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Tele-Engineering from the Inka Road

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ABSTRACT

The National Science Foundation sponsored a research project in the cordillera of western South America to reverse engineer the Inka Road. Reaching the Inka Road high in the sierra is difficult, thereby creating a challenge for bringing students and technical experts together collaboratively for the project. In order to meet this challenge, the researchers pioneered the use of a satellite-based audio and video communication tool–tele-engineering. With this tool the team in the sierra of Perú was able to examine the physical conditions of the Inka Road real-time with other engineers and students located at various universities, and with a non-engineer audience at the Smithsonian Institute in Washington DC. This paper describes how technical Inka Road aspects were collaboratively examined with remote experts and presented to a large non-engineer audience. These communication technologies are applicability in designing and constructing projects in remote locations where specialists may not be readily available and for bringing real engineering experiences into the classroom.

La National Science Foundation (Fundación Nacional de Ciencias de los Estados Unidos) ha patrocinado un proyecto de investigación en la cordillera oeste de América del Sur para realizar ingeniería inversa del Camino Inca. Alcanzar las alturas del Camino Inca en la sierra es difícil, es un desafío llevar juntos y en colaboración para el proyecto a estudiantes y expertos técnicos. Para superar este reto, los investigadores exploraron el uso de una herramienta de comunicación de audio y video basada en el satélite-tele-ingeniería. Con esta herramienta el equipo en la sierra del Perú fue capaz de examinar las condiciones físicas del Camino Inca en tiempo real con otros ingenieros y estudiantes ubicados en diversas universidades, y con un público no-ingenieril en el Instituto Smithsoniano en Washington DC. Este trabajo describe cómo los aspectos técnicos del Camino Inca fueron examinados en colaboración con expertos a distancia y presentados a una gran audiencia no ingenieril. Estas tecnologías de la comunicación son de aplicación en el diseño y construcción de proyectos en lugares remotos donde los especialistas puede que no estén fácilmente disponibles y para traer las experiencias reales de ingeniería a las aulas.

Keywords: communication tools, education, satellite, sustainability, tele-engineering.

1. INTRODUCTION

The Inka Road or Qhapaq ñan in scale alone is one of man's monumental engineering achievements. It united the four regions of an Empire that encompassed present-day Ecuador in the north, Perú, Bolivia, central Argentina, and Chile in the south. Built without the use of iron, the wheel, or stock animals, this road system represents

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important milestones in the development of civil engineering knowledge including the idea of suspension bridges (Schexnayder et. al. 2011).

1.1 INKA ENGINEERING

Some of the greatest challenges facing the engineering community today involve reducing the impact of the built environment, while minimizing consumption of natural resources. Unlike many modern engineering works that initiate these problems, the evidence indicates that the Inka civilization of western South America adapted its structures to the natural environment and always sought to preserve harmony with the land. An ever-present theme in Inka construction is the cultural belief that the Earth is sacred and they carefully employed what Pachamama (Mother Earth) provided. Engineers need to be aware that man still has much to study and learn from nature's frame – the elements.

Recognizing and documenting the Inka's fundamental knowledge of natural forces can help modern engineers create more sensitive approaches to modern building processes. However, little has been published that considers how the Inka planned, engineered, and built the infrastructure that supported the Empire (Petroski 2009; Wright and Zegarra 2000, and Wright 2006). Other than hydraulic work by Wright and the Inka suspension bridge work completed by M.I.T. professor John A. Ochsendorf (1996) facts about Inka engineering are minuscule. Therefore, a research team sponsored by the National Science Foundation (NSF) together with support from the Smithsonian Institute's National Museum of the American Indian is studying Inka Roads with the objective of integrating ancient technologies into sustainable solutions for the future.

1.2 HOW TO COLLABORATE

Travel to the Inka Road in the high sierra of South America (above 3,000 m) is difficult and exhausting, thereby creating a challenge for bringing large groups of students and technical experts together collaboratively for research activities. In order to meet this challenge in 2010, the NSF research team pioneered tele-engineering using satellite-based audio and video communication tools. The on-site researchers were able to share and explain the physical conditions of the Inka Road with engineers and students at location in both North and South America. Participants at their home locations were able to view and have interactive discussions in real time with the team in the field. This cooperative sharing of engineering information about the Inka road was well received by all participants and allowed the researchers to introduce ideas to a much broader audience and to bring technical questions to experts at multiple locations in the Americas.

That exploratory work proved the feasibility of using tele-engineering and tele-presence to both investigate the engineering attributes of the Inka Road and more broadly share engineering knowledge though modern communication.

2. TELE-ENGINEERING

The idea of using new wireless communication technologies to connect experts in distant urban centers to problems in rural or remote areas is penetrating all professions. Massachusetts Institute of Technology has pioneered the use of cell phone communication to send X-rays from a rural site in the Philippines to doctors in urban clinics for screening. Leo Anthony Celi, a physician who worked on the project said "We started with X-rays, but there's no reason we can't also transmit ultrasound videos, echocardiograms, and other medical imagery.'' (Denison 2009) An international tele-medicine project is connecting patients at a Hospital in Haiti face-to-face with medical experts at the Mayo Clinic, John Hopkins and other medical institutions in the United States (NewCom International 2011).

Engineering organizations, including the Corp of Engineers of the U.S. Army, have begun to use advanced communications links to support on-site engineers with specialized technical expertise. This leads to better solutions when faced with complex problems. Universities the world over had embraced distance education using satellite, videotape, and the Internet to provide learning opportunities that transcend the barriers of distance, time, and accessibility but these are primarily broadcast from the university.

Since the latter half of the 1990's many organizations have pioneered research and development in the area of tele-engineering that is often referred to as "distance" or "reach back" engineering, the idea being to bring the problem to the expert and then transmit supporting technical advice out. The primary benefits of tele-engineering are rapid response, efficiency of distribution, availability of specialty engineering resources, and collaboration. Tele-engineering allows access to technical information on demand and access to experts from practically any location in the world.

In the university the earliest approaches to using the new communication tools were information flow from the classroom, distance education classes, now researchers are reversing the information flow and seeking ways to use the new technologies to bring information into the classroom. No longer must a student physically travel to a distant location to observe first hand. The Construction Engineering Program at Iowa State University (ISU) in Ames, Iowa is leveraging information technology to benefit student learning (Jaselskis et. al. 2010). By means of mobile, portable video equipment to transmit video signals ISU is bring the construction site into the classroom. Using a handheld camera and head-set microphone, project personnel walk a jobsite, narrate, and beam live construction action back to the classroom in real-time via wireless internet technology. Students are able to view project conditions and converse with on-site personnel as construction progresses. This gives the students a realistic experience with project management situations and the tempo of work operations. At ISU the researchers have sought to always use off-the-shelf technology familiar to the online learning community (Jaselskis et. al. 2010). Lessons learned from the ISU experience include:

- Sites need to be selected carefully with the objective that the virtual tour can be conducted continuously; gaps in the broadcast are very detracting.
- Maintaining a WiFi signal can prove difficult. The WiFi antennas need to be strategically placed. (WiFi is a networking technology that allows devices to communicate without wires.) Loss of signal during a virtual tour is frustrating because of the time it takes to reconnect the communications link.
- Most camcorders require operation by hand; this can be a problem when the operators require the use of their hands for other reasons (safety).

2.1 Use of Tele-Engineering on the Inka Road

The tele-engineering activity that took place on the Inka Road required a satellite to transmit and receive visual and sound signals. Before going to the sierra, several tests were conducted to determine the appropriate bandwidth necessary for producing a high quality broadcast. It was determined that 512k bits per second would be sufficient assuming that the research team would not move the camera too quickly.

Two members of the researcher team spent one and a half days at a satellite link company training to use the satellite equipment. The training included instruction on equipment set-up and how to locate a satellite and broadcast. This training allowed the team to ascertain which equipment would work best for the conditions expected on the Inka Road (e.g., satellite router, antenna, cable, WiFi access point, power conditioner, portable computer, GPS, and the appropriate assembly tools). Table 1 provides a list of the satellite equipment.

Additional satellite testing took place in the months before traveling to South America. Two different satellites AMC-21 and HISPASAT 1 were used during this testing phase. Each satellite is positioned approximately 32,180 km (20,000 miles) from earth in a geostationary orbit and it requires knowledge of their elevation and azimuth in order to send and receive signals. AMC-21 provides communications services over the US, Caribbean, and Central America. HISPASAT covers both North and South America, so it was used by the team while on the Inka Road in the cordillera of western South America. The testing proved valuable as it was realized that the satellite base needed to be modify to allow the antenna to move lower than its original setting angle. The team also learned how to reconfigure the satellite router with new software if the original software became corrupted. Testing allowed the team to become proficient in assembling and disassembling the equipment.

The final testing/practice took place in the Llaca Valley outside of Huaraz (3,080 m) where the team spent a day acclimatizing to the altitude. This was the first opportunity to test everything using a portable generator power source. On the Inka Road the generator was the only power source available. Because Huaraz was the last town where needed supplies could be purchased this test was very important for identifying equipment problems before venturing onto the Inka Road.

Table 1. Equipment list

Satellite Equipment
1.2 meter diameter Ku band antenna
1.2 meter diameter mount (Patriot model)
LNB Ku-band
4W Ku-band BUC
iDirect 3100 modem
50 feet of coax cable, 2 feet of orange cross over cable & 2 feet of blue Ethernet cable
GPS unit for modem and cable
WiFi Equipment
Linksys WiFi Access Point
Portable Computer & Equipment
Dell Latitude E6410 ATG
Sony Vaio Handheld Microprocessor/Computer, Model VGN-UX490N (1)
Logitec Webcam
100 Gigabit Free Agent Portable External Drive
Diamond MSP100B 4 Watts 2.0 Mini Rockers Mobile Speakers Black
Satellite Phone
Iridium 9555 Std Package w/ 500 minute global prepaid SIM card (SatPhone Store)
Compass/Inclinometer
Suunto Tandem-360PC/360R Compass and Clinometer
Portable GPS Unit & Tripod
Garmin 010-00777-00 Foretrex 401 Portable GPS System
Tripod for mounting GPS unit (for iDirect 3100 series router)
Mobile Camera Equipment
Flip Ultra HD Camcorder, 120 minutes (Black)
Logitech Webcam
Luggage /Pelican Cases for protection of equipment
SUB 0 30 in. Roller Case by International Traveler Model 1188-30 Black (3 minimum)
Pelican Case with Polyurethane Foam (cases)
Northface Base Camp XL Yellow (quantity of 2 recommended)
Case Gun DLX Tactical (812614--877)

2.2 TRANSPORTATION

In the cordillera it was a challenge transporting all of the satellite equipment along the Inka Road. Everything had to be packed in such a way that it could be transported on pack animals through the rugged mountainous terrain. Burros carried the heavier equipment such as the satellite gear, the antenna (dish) with its base, and a generator and fuel cans, Figure 1. Additionally the team carried extra batteries and a charger; wood shims for leveling the antenna base and wood slats for antenna base; miscellaneous tools and extra hardware; coax cable connectors and Marratech Software for video conferencing.

Figure 1: Burros loaded with the Satellite (dish in the blue box and stand pieces in the yellow bags)

Llamas carried all of the team's personal effects. The team hiked the Inka Road for 9 days and was able to broadcast successfully 6 times. On the first day the team set up the equipment at the broadcast location hoping to connect with the Smithsonian on a prearranged schedule. The location was in a narrow river valley with the mountains providing only a V-shaped opening to the sky. After numerous attempts to locate the satellite signal, the team found that it was not possible to broadcast from the location because of mountain interference with the reception. This proved a valuable lesson regarding the necessity of carefully selecting satellite sites when in mountainous terrain.

3. BROADCASTING RESULTS/EXPERIENCES

After learning the lesson of properly locating the satillite, the broadcasts were very successful. The research team provided six satellite broadcasts from different locations along the Inka Road, Table 2. With each broadcast, the team's proficiency improved to the point where the satellite equipment could be set up in approximately 25 minutes and repacked in about 20 minutes. The success was in large part due to good team rapport and communication.

The Sony Vaio computer used by the team worked well because of its small, compact size but the screen was difficult to read. This was an issue each time the team had to reboot the system due to a dropped WiFi signal. The WiFi access point was limited in terms of its range, between 50-75 feet. There were several times when to reach an interesting feature the broadcast camera was carried beyond the range. It was found that using a full size laptop computer for the broadcasts worked much better because of its higher processing speed and screen size. Image quality was satisfactory if the team did not move the web camera too quickly.

On the Inka Road the equipment was set up in a timely manner and the satellite signal located relatively quickly. Figure 2 shows the communication tent that was used to protect the equipment. Figure 3 shows that antenna and transmitter and receiver. Note the importance to weight the base so that the wind would not move the antenna from its target.

Table 2. Inka Road Itinerary

Day	July	Location	Finish Location	Travel activity	Broadcast Schedule
	Sun. 11	Lima	Huaraz	Hotel in Huaraz	**No Broadcast Scheduled**
	Mon. 12	Huaraz	Huaraz	Acclimatization, Llaca Valley	Test Satellite Equipment
1	Tues. 13	Huaraz	Huari	Pomachaca bridge measure retention walls and foundation	Pomachaca Bridge, **unable to broadcast**, mountain blocking satellite signal
2	Wed. 14	Huari	Soledad de Tambo (11,600 ft)	Stairs, drainage, paving, walls around Soledad	**Broadcast** from Soledad de Tambo (successful) Sent video file to ftp site.
3	Thur. 15	Soledad de Tambo	Soledad de Tambo (11,600 feet)	Drainage channels, pavement, stairs and bridges.	**Unable to broadcast**, due to mountains blocking signal. Used satellite phone and pre-sent video in lieu of broadcast.
4	Fri. 16	Soledad de Tambo	Tauli	Bridge, stairs, drainage and paving.	**Broadcast** from just below the Waga Punta Pass (successful).
5	Sat. 17	Tauli	Tauli	Section leading up to Waga Punta; bridge, stairs are graded; steep road grade	**Broadcast** Allpachaca Bridge
6	Sun. 18	Tauli	San Cristobal	**S**mall stone bridge; retaining wall.	**Broadcast** from Ayash Ancient Civilization Pre Inka Huamanin (enroute to San Cristobol) (successful)
7	Mon. 19	San Cristobal	Ayash (14,500 feet)	Measurements of the Inka Bridge at Ayash.	**Broadcast** from the King's Steps. Andrew Earle provided expertise on the Hydrology of the Road.
8	Tues. 20	Ayash	Huallanca	Huamanín Punta; Drainage channels, walls, stairs.	**No Broadcast Scheduled**
9	Wed. 21	Huallanca	Lima	Huánuco Pampa archaeological site.	**No Broadcast Scheduled**

Figure 4 shows the team setting up the satellite equipment in the middle of the Inka Road just below a 4,500 m Pass. This was a beautiful location and due to the elevation, the team had no difficulty obtaining the satellite signal. The broadcast from this location lasted approximately 40 minutes. A video of this broadcast can be viewed on the web at: http://www.youtube.com/watch?v=GQpgK3vt8fo. While connected to the Smithsonian from this site the team was also able to download two video files that had been produced the evening before. These became part of a permanent file cache for viewing by those at the Smithsonian.

Figure 2: Communication tent

The team set up at one location and thought it had adequate WiFi signal coverage for the features that were to be shown. At this location and all previous sites a pre-test was preformed indicating no problems with the WiFi signal. When the broadcast began everything worked well until the moderator with the mobile communication gear reached the limit of the WiFi signal. The signal was dropped thus terminating the broadcast. This type of occurrence is a critical issue. When the signal is dropped the computer must be rebooted, a process that takes several minutes, therefore the broadcast is interrupted with the audience at the receiving sites not knowing what happened. The team resorted to using a satellite phone to remain in voice contact with the receiving audience while the computer rebooted.

Figure 4: Satellite antenna with transmitter and receiver

During one of the broadcasts the research team was able to use the concept of tele-presence to bring a hydrological expert from his office in the U.S. to our location on the Road. He was able to examine a particular culvert (Figure 6) and channel feature that was of interest to the team. This expert conversed with the team asking questions and by directing the camera position could to see the culvert features from different angles and distances. As a result, the researchers were able to better understand the reasoning behind the culvert design and the appreciation Inka engineers had for the dynamics of the watershed.

Figure 4: Setting up the satellite equipment

Capped culverts constructed of large stones are common along the road. At this location there are three stone-capped culverts. Culverts 1 and 2 are often referred to as the Allpachaca Bridge. The road walkway is constructed with flat capstones that are readily available in the area. Stone culverts such as those shown in Figure 5 generally have spans of 46 to 91 cm (1½ to 3 ft) and some researchers refer to them as bridges or stone bridges, probably because in Quechua, chaca means bridge. Just beyond the three capped culverts is an open culvert.

Figure 5: Inka Road Culvert north of Taulli

At this location the Inka engineers faced three water issues. Culverts 1 and 2 are arranged to handle a mountain brook that is entering from the lower right. Scaling from the topographic map, the drainage area of this brook is slightly greater than 2 square kilometers. Culvert 3 carries the water from a mountain spring that is immediately adjacent to the road. The open culvert handles water running down the road. This water is the result of a slight rise in grade beyond the brook and spring. The three water issues the Inka Engineers faced; mountain brook, spring, and side drainage are all the result of an ancient volcanic dike (the black stone that protrudes center right in the upper part of the picture). The dike runs through mountain just beyond the culverts and perpendicular to the road. This wedge of hard rock forces all of the water flowing from the north (to the left) to turn and go down the side of the mountain. The arrangement of these culverts indicates that the ancient engineers fully understood the multiple parts of the water situation and conformed these drainage structures to handle the anticipated flows.

3.1 CHALLENGES

There were several challenges that the team encountered in bringing the Inka Road to visitors at the Smithsonian Institute and universities in North and South America:

- Matching field work with the fixed schedule of universities be came a challenge because the team's schedule could easily change due unexpected/unplanned conditions in the field, like trying to find an unobstructed aiming location to set the satellite. The steep rise of the mountains was often an issue.
- Difficult terrain, altitude 3,000 to 4,600 m
- Learning about the equipment and being able to trouble shoot from a remote location
- Transportation logistics in terms of packaging and transporting the gear to a suitable broadcast location
- Preparing meaningful broadcast (while trying to catch your breath)
- Maintaining a robust WiFi signal on the site

3.2 RECOMMENDATIONS

Additional bandwidth is necessary to improve image quality. The research team found that moving the web camera too quickly lead to a degradation of image quality (a stationary camera was ideal). The use of a different access point with a stronger WiFi signal will increase the effective range of web camera contact and therefore provide greater coverage during each broadcast. This will reduce the chances of a dropped signal. Moreover, simply having the technology to broadcast is not enough. The real value lies in the quality of the broadcast both in terms of content and image/video quality. It was suggested that cooperating universities bring in more experts during the broadcast who can provide more specific information about the features being studied.

4. CONCLUSIONS

A significant effort went into the planning and preparation for engaging students and experts at multiple locations in the Inka Road research and the endeavor proved a success. The notion of being able to bring in experts using tele-engineering techniques was tested and proved to be possible from a very challenging location.

The research team's observations in the field were captured by the camera and using satellite technology projected on large screens in auditoriums and computer screens at multiple locations. Tele-engineering techniques can provide large numbers of students active participation in research experiences. To that end it is very important that educators have an awareness of how to achieve transmission quality. The two critical issues identified during the Inka Road experience were bandwidth and WiFi signal. The quality of the video image communication significantly affects the research experience and it is important to ensure signal continuity; to overcome or minimize the restraints of WiFi connectivity that can interrupt a session. The use of the satellite posed no problem beyond the need to carefully select set-up site that do not present line of sight issues.

One of the most important features of the tele-engineering is the ability to receive feedback from the audience/students. This open communication can direct the direction (field of vision) of the camera and thus improve content. It was also found that prior to broadcasting it is necessary to establish the theme of interest for the transmission. A defined broadcast script together with detailed planning of what the camera will capture must be outlined before each transmission. Previously recorded material can be used during the transmission, together with sketches, maps, or calculations that help the audience comprehend the physical situation. Issues that cannot be resolved immediately should be taken up in a subsequent transmission. Finally it is vitally important to encourage feedback from viewing participants. Tele-engineering is a new experience but once the students are engaged they help to make the broadcast much better.

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REFERENCES

Denison, D. C. (2009). "Using Cellphones to Change the World," The Boston Globe, 14 Oct.

Jaselskis, Edward J.; Jahren, Charles; Jewell, Paul G.; Floyd, Eric; and Becker, Timothy C. (2010). "Virtual Construction Site Field Trips using Remote Classroom Technology," *Proceeding of the 2010 Construction Research Congress*, May 8-11, ASCE, pp. 236-245.

Jaselskis, Edward J.; Ruwanpura, Janaka; Becker, Timothy; Silva, Lahiru; Jewell, Paul; and Floyd, Eric (2011). "Innovation in Construction Engineering Education Using Two Applications of Intenet-based Information Technology to Provide Real-Time Project Observations," NSF Construction Engineering Conference, Blacksburg, VA, Sept. 30-Oct. 1.

Lost Crops of the Incas: Little-known Plants of the Andes with Promis for Worldwide Cultivation (1989). National Research Council, National Academy Press, Washington, D. C., p. 1.

NewCom International (2011). "NewCom International Telemedicine Project Connects Haiti Hospital with Top Doctors in the U.S.," 14 Feb., <http://newcominternational.com/index.php/news/149-newcom-international-telemedicine-project-connects-haiti-hospital-with-top-doctors-in-us.html>. (viewed 18 Feb. 2011)

Ochsendorf, John A. (1996). "Inca Suspension Bridges," *Structural Engineering Departmental Report 96-8*, School of Civil and Environmental Engineering, Cornell University, Ithaca, New York, August.

Petroski, Henry (2008). "Honoring Inca Engineering," *PRISM*, American Society for Engineering Education, December. <www.prism-magazine.org/dec08/refractions.cfm> (viewed Aug. 2010)

Schexnayder, Cliff; Celaya, Manuel; Recavarren, Gerardo Chang; Fiori, Christine; and Jaselskis, Edward J. (2011). "Engineering and the Elements," Journal of Construction Engineering and Management, ASCE, Vol. ?, No. ?, June.

Wright, Kenneth R. and Alfredo Valencia Zegarra (2000). *Machu Pichu: A Civil Engineering Marvel*, ASCE Press.

Wright, Kenneth R. (2006). *Tipón: Water Engineering Masterpiece of the Inca Empire*, ASCE Press.

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