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# ROTARY-WING REMOTELY PILOTED AIRCRAFT APPLIED TO VEREDAS STUDIES

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## ABSTRACT

Veredas (palm swamps) are important Cerrado biome physiognomies, and still little studied. In this context, the development of geotechnologies can provide an important contribution to facilitate further studies of these wetlands. Specifically, the use of Remotely Piloted Aircraft (RPA) to obtain aerial photographs of high spatial resolution may represent a facilitating mechanism for studies in Veredas. Thus, we aimed to evaluate the possibility of using rotary-wing RPA as a resource for obtaining aerial photographs that make it possible to delimit and distinguish different strata of vegetation cover, as well as buritis (*Mauritia flexuosa*) within this physiognomy. Aerial survey was carried out in 30 Veredas, located in three Cerrado hydrographic basins. Subsequently, aerial photographs were processed in order to check the possibility of extracting the desired information. Our study showed that the Phanton 4 Pro system equipped with a digital camera, model FC6310, with 20 MP CMOS sensor, mechanical shutter and FOV 84° 8.8 mm / 24 mm lenses, small-format camera used in this research, is a reliable means for obtaining aerial photographs and can be used as a source of information for environmental studies of Veredas.

**Key words:** Hydromorphic fields. Geotechnology. Aerial photograph. Environmental studies.

# AERONAVE REMOTAMENTE PILOTADA DE ASAS ROTATIVAS APLICADA AO ESTUDO DE VEREDAS

## RESUMO

Veredas são importantes fisionomias do bioma Cerrado, e ainda pouco estudadas. Nesse sentido, o desenvolvimento de geotecnologias pode fornecer importante contribuição para facilitar a realização de novos estudos dessas áreas úmidas. Especificamente, o emprego de Aeronaves Remotamente Pilotadas (ARP) na obtenção de fotografias aéreas de alta resolução espacial, pode representar um mecanismo facilitador de estudos em Veredas. Assim, objetivamos avaliar a possibilidade de utilização de ARP de asas rotativas como recurso para obtenção de fotografias aéreas que possibilitem a delimitação e a distinção dos diferentes estratos da cobertura vegetal, bem como dos buritis (*Mauritia flexuosa*) no interior dessa fisionomia. Foi realizado levantamento aéreo em 30 Veredas, inseridas em três bacias hidrográficas do Cerrado. Posteriormente, processamos as fotografias aéreas, a fim de verificar a possibilidade de extração das informações pretendidas. Nosso estudo mostrou que o sistema Phantom 4 Pro equipado com câmera digital, modelo FC6310, com sensor CMOS de 20 MP, obturador mecânico e FOV 84 ° 8,8 mm / 24 mm, câmera de pequeno formato utilizada nesta pesquisa, é um meio confiável para a obtenção de fotografias aéreas e podem ser utilizadas como fonte de informações para estudos ambientais das Veredas.

**Palavras-chave:** Campos hidromórficos. Geotecnologia. Fotografia aérea. Estudos ambientais.

## INTRODUCTION

Brazilian Cerrado form a mosaic of physiognomies, consisting of herbaceous vegetation (mainly grasses), as well as shrubs and sparse trees. They are usually found in soils that are acidic, gently undulating and with a well-developed water network (WALTER; CARVALHO; RIBEIRO, 2008). One of these important, complex and unique phytophysiognomies is the Vereda (palm swamp), which has different geomorphic features, hydromorphic soils rich in organic matter, with predominant palm tree *Mauritia flexuosa* occurrence, popularly known as buriti (MELO, 2008). Veredas show water emerging from the soil and function as discharge zones, which maintain water courses perenniality connected to them (MELO, 2008). In addition, function as refuges and animal watering, maintain interrelations with other subsystems and play a role of natural ecological corridors, allowing the biotic flow of plant and animal (MELO, 2008; CASTRO, 1980). They are also important for soils conservation and biodiversity maintaining, especially the herbaceous-gramineous component. Even with such importance and functionality, Veredas have been degraded, often transformed into dams for irrigation or occupied by crops, no longer serving as corridors and biota shelters (MELO, 2008). As an aggravating factor, there are few studies on its geoenvironmental aspects (MELO, 2008), and knowledge is still incipient to cover the particularities found in the vast Cerrado expanse. In addition, they are ecosystems sensitive to change and with low resilience potential (BRANDÃO; CARVALHO; BARUQUI, 1991). Thus, it is necessary to conduct studies for better detail environmental dynamics.

In this context, geotechnologies can bring an important contribution, with reduction of costs, greater ease and speed in obtaining information (VEIGA and SILVA, 2004). With several components, geotechnologies can contribute to studies in different areas of knowledge, how instrument of landscape analysis and technological advances. Although Remotely Piloted Aircraft (RPA) is not such a recent technology, its systematic use as a geotechnology tool is still at an early stage, especially in Brazil. Several studies are still focused on the evaluation of the applicability of RPA as a source of data for studies in methodological development which makes this applicability possible. In Brazil, studies are recent and concentrated in this last decade (*e.g.* LONGHITANO, 2010; FERREIRA, 2014; SERRA, 2014; ALVES JÚNIOR et al., 2015; FRANÇA, 2015; LUZ and ANTUNES, 2015; SOARES, 2018).

For a long time, photographs served as the basis for representing and locating objects in space. However, the cameras were limited to the point of view near the surface, which was altered with the aerial photographs (FRANÇA, 2015). The emergence of aerial photographs, in addition to technological and aviation advances, led to the development of RPA with potential aerophotometrics (LONGHITANO, 2010). With advanced technological support, RPA has become an alternative technology for large-scale mapping (EISENBEISS, 2009).

In Brazil, RPA are widely known as drones. According to the International Civil Aviation Organization (OACI), unmanned aircraft (UA) are subdivided into three categories: Remotely Piloted Aircraft (RPA), Model Aircraft and Autonomous Aircraft. The first two are unmanned aircraft and piloted from a remote piloting station. However, RPA, unlike model aircraft, are used for non-recreational purposes and have the ability to integrate and interact with the environment in real time. Differently, unmanned aircraft classified as autonomous, not allowing human intervention once the flight begins (BRASIL, 2020). In Brazil, RPA are classified according to maximum takeoff weight and divided into classes: 1. greater than 150 kg; 2. greater than 25 and up to 150 kg; 3. up to 25 kg (BRASIL, 2017). These aircraft can also be divided into fixed wings or rotary wings.

In recent years, RPA photogrammetry applications have become common due to the dissemination of low-cost Global Positioning System/Inertial Navigation System (GPS/INS) (EISENBEISS, 2004), which, together with stabilization and navigation units, enable precise flights (EISENBEISS, 2009). The use of RPA has been greater among professionals working with the geotechnologies tools, mainly due to the relatively low cost when compared to traditional aerophotogrametric surveys (ALVES JÚNIOR et al., 2015; LOPES, 2015). The good performance at low altitudes and flexibility in maneuvers has increased the use of these aircraft in environmental cartography. Yet, can serve as a support to mapping of natural resources and environmental impacts, in a highly detailed spatial and temporal scale; mapping of land use and occupation, vegetation and large mammals (KOH, 2012, apud SOARES, 2018); studies on changes in the landscape (FRANÇA, 2015); monitoring and prevention of fires (GONZALES et al., 2016; SOARES, 2018); as an auxiliary resource for monitoring degraded areas, erosions, sanitary control and fires (SOARES, 2018); verification of risk areas (COSTA JÚNIOR, 2017). They can also offer a good level of detail and accuracy, bringing the possibility of being incorporated into Geographic Information System (GIS) (ROBERTO, 2012). Thus, the main advantages of remote sensing by RPA can be reduction of costs; greater flexibility of temporal resolution for the acquisition of high spatial resolution images; the possibility of performing missions under adverse conditions; less need for spending on pilot training; greater ease and speed to incorporate new technologies (LONGHITANO, 2010); capacity to acquire data quickly, including in real time (EISENBEISS, 2004).

Although fixed-wing RPA are the most widely used equipment in aerophotogrametric survey, currently, rotary-wing RPA have also been used. They have been gaining ground for more specific applications, such as transmission line inspections and small areas mappings. The advantages of this type of aircraft in comparison to fixed-wing ones are the ability for vertical landings and takeoffs, requiring little space; easy operation and navigability; in addition to the possibility of static flight and lower flight. As disadvantages, they have reduced flight time, making it impossible to use them to cover large areas, and the limitation of physical space to attach different types of sensors. However, fixed-wing aircraft have advantages of higher speed and flight autonomy, being able to cover larger areas; increased payload capacity, making possible to use more than one sensor system or a simpler exchange of sensor systems. The negative points of fixed-wing RPA are the need for more suitable locations for landings and takeoffs and not performing static flight and low-altitude flight. Although rotary-wing RPA have limitations, some studies have used this type of aircraft, such as the experimental hexacopter with the 3dr APM controller (*e.g.* LOPES, 2015); experimental hexacopter based on components of the manufacturer Mikrokopter and with autopilot from Ardupilot Mega (*e.g.* SILVA et al., 2014); experimental quadcopter built with the free software controller Ardupilot® (*e.g.* SOARES, 2018); and quadcopter MD4-1000 (*e.g*. PEGORARO and PHILIPS, 2011).

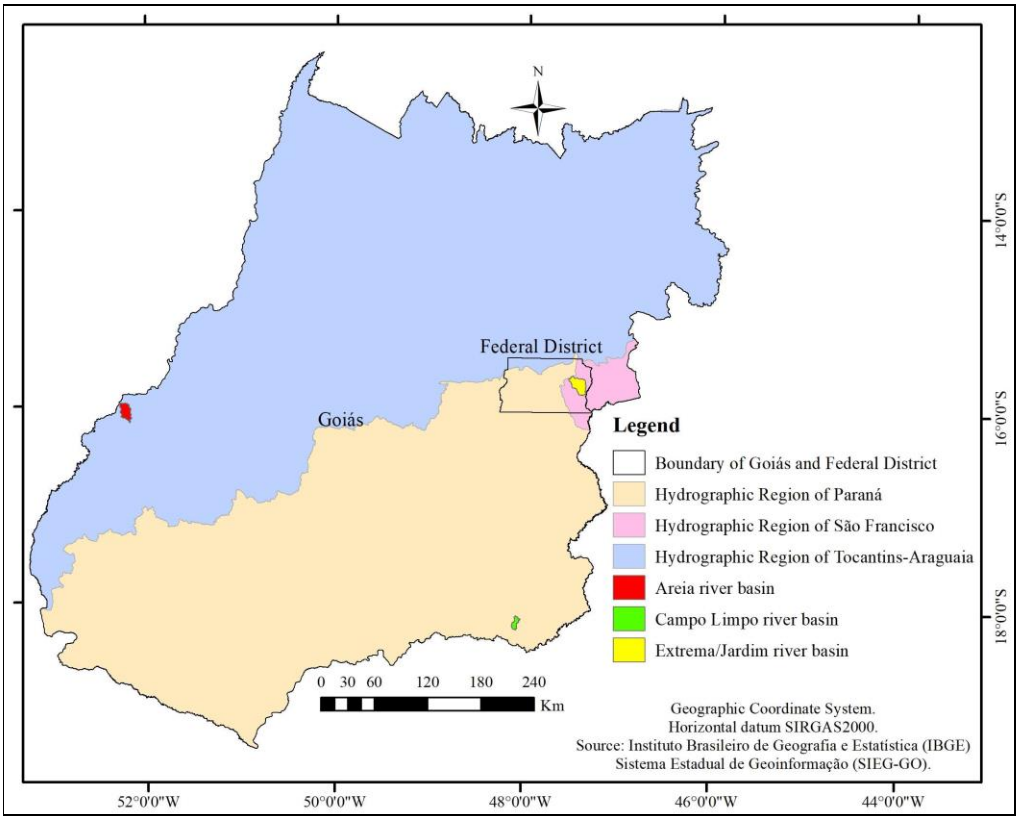
In our study we used Phantom 4 Pro model, which was not specifically designed for aerial survey. However, due to the quality of its controller systems and its embedded camera, it had this possibility of use (*e.g.* FIGUEIREDO and FIGUEIREDO, 2018). In technical case, Silva Neto et al. (2018) tested this model and validated the possibility of its use with capacity to generate aerial mapping with classification A, according to the Standard of Cartographic Accuracy for Digital Cartographic Products (PEC-PCD), at 1:1000 and 1:500 scales.

So, the current study aimed to assess the possibility of using rotary-wing RPA as a resource to obtain aerial photographs that make it possible to delimit and distinguish the different strata of vegetation cover, as well as buritis inside Veredas. For this, we selected 30 Veredas distributed in three important hydrographic basins of the Cerrado biome. After defining the study areas, we performed the aerial survey, with further processing and data analysis.

## MATERIAL AND METHODS

For aerial photographs collection, three hydrographic basins were selected in the Cerrado core area, with tropical climate, and distinct Veredas in evolutionary, geomorphological and biogeographic processes. The basins selected were Areia river basin, located in Tocantins/Araguaia hydrographic region; Campo Limpo river basin, located in Paraná hydrographic region; and the basins of Extrema and of the upper course of the Jardim river, called the Extrema/Jardim river basin, located in São Francisco hydrographic region (Figure 1).

Figure 1 - Hydrographic regions of Goiás and the Federal District with hydrographic basins selected for the study.




Source - Prepared by the author from IBGE databases made available by SIEG (GOIÁS, 2020).

Areia river basin has an area of 187.99 km² and is located in the western Goiás state, municipalities of Aragarças and Bom Jardim de Goiás. Geologically located in Paraná Sedimentary Basin, Itararé Group, Aquidauana Formation. According to the geomorphological synthesis of Mamede (2000), the basin is situated in the Araguaia Depression. *Latossolos* (Oxisols), *Argissolos* (former Podzolic - Ultisols) and *Neossolos* (Entisols) (IANHEZ et al., 1983.) predominate in the region. The vegetation is composed of Forest formations (Cerradão, Riparian Forest and Gallery Forest) and Savanna formations which occupy most of the basin, mainly the dense Cerrado *sensu stricto*, with considerable presence of Veredas.

Campo Limpo river basin has an area of 73.78 km² and is located in the southeast Goiás, municipalities of Goiandira and Cumari. In the geological context, is part of the southern segment of the Brasília Belt, in the following units: Orthogneiss-Granitic (Jurubatuba Suite) and Araxá Group (Unit A). Considering the geomorphological compartmentalization of Mamede (2000), it is situated in the *Planalto do Alto Tocantins-Paranaíba* (Upper Tocantins-Paranaíba Highland) unit, which is part of the *Planalto Central Goiano* (Central Highland of Goiás). The two main soil classes are *Cambissolo Háplico Distrófico* (Inceptisol) and *Latossolo Vermelho Ácrico* (Oxisol) (CTE SISTEMA NATURAE, 2006). The vegetation is formed by Riparian and Gallery Forests, Cerradão, Cerrado *sensu stricto*, Vereda, Campo Sujo and Campo Limpo.

Extrema/Jardim river basin has an area of 468.88 km² and integrates the Preto River basin in the eastern Federal District, in the administrative regions of Planaltina and Paranoá. Its geological basement is formed by the groups Paranoá, Canastra and Bambuí, with great presence of ferruginous detritic-lateritic covers and small portions of alluvial deposits (CAMPOS; XAVIER; FREITAS-SILVA, 2016). Plateau areas occur (Pipiripau and São Bartolomeu-Preto) and intermediate dissection area (NOVAES PINTO, 1994). The basin is characterized by the marked presence of the *Latossolos* (Oxisols) (80.39%) and smaller amounts of *Cambissolo* (Inceptisol) (15.69%) (REATTO et al., 2004). The predominant physiognomies are Semideciduous Tropical Forest, Cerradão, Cerrado *sensu stricto*, Cerrado Ralo, Campo Sujo, Gallery Forest and Campo Limpo.

The basins were delimited from Shuttle Radar Topography Mission (SRTM) images provided by the National Institute for Space Research (INPE/TOPODATA, 2018). The images were used to demarcate the topographic divider, creating the perimeter of each basin. Arc Gis 10.1 software, licensed by Geoinformation Laboratory of the Federal University of Jataí (UFJ), was used in this stage.

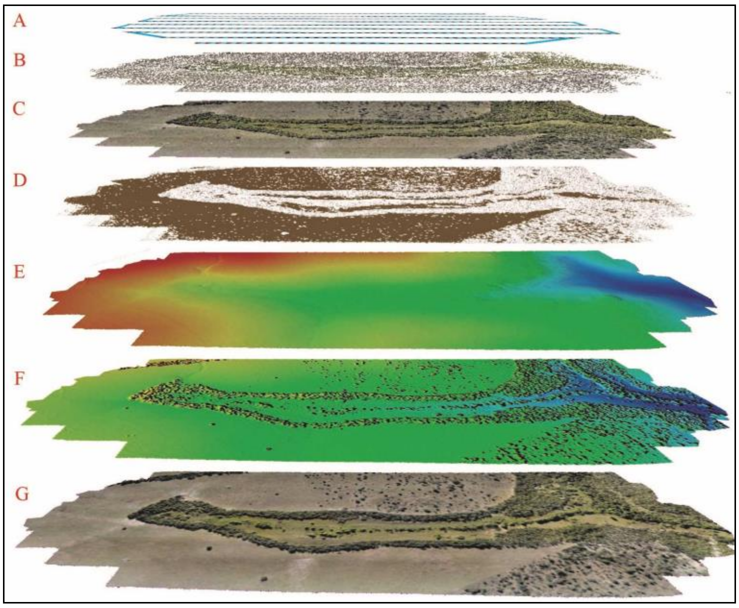
After mapping, we carry out field incursions between July and October 2017 to know the research areas and identify Veredas. First, we used a Global Navigation Satellite Systems (GNSS) receiver to record the coordinates of the Veredas found. Between the months of April and September 2018, we perform a second field to select Veredas accompanied by aerial survey. Given the difficulty in working with all basins, we chose to select ten Veredas in each area. This quantity does not prevent the study from being conducted and, at the same time, allows good representativeness. For selection, we searched areas distributed throughout the basin, in addition to Veredas with different geoenvironmental features.

Aerial survey was carried out using rotary-wing RPA of the DJI brand, Phantom 4 Pro model. This RPA has a flight autonomy of 30 minutes, is equipped with *GNSS* receiver (*GPS/GLONASS*) The original Phantom 4 Pro camera, model FC6310, was used with 20 MP CMOS sensor, width of 13.2 mm, height of 8.8 mm, focal length equivalent to 35 mm of 24 mm and true focal length of 9.1561 and FOV 84º 8.8mm lens. We set up the camera with automatic International Standards Organization (ISO) speed, automatic f / stop number scale and automatic shutter speed. The generated images have a width of 4864 pixels, height 3648 pixels, horizontal resolution 72 dpi and vertical resolution 72 dpi.

The automated flight was planned and executed using Drone Deploy software. Flight height was determined at 134 meters to obtain a mean Ground Sample Distance (GSD) of four centimeters. For better accuracy of the orthomosaic, we used frontal overlap of 80% and side overlap of 60% (*e.g.* SILVA NETO et al., 2018), as this RPA is not designed for that specific use. In the definition of the overlap we also considered the recommendations of 50% minimum overlap (COELHO and BRITO, 2007). However, the numerical values shown may vary depending of the aerophotogrametric coverage purpose (COELHO and BRITO, 2007).

Aerial photographs were processed in Agisoft PhotScan 1.4.4 software (free trial license), based on photogrammetric processing techniques involving internal orientation, external orientation and aerial triangulation (ROBERTO, 2012). Processing step is divided into (Figure 2): importing of input data, conversion of the coordinate system, calibration of the camera, assessment of photo quality, project setting, photo alignment (A), tie point cloud (B) editing to remove inconsistencies, camera optimization, point cloud densification (C), point cloud classification (D), generation of Digital Surface Model (DSM) or Digital Terrain Model (DTM), creation of Digital Elevation Model (DEM) (E), contour line generation (1 m equidistance) and orthomosaic creation (F).

Figure 2 - Products generated in the different stages of processing aerial photographs of part of the Vereda A05.




A - alignment of aerial photographs by flight lines; B - tie point cloud; C - dense point cloud; D - classified point cloud; E - Digital Elevation Model; F - Digital Surface Model; G – Orthomosaic.

Source - Prepared by the author using Agisoft PhotScan 1.4.4 – 2020.

Once the contour lines and the orthomosaic were obtained, making possible to delimit Vereda through Agisoft PhotScan 1.4.4 software, based on the altimetric dimensions and the differentiation of the vegetation cover. Subsequently, the polygon with the Vereda limit was exported to *Arc Gis* 10.1 software (ESRI, 2012), in which it was combined with the basins drainage network. Then, we performed a visual analysis of orthomosaics to verify the capacity to identify differences in the vegetation cover physiognomy. This, the presence of tree components and sub-shrubs, as well as the occurrence of buritis, was distinguishable by the orthomosaic of aerial photographs.

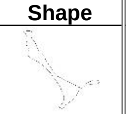
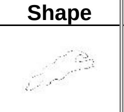
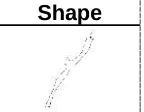
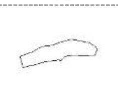
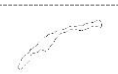
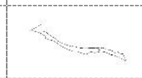
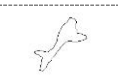
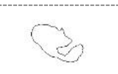
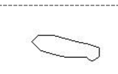
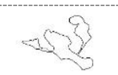
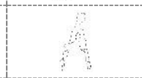
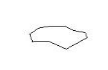
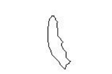
## RESULTS AND DISCUSSION

### Veredas Dimension and aerial survey

The studied Veredas showed notable differentiation in geoenvironmental aspects, regarding spatial dimension and vegetation inside. Areia river basin has predominantly gently undulating and flat relief, which contributes to the development of large areas of poor drainage and the consequent formation of large Veredas, whereas Campo Limpo river basin, the Veredas are smaller, due to the greater presence of undulating relief. Extrema/Jardim river basin, represented by plateaus and area of intermediate dissection, has various Veredas with variable dimensions, in addition to considerable Veredas typical of slopes.

The smallest Vereda studied (Table 1) has an area of 0.3 hectares (Vereda CL16, Campo Limpo river basin), and the largest one has an area of 50 hectares (Vereda 09, Areia river basin). In addition to the dimensions, the shape is also varied, from an almost circular shape (Vereda EJ14, Extrema/Jardim river basin) to elongated and narrow (Vereda EJ04, Extrema/Jardim river basin). Thus, due to the reduced size and shape, some of these Veredas can be difficult to analyze through satellite images traditionally used in environmental studies, since some of these are represented by a small pixels number = (*e.g.* Vereda CL16 of the Campo Limpo river basin is represented by only two pixels in Landsat image), due to the spatial resolution. Faced with this problem, the use of RPA is an alternative of lower financial cost to obtain high-resolution spatial images of Veredas.

Table 1 - Area and shape of the Veredas

| Campo Limpo river basin | | | | Extrema/Jardim river basin | | | | Areia river basin | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Nº** | **Vereda Code** | **Area (ha)** | **Vereda Shape** | **Nº** | **Vereda Code** | **Area (ha)** | **Vereda Shape** | **Nº** | **Vereda Code** | **Area (ha)** | **Vereda Shape** |
| **01** | CL01 | 10.14 |  | **11** | EJ02 | 31.13 |  | **21** | A01 | 12.01 |  |
| **02** | CL02 | 2.20 |  | **12** | EJ04 | 22.66 |  | **22** | A05 | 29.48 |  |
| **03** | CL04 | 4.49 |  | **13** | EJ07 | 8.18 |  | **23** | A07 | 7.72 |  |
| **04** | CL03 | 2.11 |  | **14** | EJ09 | 7.06 |  | **24** | A09 | 50.15 |  |
| **05** | CL11 | 1.72 |  | **15** | EJ10 | 5.31 |  | **25** | A12 | 13.08 |  |
| **06** | CL16 | 0.30 |  | **16** | EJ14 | 5.43 |  | **26** | A18 | 33.68 |  |
| **07** | CL23 | 0.86 |  | **17** | EJ17 | 5.68 |  | **27** | A30 | 14.68 |  |
| **08** | CL26 | 8.51 |  | **18** | EJ18 | 24.31 |  | **28** | A39 | 16.43 |  |
| **09** | CL29 | 1.15 |  | **19** | EJ26 | 2.34 |  | **29** | A41 | 16.85 |  |
| **10** | CL30 | 0.88 |  | **20** | EJ28 | 1.36 |  | **30** | A50 | 40.88 |  |

Source - Prepared by the author from aerial survey - 2020.

These differences impact the stages of aerial survey and data processing. Given the larger spatial dimension of the Veredas in Areia river basin, extending towards the watercourse for several kilometers, some of them could not have their entire area covered in the aerial survey, due to the impossibility of coverage in a single flight. This did not occur either in Campo Limpo river basin, due to its smaller spatial dimensions, or in Extrema/Jardim river basin, given its intermediate dimensions. Use more than one flight to cover a single area generates greater difficulties. For example, in marking support points (when used), requires a longer time in the aerial survey and greater number of batteries for RPA, and creates greater difficulty in processing data due to the need for joining blocks of aerial photographs of different flights, and this process can also generate distortions.

Specifically, the rotary-wing RPA used here has low flight autonomy (about 30 minutes), which makes it impossible to cover areas greater than 75 hectares, for the height and overlaps established in this project. Therefore, the characteristics of the RPA employed are ideal for aerial survey of small areas. However, it proved ideal for aerial survey in Veredas, due to the ease of landings and takeoffs even in hard-to-reach locations, which would be extremely difficult with a fixed-wing aircraft. Therefore, for larger areas, an RPA with greater flight autonomy is recommended, such as those with fixed wings. In a comparison between rotary-wing RPA and fixed-wing RPA, Arias, Campiteli and Silva Neto (2017) demonstrated the higher efficiency of fixed-wing aircraft in an area of 600 hectares.

## Specificities of flight plan for aerial survey in Veredas

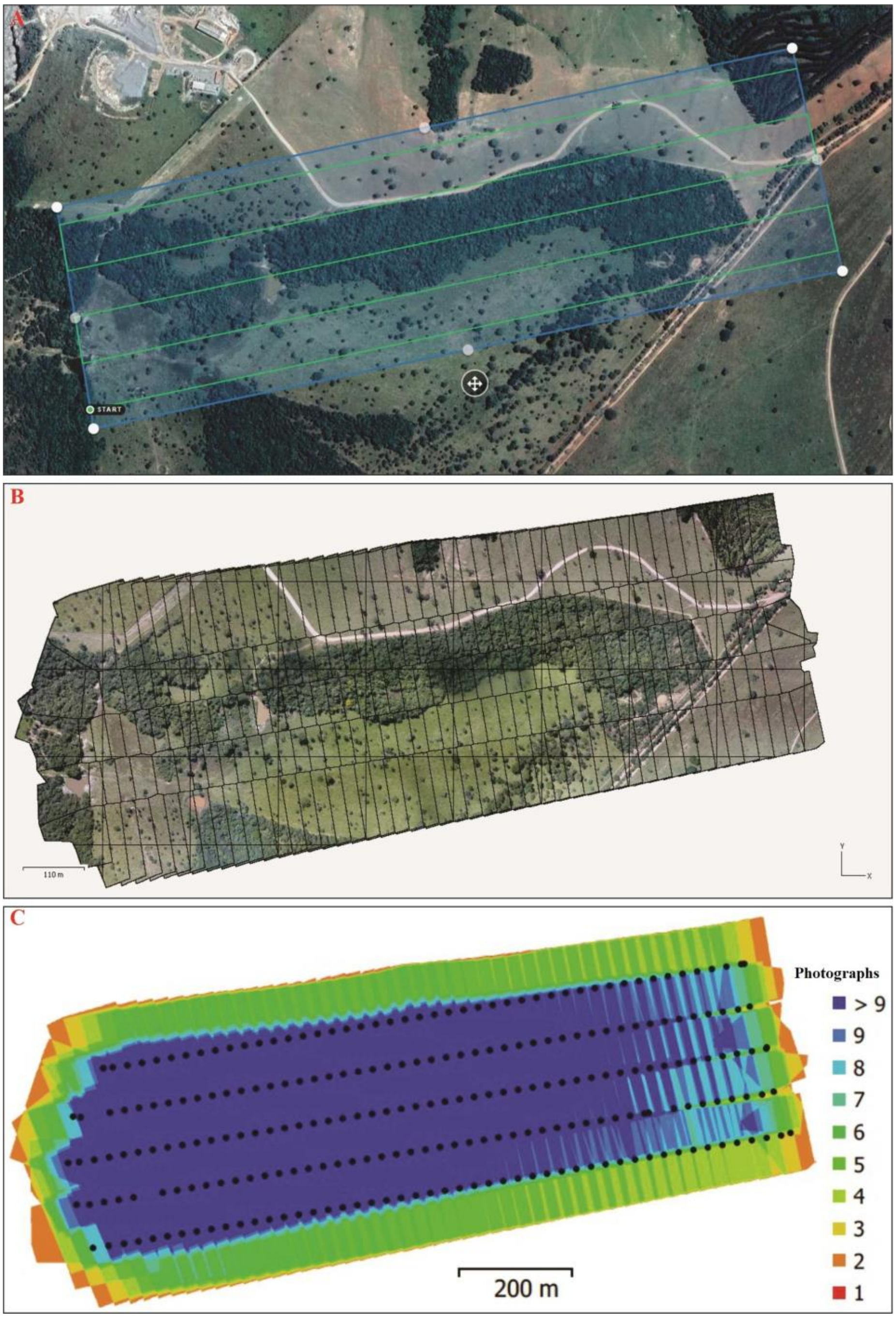
Some aspects should be considered to perform the aerial survey, since the spatial resolution of aerial photographs is influenced by factors such as the camera focal length and opening angle, as well as flight height (COELHO and BRITO, 2007). It is also necessary to consider the direct relationship between flight height and GSD. The higher the flight, the higher the GSD, and vice versa, while the higher the spatial resolution, the GSD says. However, a smaller GSD also means a smaller area covered by a single aerial photograph.

Thus, we seek to determine a standard for flight height, aiming to cover the entire length of the footpath in a single flight, also a GSD that would allow us to recognize the physiognomy. By analyzing some test orthomosaics, we found that an average GSD of 4 cm provides a good view of the vegetation cover of the Veredas. On the other hand, by reducing the flight height to achieve a smaller GSD, the coverage of the area decreases, making it impossible to cover the entire length of the Veredas in a single flight. Moreover, the larger the number of aerial photographs, the larger the file size, directly affecting the processing stage.

Another factor to be considered in the aerial survey is the aerial photographs overlap. Generally, the images are captured successively along parallel flight lines and obtained with longitudinal and lateral overlap between them, allowing the composition of stereoscopic pairs (FERREIRA, 2014). Through the different target positions of the same point on the ground it becomes possible to visualize this three-dimensional (FERREIRA, 2014). As we used RPA originally designed for recreational use, we had to employ overlaps larger than those ones traditionally used by other RPA (front 80% and side 60%) specific for aerial survey. This generated a greater number of photographs, ensuring the possibility of analysis by stereoscopy.

Also in relation to flight planning, in the orthomosaic there is a decrease in the level of overlap, from the core of the imaged area towards its edges. This effect is expected, due to reduction of rounding at the edges (FRANÇA, 2015) (Figure 3). Thus, in flight planning, we keep Veredas in the center of the interest area, covering the surroundings during flight, so that the overlay of images in the Vereda area remains acceptable.

Figure 3 - Flight plan and overlap of aerial photographs in the composition of the orthomosaic of Vereda CL02, Campo Limpo river basin, Goiandira (GO), 2018.




A - Flight plan in Drone Deploy software; B - Orthomosaic with demarcation of the limit of each aerial photograph; C - Color scale showing the number of aerial photographs per reference point.

Source - Prepared by the author from aerial survey - 2018.

Figure 3A shows the planning of flight lines in the Drone Deploy application. Flight plan includes 240 photographs, an area of 48 hectares, 13.48 minutes of flight, height of 134 meters, and average GSD of 4 cm. However, after the processing of aerial photographs, more accurate information is obtained through the processing report, confirming the 240 photographs. However, the effective flight height was 153 meters and the ground resolution was 3.76 cm/pix. With this information we noticed that due to the undulations of the relief and the takeoff point of the RPA, there were differences between the planned and the actual flight height and GSD. Despite that, we obtained spatial resolution above the one planned.

In Figure 3B it is possible to verify how the orthomosaic was composed, and each smaller rectangle is equivalent to the part of the aerial photograph that was orthorectified and used in the mosaic composition. As the flight was planned for the Vereda to be in the central area, it had more photographic records and, consequently, with more accurate information. Figure 3C shows exactly the number of existing photographs for the same point, and it is possible to verify the edge effect reported by França (2015).

**Possible analyses from the main products generated**

After the stages of planning and execution of the aerial survey flight, with the processing of photographs, several products were generated. Among these, we used the orthomosaic and the DEM for studying the Veredas. Orthomosaic contains objective terrain representations on a scale very close to the surface, and makes it possible to identify existing spatial divisions with oriented detailing of geographic objects of interest for the study (FRANÇA, 2015).

Given the flight parameters used in the aerial survey, we obtained orthomosaic with an average spatial resolution of 4 cm for all the Veredas. With this resolution it was possible to distinguish small variations in the physiognomy of vegetation inside the Veredas (Figure 4) (*e.g.* predominance of nonwoody and woody species), recognize the buritis and their arrangement, and verify the presence of drainage channels, areas with water above the soil surface and erosive processes.

Figure 4 - Orthomosaic of the Vereda A07, Areia river basin, Goiás, 2018.


Source - Prepared by the author from aerial survey - 2018.

Figure 4A shows Vereda orthomosaic with high spatial resolution (3.59 cm/pix), with detail for some specific areas. Figure 4B shows buritis canopy with varying dimensions, surrounded by predominantly herbaceous vegetation. It is also possible to observe areas where there is water above the soil surface. In Figure 4C, it is possible to see a Vereda stretch in which different areas occur, with tree vegetation and herbaceous vegetation. Therefore, the quality of the orthomosaic and the various possibilities of analysis are evident. Due to the high resolution of orthomosaics generated from the aerial survey using a rotary-wing RPA of the DJI brand, Phantom 4 Pro model, it was possible to distinguish the buritis in the vegetation cover, verifying whether they occur linearly (Figure 5) or sparsely (Figure 6).

Figure 5 - Central strip of buritis in Vereda in the Areia river basin, Goiás, 2018.

Source - Prepared by the author from aerial survey - 2018.

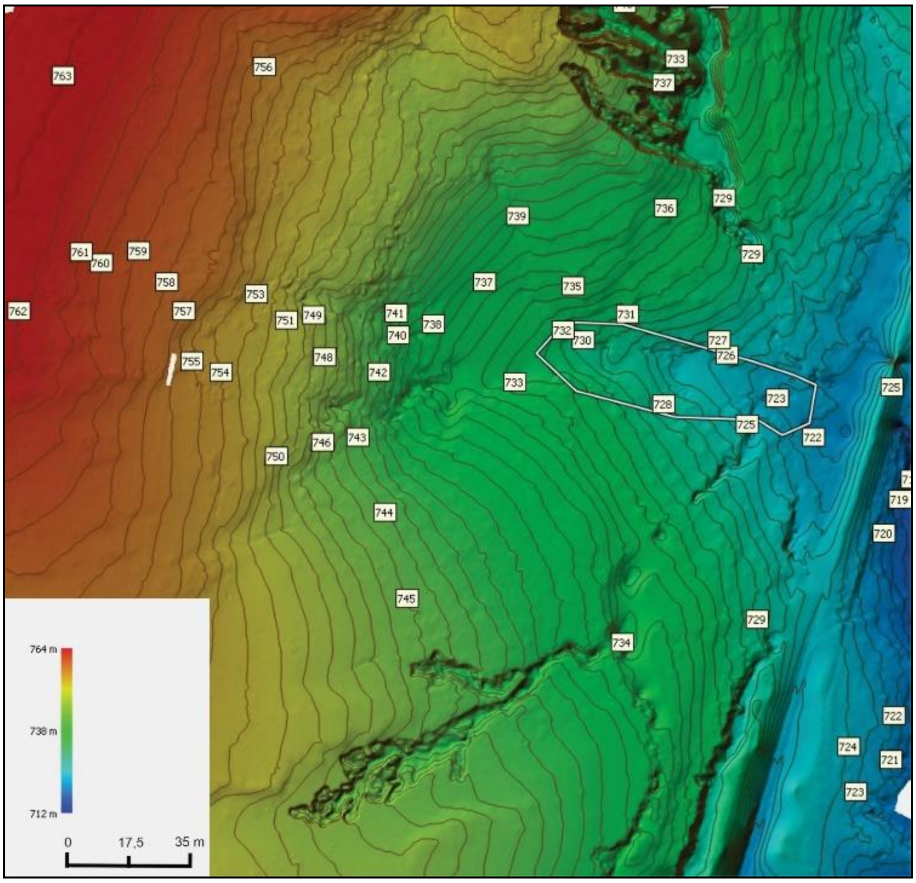
Figure 6 - Vereda with buritis distributed throughout its length, Areia river basin, Goiás, 2018.

Source - Prepared by the author from aerial survey - 2018.

The orthomosaic portrays a new angle of view of this ecosystem with capacity for great detailing, opening a range of study possibilities. Although we used this resource exclusively for the study in Vereda, it can be inferred that the orthomosaic obtained from aerial survey with RPA has great potential for environmental studies. RPA have several advantages, such as the reduction of field trips, greater agility in field work, in addition to the possibility of obtaining information from areas of difficult access, such as the interior of the Veredas, which in general is flooded. In this context, as we demonstrated, the orthomosaic has characteristics that make it a new research tool.

From the analysis by stereoscopy of aerial photographs, it was also possible to generate the DEM, which constitutes a representation of physically or artificially created surfaces, through mathematical processes, generating image with altimetric records structured in georeferenced lines and columns (BRAZ; XAVIER; GARCIA, 2018). The construction of the DEM of each Vereda and its vicinity (*e.g.* Vereda CL23 of the Campo Limpo river basin, Figure 7) was fundamental for a better understanding of the geomorphological positioning of the Veredas and their delimitations. In addition, the DEM can still be used in the analysis of erosive processes, impoundments, sedimentation, drainage channels, among other analyses in Vereda. The DEM can be used, for instance, to calculate the volume of soil transported from the interior of a gully or the volume of water from an impoundment in Vereda.

Figure 7 - Digital Elevation Model with contour lines, equidistance of 1 meter, Vereda CL23, Campo Limpo river basin, Goiandira (GO).




Source - Prepared by the author from aerial survey - 2018.

Figure 7 shows in the central portion the polygon representative of the perimeter of the CL23 Vereda, and also the relief of the matrix surrounding Vereda. The high spatial resolution of aerial photographs enabled the construction of DEM with the extraction of small equidistance contour lines. These lines with an equidistance of one meter, helped to understand the elevation and slope surface variation. The high level of detail made it possible to visualize small variations of the relief, such as the occurrence of two areas with gullies, located in the upper and lower parts of Figure 7.

Currently, there is widespread use of the DEM, mainly due to the possibility of measurements and objects that can be derived by the analysis of elevation data (HENGL and MACMILLAN, 2009). There are several possible applications, such as calculation of volumes, construction of profiles and cross sections, generation of shaded or grayscale images, maps of slope and orientation (aspect), three-dimensional perspectives and calculation of areas and distances on actual surface (FERNANDES and MENEZES, 2005). It is also possible to locate materials on the surface and precisely calculate slopes, drainage networks and their possible areas of erosion and material deposition, among others (LEGARRETA and PIROLA, 2015).

Although the DEM has contributed to the understanding of the geomorphological Veredas features and their vicinities, there are important issues to be observed. The first refers to the use of support points during the aerial survey. As no support points were used, the error of planimetry and altimetry is considerably higher than if they had been used, making it necessary to conduct a more careful analysis of the results. Thus, during the processing of aerial photographs to generate the DEM, in the classification stage, we used in addition to the automatic classification, the manual classification, aiming to reduce the error in the class defined as terrain. Thus, it was possible to obtain a DEM more consistent with reality.

Another issue concerns the source of the data used in the DEM construction. The RPA sensor used here (RGB camera) captures part of the electromagnetic radiation reflected by the soil surface, vegetation and other objects, being different from other data sources used in the construction of DEM, such as Radio Detection and Ranging (RADAR) images. These are obtained from wavelengths which cross, for example, the treetops, or from topographic surveys from which altitude values are obtained directly on the surface. The DEM generated through aerial photographs has lower accuracy in areas with dense tree vegetation. In these areas, the possibility of aerial photographs capturing ground levels or undergrowth is lower. Thus, the definition of elevations for the soil is compromised, since they are established by triangulation between the points of aerial photographs, which are classified as terrain. So, when the aerial photograph has few points classified as terrain, the altimetric accuracy is reduced. In practice, for the Veredas with less dense vegetation cover, the altimetry of the terrain is more accurate and the opposite is seen in Veredas with denser vegetation cover.

The high spatial resolution of the orthomosaic and the construction of the DEM, combined with the period of aerial survey, dry period, which promoted good differentiation of the vegetation in the Vereda (wet area) and in its surroundings (dry area), contributed to successfully delimiting this Veredas from changes in soil color and/or vegetation, as well as making measurements of distances and calculations of area with high accuracy.

The contour lines extracted from the DEM were projected onto the orthomosaic and contributed for the definition of the limit of each Vereda to respect the terrain irregularities, enabling comparisons between the landscape differentiation between vegetation cover and terrain. The limit of each Vereda has been demarcated in image processing software itself and has the advantage of being able to be exported in GIS-compatible format.

In view of what has been presented, we have demonstrated that geotechnologies effectively contribute to environmental studies, and RPA are a geotechnology of great potential and with good results. With recent introduction in the field of geotechnologies, RPA have shown versatility, with a wide range of applications. This has been proven by the good performance in the acquisition of high-resolution aerial photographs of the Phantom 4 Pro rotary-wing RPA. These high-quality photographs enable applicability in several studies. In addition, they represent a new mechanism to assist studies in Veredas, which contributed to the delimitation and vegetation cover characterization.

This use of aerial photographs obtained by RPA for the study in Veredas is unprecedented. In addition to reducing time and effort of field displacement, the use of this technology enabled a view of the Veredas capable of providing numerous analysis elements. Therefore, analysis based on an orthomosaic is a new resource in the study of natural environments, bringing a new tool hitherto not available to the scientific community. This provides a broader view of the landscape and with great level of detail, contributing greatly to its study.

With the high-resolution orthomosaic we confirmed the existence of physiognomically diverse Veredas, ranging from vegetation cover formed by nonwoody component with buritis to tree strata with buritis, demonstrating that the designation of vegetation complex employed by Brandão, Carvalho and Baruqui (1991) is perfectly appropriate for this physiognomy. Precisely for being a vegetation complex formed by different vegetation covers, the use of high-spatial-resolution orthomosaic can contribute to a better Vereda vegetation knowledge.

Finally, it is worth pointing out that the use of RPA has considerably increased in recent years, leading the authorities to seek ways to control such use, due to the risk it represents. Specifically in Brazil, the use of RPA is controlled by the Brazilian Special Civil Aviation Regulation nº 94/2017 (*Regulamento*

*Brasileiro de Aviação Civil Especial* - RBAC-E nº 94/2017) of the National Civil Aviation Agency (*Agência Nacional de Aviação Civil* - ANAC) (BRASIL, 2017), which is complementary to the Rules of Operation of RPA established by the Department of Airspace Control (*Departamento de Controle do Espaço Aéreo* - DECEA) (*e.g.* ICA 100-40, BRASIL, 2020) and the National Telecommunications Agency (*Agência Nacional de Telecomunicações* - ANATEL).

## CONCLUSIONS

Our study demonstrated that RPA is a geotechnology of great potential for environmental studies and with good results already proven. However, care must be taken when choosing the ideal type of RPA for each area to be studied. Due to their characteristics, among them, the greater flight autonomy, fixed-wing RPA are more suitable for larger areas, whereas rotary-wing RPA, such as the Phantom 4 Pro model, are suitable for smaller areas and with no open sites ideal for landing and takeoff of fixed-wing RPA, as it occurs in Veredas.

The Phantom 4 Pro rotary-wing RPA, equipped with a digital camera, model FC6310, with 20 MP CMOS sensor, mechanical shutter and FOV 84° 8.8 mm / 24 mm lenses, small-format camera used in this research, proved to be a platform with good performance for obtaining aerial photographs of high spatial resolution of Veredas. In turn, these photographs showed high quality, enabling applicability in several studies. They also showed excellent performance in the study of the Veredas, mainly due to the level of detail, which allowed the distinction of features of a few centimeters. They also had the advantage of temporal resolution, since they can be obtained at any moment and time interval. In addition, we proved their effectiveness in delimiting the area of each Vereda and in distinguishing the different strata of the vegetation cover.

However, applications of RPA in environmental analysis are still recent and their use in Veredas is unprecedented. Therefore, further studies are needed with the application of this geotechnology in order to improve its use, which should check for the possibility of even lower GSD, to enable better visualizations of each individual of the vegetation cover. Studies using support points should also be carried out to verify the improvement in planimetric accuracy.

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