Using RPAS for the detection of archaeological objects using multispectral and thermal imaging

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ABSTRACT
A locality that we studied was an archaeological site located near the village of Ctíněves, in the district of Litoměřice in the Czech Republic. The archaeological site is a polycultural site. It is very significant and plays an important role in the Czech archaeology. During our research, we found that cropmarks that were visible in 2016s were not visible in 2017 at all. This has brought us to study climate conditions and their influence on cropmarks. We studied nine other archaeological sites in the neighborhood of our site. During this research, we were looking for cropmarks and what kind of crop was planted there. We were searching for a correlation between climate conditions and cropmark visibility in this part of the study. Our second part of the study focused on the crop used at the site and whether there was an influence on the cropmarks. We tested grain, corn and rapeseed oil. Grain had the best results for cropmark visibility in our case. Rapeseed oil results suggested that cropmarks are significantly reduced. Our last area of interest dealt with using a thermal imager for archaeological features detection on the site without crops. We made several flights with the thermal imager, some of them before sunrise and some after sunrise. Our results showed several types of features on a football pitch, which is located on part of the archaeological site.

Introduction
Remotely piloted aircraft systems (RPASs) or unmanned aerial vehicles (UAVs) or unmanned aerial systems (UASs) are widely used in many areas, and their importance is still growing. A size of RPAS can be different from about 10 cm or less, to bigger ones with a size in meters. Such bigger RPAS can be equipped by many precise and expensive sensors, for example, multispectral cameras, hyperspectral cameras or laser scanners (Jon, Koska, & Pospišil, 2013). Thanks to miniaturization and more favorably priced sensors and better availability, even smaller RPAS (about 1 m and less) can be equipped by sensors such as thermal imagers, multispectral imagers, hyperspectral imagers and laser scanners. These sensors bring new data to the field of archaeology. It was difficult to get data in the past because of high price of sensors, and it was usually necessary to use a plane as a carrier of these devices. Better availability of sensors and RPAS give us new opportunities in the field of cultural heritage. Three-dimensional (3D) documentation of historical objects is one of the most common tasks in this field. It is possible to do documentation of smaller objects such as water wells, garden rocks (Kaneda, Nawabi, & Yamaguchi, 2015) or bigger buildings such as castles (Bolognesi, Furini, Russo, Pellegrinelli, & Russo, 2015), as well as structures such as the theater area of Pompeii (Saleri et al., 2013), urban medieval sites (Nistor, Mihaï, Toma, & Carlan, 2017) and geoglyphs in Nazca (Bikoulis et al., 2016). Researchers can combine UAV data with terrestrial photogrammetry and laser scanning (Lambers et al., 2007). Archeologist can use RPAS for documentation of archaeological excavations in time (Malinverni, Barbaro, Pierdicca, Bozzi, & Tassetti, 2016). RPAS equipped with different sensors can be used for archaeological survey. Even ordinary cameras give us an opportunity for more detailed orthophotos and digital surface model (DSM). By analyzing orthophoto and DSM, many different objects/features can be found, for example, ancient Roman gold mining sites (Fernández-Lozano & Gutiérrez-Alonso, 2016), ancient fields and irrigation canals (Parcero-Oubiña et al., 2017), buried Medieval landscape (Reu, Trachet, Laloo, & Clercq, 2016) or field fortifications from the Thirty Years’ War (Hulkova, Matouskova, Pavelka, & Janata, 2017). Aerial thermography brings the possibility to find and study subsurface archaeological objects/features such as extinct settlements (Casana, Kantner, Wiewel, & Cothren, 2014). Our archaeological site and its neighborhood too were

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studied many times in the past. A lot of work was made by Czech archaeologists (Gojda & Hejczman, 2012; Gojda, Krivánek, Meduna, Rytíř, & Trefný, 2010; Gojda, Trefný, & Janíková, 2011).

Archaeological site

The archaeological site is located near the village of Ctiněves, in the Usti region of the Czech Republic, see Figure 1. It is one of the most important archaeological sites located near the hill Říp (455 m a.s.l.). This site has been mentioned several times by different chroniclers since sixteenth century, for example, by Václav Hájek z Libočan and by Bohuslav Balbin in the seventeenth century. Václav Krolmus described a tumulus located at this site in his research in the first half of nineteenth century. Professional archaeologists such as K. Žebera, J. Straka, K. Sklenář, M. Slabina and J. Hrata visited this site in the second half of twentieth century. There is one important recent research made by M. Gojda. He led the excavations of the tumulus located at this site between years 2009 and 2010. Most findings from the site belong to the Knovíz culture. The Knovíz culture is an Urnfield culture from the Bronze Age. As this is a polycultural site, some finds are dated into the Paleolithic era, some belong to the Corded Ware culture and some to Roman period (Gojda & Trefný et al., 2011).

Dimensions of the archaeological site are approximately 300 × 220 m. There is a football pitch on the right side of the site, see Figure 1 top right (the green area). The tumulus is placed in the southwest part of the archaeological site. Almost all area is randomly covered by point features. Their diameter is approximately 1 m, some of them are smaller and some are larger. The highest concentration of these point features is in the south part of the site. It has not yet been resolved yet whether all of these point features belong to the Knovíz culture. There are some opinions that these features can be pits and/or urn graves. Shards found at this place suggest that some features could be urn graves of the Knovíz culture. However, excavations are necessary to fully explain meaning and origin of these features.

Equipment used

RPAS eBee was used for imaging. The area was imaged on 16 June 2016 and 20 April 2017. A multispectral camera multiSPEC 4C was used for imaging. The multiSPEC 4C provides data in four bands: near-infrared (NIR), red edge, red and green. The multiSPEC 4C bands are shown in Figure 2 on the left. The second camera used for imaging was the thermoMAP. This thermal imager response is shown in Figure 2 on the right. The ground sampling distance (GSD) of multispectral images was approximately 11 cm for both years, and GSD of thermal images was about 16 cm for year 2016 and about 20 cm for year 2017. It was approximately 160 images taken by the multispectral camera and over 2000 images by the thermal imager. The thermal imager was used for continuous imaging and the multispectral camera for imaging in a precise position. Overlap and side lap of images were chosen at 60%. Thermal imager side lap was set at 60%. The accuracy of the projection center coordinates was equal to the GNSS code measurement (meter accuracy). The flight over the area was done together with perpendicular flight. Moreover, there were used other cameras for imaging in 2016 – Canon PowerShot S110 (NIR, R, G), Canon PowerShot ELPH 110 HS (NIR, G, B) and Canon IXUS 127 HS (R, G, B).

Data processing

Images were processed by Pix4D software. The processing was done without ground control points (GCPs), and it influenced the georeference of the orthophoto. There can be small shifts
usually up to few meters. Orthophotos can be shrunk a little, but the scale of the orthophoto is very close to 1. Outputs used for analysis created the orthophotos. The GSD of orthophotos corresponds to the GSD of the taken images. For multispectral orthophotos, it is about 11 cm for both years. For thermal orthophotos, it is about 16 cm for year 2016 and 20 cm for 2017. Thermal orthophotos are shown in Figure 3, and NIR orthophotos (from multispectral camera) are shown in Figure 4.

Mainly, it was important to georeferenced data. There were some residual shifts of orthophotos because of images processing without GCPs. Orthophotos had to be stretched for better visibility of data, for example, thermal orthophotos are 16-bit data and multispectral orthophotos are 8-bit data. Urn graves and tumulus are visible in a very short band of thermal data. This visualization was done for all of the orthophotos.
Data evaluation

Comparison of the thermal and NIR orthophotos from years 2016 and 2017 is shown in Figures 5 and 6. As you can see, there are no cropmarks of point features and tumulus in 2017. Figure 5 shows a comparison of a part of the thermal orthophotos depicted tumulus and its surroundings. The tumulus and point features were clearly visible in 2016. However, there are no cropmarks of the tumulus and point features for the thermal orthophoto taken in 2017.

Figure 6 shows the same area as Figure 5 for NIR orthophoto of the multispectral camera. The results are the same as for the thermal orthophoto, that is, very visible were the tumulus and point features in 2016, and there were no cropmarks in 2017.

By achieving these different results, we had to compare conditions for the occurrence of cropmarks of archaeological features. We can study the following: climatic conditions during the winter and the spring, influence of crops used and use of the thermal imager after crop season. This brings us to the following questions. Is there a correlation between cropmarks and climatic conditions during the crop season? What influence does the used crop have on cropmarks? Is it possible to identify archaeological features on the site without crops using thermal camera? More experiments were done to answer these questions.

Influence of climatic conditions and used crop to cropmark visibility

The following experiment was done to answer the first two questions. Another nine archaeological sites were chosen at the area, all of them were around the hill Říp. To find some correlation, it was observed whether there were cropmarks at the site during the year and what kind of crop was planted there. Orthophotos of the Mapy.cz, of the State Administration of Land Surveying and Cadastre (ČÚZK) and of the Google were used for our analysis. The data were available since 2003, but the quality was different. Sometimes, it was hard or impossible to decide which crop was used at the site. The list of archaeological sites used for analysis together with their WGS84 coordinates is as follows: Čtiněves 50.3764N, 14.3090E; Černouček 50.3566N, 14.3024E; Ledčice–Černouček 50.3505N, 14.2993E; Ledčice 50.3424N, 14.2969E; Ledčice fencing – 50.3333N, 14.2784E; Straškov–Vodochody 50.3622N, 14.2566E; Bříza–Račíněves 50.3664N, 14.2131E; Představky–Podlisky 50.4134N, 14.2121E; Roudnice nad Labem 50.4077N, 14.2418E; and Kostomlaty pod Řípem 50.3855N, 14.3318E.

Table 1 shows results of our cropmark visibility observation. Some years are missing in Table 1. We were not able to find any sources for years 2009 and 2012. We found just four planted sites without cropmarks in 2008 and only three sites without cropmarks planted in 2011.
Correlation between climate conditions and cropmark visibility

To answer whether there is a connection between climate conditions and cropmark visibility, we took years with cropmark visibility over 75% and years with cropmark visibility under 25%. These two sets were compared. Climatic data are freely available at sites of the Czech Hydrometeorological Institute. Data were available for the Doksany station (WGS84 – 50.4583N, 14.1703E, 158 m a.s.l.), which is the closest to the archaeological site, about 13.5 km far away. There has been only monthly station data as a graph since 2011. We tried to find correlation for mean air temperature, sum of precipitation, maximum of snow cover depth and sum of sunshine duration. Data interpolation had to be used for our analysis. Accuracy of our data interpolation was limited by pixel value. Pixel values are equal to 0.15°C for mean air temperature, 0.70 mm for sum of precipitation, 0.2 cm for maximum of snow cover depth and approximately 1.5 h for sum of sunshine duration. This station is about 31 km far away from our archaeological site.

Figure 7 shows monthly mean air temperature. As you can see, there is no correlation between years with good cropmark visibility (2015, 2016 and 2018 – warm colors) and years with no cropmarks (2013, 2014 – cool colors). If we focus on winter season or spring season, there is no pattern which could be found. There is a little higher temperature in May for years with cropmarks. We studied daily data from Praha–Ružyně station for verification of this phenomenon. We did not find significant pattern here as in the previous case, see Figure 8. Warm colors are years with good cropmark visibility (2015, 2016 and 2018) and cool colors are years without cropmarks (2013, 2014). If we focus on winter season or spring season, there is no correlation between cropmark visibility and monthly mean air temperature. The higher temperatures in May, which were visible in Figure 7, are not confirmed in Figure 8.

If we focus on a sum of precipitation per month, we can see that there is also no significant correlation, see Figure 9. You can see the decrease of sum of precipitation in May for years with cropmarks. If we compare it with larger data-set for Praha–Ružyně station, see Figure 10.
Figure 8. Monthly mean air temperatures for the Praha–Ruzyně station.

Figure 9. Sum of precipitation per month for the Doksany station.

Figure 10. Sum of precipitation per month for the Praha–Ruzyně station.
we achieve the same results as in the case of monthly mean air temperature.

We continued by evaluating maximum snow cover depth and the sum of sunshine duration. We did not find a correlation or a pattern between climate conditions and cropmark visibility.

Influence of used crop on cropmark visibility

For studying the influence of crops used, we tried to identify what kind of crop is planted at a site. We used data from years 2006 (Mapy.cz), 2010 (Mapy.cz, ČÚZK), 2015 (Mapy.cz, ČÚZK), 2016 (Mapy.cz, Google), 2017 (ČÚZK, Google) and 2018 (Google) for our analysis. Cropmarks were well visible in these years. Some sources have low resolution, bad color correction and so on. For example, data from year 2007 are available at the ČÚZK. An analogue camera was used that year. Photographic films were scanned and then digitally processed. This process brings a low color quality of orthophoto. However, there was good data quality for year 2006 at Mapy.cz. The orthophoto was created by Geodis s.r.o., and images were taken by digital camera. This orthophoto is the same as in Google Earth (2006). Images were sometimes taken in different months and even years for an orthophoto. Imaginary lines divide our area, and it defines the year of the orthophoto updates. For example, some sites were imaged by the ČÚZK in 2010 and some in 2011. Some sites were imaged on 22 May 2016 and 19 September 2016 by Mapy.cz. The archaeological site was sometimes divided by different crops. In this case, we included both crops into our analysis. Our observations are shown in Table 2.

If we focus on grain without further specification, we can find that grain cropmarks are visible in 34 cases. We have to take into account cropmark visibility. This was achieved by weighting. Weights were 1 for well cropmark visibility, 0.5 for cropmark visibility of main features and 0 for no cropmark visibility. Weighted visibility of cropmarks is 30.5. This leads us to cropmark visibility in the grain to 89.7%. Cropmarks were visible in five cases for the corn. By the same methodology, we achieved weighted visibility equal to 4. Cropmark visibility in the corn is 80%. There were just five cases of corn planting, which is too little for significant statistics. Finally, we can estimate cropmark visibility in the rapeseed oil. We found 10 cases with rapeseed oil. Weighted visibility is 4.5, and cropmark visibility is determined to be 45%.

It seems that rapeseed oil significantly decreased cropmark visibility. We found one example showing really visible cropmarks in rapeseed oil. It is site Představíky–Podluky, which was imaged by ČÚZK on 19 May 2017. However, cropmarks were significantly reduced in the rapeseed oil in other cases as shown in Figure 11.

Rapeseed oil is in the right part of Figure 11 on the left side of the image and grain is on the right side of the image. The distance between these sites is about 500 m and a road goes between them. As you can see that there were almost the same climate conditions in years 2006 and 2017. We can find that on the basis of cropmarks; see the settlement in Figure 11. The only significant influence is the crops used. Another similar example was recorded at Ledčice–Černouček site in year 2015 at ČÚZK.

We found that corn had better cropmarks at the beginning of July 2010 than later. ČÚZK did imaging on 3 July 2010. We estimated imaging of Mapy.cz to the end of August or September 2010 since more than half of the fields were harvested at the time. You can see examples at ČÚZK and Mapy.cz at sites Černouček (2010), Ledčice–Černouček (2010, 2015), Ledčice (2010) and Ledčice fencing (2010).

Identification of archaeological features on sites without crop by thermal imager

Our last experiment was done at the archaeological site Ctiněves on 13 October 2018. The area of site was imaged by a thermal imager at 5:30 a.m., 7:00 a.m., 8:30 a.m. and 10:00 a.m., the first time of the flight was equal to a period of the astronomical dawn. The second time of the flight corresponded to the civil dawn.

| Table 2. Observation of used crops; a visibility of cropmarks is listed before slash, 1 – well visible cropmarks, 0–1 – main objects are still visible, 0 – no cropmarks; identified crop is listed after slash, C – corn, G – grain, R – rapeseed oil, u – unidentified crop, 0 – no crop. |
|---|---|---|---|---|---|---|
| Ctiněves | 1/G | 0/u | 1/G | 1/G | 0/R | 1/G |
| Černouček | 1/G + G | 1/C + R | 0/u + R | 1/G + G | 1/G + u | 1/0 + G |
| Ledčice–Černouček | 1/G | 1/C | 1/G | 0/C | 1/G | 1/G |
| Ledčice | 1/G | 1/C | 1/G | 0/u | 1/u | 1/u |
| Ledčice fencing | 1/G | 1/C | 1/R | 0–1/G | 1/R |
| Straškov-Vodochody | 1/G | 1/G | 1/G | 0/u | 1/G |
| Brža–Račíny | 0/u | 1/G | 1/G | 1/G | 0–1/u |
| Představíky–Podluky | 1/G + u | 1/G | 0/R | 1/G | 1/R | 1/G |
| Roudnice nad Labem | 1/G + 0 | 0/u + 0 | 0–1/R | 1/G | 0/R + G + u | 0/R + G + 0 |
| Kostomlaty pod Řípem | 1/G | 0/G | 0/G | 1/G | 1/G | 1/G |
GSD was set to 15 cm, side lap was set to 70% and imaging was set to continuous. Flights were made together with perpendicular flight lines. One flight could not be completely finished because of low batteries. This influenced the processing and quality of orthophoto. The last two flights were made in daylight. These last two flights did not show any signs of archaeological features as shown in Figure 12. The site was completely influenced by sunshine.

The thermal orthophoto (taken at 5:30 a.m.) shows some features at the football pitch, see Figure 13. The rest of archaeological site is without any signs of point features or tumulus. It could be caused by the ploughing of the field by disk coulter. The field was still soft and the top layer of the soil was full of air. This created a layer of insulation, and it was impossible to detect any signs of point features or tumulus. As you can see, the direction of ploughing is very visible. The path going from the village to the football playground is visible too.

Figure 14 is a detail of the football pitch taken at 5:30 a.m. We can see several interesting features there. Large circles “A” having about 1/3 of width of the pitch are probably related to the watering of the pitch. There are linear features “B” going through the whole area from the left to the right and the lower one of them is going even behind the pitch. The feature “C” looks like car tracks. However, features “B” and “C” are visible at Mapy.cz in years 2010 and 2016 and at ČÚZK in 2010 at the same position and the same shape. This fact supports an idea about the same origin of features “B” and “C”. There are small circle features “D,” prob-
ably caused by mushrooms known as fairy rings. There are some point features “E” which could be the same point features as the ones on the archaeological site. These features have similar diameter as point features at the site. This is supported by conversation with the groundman at the place. He claimed that there were sometimes point features of the same size as on the archaeological site. It was observable during the summer when the playground was not watered enough. Moreover, it would be natural for the archaeological site to continue through the pitch.

Our first results show possibilities of thermal imager for archaeological features detection, but still more research has to be done. The advantage of this method is that our observation is independent on the cropmarks at the site and allows us to make measurements in a wider range of the year.

**Conclusion**

We found very visible cropmarks at the archaeological site during our research in 2016. However, no cropmarks were visible at the site in 2017. This fact brings us to the question whether there is a connection between cropmarks and climatic conditions during crop season. To answer this question, we found another nine archaeological sites. We studied cropmark visibility at these sites since 2003. Afterward, we compared climate conditions of years with good cropmark visibility and years without cropmarks. We did not find a significant pattern or correlation of climate conditions and cropmark visibility.

Then, we studied the influence of crops used on the cropmark visibility. Our results suggest that there was an influence to the cropmark visibility. Cropmarks were best visible with grain, and we achieved visibility close to 90% for years with suitable conditions for cropmarks in our research. Corn reached 80%, but we had too small sample composed of only five examples. Moreover, cropmarks in corn were better visible in July than in later months. Our last crop to study was rapeseed oil. Our results showed just 45% cropmark visibility in 10 cases. We found few cases where the visibility of cropmarks in the rapeseed oil was good. However, more of them had lower visibility of cropmarks as was shown in the example. We found that rapeseed oil reduces cropmark visibility.

Finally, our research was focused on using a thermal imager for the identification of archaeological features on the site without crop. We made several flights at different times over the site. Our best results were acquired before sunrise at night. Later flights were also influenced by sunshine. The sites were ploughed by disk coulter, which made a layer of insulation. Due to this layer, we were not able to find any archaeological features at the site. However, thermal imagery brought a new point of view to the football pitch. We found several kinds of features there. Some of them were from recent times, for example, linear features and large circles; some of them were probably caused by mushrooms known as fairy rings; and some of them could be archaeological features.

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