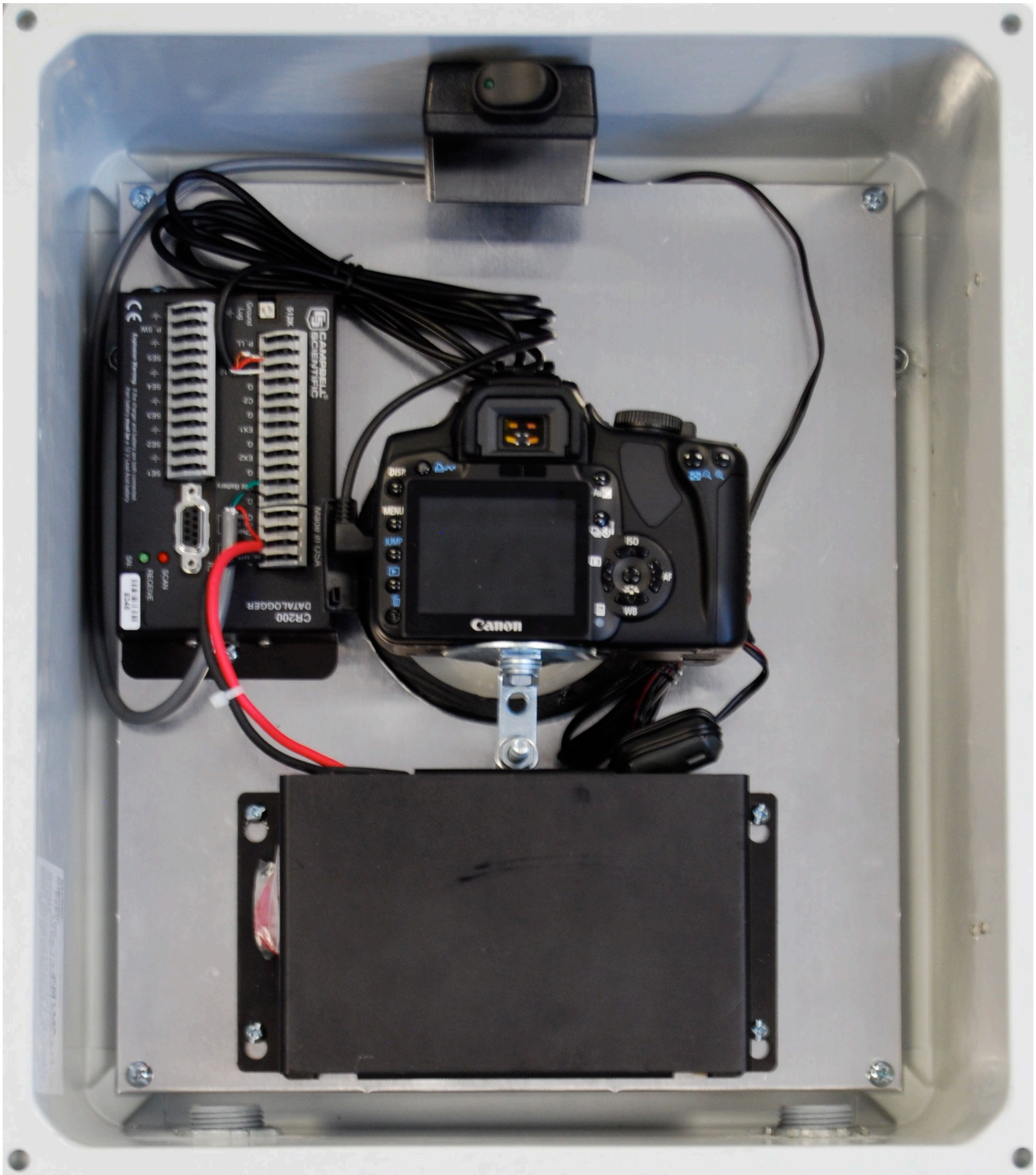

Figure 9. Automatic imaging system assembled in the enclosure, fully wired and mounted.

System Operation

Typical operation of the system is unattended and automatic. The data logger is programmed to collect data on a regular schedule, and analyze the data to determine when conditions are appropriate to trigger the camera. For example, our typical applications are related to dust studies and so we program our controllers to monitor the 10-minute wind speed average during daylight hours for a preset threshold. If, in a 10-minute interval, the mean speed exceeds the preset threshold then the camera captures an image, and routine data collection continues. Because not all days will have winds exceeding the chosen trigger threshold, we often augment this regime with a regularly scheduled image capture (for example, at noon every day). Data retrieval with this system is performed manually, and requires visitation to each sensor site periodically (perhaps once per quarter or twice a year) to retrieve images from the camera and download data from the logger.

Camera Image Retrieval

There are two possible methods for retrieving images from the Digital Rebel™ camera. The most straightforward method is to eject the storage card from the camera and replace it with an empty and appropriately formatted card. This requires having multiple cards (usually double the number of cameras in your network), but as flash storage media are reasonably inexpensive, this is not a heavy cost burden. The replacement card must be emptied previous to reuse or reformatted by the camera upon insertion. The second method is to connect a USB cable from the camera's USB port to a portable computer and initiate download procedures via the computer. Typically, Windows, OS X, and Linux operating systems will automatically recognize the attached camera as an external storage device and prompt for a download of images from the camera to the system. In this case, after transfer is complete, the user must make sure that the images are deleted from the camera storage, either by deleting them through the computer interface, or by turning on the camera and initiating a full deletion of all stored images from the camera menu system.

Data Retrieval

Recovering data from the Campbell Scientific data logger requires the use of a 9-pin RS-232 serial cable, a laptop or mobile device, Campbell Scientific support software, and perhaps a USB-to-serial adapter, depending upon whether the computer that will be used has an external serial port. Campbell Scientific makes freely available a basic support software package, pc208, which provides a communication interface for the most popular models of their data loggers including the CR200 series. This software is not usually sufficient for writing the programs necessary to interface with the camera, and so purchase of Campbell Scientific's pc400-series software may still be required for programming. The fundamentals of communication are the same in any of the Campbell Scientific support software: a serial port connection is physically cabled between the computer and the data logger, and the support software is initiated and configured to communicate on the appropriate serial port (either COM1 for a true 9-pin cable connection or typically COM3/COM4 if using a USB-serial adapter). The support software is configured to the appropriate data logger model, in our case the CR200 series, and in some cases with a unique site or station identifier of your choosing, and connection is initiated. Upon connection it is possible to synchronize the data logger clock with the computer clock, inspect live data values on the data logger, upload new programmatic changes, or download the stored data from the data logger. Depending on the software used, data download may commence from the last retrieved values or from the beginning of the memory. By default Campbell Scientific data loggers use their memory as a loop, so when the available data storage is filled it will begin overwriting the oldest values stored in the tables. Because of this feature it is necessary to carefully calculate the number of records that will be written before you revisit the station and download the values, so as to ensure no data will be lost.

System Maintenance

Regular system maintenance requirements are minimal. We have found the Campbell Scientific data logger to be very robust with a reasonably accurate clock. While some clock drift does occur over time, this is easily adjusted upon each download or connection to the data logger. The camera clock will also drift over time and must be manually adjusted to match data logger time within a reasonable margin. Periodic cleaning of the camera window port will likely be necessary, as well as cleaning of the solar panels. The sealed lead acid battery, which gets charged by several hours of daylight each day, will have a very long life in a deployment. We only consider replacing our batteries after 2–3 years in the field. Logging and monitoring the battery voltage via the data logger is a good way to obtain early warning of diminished battery life; a rapid drop in voltage after sundown or deep into the night is one indication that the battery is no longer recharging or maintaining its full original capacity.

Example Deployments and Uses

The system described above has had great success in recording events and creating time lapse records for multiple uses in a wide variety of settings. We initiated this development to address instabilities of an earlier system that relied upon a electro-mechanical actuator to depress the shutter button on a camera (Tigges and others, 2001). Due to variations in humidity and temperature, and accumulations of dust, this earlier design could potentially trigger intermittently. Our new design relies upon digital triggering and an external data logger to record and control the system activity.

Figure 10. Dust monitoring system deployed in the Mojave Desert on a mountaintop to provide a wide-area perspective.

Figure 11. Dust storm in the Mojave Desert, captured simultaneously from two different perspectives using this automated imaging system.

As mentioned previously, this system has been used to react to and record changes in remote locations, most notably for our study of dust storm genesis and frequency in multiple locations in the Mojave Desert of the American Southwest (figs. 10 and 11; Reynolds and others, 2009). Example images of an active dust storm being recorded from two different perspectives simultaneously are shown in figure 11.

Figure 12. Coral reef monitoring in Moloka‘i, Hawai‘i.

Additionally, these systems have been deployed to monitor beach and sand bar flux on the Colorado River in the Grand Canyon (Grams and others, 2010), in Moloka‘i, Hawai‘i (fig. 12), to monitor sediment flux and resuspension effects on coral reef health (Field and others, 2008), in Guam to monitor near-shore sediment circulation patterns (Storlazzi and others, 2009), in New Mexico to monitor visible air quality, and on the Navajo Nation to assess dust emissions and record sand dune movement (fig. 13.)

Under varying conditions, the system as described has proven its reliability over 7 years of continuous use in the Mojave and multi-year deployments in the Pacific islands and Grand Canyon. These projects have used the cameras as simple time-lapse platforms as well as more sophisticated environmental reactive systems using sensor thresholds as triggers to visually record remote events.

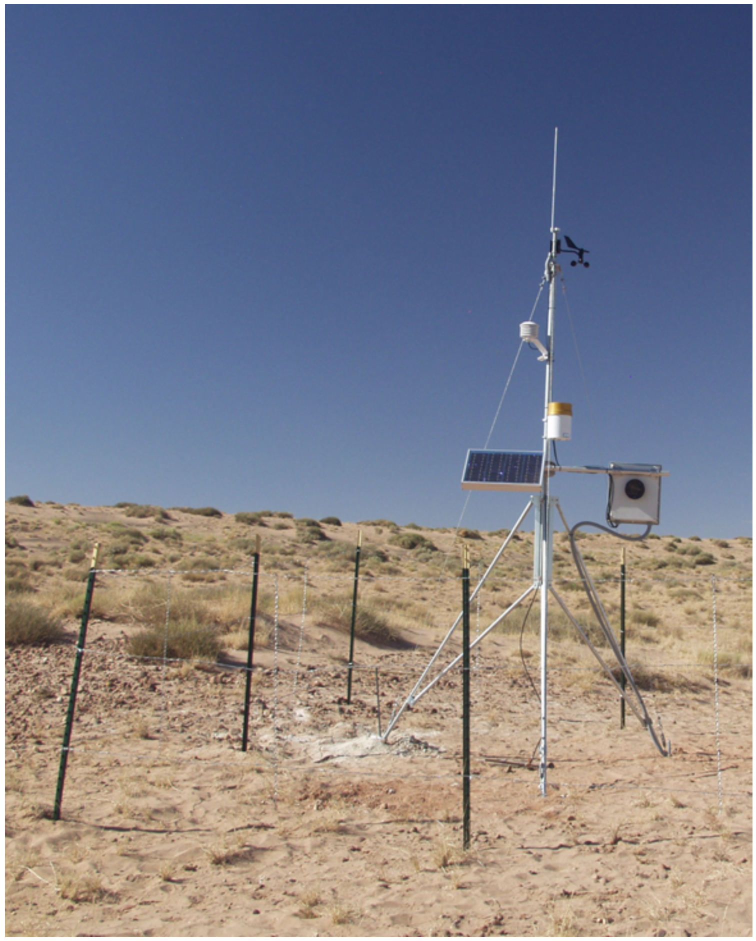

Figure 13. Deployment of an automated imaging system on the Navajo Nation for sand dune and dust monitoring.

Acknowledgments

This work has been supported through the funding of the U.S. Geological Survey programs in Geographic Analysis and Monitoring, Land Remote Sensing, Earth Surface Processes, and Coastal and Marine Geology. We would especially like to thank Pat Chavez for believing in automated in-situ sensing techniques and supporting and encouraging the development of this system. We would also like to thank Mike Field and Richard Reynolds for financial support and providing practical applications for which this work was further developed and tested. Additionally, we thank Rich Tigges, Stuart Sides, and Deborah Soltesz for blazing a trail in developing these systems. And finally we thank Leila Gass, Stuart Sides, Frank Urban and Claire Landowski, all of the USGS, for their patient and insightful reviews of this document.

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Storlazzi, C.D., Presto, M. K., and Logan, J.B., 2009, Coastal circulation and sediment dynamics in War-in-the-Pacific National Historical Park, Guam: U.S. Geological Survey Open File Report 2009–1195, 79 p.

Tigges, R.K., Sides, S., and Ohms, M., 2001, Automated Remote Digital Imaging System (ARDIS)—Applications for Monitoring Dust Emissions in the Mojave Desert, California: U.S. Geological Survey Open File Report 01–230, 72 p.

Appendix A. Equipment/Component List

Hardware

- CR-200 Campbell Scientific data logger (see http://www.campbellsci.com)
- Serial cable and (or) USB-serial adapter
- Camera:
  - Canon Digital Rebel camera (e.g. Canon Digital Rebel XTi)
  - Canon Digital Rebel power adapter (e.g. Canon ACK-E5 AC adapter kit)
  - 2.5 millimeter (mm) stereo pigtail (trigger cable)
- Power control switch and voltage regulator circuit:
  - Circuit board
  - Switch (automotive grade 12 V illuminated switch)
  - 9 V 1 A linear regulator (e.g. LM7809 TO-220)
  - 3 conductor 18-gauge wire
- 12 V 7 Ah sealed lead acid battery (e.g. EnerSys NP7-12)
- 10-watt solar panel (e.g. Campbell Scientific SP10)
- Enclosure:
  - Lens hood and nut (4" male thread ABS slip)
  - Glass lens (cut by local glass shop)
  - Enclosure box (e.g. Allied Moulded AM1206L with backplate)
  - Mounting hardware (e.g. NU-Rail 1in. #50 wall flange)
- Tripod or tower (e.g. Campbell Scientific CM6 or CM10)
- Mounting cross-arm (e.g. 1" NPS Galvanized Steel or Aluminum Pipe)
- Mounting cross-arm bracket (e.g. Nu-Rail 1 x 1-1/4in #10 offset reducing cross)

Software

- Campbell Scientific Support Software (at least one):
  - pc208
  - pc400
  - Loggernet
- Image processing or viewing software

Appendix B. Code Sample

```
'Example program to run camera off of CR200

'Constants and utility vars
Dim Hour

'flags
Public CaptureImage 'flag to take a shot
Public PowerCam 'flag to turn cam on

'Subroutine to trigger C1 to capture image on camera
Sub Camera_Shoot
	SWBatt (1) 'turns on power to camera
	Delay(5,Sec) 'let camera power stabilize and cam bootup
	PortSet(1,0) 'low is on -- C1
	Delay(1,Sec) 'hold low for signal to reach
	PortSet(1,1) 'high is off -- C1
	Delay(10,Sec) 'delay for shot and write to cf card
	SWBatt(0) 'turns off power to the camera
	CaptureImage=0 ‘reset flag in case set by user
EndSub

'Main Program
BeginProg
	PortSet(1,1) 'Port 1 is C1 on the cr200: we set to high by default and drive low to trigger cam
	Scan (1,MIN)

		'get hour for testing 4th entry in return result is hour
		RealTime(Hour,4) 'Hour of Day

		if IfTime(0,60,Min) then 'do something if its top of hour
			if ((Hour>=6 and Hour<=18)) then 'is it a trigger time ex 12pm
				call Camera_Shoot
			endif
		endif

		'If the user sets CaptureImage over serial port then take a shot
		if CaptureImage then
			call Camera_Shoot
		endif

		'allow user to power up and down cam with serial port
		if PowerCam then
			swbatt(1)
		else
			swbatt(0)
		endif

	NextScan
EndProg
```