ABSTRACT: As the population of the Salt Lake Valley and popularity of backcountry skiing in the Wasatch continues to grow, so do the logistic difficulties of control missions on avalanche paths above highways. On any given morning after a storm, ski touring parties can be out in the starting zones well before sunrise. Utah Department of Transportation (UDOT) avalanche forecasters utilize many various methods to alert the public of impending backcountry closures and control work. UDOT forecasters tested thermal imaging devices for the 2015-16 season. Field tests with infrared radiation thermography (IRT) allowed forecasters at the gun mount and on the road to scan for heat signatures of ski tourers.

During testing, UDOT forecasters realized another powerful capability of IRT: in darkness, low light or flat light conditions, they could clearly see the thermal signatures of artillery placements and detonations as well as any control results. There are limitations to thermal imaging; intense storms or thick clouds mask the subtle differences in heat produced by skiers or avalanches. Further, heat signatures from trees, rocks and other natural features can be mistaken for skiers or hide skiers. Nonetheless, UDOT forecasters intend to continue to use IRT as another tool to enhance their highway avalanche safety program.

KEYWORDS: thermal imaging, avalanche control, IRT

1. INTRODUCTION

Those who are responsible for avalanche forecasting and hazard reduction on public lands outside ski resorts face unique operational challenges. It is critical to ensure that avalanche starting zones, tracks, and runouts are clear of people before control missions begin. Despite highway signs, road closures, backcountry closures and outreach via social media, eager backcountry users continue to attempt to enter these areas. Programs such as ours that still rely heavily on military artillery are especially aware of the potential for tragedy should backcountry users be in target areas during control missions. Such an accident would jeopardize military weapons avalanche safety programs throughout North America.

In an effort to better detect individuals violating backcountry and road closures during control missions, UDOT Little Cottonwood Canyon Supervisor Matt McKee looked into acquiring night vision goggles. After asking various partner organizations within the Utah government and a bit of research, the decision was made to test infrared radiation thermography (IRT). This technology allows us to search starting zones for heat signatures and even check parked cars for ambient engine heat. Unlike night-vision technology, thermal imaging can be used during daylight hours.

Through preliminary testing on non-control mornings, we found we could easily pick out individual ski tourers as well as their tracks in the cold snow. Our plan, if it were discovered that IRT was a useful tool, would be to compile a set of standard operating procedures for our program. On control mornings, we could have a forecaster with a pair of thermal imaging binoculars scan the most popular backcountry trailheads, up tracks, and starting zones prior to a firing mission. It was on one of these mornings when the visibility for both the gun crews and forward observers on the road was poor due to pre-dawn flat light, that we realized the full potential of IRT.

2. BACKGROUND

Little Cottonwood Canyon (LCC) is located in the central portion of the Wasatch Mountains of northern Utah, USA. State Highway 210 (SR 210) runs through the canyon connecting the Salt Lake Valley to Snowbird and Alta ski resorts as well as the town of Alta (Fig 1). It climbs from an elevation of 1646 m at the mouth of the canyon to 2650 m at its terminus at the base of Alta Ski Area.

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The primary tools for UDOT's avalanche control above SR 210 are two 105mm howitzers firing military anti-personnel rounds. The P-Ridge weapon sits atop Peruvian Ridge at Alta Ski Area and targets upper LCC from Mount Superior to Grizzly Gulch (fig 2). It is this swath of ridgeline that is most accessible and therefore most popular with the ski touring public. Despite the efforts of UDOT forecasters to alert the public of impending control missions, it is not unusual to encounter up to a dozen touring parties preparing to leave their vehicles on any given morning. This emphasizes the need for improved methods to help ensure that our avalanche paths are clear of public prior to firing.

3. PREVIOUS WORK

Ours was clearly not the first project to point a thermal imaging camera at the snow. In the world of snow and avalanche science, Cora Shea and Bruce Jamieson introduced IRT to our community at ISSW 2010 (Shea and Jamieson, 2010). Their paper, *Use of Thermal Photography to Measure Snowpack Properties*, along with follow-up papers and presentations (Shea and Jamieson, 2011; Shea et al., 2012; Schirmer and Jamieson, 2014) provide an excellent background on thermal imaging technology as well as uses and limitations of thermography on snow.

Recent research of thermal energy in avalanches has utilized IRT to help quantify the increase in energy due to friction and entrainment of warmer snow. As pointed out by Steinkogler et al. (2013 and 2015), measuring temperatures inside a flowing avalanche by traditional means is difficult and dangerous (if not impossible) and IRT data allowed them to "observe the avalanche phenomenon with different eyes."

4. METHODS AND OBSERVATIONS

4.1 Choosing a device

The UDOT avalanche safety program began exploring options for a suitable thermal imaging device in May 2014. Our relationship with the US Army related to avalanche artillery use led us to James Alderson, our Army liaison. The Army has many resources related to thermal imaging, but when James was asked if there were any surplus units that might fit our needs, he recommended we search the private sector.

Through Internet searches, many products were found that are used in the hunting community, but not many had both the high resolution and long distance capabilities we needed. The best options we found were from the San Francisco-based company *Armasight*, a producer of night vision, thermal, and daylight imaging products for outdoor enthusiasts, law enforcement, and military customers. After discussions with company representatives we decided on the *Helios 640 HD*
Thermal Imaging Bi-Ocular (fig 3). This is a solid-state, uncooled, long-wave infrared, handheld thermal imager intended for day and nighttime missions. This product originally designed for big game hunters is now finding a use by avalanche hunters. We should note that FLIR Systems purchased Armasight Inc. during the summer of 2016, (Armasight, 2016).

Fig. 3: Helios 640 HD thermal imaging bi-ocular (Armasight photo, top; UDOT photo, bottom).

Our program originally tested two versions of the Helios 640 HD, one with a 100mm lens and another with a 75mm lens. Both models have a 30 Hz refresh rate, pixel size of 17 µm, and utilize a FLIR Tau 2 VOx microbolometer array (Armasight Inc., 2015). Again referring to Shea and Jamieson (2010), a microbolometer array uses heat-sensitive pixels that translate heat differentials into voltage differentials that are then displayed as colors. Crucial to our original plan of spotting skiers, both models are equipped with a digital zoom function providing 2x, 4x, and 8x magnification of the image. The 75mm model we tested in the spring had the capability to save still pictures and video via an optional 64gb DVR attached to the unit.

Among the user-controlled features is the ability to change the display band combinations or “image palettes” (Armasight, 2015). Through testing we found the best combinations for our purposes to be Rain; color-based image with blue designating cooler objects and yellow to red designating warmer, Ice-Fire; gray-scale image with yellow to red highlights for the warmest features, and Black-Hot; gray-scale image with black the warmest and white the coolest (fig 4).

Fig. 4: Samples of imaging palettes from April 15, 2016 Mount Baldy mission.

4.2 Field Testing

As stated before, we tested two different Armasight bioculars throughout the 2015-16 season, but only had the optional DVR for a short period of time in the spring. All the IRT images used in this paper were taken during one control mission on the morning of April 15, 2016. This was actually an Alta Ski Area mission from their Mount Baldy weapon, which is located adjacent to UDOT’s P-Ridge mount. A UDOT forecaster with the 75mm lens was at the gun acquiring still images and video. Distances to the targets from this point range from 900 to 1300 meters. 12 rounds were fired at 12 targets on Mount Baldy (elevation 3350 m) re-
resulting in several soft slab avalanches up to size 2. Crown depths averaged around 25 cm with widths ranging from 20 to 40 m.

UDOT weather records from that morning show overcast skies with snow showers, air temp -6 C, and HST of 15 cm with 34 mm of water at the UDOT Alta Guard study plot (2683 m).

Looking again at Figure 4, one can see the progression of the avalanche in the center of each image from the upper left thermograph to the thermograph at bottom right. In all images the increase in thermal energy is evident as the avalanche begins to move, increases in speed and entrains snow.

We actually received our first unit for testing in early January 2016 and started field tests. From the UDOT office above Alta, we scanned the backcountry terrain above town and looked toward the open terrain of Alta Ski Area. We quickly discovered we could see skiers up to 2 kilometers distant along with the ski tracks that they left, even during moderate snowfall periods. Further we could see thermal images of older tracks ski tracks as remained warmer than the surrounding undisturbed snow surface.

Figure 5 shows a palette comparison using thermographs of hikers in the snow. In this example we see Alta ski patrollers and the tracks they left behind hiking up a hand route around 450 meters from the Baldy gun mount. Once again, the gray-scale palettes prove to be the best for our purposes of spotting ski tourers. Figure 6 shows the capabilities of the digital zoom function looking again at the same pair of patrollers.

A mid-January storm cycle gave us an opportunity to test the thermal imaging binoculars during control missions. From January 15-21, 2016 we received 89 cm of snow with 77 mm of water at the Alta Guard study plot. Skies were generally overcast and air temperature was around -4 C. There were several firing missions from both UDOT weapons and the Alta Mount Baldy weapon. Forecasters at the mounts and on the road had the binoculars with them. For the most part, all observers were impressed with the capabilities of IRT during these missions.

In one particular situation after a shot from the Alta Mount Baldy weapon, there was no audible report downrange or visible impact crater as it was still dark. However with IRT, the UDOT observer could clearly see the flight of the bullet and the still-warm impact crater, thus verifying that the round did hit, did not detonate, and eliminating the possibility that an overshoot had happened. The gun crew was able to carry on with the firing mission knowing there was no problem with the mechanics of the gun, the targeting data, or their procedures.

The next morning at the same weapon, again in pre-dawn darkness, IRT confirmed no visible results from a given shot. A second shot, placed lower within the same snowfield triggered a size 3 avalanche, with its propagation, debris flow, dust cloud, and deposition all plainly visible though IRT. This shot also sympathetically released the upper snowfield taking out the previous shot placement. The next shot was to be fired in an adjacent starting zone, but thanks to confirmation through IRT we could verify that the area had already released and the crew was able to use that next shot elsewhere. Further, even when no avalanche was
triggered, the crater created by an explosion remained visible with IRT for 10 or more minutes after detonation.

On this morning, it was also necessary to shoot a small path above the highway and Alta’s Wildcat parking lot. Typically we use a 1.8 kg booster on a bamboo placed by hand for this shot. Though it was still dark, this mission was plainly visible though the bioculars from the P-Ridge mount at a distance of around 1100 m. The observer could see the forecaster walk from his truck to below the start zone then set and ignite the charge. Even the heat of the burning fuse and smoke were clearly visible at this range. The resulting avalanche was relatively small (20 cm deep by 20 m wide) but even so, the IRT image showed surprising detail in the propagation of the soft slab. Later that morning during daylight hour control work within the ski area, IRT of avalauncher rounds from a range of around 1900 m showed similar detail in the mechanics of avalanche release.

The next testing session was on January 21, 2016 again at Peruvian Ridge, but this time using the UDOT weapon targeting Mount Superior 2200 meters downrange. Our observer at the weapon described the following: “I watched the projectile hit the target and detonate without immediately triggering an avalanche. Moments later, I could see the fracture opening and propagating 30 meters to the west of the impact point in a slightly different terrain feature. This became a size 2 avalanche that ran into the main path then triggered another slab 30 meters above the shot hole resulting in a larger size 2 avalanche.” Other observers who did not have the advantage of thermal imaging saw none of this due to early morning flat light conditions. Figure 7 is a photo of this avalanche taken after the mission during daylight.

Through these testing sessions, we found another key capability of thermal imaging; the ability to confirm not only shot placements and detonations, but also the extent and details of results. On any given control mission, the verifying artillery target hits, detonations, and any results is critical to avalanche forecasting and highway operations. Periods of poor visibility can make this difficult and sometimes can lead to delayed openings until results can be verified. Figure 8 shows a sequence of images from the Baldy weapon with the bullet in the air, impact, detonation, and initiation of an avalanche.

The limitations of IRT in 2016 showed promise for using thermal imaging in our program, but as we found on days with differing conditions, thermal imaging does have its limitations. Testing during storms showed us that low clouds and heavy snowfall almost completely obscure the thermal image. Thick clouds emit as much radiation towards the snow as the snow emits towards space, (Shea and Jamieson, 2011), thus masking any

Fig. 7: Results from January 21 2016 mission.

Fig. 8: Sequence of IRT video screen shots from the April 15 Baldy mission. In A, the flying bullet is visible (circled in yellow) as is the initial detonation in B. C and D show initiation and propagation of the fracture. The slab starts to move in E and entrains snow in F as it moves downslope.

4.3 Limitations of IRT

Our testing of IRT in 2016 showed promise for using thermal imaging in our program, but as we found on days with differing conditions, thermal imaging does have its limitations. Testing during storms showed us that low clouds and heavy snowfall almost completely obscure the thermal image. Thick clouds emit as much radiation towards the snow as the snow emits towards space, (Shea and Jamieson, 2011), thus masking any
return thermal energy from an explosion, skier, or avalanche.

We found that infrared radiation from vegetation or warm rocks could mask the skiers we were looking for. We all had a re-education in basic physics when we tried to view through glass, which is effectively opaque to longwave radiation. Whether looking out from our trucks towards starting zones or looking into a car for sleeping dawn patrollers, the glass essentially threw a sheet over our heads. Likewise, a “heat curtain” effect blinded us if we were near a warm building or again in our warm trucks, even when viewing through open windows.

5. CONCLUSIONS

These thermal imaging devices provide another level of protection for ensuring artillery target areas along with avalanche tracks and runouts are clear of the public prior to control missions. While they will never give us 100% assurance, they do have a place in the UDOT Avalanche Safety Program. Likewise, IRT has proven to us to be a powerful tool for verifying artillery hits and detonations as well as any resulting avalanches. Despite the limitations of IRT, we feel this can help increase our levels of efficiency and safety during many control missions.

In June 2016, UDOT purchased four Helios 640 HD units with optional DVRs that will be incorporated into our program for the 2016-17 winter season. Two units have the 100mm lens and two the 75mm lens. The 100mm units will be used at our locations with the longest ranges while the 75mm units will be for closer targets and along the road to scan trailheads and parking areas. Standard procedures will now include IRT visualization of all targeted avalanche paths and trailheads prior to control missions. We will use the DVRs to document artillery detonations or duds along with results. We hope these IRT photos and videos can be used to advance the study of avalanche initiation and propagation along with flow dynamics.

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We must also honor the memory of Dr. Cora Shea, who our community lost in 2012. Her initial work on thermal imaging of snow has been invaluable to this project. We miss her along with her beautiful and brilliant mind.

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