Remote-Controlled Pan, Tilt, Zoom Cameras at Kīlauea and Mauna Loa Volcanoes, Hawaiʻi

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By Richard P. Hoblitt, Tim R. Orr, Frederic Castella, and Peter F. Cervelli

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Introduction

Lists of important volcano-monitoring disciplines usually include seismology, geodesy, and gas geochemistry. Visual monitoring—the essence of volcanology—is usually not mentioned. Yet, observations of the outward appearance of a volcano provide data that is equally as important as that provided by the other disciplines.

The eye was almost certainly the first volcano monitoring-tool used by early man. Early volcanology was mostly descriptive and was based on careful visual observations of volcanoes. There is still no substitute for the eye of an experienced volcanologist. Today, scientific instruments replace or augment our senses as monitoring tools because instruments are faster and more sensitive, work tirelessly day and night, keep better records, operate in hazardous environments, do not generate lawsuits when damaged or destroyed, and in most cases are cheaper. Furthermore, instruments are capable of detecting phenomena that are outside the reach of our senses. The human eye is now augmented by the camera. Sequences of timed images provide a record of visual phenomena that occur on and above the surface of volcanoes. Photographic monitoring is a fundamental monitoring tool; image sequences can often provide the basis for interpreting other data streams.

Monitoring data are most useful when they are generated and are available for analysis in real-time or near real-time. This report describes the current (as of 2006) system for real-time photograph acquisition and transmission from remote sites on Kīlauea and Mauna Loa volcanoes to the U.S. Geological Survey Hawaiian Volcano Observatory (HVO). It also describes how the photographs are archived and analyzed. In addition to providing system documentation for HVO, we hope that the report will prove useful as a practical guide to the construction of a high-bandwidth network for the telemetry of real-time data from remote locations.

A companion paper (Orr and Hoblitt, 2008) describes non-telemetered time-lapse camera systems used by the Hawaiian Volcano Observatory on Kīlauea volcano.

Previous USGS Volcano-Imaging Systems

The U.S. Geological Survey (USGS) first employed a real-time volcano imaging system at Mount St. Helens in 1980 (Miller and Hoblitt, 1981). This closed-circuit microwave television system was assembled by Sandia National Laboratories. The system operated successfully, but was power hungry, troublesome to maintain, and expensive to operate. It was succeeded by a telemetered slow-scan television system (Furukawa and others, 1992) that was installed in 1987. This system used substantially less power and was easier to maintain than its predecessor. The slow-scan system operated successfully for about 5 years, until maintenance costs could not be justified by Mount St. Helens' lack of activity.

The first telemetered volcano-imaging system was installed at Pu'u 'Ō'ō in 1997 (Thornber, 1997). This system was assembled from commercially available hardware and software. It operated successfully through 2002. Thereafter, aging components led to increasingly frequent failures. In 2003, when it became apparent that this system was approaching the end of its service life, we researched commercially available camera and telemetry systems. The system we eventually constructed is described below.

Network Overview

The camera network has two branches that, though they differ in detail, are functionally equivalent. One leg delivers images to HVO from the north rim of Pu'u 'Ō'ō crater, and the other delivers images from the northwestern rim of Moku'āweweo caldera on Mauna Loa (fig. 1).

The architectural model used for both branches is shown in figure 2. Each branch consists of three geographically separated nodes: the camera node, the repeater node, and the base-station node. The camera node consists of an IP (Internet Protocol) camera, serial devices, a serial-device server, a 802.11x wireless-bridge radio, and remote power units.
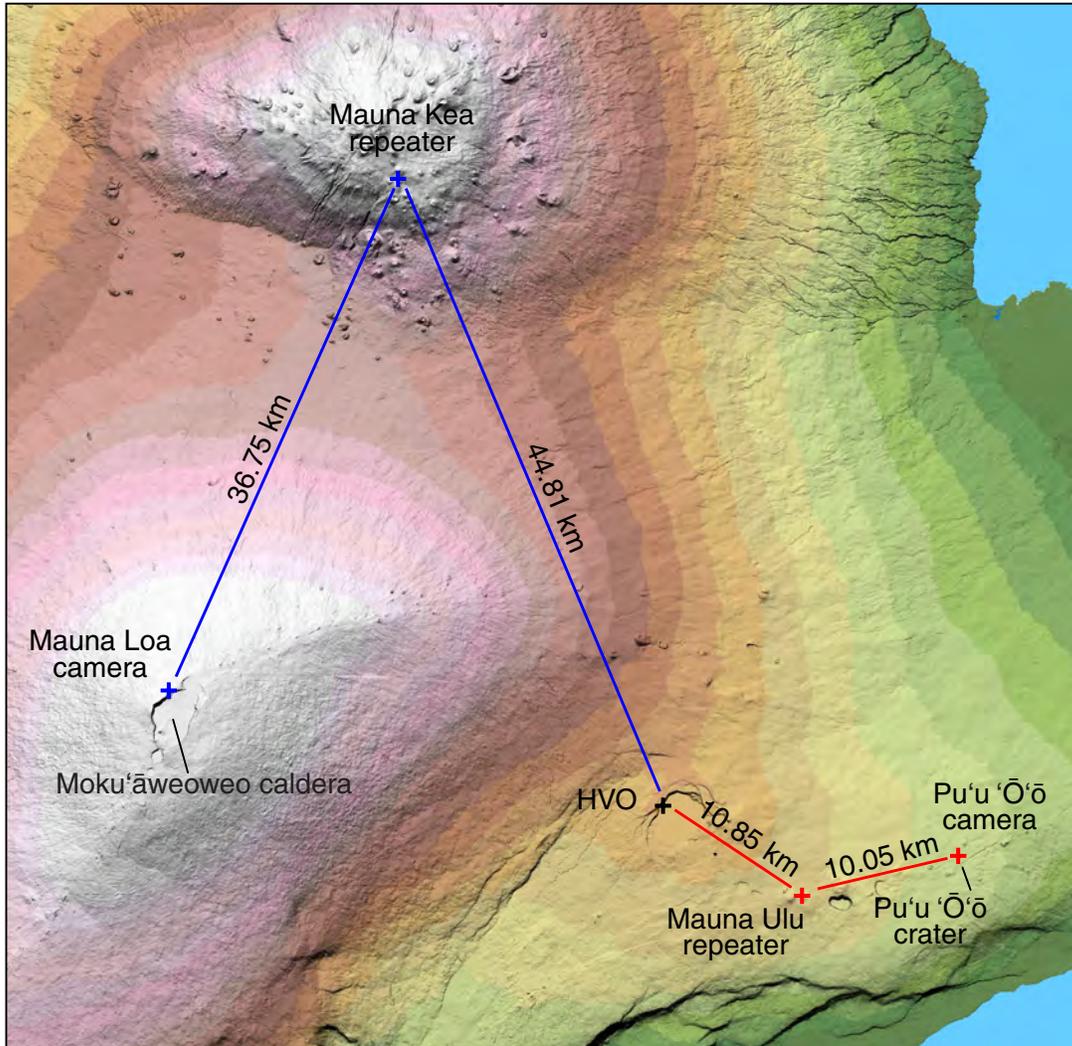
Figure 1. Map showing the locations of the Hawaiian Volcano Observatory (HVO), the cameras on Mauna Loa and Pu'u 'Ō'ō, and the telemetry repeaters.

The repeater node consists of serial devices, a serial-device server, two wireless-bridge radios configured as a repeater, and remote power units. The base-station node consists of a wireless-bridge radio connected to a private LAN (Local Area Network at HVO).

Camera Node

The major components of the camera node are shown diagrammatically in figure 3. The camera was the first component that we selected. This component selection constrained the choices available for the power and telemetry components. We selected a Canon VB-C10 network camera (fig. 4) for installation on Pu'u 'Ō'ō. The Pu'u 'Ō'ō branch was the first branch of the network that we constructed.

Canon VB-C10 Network Camera

The salient features of the VB-C10 are:
- Connects to an Ethernet-based IP network
- Standard TCP/IP Interface with RJ45 Ethernet connector
- 16 X optical zoom
- Pan: +/–100 degrees
- Tilt: +90/–30 degrees
- Image size adjustable from 160 x 120, to 320 x 240, to 640 x 480 pixels
- Frame rate up to 30 fps (320 x 240 pixels)
- Power consumption with no Pan-Tilt-Zoom: ~6 watts
- Power consumption with maximum Pan-Tilt-Zoom: ~10 watts
- Minimum illumination: 6 lux
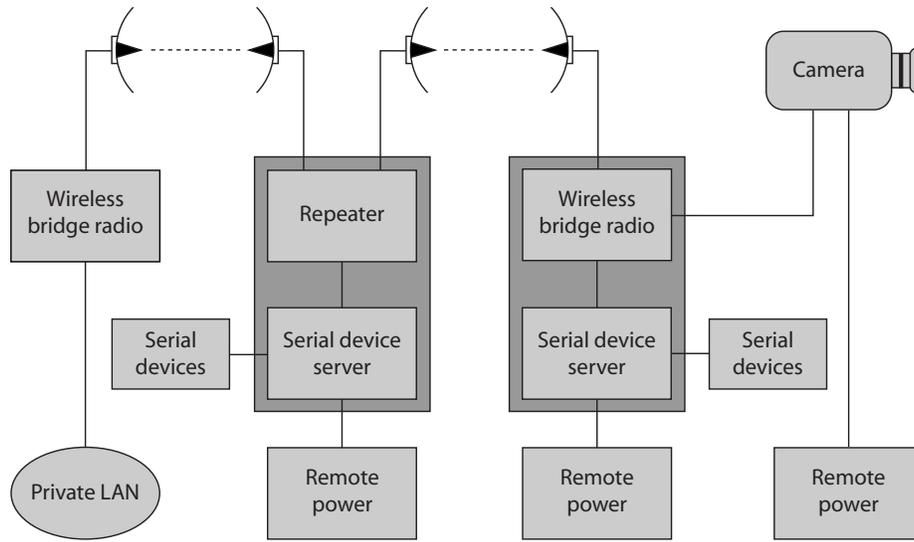
Figure 2. Diagram showing the architecture of the Hawaiian Volcano Observatory volcano-imaging system.
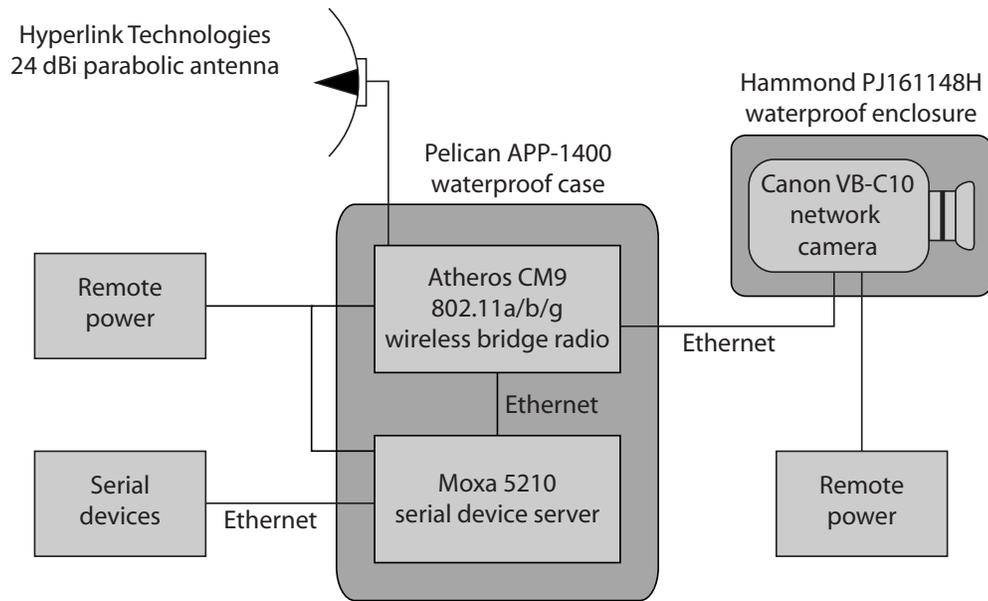
Figure 3. Major components of the camera node.

Figure 4. Canon VB-C10 network camera (left); Canon VB-C50i network camera (right).

Figure 5. Canon VB-C10 network camera mounted inside a Hammond PJ16148H enclosure.

Canon VB-C50i Network Camera

By the time that we began work on the Mauna Loa network branch, the VB-C10 had been superseded by the VB-C50i, which we acquired.

The salient features of the VB-C50i are:

- Connection to an IP-based Ethernet LAN
- Standard TCP/IP Interface with RJ45 Ethernet connector
- 26 X optical zoom, 12 X digital zoom
- Pan: +/–100 degrees
- Tilt: +90/–30 degrees
- Image size adjustable from 160 x 120, to 320 x 240, to 640 x 480 pixels
- Frame rate up to 30 fps (640 x 480 pixels)
- Power consumption with no Pan-Tilt-Zoom: ~6 watts
- Power consumption with maximum Pan-Tilt-Zoom: ~10 watts
- Minimum illumination: 1 lux
- Audio capability
- Software-development kit available
- Input voltage specified as 13 Volts DC, but 12 Volts DC from solar panel regulator is adequate

Camera Enclosure

Because of the extremely corrosive conditions at Puʻu ʻŌʻō, we selected an enclosure and connectors having exposed surfaces made of corrosion-resistant material. Each camera was mounted on an aluminum panel inside a Hammond Mfg. Model PJ16148H enclosure (fig. 5). We chose this enclosure because it is wide enough to allow a pan range of about 140º. The base of the camera body includes a tripod socket, which made mounting the cameras to the panels easy.

The salient features of the PJ16148H are:

- Waterproof, corrosion resistant fiberglass (NEMA 4X)
- 16.27 inches wide x 14.4 inches deep x 8.13 inches high (all outer dimensions not including the hinged top)
- Stainless steel hinge
- Top has a rubber gasket seal
- Tapped brass inserts inside the box to accommodate an optional aluminum mounting panel
- Tapped brass inserts on the outside bottom corners to mount the box to a stable platform

Figure 6. Camera enclosure and mounting tripod on the rim of Puʻu ʻŌʻō crater. The power and Ethernet connectors have been waterproofed with liquid electrical tape.
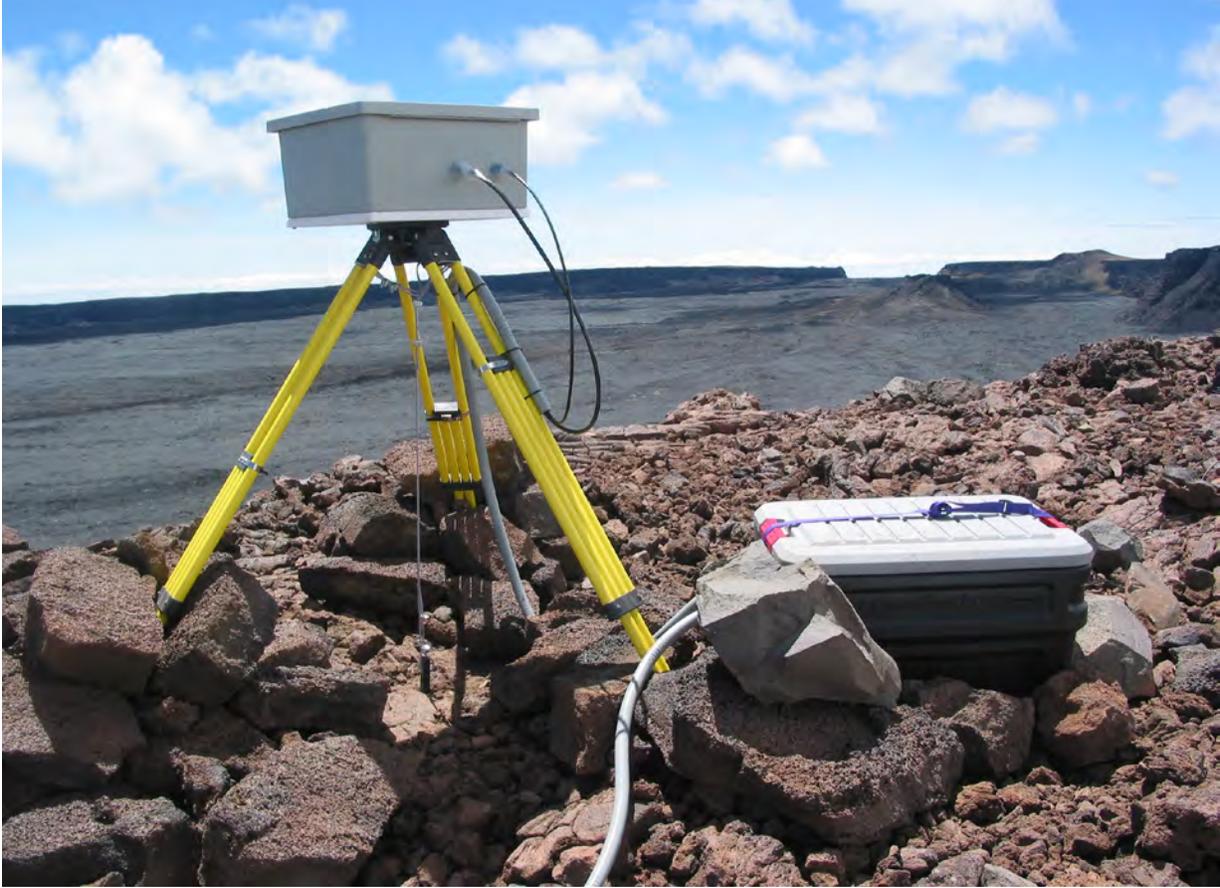
Figure 7. Camera enclosure and mounting tripod on the rim of Moku'āweweo caldera near the summit of Mauna Loa. The power and Ethernet connectors have been waterproofed with silicone sealant.

We cut a 13 inch x 5.5 inch rectangular hole in the long side of the box to accommodate a window. On the Pu'u 'Ō'ō camera enclosure we glued a piece of $\frac{3}{16}$-inch-thick window glass over the hole on the inside of the box by using silicone adhesive. On the Mauna Loa camera we used the same procedure, but used $\frac{3}{16}$-inch-thick Lexan 9034 polycarbonate instead of window glass. The Lexan is not as fragile as the window glass, but is softer and prone to scratching while cleaning the window.

On the back wall of the box, opposite the window, we installed a Conxall 2-pin, panel-mount receptacle connector (Conxall CXS3102A14S-9S-300) for power. We installed a terminal strip next to the power connector, then, for polarity protection, placed a diode across the power inputs and a fuse in series with the positive input. For the Ethernet connection, we installed a RJ-45 bulkhead coupler (Woodhead L.P. ENSP1F5).

The enclosures were mounted on tripods to facilitate camera aiming. For Pu'u 'Ō'ō (fig. 6), we removed the legs from a surveyor's tripod and attached them to a $\frac{3}{8}$-inch-thick aluminum plate. The corners of the plate were drilled to align with the screw holes in the bottom of the enclosure, and the plate was attached to the bottom of the enclosure with stain-

less steel machine screws. This configuration works well, but fabrication of the plate was time-consuming and expensive.

For the Mauna Loa enclosure (fig. 7), we used an alternative design. Instead of an aluminum plate, we used a $\frac{3}{4}$-inch-thick polyethylene sheet that had been tapped in the center to accommodate the mounting screw of a standard surveyor's tripod. The corners of the sheet were drilled to align with the screw holes in the bottom of the enclosure, and the sheet was attached to the bottom of the enclosure with stainless steel machine screws. This approach works well and provides a number of advantages. The surveyor's tripod can be used without modification. The polyethylene sheet is inexpensive, easy to work, and is virtually impervious to volcanic gasses.

Camera Enclosures—Room for Improvement

The Hammond enclosures do not hold up well in the harsh conditions at Pu'u 'Ō'ō. The rubber lid gasket compresses with time, perhaps due to chemical attack, and the watertight seal fails. The silicon sealant used to mount the glass window tends to separate from the fiberglass box and, therefore, must be replaced once or twice a year. The bottom corners of the box slowly

develop cracks—probably due to corrosion and expansion of the brass inserts. We are seeking a more robust enclosure.

The RJ-45 Ethernet couplers occasionally developed leaks and allowed water to enter the enclosure. We would have replaced them if we could have found a better alternative. The problem appears to be due to gasket failures on the panel receptacle, as well as on the plug. The leakage problem can be overcome by applying generous quantities of waterproof sealant to external connections.

Wireless Bridge Radio

Once we selected an IP camera, we were committed to Ethernet-bridge radios for telemetry. Initially, we considered using 900 MHz Ethernet-bridge radios, as the previous camera system used 900 MHz Freewave wireless modems to telemeter the camera's RS232 serial output. However, the growing popularity of the 802.11 (Wi-Fi) family of wireless LAN standards prompted us to look at mass-market 2.4 MHz wireless-bridge radios. The chief advantages of these radios over the 900 MHz alternatives are low cost and high bandwidth; the chief disadvantages are shorter range, greater power consumption, security concerns, and a strictly unobstructed line-of-sight requirement between antennas. The possibility of getting more bandwidth for less money prompted us to experiment with Wi-Fi radios to telemeter camera images from Puʻu ʻŌʻō to HVO. Encouraged by positive results, we decided to purchase some back-up radios of the same type used in the initial experiments. However, the radios were no longer available. Wi-Fi hardware is evolving so rapidly that components are apt to become obsolete quickly. Thus, although newer components might be more capable, system replacements will require at least some redesign, rebuilding, reconfiguration, and retraining to accommodate changes in technology. The current Wi-Fi telemetry at HVO utilizes miniPCI radios on a SBC (single-board computer). Specifically, we used Wistron Neweb CM9 Atheros Radios (fig. 8) on a PC Engines WRAP 1.E systems board (fig. 9).

The salient features of the CM9 are:
- 802.11a/b/g protocols
- Mini-PCI form factor; Mini-PCI Version 1.0 type 3B
- Frequency ranges: 2.400–2.483GHz, 5.15 ~ 5.35GHz, 5.725 ~ 5.825GHz
- Channels supported:
  - 802.11b/g : 11
  - 802.11a: 12 non-overlapping channels (5.15 ~ 5.35GHz, 5.725 ~ 5.825GHz)
- Security: 64-bit,128-bit, 152-bit WEP Encryption; AES-CCM & TKIP Encryption
- Output Power:
  - 802.11a: 17dBm @6Mbps; 13dBm @54Mbps
  - 802.11b: 18dBm
  - 802.11g: 18dBm @6Mbps; 15dBm @54Mbps

Figure 8. Wistron Neweb Model CM9 radio.

- Data Transfer Rate:
  - 802.11a (Normal mode): 54, 48, 36, 24, 18, 12, 9, 6 Mbps, auto-fallback
  - 802.11a (Turbo mode): 108, 96, 72, 48, 36, 24, 18, 12 Mbps, auto-fallback
  - 802.11 b/g: 11, 5.5, 2, 1 Mbps, auto-fallback, up to 54 Mbps
  - 802.11 g (Super mode): up to 108 Mbps
- Operation Temperature: 0 ~ 70°C
- OS supported: Windows® 98SE, ME, 2K, XP
- Antenna Connector: 2 x SMT Ultra-miniature coaxial connectors
- Inexpensive

The salient features of the WRAP SBC are:
- Two Ethernet channels
- Two Mini-PCI sockets
- Two 266 MHz CPU
- 64 MB SDRAM
- 7 to 18V DC power through DC jack; optional PoE

- One serial port
- CompactFlash header for OS and applications
- Measured power consumption: 360mA @ 12 V with two CM9 radios
- Footprint: 6 x 6 inches (152 x 152 millimeters)
- Inexpensive

A WRAP 1.E SBC with one or two CM9 radio(s) was mounted inside a Pelican model APP-1400 polypropylene enclosure (fig. 10). ABS plastic standoffs were glued to the interior floor of the Pelican case by using 3M Scotch-Weld DP8005 structural adhesive. Note that DP8005 is designed to adhere to polypropylene and polyethylene; ordinary adhesives will not adhere to these plastics. A 10.4-inch x 7.7-inch sheet of 3⁄16-inch-thick ABS plastic was attached to the standoffs by using self-tapping metal screws. The SBC was then attached to the ABS sheet by using self-tapping metal screws. We installed a terminal strip for DC power inputs on the ABS sheet next to the SBC. For polarity protection we placed a diode across the power inputs and a fuse in series with the positive input.

On the back wall of the box we installed two type N female bulkhead to U.FL pigtails (fig. 10)—one for each
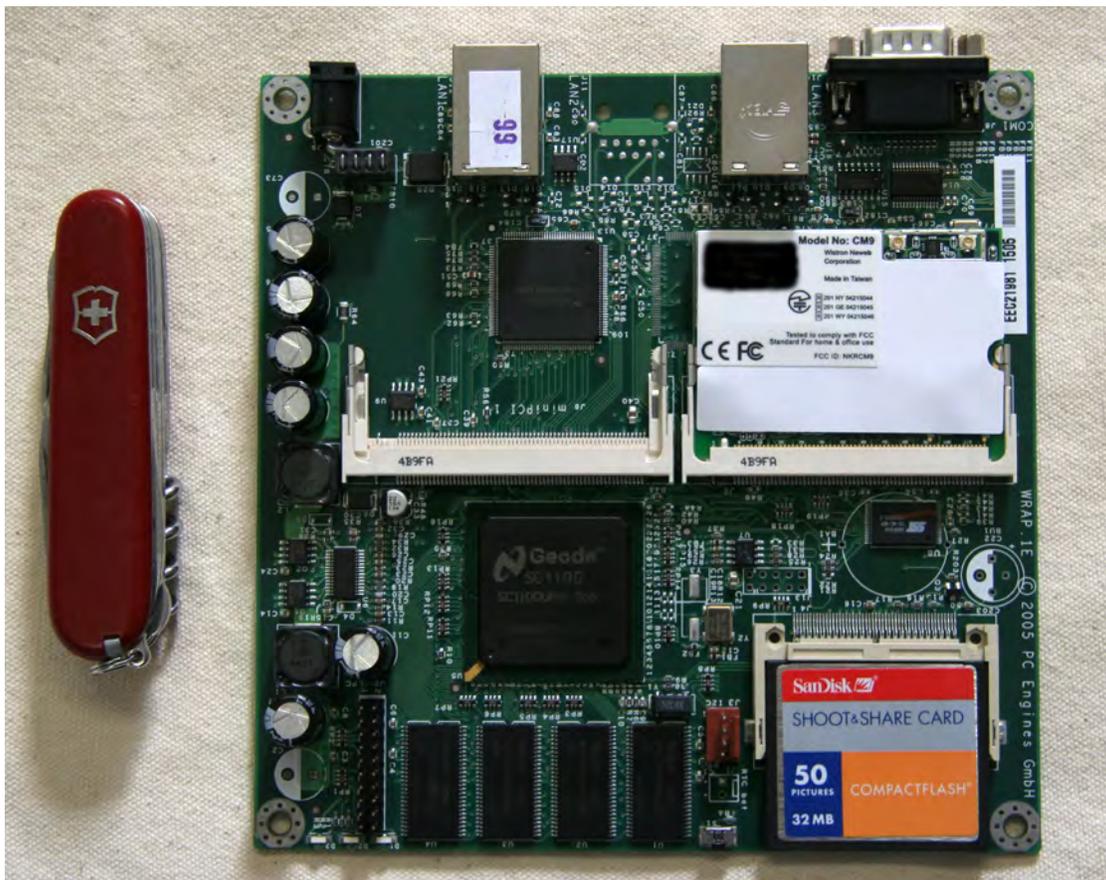
Figure 9. PC Engines WRAP 1.E systems board with one Wistron Neweb Model CM9 radio and 32 MB flash memory card. The Swiss Army knife is shown for scale.
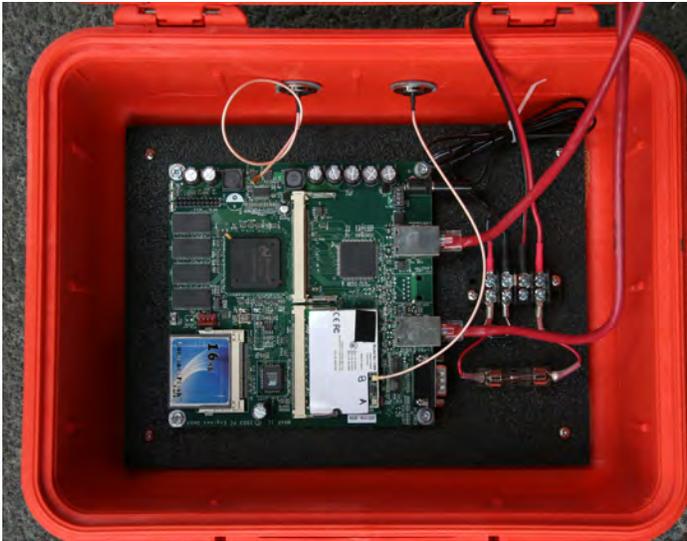
Figure 10. PC Engines WRAP 1.E systems board with one Wistron Neweb Model CM9 radio and 16 MB flash memory card mounted in a Pelican APP-1400 enclosure. The two Ethernet crossover cables and the power cable that pass out of view to the upper right are connected to bulkhead connectors on the enclosure cover (see fig. 11).

Figure 11. Cover of the Pelican APP-1400 enclosure containing the WRAP SBC and radio. The connector at the top of the photo is for power; the two lower connectors are RJ-45 bulkhead couplers.

radio. On the enclosure cover we installed a bulkhead power connector and two RJ-45 bulkhead couplers (fig. 11). The power connector was a Conxall 2-pin, panel-mount receptacle connector (Conxall model CXS3102A14S-9S-300), and the RJ-45 couplers were Woodhead L.P. model ENSP1F5. Ethernet crossover cables connect the RJ-45 couplers to the Ethernet ports on the SBC.

The salient features of Pelican enclosures are:

- Watertight, corrosion-resistant polypropylene
- Hinge has stainless steel pin
- Top has a rubber gasket seal
- Most trouble-free enclosure in the wet, corrosive conditions at Puʻu ʻŌʻō

Antenna

We used Hyperlink Technologies model HG2424G heavy-duty grid WLAN directional antennas at each node on both network branches. Antennas were attached to 2-inch schedule-40 galvanized or stainless steel pipes anchored in concrete. At Puʻu ʻŌʻō we used stainless steel pipe. These antenna masts also served as supports for solar panels (fig. 12). The maximum pipe diameter that the mounting bracket supplied with HG2424G will accommodate is 2 inches. Because 2-inch schedule-40 pipe has an outer diameter of 2.375 inches, we had to modify the brackets to accommodate a 2.5-inch U-bolt.

The salient features of the HG2424G are:

- Designed for 2.4 GHz ISM band, suitable for 802.11b/g

- 24 dBi gain
- Designed for long-range point to point applications
- Low wind cross-section
- Proven to be robust in adverse conditions
- 8° beam width
- Inexpensive

Remote Power Unit

We experimented with several different configurations for the remote power units. The configuration we found to be the most satisfactory is described here (fig. 13). The basic unit consists of a 12 volt, 60 watt solar panel (for example, Solarex MSX60), a solar panel charge controller (for example, Morningstar SS-10-12V), and two high-capacity 12 volt storage batteries (for example, ACDelco M27MF) wired in parallel. One to four of the basic units were installed at a given node. The charge controllers were mounted inside a Pelican APP-1400 enclosure with two pass-through connectors for each solar panel—one for the panel cable and one for the battery cable—and two additional pass-through connectors for load. If two or more basic units were present at a given site, they were connected to load through a matrix of Schottky isolation diodes inside the enclosure. Thus, a single component failure will only disable a single power unit. The batteries and the charge controller enclosure were placed inside a larger enclosure. For corrosive environments we usually used Rubbermaid 35 gallon or 48 gallon ActionPackers, which are made of polyethylene. For less corrosive environments we

Figure 12. Hyperlink Technologies model HG2424G antenna at the camera node on Mauna Loa. The pipe supporting the antenna also supports two 60 watt solar panels; the other pipe supports two additional 60 watt panels. The radio, four charge controllers, and eight batteries are in the steel box. The camera enclosure, which is on the caldera rim, is visible in the background.

used large (4-feet wide x 2-feet deep x 2-feet high) painted steel tool boxes (fig. 12), which may be purchased at home-improvement stores.

The remote power unit described here works well in Hawai'i, which has ample sunshine and generally mild temperatures throughout the year. Environments without these advantages probably will require more power units than we found necessary, or perhaps a completely different design.

Moxa NPort 5210 Serial Device Server

Once the Pu'u 'Ō'ō camera became operational, we found that we had surplus bandwidth available. By co-locating other monitoring instruments near the remote network nodes we could put this surplus bandwidth to work. Instruments that dispense serial data can be connected to the IP network through a serial-device server. Each serial data channel requires a separate input port on the device server. The example given here—the Moxa NPort 5210—has two serial input channels (fig. 14).

The salient features of the 5210 are:

- Connect RS-232 serial devices to an IP-based Ethernet LAN
- Standard TCP/IP Interface with RJ45 Ethernet connector
- Two RS-232 serial input ports
- Transmission speed: 110 bps to 230.4 Kbps
- Protocols: ICMP, IP, TCP, UDP, DHCP, BOOTP, Telnet, DNS, SNMP, HTTP, SMTP, SNTP
- Power consumption (measured): 200 mA @ 12V
- Power consumption (manufacturer's max): 305 mA @12V
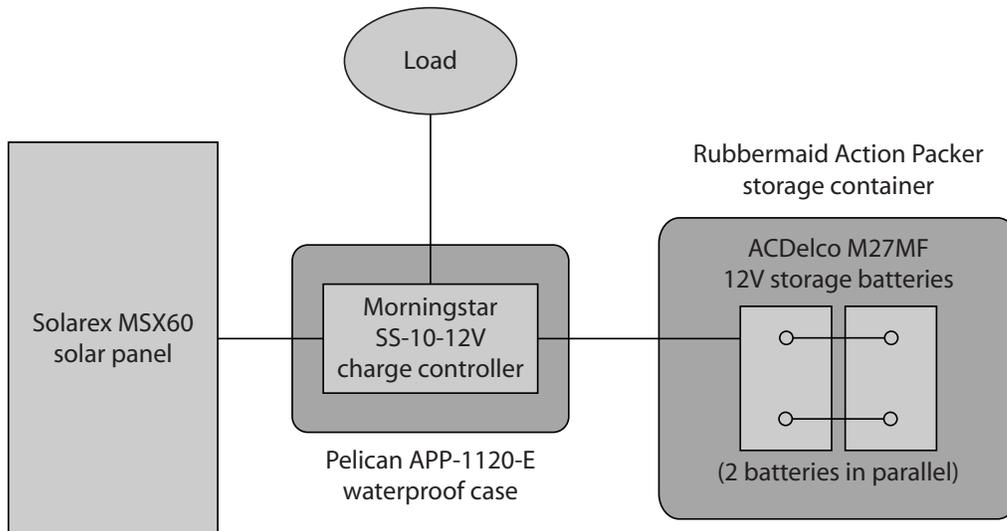
Figure 13. Diagram showing the layout of a basic remote power unit.

• 12-30 Volts DC input voltage range; works well with 12 Volts DC from solar panel regulator
• Configuration software

Repeater Node

A repeater node is similar to a camera node (fig. 15). Instead of one CM9 radio and one HG2424G antenna there are two of each: one radio/antenna to receive the signal from the camera node and one radio/antenna to transmit the signal to the base station (fig. 16). The repeater nodes have remote power—two basic power units work well—and a serial-device server to connect to co-located serial instruments. The repeater nodes could have easily accommodated cameras, but these sites did not have views that warranted cameras.

Base-Station Node

The base-station node consists of two CM9 radios and two HG2424G antennas—one radio/antenna for each of the two wireless-network branches (fig. 17). No enclosures or remote power units are necessary because the radios are inside HVO. The two wireless bridges are connected to a private LAN.

Figure 14. Moxa NPort 5210 Serial Device Server (front and back views).
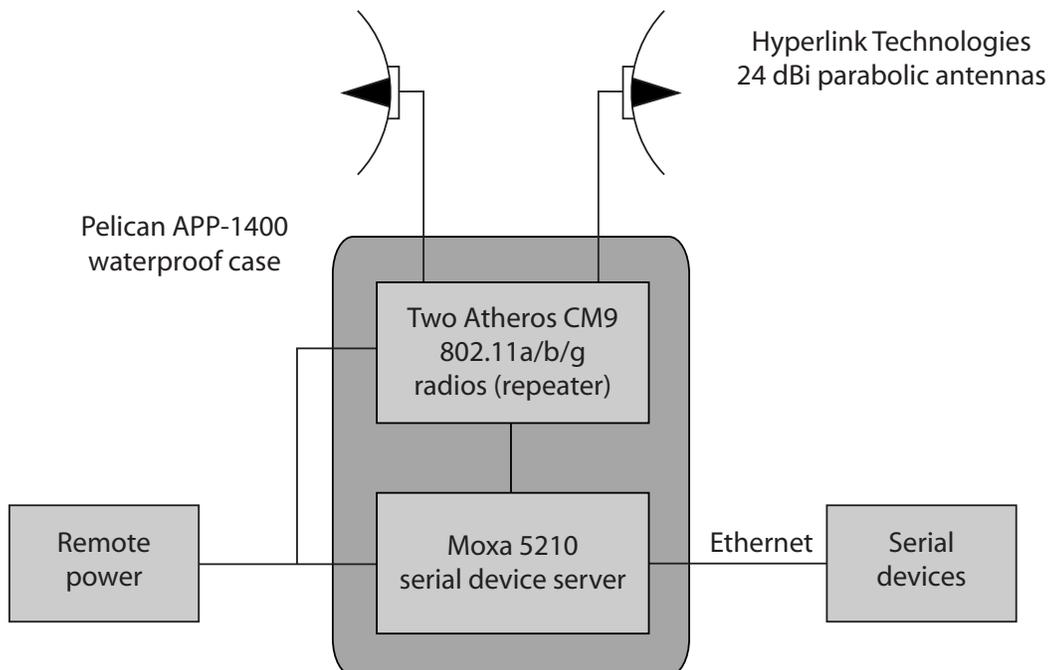
Figure 15. Diagram showing the main components of a repeater node.

Figure 16. Mauna Ulu repeater node.

Software

The operating system for the WRAP SBC is StarOS Station Server, from Valemount Networks Corporation. This Linux-based operating system is installed onto a compact flash card that is mounted on the WRAP board. Configuration of the WRAP SBC is done by connecting a PC to one of the Ethernet ports on the WRAP board by using a crossover cable. The IP of the PC must be changed such that the PC and the WRAP board are on the same subnet. For a WRAP board set with factory defaults, your PC network settings should be changed to reflect the following:

- IP   192.168.1.xxx (xxx represents an integer from 0 through 255)
- Subnet Mask: 255.255.255.0
- Gateway: 192.168.1.254

For a WRAP board that has been configured with custom settings, it is imperative that the proper network settings, as well as the username and password, are known. Without these, the WRAP board will have to be reset to factory defaults.

After the physical connection is made, the connection to the software is established by using an SSH (secure shell) client, such as PuTTY. The IP address of the board, along with a username and password, must be known to connect. The factory defaults for these values can be found in the StarOS manual. Upon connection, the main StarOS screen will appear, showing several basic parameters reflecting the current state of the station.

It is possible to assign an IP address to each interface on the board, for a maximum of four IP's—one for each of the

Hyperlink Technologies
24 dBi parabolic antennas

(To Mauna Ulu)

(To Mauna Kea)

Private LAN

Ethernet

Two Atheros CM9
802.11a/b/g
wireless bridge radios
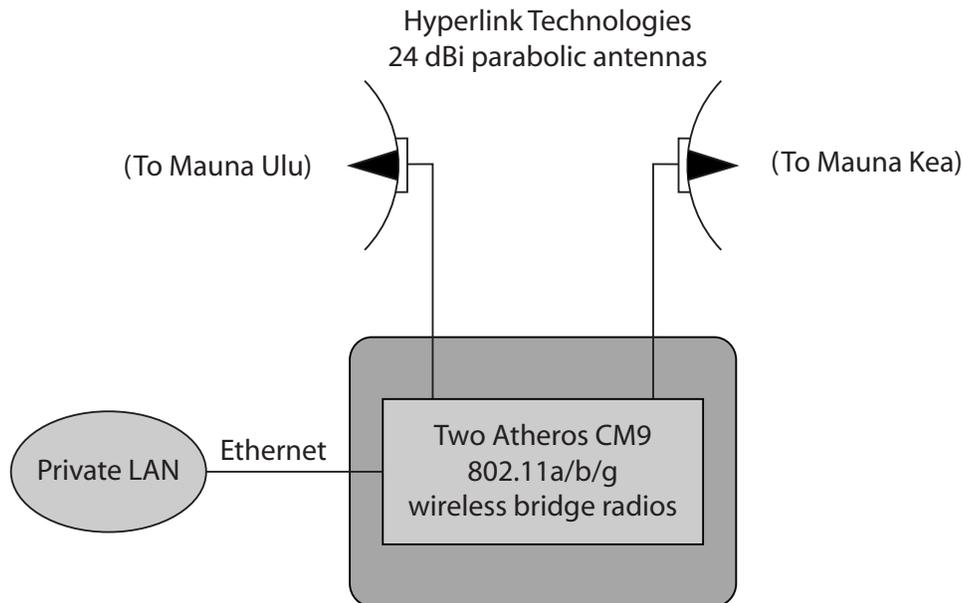
Figure 17. Diagram showing the main components of the base-station node.

two radios, and one for each of the two Ethernet ports. Each of these IPs, however, must be assigned to a different subnet, leading to complicated route tables for the board, as well as for every router that is connected. A simpler solution is to use the Ethernet bridge feature of the StarOS software to link each of the interfaces, allowing the entire board to be on the same subnet with the same IP. For security reasons, we have assigned unique IPs to each active interface on the base station, while bridging each of the field stations. This provides security at the base station, while allowing all field stations on each of the two Wi-Fi links to be on the same subnet.

Routing-table entries, composed of subnets, netmasks, and gateways, along with the IP addresses and bridges, constitute the spine of the wireless network and are vital to its function. This routing table must be configured for each station to define the various subnets, as well as for the computers that will communicate with those subnets. For our purposes, each wireless branch comprises a separate subnet.

Each wireless radio can operate as an access point (master), which can connect to several stations, or as a station (slave), which can connect to a unique access point. In our situation, both radios of the Mauna Ulu repeater and both radios of the Mauna Kea repeater are access points, and all other radios are stations. The encryption that is used allows only one specific slave radio to connect to one master radio at each of these access points. To differentiate the links of each subnet, the antennas are aimed in different directions, and the network parameters, such as network name and channel, are different.

There are several parameters that can be configured for each radio. Since the radios are the key to the system, they need to be configured appropriately. A single mistake could result in the loss of the connection. The important parameters are as follows.

Network name—This is the name of the radio link. It has to match the name assigned to the other radio of the link.

BSS channel—This sets the frequency channel used. If the radio is a master, choose a channel number or leave the selection set to "auto". If the radio is a slave, leave the channel set to "auto", and the master will choose the channel.

Transmit rate—This parameter adjusts the rate of transmission, and it is best to leave this parameter set to "auto" so that if the signal strength becomes too low, the radio can adjust to a lower transmission rate to increase the sensitivity.

Long distance—The distance between stations is specific in this parameter. Experience has shown that adding three to five miles to the actual length improves the connection.

Country code—This code is necessary to set the legally allowed frequency channels.

TX power override—This sets the maximum output power. We have set this parameter to 30 dBm to ensure that the output power will never be limited. The actual power will be the radio's maximum—in our case 18 dBm.

Antenna—This determines the physical antenna output used on the radio card—A or B. The antenna outputs on the radio cards are not externally apparent. The connection closest to the right edge of the card is output A, while the innermost output is B (fig. 8). The "Diversity" option is not used with directional antennas.

Enhanced features—These options are specific to data transmission, and should be left on for better performance.

Network type—This specifies whether the radio is a master (access point) or a slave (station).

Operation mode—This option sets the radio to use 802.11a, 802.11b, or 802.11g as the operation mode. The mode should be specifically identified on the access points, while this parameter can be left at "auto" for the stations. Because of the type of antennas we have used, we are restricted to the 802.11b and 802.11g modes, which operate at a frequency of 2.45GHz. We have found that the 108Mb turbo option does not work for long-distance links.

Operation

Although the cameras respond to manual pan-tilt-zoom commands, we rarely use manual control. Instead, we have automated the commands necessary to create multiphoto panoramas at regular intervals. We archive a panorama of Puʻu ʻŌʻō once every minute; for Mauna Loa the interval is once every ten minutes. At any time, multiple Observatory users can view the archived images as static images or animation sequences. Each morning we typically view an animation of the images collected the previous night, using software we wrote specifically for this purpose. It only takes a few minutes to review the animation sequences. We also post the panoramas on the HVO's public website, where Puʻu ʻŌʻō and Mauna Loa panoramas are updated every five and ten minutes, respectively.

Performance

The camera network has proven to be more robust than we expected. Following an initial trouble-free period, we began to experience problems with the Puʻu ʻŌʻō network branch. Most problems were caused by moisture leaking through or around exposed connectors or enclosure seals. A charge controller failed for unknown reasons. We solved the problems by completely rebuilding the enclosures containing the radios, replacing the radios and the SBC with those

described above, and scrupulously sealing all exposed connectors. We also replaced the charge controller.

We applied the lessons learned on the Puʻu ʻŌʻō branch to the design and construction of the Mauna Loa branch. As of this writing, the Mauna Loa branch has been in service for eight months and has not yet experienced a failure, despite an unusually long period of wet, cold, often freezing, weather.

The Puʻu ʻŌʻō branch—composed of two 10 km telemetry legs—has a bandwidth of about 24 Mbps. The Mauna Loa branch—composed of a 37 km leg and a 45 km leg—has a bandwidth of about 5 to 6 Mbps.

Security

Motivated by security concerns, the Department of the Interior issued OCIO Directive 2004-018 on April 8, 2004. This Directive prohibits the use of any wireless LAN or 802.11 wireless appliances on government furnished computers or computing devices. Waivers to this prohibition may be granted for networks involving law enforcement, fire operations or systems involved with the protection of life or property. The HVO wireless LAN was granted a waiver to operate the system described in this report.

On January 12, 2005, the USGS was given Delegation of Authority to OCIO Directive 2004-18 for wireless LAN waivers. The USGS was the only DOI bureau that was delegated this authority. As of February 15, 2006, the following requirements apply to USGS employees.

1. The installation must conform to the Wireless Security Technical Implementation Guide.

2. All wireless devices accessing USGS information systems must have supervisory approval.

3. Wireless access points must be formally approved, in accordance with Delegation of Approval granted to the USGS on January 12, 2005.

4. Wireless devices accessing an approved wireless access point must be approved and inventoried by the local Security Point of Contact.

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