THE PHOTOGRAMMETRIC POTENTIAL OF LOW-COST UAVs IN FORESTRY AND AGRICULTURE

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Commission I ICWG I/V - ThS-23

KEY WORDS: Digital airborne imaging systems, UAV, Agriculture, Accuracy assessment, Forestry

ABSTRACT: Micro-UAVs (Unmanned-Airborne-Vehicles or drones) with a total weight below 5 kg are interesting alternative carriers for agricultural and forestry applications. Compared to standard airborne aerial surveys UAVs are much more flexible and weather independent. As a result micro-UAV surveys will pave the way for affordable, current and accurate geo-information. Practical tests with two different systems at several locations revealed that both systems were capable of acquiring images in a systematic manner. However the necessary post processing effort in order to obtain photogrammetric products suitable for a GIS was quite high. The photogrammetric potential for direct georeferencing of micro-UAVs is quite high, but until now has not been fully exploited. This is primarily due to the fact that the manufacturers of UAVs are not aware and familiar with the special requirements of photogrammmetry and GIS data acquisition, e.g. metric cameras, systematic aerial surveys, precise values of the exterior orientation.

1. INTRODUCTION

Remote sensing applications for agriculture and forestry often require images with a high temporal resolution, e.g. Grenzdörffer, 2003. This is difficult and / or costly to obtain, either by satellite imagery or by conventional airborne data. Therefore, unmanned drones equipped with GPS and digital cameras, so called Unmanned Aerial Vehicles (UAVs), have become a focus of research. The autonomous navigation of an UAV is realised using GPS, inertial measuring techniques and the utilisation of other sensors. Only the programmable autopilot enables serious photogrammetric work, thus enabling systematic, rapid and efficient mapping of areas of interest. Remotely piloted vehicles (RPV) with a video downlink are not suited for photogrammetric work because the navigation and the image triggering can not be done systematically. The UAV technology is mainly driven by the military (>80 %) (UAS, 2007) but there are also developments in the civilian sector, e.g. Eisenbeiss, 2004. In Germany so called Micro-UAVs with a total weight of less than 5 kg may be used in the uncontrolled airspace below 300 m. Other restrictions however apply, especially in urban areas, which means that applications in sparsely-inhabited areas e.g. for forestry, nature conservation and agriculture are at the forefront of micro-UAV research.

1.1 Applications in agriculture and forestry

In forestry and nature conservation UAVs may be used for many applications, such as (Horcher und Visser, 2004):

- Forest fire detection
- Monitoring for legal restrictions and evidence in case of violations / infringements
- Locating harvest sites and inspecting forestry operations
- Monitoring and change detection within natural forests, where trespassing is difficult or undesirable

In agriculture UAVs may be used for:

- Field trials and research, e.g. Annen und Nebiker, 2007
- Determination of the biomass, crop growth and food quality, e.g. Herwitz et al., 2004
- Precision Farming, e.g. to determine the degree of weeds for site specific herbicide applications. Also a reduction of fungicides due to site specific applications in potato production is of interest, e.g. Grenzdörffer, 2003 Reidelstürz et al., 2007
- Senescence monitoring of cereals and maize for harvest- and logistic optimisation.

All of the mentioned fields of application are characterised by a relatively small extent of less than 1.500 ha and the necessity of a rapid data availability and data analysis. The required absolute positional accuracy is on the other hand quite low (< 1 m). Beside a visual analysis of the images many of the above mentioned applications require images to be integrated as georeferenced and orthorectified products in a GIS for analysis with other GIS data.

2. STATE OF THE ART

Internationally there is little work on the issue of UAVs and agriculture. Some examples may be found e.g. in the US a RPV-system named Crop Condor (http://www.calmarlabs.com/condor.html) was developed. In

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Canada the UAV-system CropCam (http://www.cropcam.com/index.htm) is in the market and in Europe a helicopter based system is under development, Annen und Nebiker, 2007.

However current civilian and affordable UAVs are still not able to fulfil the previously listed requirements. In recent years UAVs have rarely been considered for civilian photogrammetry. The system design and the photogrammetric results largely depend upon the UAV and the sensor systems, such as the digital camera and the GPS/INS used, e.g. Jang, et al., 2004, Haarbrink & Koers, 2006. The accuracy of the GPS and the inertial measurement unit (INS) determines the degree of automation by means of aerotriangulation or direct georeferencing. Using mini or micro UAV-systems with consumer type digital camera for mapping and photogrammetry, several problems have to be mastered:

- No vertical adjustment of the aerial camera, which results in tilted pictures caused by wind influences or instability of the platform. Furthermore to ensure complete photogrammetric block configuration the end lap and the side lap have to be relatively high (70 / 70 %), compared to standard aerial surveys.
- Due to the small system size and the low-cost approach, small, inaccurate GPS-receivers and INS with a strong drift are used which do not allow for direct georeferencing. The quality is not even good enough to provide reasonable starting EO-values for the aerotriangulation process.
- Consumer grade cameras have an unknown or variable interior orientation of the camera.
- Many images with small footprints, due to legal restrictions in Germany and elsewhere, RPVs and UAVs may fly only at altitudes of less than 300 m. In turn this leads to a small footprint of a single image. For instance a wide angle image will cover an area of only 200 * 300 m.
- The number and distribution of the ground control points (GCP). Due to limited accuracy of the exterior orientation, the small footprints, critical overlaps due to winds and other factors a large number of GCPs are necessary.

Beside the conventional approaches of aerotriangulation of image blocks, other procedures were developed in recent years which use existing ortho imagery of the area, e.g. the module Autosync/ERDAS Imagine, Jizhoua et al. (2004). Other approaches, e.g. Läbe und Förstner (2005) automatically determine the relative orientation of overlapping images. There is however still a strong demand for further research.

3. COMPARISON OF TWO MICRO UAVs

The empirical tests of the photogrammetric potential with two different micro-UAVs were conducted within the Masters thesis of ENGEL, 2007. In the following sections the two different systems will be presented and the results of the empirical flight tests will be presented under the special focus of their photogrammetric performance.

3.1 Micro-UAV “Carolo P330”

Mavionics GmbH develops and sells autonomous aircrafts for different civilian fields of applications. One of the systems is called „Carolo P330“, which has been used for the practical tests, see (Figure 1).

The UAV consists of a model plane, the Mavionics autopilot system, including data transmission, the mission control software (MCS) and a remote control for manual manoeuvres. The model aircraft is powered by a brushless DC-motor. The standard payload is a cheap off the shelf digital camera (Canon Powershot S60). The technical parameters of the UAV are compiled in Table 1.

Figure 1: UAV “Carolo P330” (www.mavionics.de)

The functionality and the necessary workflow for photogrammetric aerial surveys may be subdivided into three different steps:At the beginning a georeferenced map with the survey area is put into the Mission Control Software (MCS). The next step the MCS generates the flight strips with the necessary information such as distance between adjacent strips, flight height, flight speed. Every strip has a minimum of two waypoints at the beginning and the end of a strip. The turn to the next strip is flown in a constant radius. Thereby the minimum radius is limited to 30° in the roll angle by the MCS in order to avoid an instability of the aircraft. The GPS-module within the autopilot is important for the navigation and also delivers the coordinates / time of the perspective centres of the acquired images. The inertial sensor system of the autopilot which is tightly coupled with the GPS measures the rotation speed and the translatory inertia. Therefore approximate values of the exterior orientation are available.

Starting and landing of the model plane is still done manually. After the start, once the aircraft is approximately at the first waypoint, the autonomous control of the UAV takes over. During the flight the course of the model plane may be visually controlled by a laptop. After the successful aerial survey the RC-pilot takes over again and lands the UAV safely.

3.2 Low-cost Micro-UAV “SUSI”

The micro-UAV called “SUSI” serves for the state forestry administration of Mecklenburg-Vorpommern and was formerly developed by the French company ABS Aérolight. “SUSI” assists the forestry administration in their every day operation. The UAV is based on a low-weight tubular frame with three low pressure tires. Within this frame the 4.2 KW two-stroke engine, the digital camera, the servo-mechanism, the batteries, petrol tank and an additional video camera are placed. During the flight a paraglider with a surface of 3.8 m² keeps the UAV in the air. The paraglider is responsible for a slow and non problematic handling and ensures a high reliability in case of an engine failure, Figure 2

The core of the UAV is the digital camera within a gimbal-mounted platform in order to obtain near nadir looking images.

The exposure of the images is done mechanically whereby an electrical impulse triggers a mechanical device which in turn triggers the camera. Approximate values for coordinates (X, Y, Z-position) of the perspective centre and the flight direction ĸ are obtained via a GPS-logger (GlobalSat DG 100) which records a GPS NMEA-string every second.

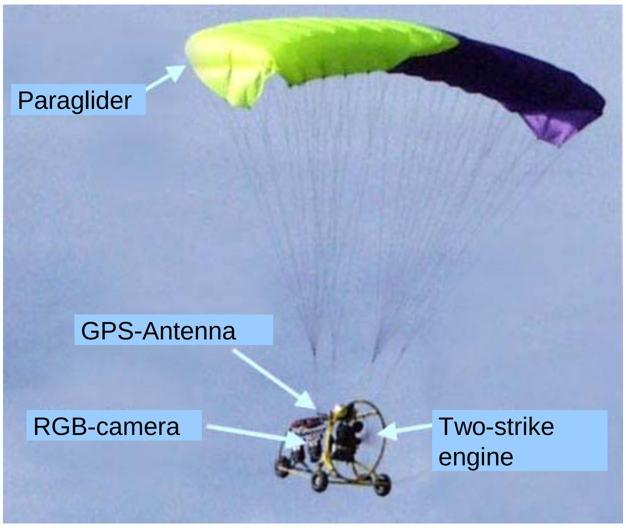

Figure 2: UAV “SUSI” in the air

After the flight the GPS-data and the recorded trigger impulses are synchronised. During the flight the GPS-data is down linked to ground and serves for the navigation of the UAV on a laptop. On the laptop the GPS-data is displayed on top of a georeferenced map or an aerial map to support the navigation and the triggering of the images once the UAV is within the survey area. The most important technical parameters of the two micro-UAVs are summarised in Table 1.

	UAV Carolo P330	UAV „SUSI“
Type of aircraft	Model plane	Paraglider UAV
Weight	5 kg (max. payload 0.4 kg)	5 kg (max. payload 5.0 kg)
Speed	16 m/s - 30 m/s	0 m/s - 8 m/s
Range	+++	++
Endurance	max. 60 min	max. 140 min
Weather and Wind dependency	++	+++
Sensor platform	Fixed, camera inside model plane	Gimbal-mounted platform
GPS transfer / recording	Downlink and onboard storage	Downlink and no onboard storage
Synchronisation GPS/camera	Not available	Not available
Sensor	Canon PowerShot S60	Sony DSC R1
Sensor size (calc.)	7.176 * 5.319 mm	21.5 * 14.4 mm
Resolution (pixel)	2,592 * 1,944	3,888 * 2,592
Pixel size (calc.)	2.7 µm	5.5 µm
Type of chip	CCD	CMOS
Exposure interval	fixed, every 5 s	manually
Exposure delay	not applied (~ 0,15 s)	not applied
Navigation	autonomously (Way Points)	Manually (display on PC)

Table 1: Comparison of the two Micro-UAVs “Carolo P330” and “SUSI”

3.3 Interior Orientation

The determination of the interior orientation is necessary for both Micro-UAV’s which use off-the-shelf digital cameras. The calibration was done with the software “Australis” , Version 6.0 from Photometrix (www.photometrix.com.au). Internally the software is based upon a free network optimisation. The test field calibration was done with a flat test field. The test field, which consists of 35 retro targets has an extent of approx. 3.5 * 4.0 m. Images were taken from 5 different positions. A total of 14 converging images were taken for a calibration. The software computes the full range of the interior orientation parameters. Because for the later processing the photogrammetry software LPS was be used, a calibration with a limited set of parameters (focal length, image center, radial distortion) was conducted. A graphic display of the radial distortion of both cameras (Figure 3) shows that the Sony DSC R1 is nearly free of radial distortion, while the Canon PowerShot reveals a very strong radial distortion of up to 100 pixels at the image corners.

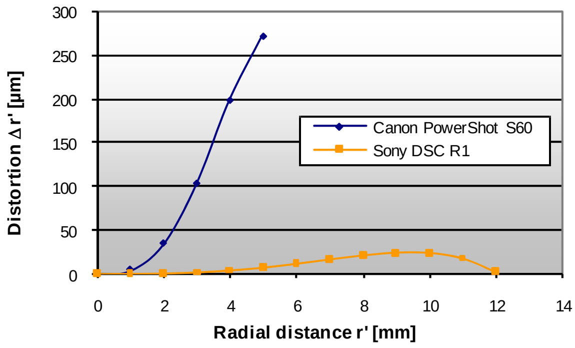

Figure 3: Radial distortion of Canon PowerShot S60 and Sony DSC R1

4. RESULTS

4.1 Test flights

A total of three test flights were conducted to obtain practical information of the photogrammetric performance of the two Micro-UAVs. Two test flights were carried out with the System Carolo P 330 on 4th May 2007. Beside the pthotogrammetric analysis the data should be used for a vitality analysis of field trials at the University of Applied Science in Soest. The weather conditions for the flights were quite suitable apart from a wind of ca. 3 Bft. Due to the small size of the first test site (200 × 450 m) Merklingen 1 (M 1 in table 2) the first flight was conducted manually. The second test site Merklingen 2 (M 2) with an area of 1000 × 750 m was flown autonomously. The test flight Wahlsdorf (W 1) (300 × 500 m) with the system

"SUSI" took place on 23.05.2007. Changing winds prohibited a systematic aerial survey, thus several attempts were necessary to cover the area appropriately.

4.2 Photogrammetric workflow

The workflow of the photogrammetric data processing from single images to an orthophoto mosaic by using the software Leica Photogrammetry Suite (LPS) 9.1 is shown in Figure 4.

The primary goal was a more or less automated workflow. Due to several problems during the aerial surveys, it turned out that several manual and semiautomatic steps are required in the processing chain of the data, Figure 4. For instance the autonomous navigation did not work properly which resulted in rather unsystematic strips. In turn after the flight the best image data from different strips had to be selected manually. Furthermore due to wind the side lap and the end lap did not always confirm to the standard configuration of a photogram-metric block. The approximate values of the GPS/(INS)-data were not accurate enough to start the process of automatic tie point generation. This is due to the fact that the small model planes reveal strong variations in the roll and pitch angle and also the time synchronisation between the GPS-data and the images was not always correct. This led to a first step of manual tie point generation. In the next step automatic tie point generation could be performed to stabilise the block. Beside precisely measured ground control points the GPS-positions of the images were introduced into the aerotriangulation with a low a priori accuracy of ± 4 m.

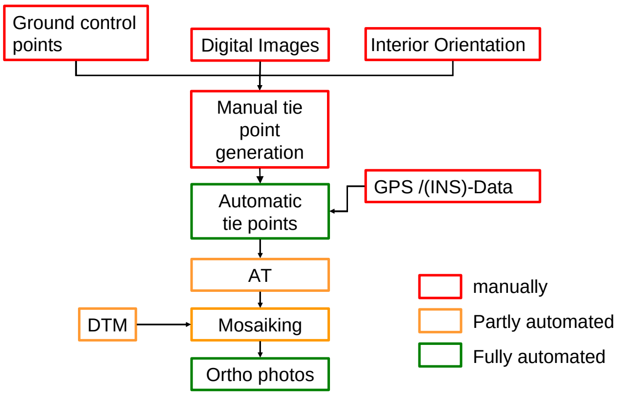

Figure 4: Photogrammetric workflow of the UAV-images

The results of the aerotriangulation of the different blocks are compiled in Table 2.

	M 1	M 2	W 1
No. of images	17	45	11
Ground resolution (GSD) [m]	0.07	0.08	0.08
No. GCPs	6	20	16
No. of Tie Points	290	1100	384
Total RMS [Pixel]	4.62	1.43	0.38
Residuals			
GCP X [m]	0.37	0.14	0.04
GCP Y [m]	0.59	0.08	0.04
GCP Z [m]	0.58	0.27	0.03
Image coordinate X [Pixel]	6.44	1.54	0.37
Image coordinate Y [Pixel]	7.75	1.17	0.54

Table 2: Results of the aerotriangulation of the three blocks

The results in Table 2 require further explanation because the circumstances of the three flights were different. To show the differences of the two imaging systems the blocks M2 and W1 will be described in more detail.

4.2.1 Flight 2 Merklingsen (M2)

For the block M2 a total of 45 images were selected. Due to the high speed of the UAV and wind gusts an end lap of 60 % could not be realised. The side lap is also low or even not existent between some of the image strips. see Figure 5.

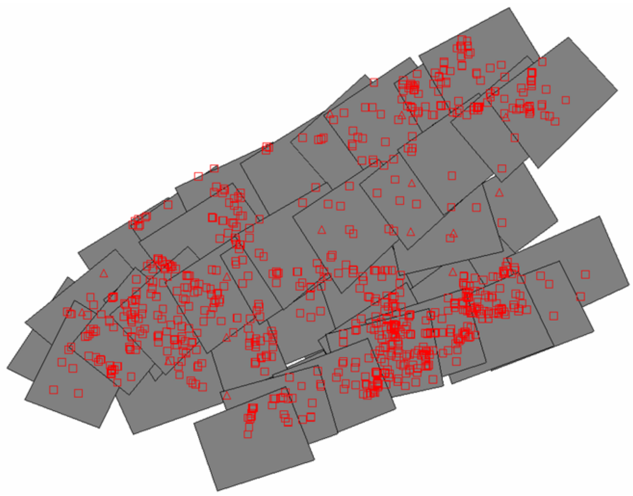

Figure 5: Block Merklingsen 2 (M2)

By using 20 precisely measured ground control points (GCP's) the aerotriangulation yielded an inner accuracy of the block with ± 1.54 pixel (= ± 4.2 µm) in *X* and ± 1.17 pixel (= ± 3.2 µm) in *Y*, measured in image coordinates. This result is within the expected limits, taking the block geometry and the geometric quality of the camera into account. The positional accuracy on the ground is 0.14 m in *X*, 0.08 m in *Y* and 0.27 m in *Z*. The accuracy in *Z* is lower than in *X* and *Y*. This is most probably due to systematic errors in the focal length, a common problem with consumer grade digital camera with a variable zoom lens, Remondino and Fraser (2006).

The radiometric quality of the images is quite different due to different shutter speeds and the fact that some of the images were true nadir images due to side winds. Even thorough dodging and colour balancing could not prevent radiometric differences in the final ortho photo mosaic, see Figure 6.

4.2.2 Block Wahlsdorf (W1)

The block Wahlsdorf (W1) consisted of two strips with a total of 11 images. It has a high side lap (60 %) and an end lap of 80 %. The aerotriangulation with 11 GCPs resulted in a high internal block accuracy (RMS) of ± 0.36 Pixel (= ± 2 µm) in image coordinates at an image scale of 1:14.300 and a GSD of 0.08 m. The accuracy in ground coordinates at the GCPs is ± 0.04 m in *X* and *Y* and with ± 0.03 m in *Z* within the expected values.

Figure 6: Orthophoto mosaik Merklingsen 2 (M2)

4.2.3 Accuracy assessment

The determination of the residuals at GCPs generally provides optimistic accuracy values. Therefore some of the GCPs were declared as checkpoints. For the Flight M 2 the average accuracy at the checkpoints were -0.13 m in X, 0.01 m in Y and 0.00 m in *Z*. For the flight W1 the average residuals were -0.04 m in *X*, -0.01 m in *Y* and -0.08 m in *Z*. The values show that the high stability of the block W1 and the high quality camera allow for a block with reliable subpixel quality. The perspective centres become well determined by the aerotriangulation. A comparison to the a priori GPS / INS values measured during the flight is given in table 3.

	M 1	M 2	W 1
Coordinates [m]			
σ (Δ X)	16.92	4.47	7.53
σ (Δ Y)	16.64	2.33	21.82
σ (Δ Z)	3.44	2.41	46.89
Attitude angles [°]			
σ (Δ ω)	8.37	8.33	-
σ (Δ φ)	8.58	5.95	-
σ (Δ κ)	26.15	20.97	-

Table 3: Standard deviations of the differences between the approximate exterior orientation parameters of the aircrafts and final values of the aerotriangulation

The high deviations reveal that the approximate values of UAVs are only a little help in the photogrammetric processing chain. Reasons for the differences are of systematic and unsystematic nature. Unsystematic sources are related to a missing /incorrect time synchronisation between the camera exposure and the associated GPS-position. Also the accuracy of the GPS itself (no DGPS), wind gusts and other factors may be sources of errors. Likewise there is the strong drift of the miniaturised inertial sensors. Another current problem is the axes of the acceleration sensors do not coincide with the coordinate axes of the camera, because the integrated GPS/INS solution has been developed for the autopilot functions of the model plane and not for photogrammetric applications.

5. PHOTOGRAMMETRIC POTENTAIL OF MICRO-UAV'S

Despite the poor results of the empirical tests there is high photogrammetric potential for direct georeferenciong of Micro-UAVs. This potential is limited by a number of factors. The theoretical optimum of the direct georeferencing is determined by the accuracy of the GPS/INS and the flying height. For instance using the new MINC autopilot system of Mavioncis with an attitude accuracy of 0.6 – 1.2° and a flying height of 300 m results in a theoretical positional accuracy of 3.15 – 6.3 m. However the theoretical accuracy level is not achievable, even for highly sophisticated solutions, Grenzdörffer and Zuev, 2007. The following Table 4 gives an overview of the relevant factors, which may influence the accuracy of the direct georeferencing of an UAV:

Source of error	**Problem**	**Possibility of correction**	**Impact on accuracy ***
Interior orientation			
Changes of centre point	With zoom lenses of consumer cameras the centre point may change	Given: camera calibration before the flight or simultaneous calibration	Systematical error, > 1 m
Changes of focal length	With zoom lenses of consumer cameras the focal length may change	Given: camera calibration before the flight or simultaneous calibration	Systematical error, > 1 m
Radial distortion	Nearly constant over time	Generally not necessary, but correction available with every calibration	Systematic, increase toward image corner
Exterior Orientation			
Time synchronisation between GPS and camera	Unknown exposure time of camera, related to GPS time stamp	Given: Synchronisation of camera and GPS	Non systematic error, > 4 m
GPS	No DGPS	Given: use of DGPS-Logger /	Large (< 4 m)

		postprocessing	
Exposure delay	Unknown, variable	Given: measurement of the exposure delay and examination of delay pattern	Systematical error, 1-3 m
Instability of the platform	No vertical images, due to winds and accelerations	Not given	Non systematic error, 3-5° → 5-9 m
External factors			
DEM (constant height value)	Differences in elevation in the area, no DEM available	Given: application of a better / more accurate DEM / ortho rectification	Non systematic error < 5 m
JPG-Compression	Poor image quality / problems at automatic tie point generation	Given: may be reduced by lower compression / more storage space	Small < 0.5 m
Wind gusts	Influences the speed of the UAV→ image overlap, block stability	Partly given: await weather with low winds	Large (> 5 m)
Image motion	Image motion due to high speeds at low altitudes above ground of the UAV, No FMC	Given: use of camera with a large pixel size per CCD-element and short exposure intervals	Medium (> 2 m)

Table 4: Factors influencing the direct georeferencing of UAVs

6. OUTLOOK AND FUTURE WORK

Despite the above mentioned problems the system SUSI is currently used in the state forestry administration of Mcklenburg-Vorpommern quite successfully for a large range of forestry applications. Yet further improvements for the two Micro-UAV systems are necessary and should eliminate their specific weaknesses. The biggest improvement of the system SUSI should be an autopilot and an automated electronic flight management system in order to perform systematic aerial surveys. A better camera with higher resolution and shorter exposure interval and the synchronisation between the triggering of the camera and the recorded GPS-signal should be the first steps of improvement for the system Carolo P 330. The second step includes improvements in the autopilot system and a translation of the attitude angles of the INS into the photogrammetric angles.

The large application potential of Micro-UAVs is directly linked to a precise and economic photogrammetric workflow. On one hand the generation of image mosaics, the incorporation of images in a GIS and 2D- or 3D-data analysis are based on precise geo referencing. On the other hand the effort for an aerial survey and the post processing of the data has to be cost efficient. It is too early for a reliable comparison of Micro-UAVs and common aerial surveys because the development of the Micro-UAVs for this kind of applications is still at an early stage.

To sum up, current micro-UAV-systems have a great potential for many applications which require up to date data of small objects. Efficient geo referencing is a key issue. Therefore it is necessary that the developers of the UAVs and autopilots have to understand the special requirements of photogrammetry. Additionally, photogrammetrists have to develop new methods for efficient geo referencing and also use the potential for direct georeferencing.

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