Estimating wood volume in sawmill yards of Brazilian Amazon by Remotely Piloted Aircraft Systems

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Abstract. The control of wood extraction in the Amazon has been a complex task for the Environmental Agencies. Verification in the field demands a considerable technical effort. Time, financial and human resources are limiting factors. On the other hand, the Remotely Piloted Aircraft Systems (RPAS) emerges as a new technology capable of revolutionizing forest monitoring by enabling the monitoring of selective logging in large or difficult to access areas. This study aimed to evaluate the usefulness of RPAS in monitoring logging areas authorized by the Brazilian Forest Service, the federal forest concessions. This study was conducted in July 2014 in the municipality of Itapuã do Oeste, Rondônia state, Brazil, in the yard of the Madeflona sawmill, using an electric propulsion, fixed-wing RPAS equipped with a digital RGB camera. The results were promising. A difference of only 2% (or 32 m^3) was recorded between the RPAS estimated volume of wood in log stacks (1,534.38 m^3) and the volume declared by the company on the day of the experiment (1,502.11 m^3). This new methodology, even on an experimental basis, may replace and/or supplement in the near future the survey in the field, adding a greater agility and precision to forestry estimates.

Keywords: DEM, DTM, timber production control, forest monitoring, forest concessions.

1. Introduction

Despite the sharp decrease in the rate of deforestation in the Amazon (a deforestation largely related to logging), according to data reported by the National Institute for Space Research (INPE) for the last decade (a decrease higher than 70% between 2004 and 2015), there are still more than 2,000 companies (often illegal) exploring approximately 14 million cubic meters of wood per year in this region (SFB, 2013).

On the other hand, the monitoring of selective logging in the Amazon has always been a challenge for government institutions and NGOs linked to the forest and/or environmental conservation sector (GUTIERREZ-VELEZ & MACDICKEN, 2009). At the federal level, the Brazilian Forest Service (SFB), a body responsible for monitoring Federal Public Forests areas under concession, has sought alternatives to fulfill its duties.

Currently, the SFB has a logging production control system for forests under concession called Chain of Custody System (SCC). Each tree with a commercial interest is registered at the forest inventory, and all its movements are traced up to the sawmill stage. Information such as geographic coordinates, species, Diameter at Breast Height (DBH), height, trunk quality, cutting date, transport date, among others, are recorded in the system by the company holding the concession and verified in field, periodically and in samples, by the Monitoring Department (GEMAF) of SFB. This verification demands a considerable fieldwork, having as limiting factors for its implementation time, financial and human resources.

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In this context, remote sensing, particularly that provided by instruments on board of a Remotely Piloted Aircraft System[1] (RPAS, also known as UAV or Drones), is emerging as a technology capable of revolutionizing forest monitoring by allowing monitoring of selective logging activities in areas difficult to be accessed, and also monitoring forest dynamics (DANDOIS & ELLIS, 2013; COLOMINA & MOLINA, 2014; ZAHAWI et al., 2015). The benefits are the significantly reducing of time, cost and risk of exposure of inspectors and analysts.

According to the current Brazilian legislation[1], RPAS is a remotely controlled platform, usually with an autonomous flight capability (programmable and guided by computer), capable of obtaining spatial high-resolution aerial images of a particular area of interest, among other applications. In addition, through processes based on stereoscopy, another product offered by this system is the Digital Elevation Model (DEM) and the Digital Terrain Model (DTM) for the imaged area. This three-dimensional information (latitude, longitude and altitude), in addition to mapping the relief, may serve as a basis for calculating the volume of imaged objects on the ground, such as stored log stacks in the yard of a sawmill or the height of trees. Thus, RPAS, together with information from the Chain of Custody System, has a potential to collaborate in monitoring the volume of logging in areas under SFB concession, with the advantage of the element of surprise (i.e., confidentiality and low-risk sampling missions) and a planialtimetric accuracy.

In the development field and geotechnology transfer, the Federal University of Goiás (UFG) assess, through its Image Processing and Geoprocessing Laboratory (LAPIG), the use of RPAS since 2012, when it acquired its first device in this category. Thus, through a technical cooperation initiated in 2014 between UFG and SFB, regarding a forest concession area in Rondônia (municipality of Itapuã do Oeste, Jamari National Forest), the utility of RPAS was tested regarding forest monitoring, whose challenges and mission results are presented and discussed here.

2. Materials and Methods

2.1. Study area

The study area was defined as the storage yard of the sawmill belonging to the Industrial Madeireira Flona do Jamari (Madeflona), located in the municipality of Itapuã do Oeste, Rondônia state, with a logging concession in the Jamari National Forest (Figure 1).

The company Madeflona has a SFB concession since 2008, and its sawmill performs the processing of wood obtained in its Forest Management Units (FMU) located in Jamari and Jacundá National Forests, both located in Rondônia state. The wood processing capacity of this unit is approximately 70 m^3 day^{-1}.

[1] Updated term, defined by the Ministry of Defense - Chief Air Force Command, Department of Airspace Control (DCEA), ICA 100-40/2015, published in the BCA No. 212 of November 19, 2015 (DCEA, 2015).

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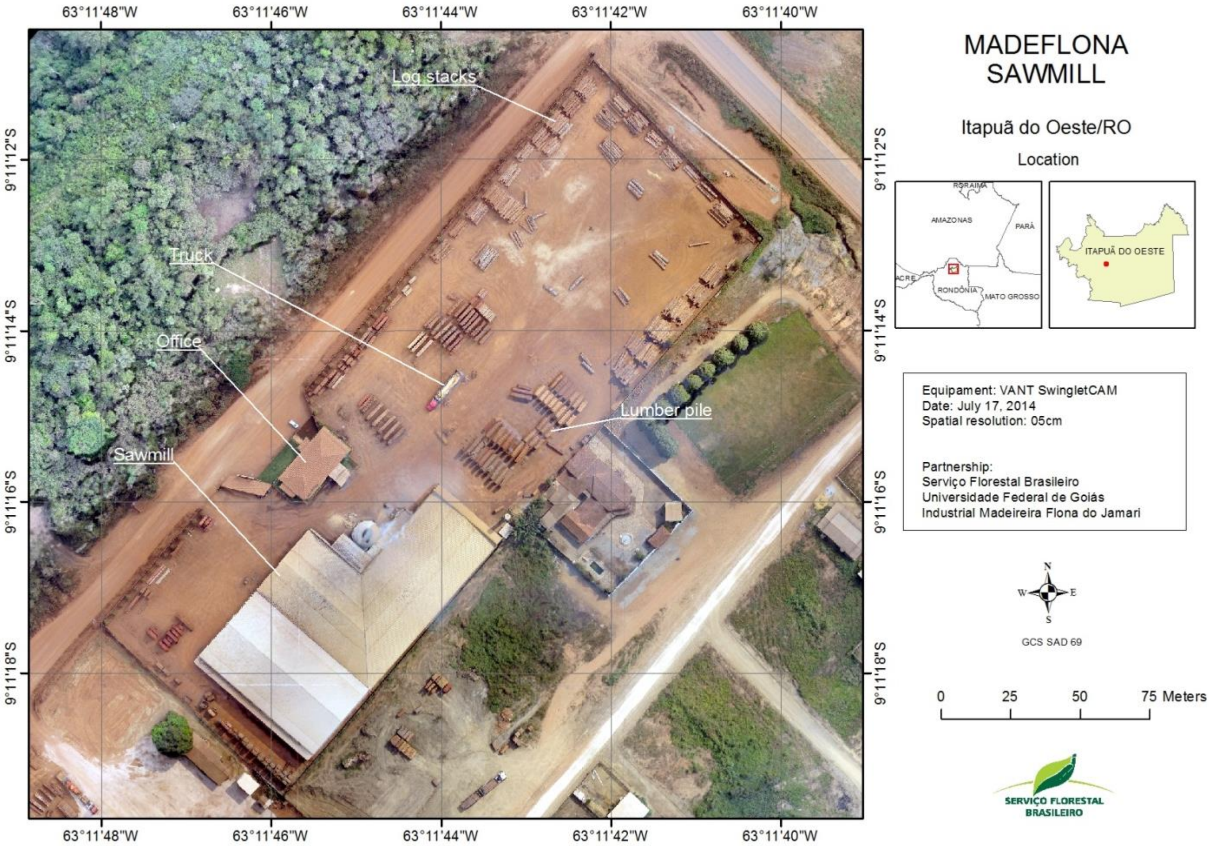

Figure 1 - Spatial high-resolution orthorectified Mosaic (5 cm) obtained by the RPAS Swinglet CAM over the Industrial Madeireira Flona do Jamari (Madeflona) sawmill, Itapuã do Oeste, RO state.

2.2. Experimental design and Equipment

The RPAS used was a Swinglet CAM model, with electric propulsion, produced by the SenseFly Company (Figure 2). It is a "Fixed-Wing" micro-RPAS device (below 1 kg) designed with EPO (a type of more resilient Styrofoam) to fly with winds up to 30 km/h, preferably without rain. The camera (digital RGB, with 12 megapixels) was fixed in the body of the aircraft, subject to all climatic conditions and platform attitude (i.e., direction of flight and wing or nose movements). The battery provides approximately 35 minutes of flight, currently one of the longest in this category of equipment.

The photographs obtained by the Swinglet CAM were taken preferably at a height of 100 meters, resulting in a spatial resolution (or Ground Sampling Distance, GSD) of approximately 5 cm (nominal GSD: 4 cm). Only one flight was carried out, covering an approximate area of 50 hectares, enough to cover the entire sawmill and its immediate surroundings. The longitudinal overlap was 60% and the lateral was 50%. The flight planning was designed with the eMotion software (Flight planning & control software, https://www.sensefly.com/drones/emotion.html). The time for collection of aerial photographs was approximately 20 minutes.

No extra footholds/control with global navigation satellite system were used in this evaluation (they could be used for the improvement of georeferencing of aerial photographs/orthomosaic) given the good planialtimetric precision obtained with the flight instrument (with an internal GPS signal receiver), sufficient for the purposes of this experiment, as well as due to the inspection purpose at the time of the mission (common to SFB field incursions in the study area).

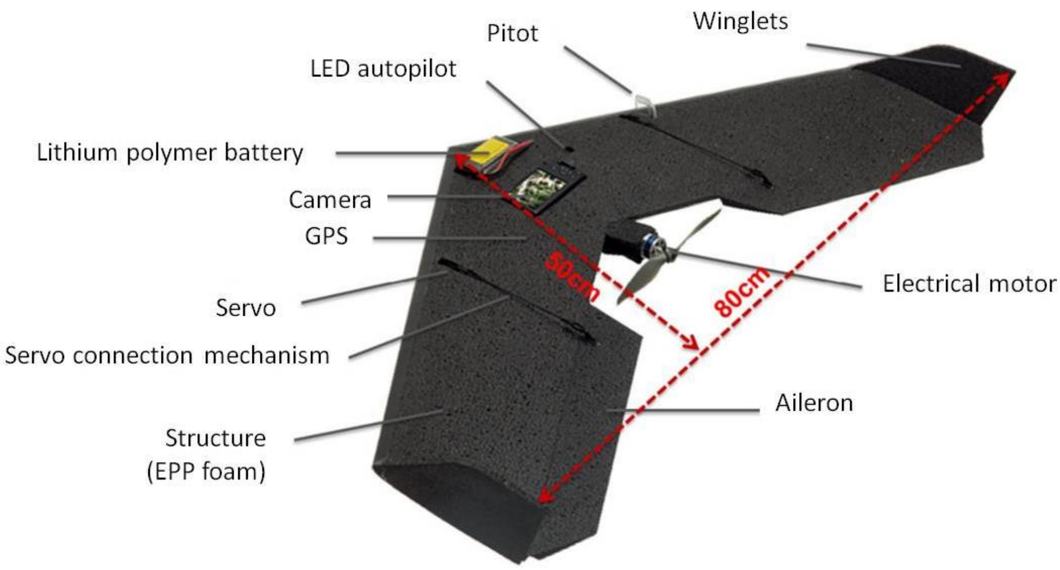

Figure 2 - Top view of the Swinglet CAM with all its equipment. Adapted from Alves Jr. et al. (2015).

2.3. Data processing

The orthorectified and the Digital Elevation Model (DEM) were obtained from the image processing software Pix4Dmapper (version 1.2.82, UFG/LAPIG license). From the 120 photos taken, only 10 were discarded automatically because they did not meet the criteria/standards set by this software. The processing time of the aerial photographs and the generation of products was approximately 30 minutes. For the analysis of the orthorectified mosaic and the DEM, as well as for the generation of the Digital Terrain Model (DTM), we used the ArcGIS software (UFG/LAPIG license), a Geographic Information System (GIS).

Specifically for the generation of the DTM, ground samples throughout the sawmill’s area and its surroundings were digitalized, excluding the objects above ground. Through interpolation of the ground samples (ArcGIS' *Kriging* tool), it was possible to create the Digital Terrain Model of the area in TIFF format. In a second step, the subtraction of the DEM from the DTM was performed (ArcGIS' *Raster calculator* tool), producing a difference image (Figure 3) with a spatial resolution of 5 cm, where each pixel represents the height relative to the ground level.

In the aerophotogrammetric orthomosaic, all logs stacks present in the yard of the sawmill were digitalized (Figure 4) and the area of each one was calculated (ArcGIS' *Calculate geometry* tool).

To calculate the volume of wood stacks, the clipping of the difference image (DEM – DTM) was performed with the polygons from stacks (*Clip* tool). The attribute table of the cropped image (height information and area of each pixel of each stack) was exported to Excel spreadsheet format. The calculation of the stack volume took into account the weighting of the number of pixels (its unit area is 0.0025 m^2) multiplied by its height in meters. Thus, the stere volume was obtained in m^3.

For converting the stere volume into wood volume, it was necessary to apply a stacking factor that ensures the exclusion of empty space existing between each of the stacked logs. As this information was not obtained during the field visit, an analysis based on SFB's collection of photographs was performed to determine it.

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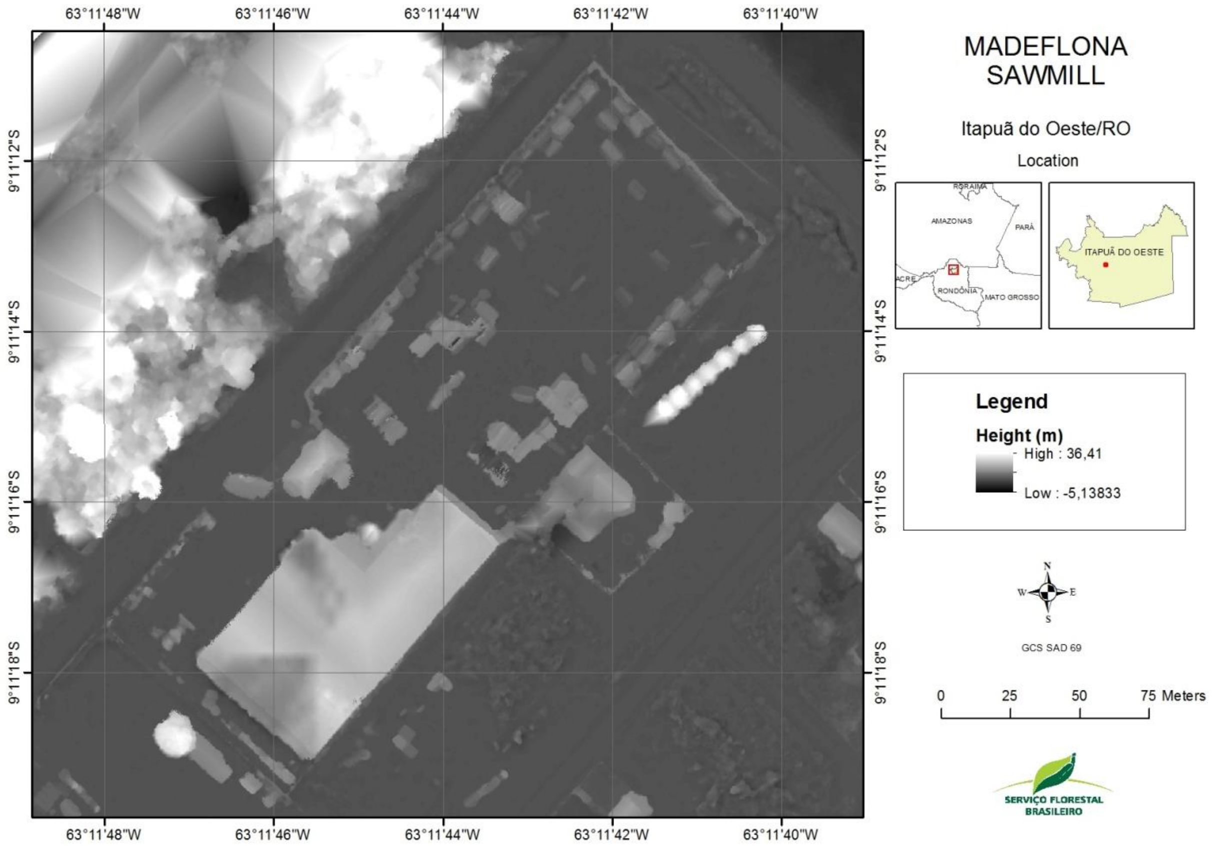

Figure 3 - Difference image between the Digital Elevation Model and Digital Terrain Model of the Industrial Madeireira Flona do Jamari (Madeflona) sawmill, Itapuã do Oeste, RO state.

Figure 4 - Log stacks identified in the sawmill stockyard belonging to the Industrial Madeireira Flona do Jamari (Madeflona), Itapuã do Oeste, RO state, on July 17, 2014.

Therefore, 12 random photos from the collection were selected. They were taken facing the stack of logs. For each of the pictures, the relation between wood area and empty spaces was calculated (Figure 5). The average of the results was adopted as the stacking factor.

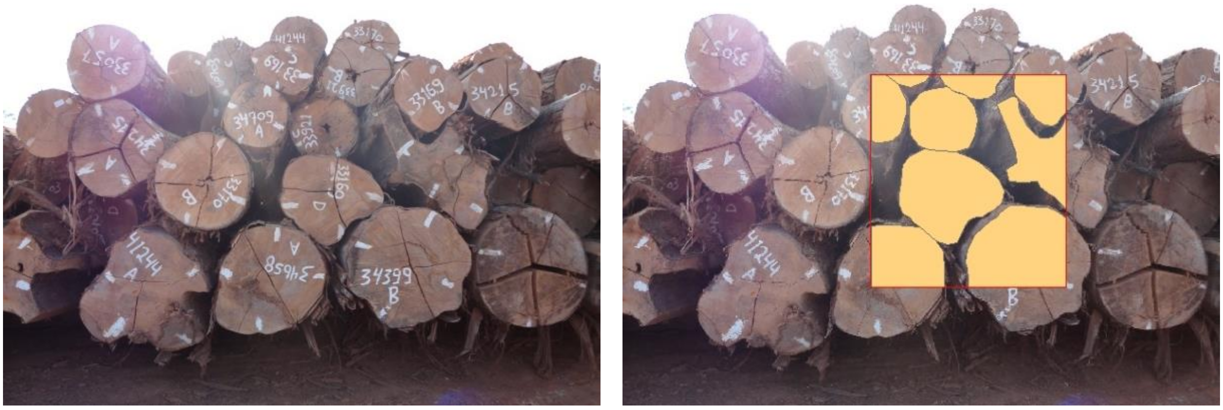

Figure 5 - Example of picture used for determining a stacking factor. The calculation of the stacking factor was made by identifying the log area (yellow polygons) and the empty spaces, inserted into a flat polygon (rectangle with edges in red). For each of the photos, only its most perpendicular portion in relation to the evaluation plan was used.

3. Results and Discussion

Because it is an electric and low-power equipment, some problems were observed during the RPAS photographing period. Among these, it is emphasized that the photos are not vertical, since the flight height varies (albeit very small), and there were changes in the behavior of the aircraft (lateral and nose tilt). In other words, pictures taken with this camera and platform model tend to present problems of scale due to the variation of height or the instability of the device's behavior (kappa, omega and phi angles). For this reason, the photographs have side drag (crab) and geometry problems, which affect the longitudinal and lateral coverage. Alves Jr. et al. (2015) reported this deficiency upon flying with the same aircraft model over an environmental conservation unit in the municipality of Goiânia, and over an urban/rural area in the municipality of Goiás, both in Goiás state, Brazil.

For this reason, both the longitudinal and the lateral overlap failed to meet flight plan specifications. Consequently, due to crosswind, the trajectory of this RPAS on flight lines was not straight. Despite all the problems reported in the imaging phase, there was no region in the mosaic that did not appear in at least two photographs (in some cases, the overlap of a point occurred in six or more photographs). Therefore, in the whole area covered by the aerial survey, it was possible to determine all three-dimensional coordinates of a point, and thereby obtain the DEM of the study area.

Altogether, after all steps described in the methodology, 43 log stacks were identified in the yard of the sawmill belonging to the Industrial Madeireira Flona do Jamari (Madeflona) in Itapuã do Oeste, RO state, on July 17, 2014. The area occupied by the stacks was 1,423.82 m^2, while its stere volume was 2,077.92 m^3.

The average stacking factor was 74% ± 7%. Thus, the estimated wood volume in logs stacks was 1,534.38 ± 145.41 m^3. The company declared to have at the day of the experiment (July 17, 2014) 1,502.11 m^3 of logs stored in the yard of the sawmill. The difference between the estimated volume, using data collected with the RPAS, and the volume declared by the company was only 32.27 m^3, i.e., 2%.

Specifically to the DEM quality product, numerous tests have been carried out in recent years to verify the accuracy of DEM generated from a micro-RPAS. Hugenholtz et al. (2013) have studied and compared a 1 m spatial resolution DEM (obtained by RPAS) with Ground

Control Points (GCP) collected with Real Time Kinematic (RTK) GPS, reaching a vertical difference (RMSE) of only 0.29 m. Ouédraogo et al. (2014) found a RMSE ranging from 0.09 to 0.139 m, a comparable accuracy to high precision LiDAR data. Gonçalves & Henriques (2015), which worked with a sub-meter spatial resolution (10 cm) DEM, using the same RPAS and software of this study, obtained a vertical RMSE from 3.2 to 4.5 cm. These results support the capacity to obtain high precision DEM by RPAS, primordial fundament for remote logs stacks volume calculation.

An already known problem in measuring the volume of logs stacks is the “cage”, i.e., an excessive proportion of empty space between logs usually caused by "bad de-branched" logs or in an "oblique" position below the surface of the stack. Thus, a wood stack provided with cages, not equated in the determination of its stacking factor, would be overestimated regarding its volume. Another problem, not found in this study, but possible, is the storing of logs in trenches (below the surface base level).

The old version of the Chain of Custody System (SCC), which operated from 2009 to 2014, did not perform the inventory record of wood in sawmills of concessionaries. Therefore, it was not possible to use it in this test and compare the data obtained from official records. The new version of the SCC provides the record of this information, with the possibility of using it as a ground truth for future experiments.

4. Conclusions

The high-resolution DEM and aerophotogrammetric orthomosaic (5 cm) generated by our RPAS - Swinglet CAM (Sensefly) are shown as effective tools for identifying/visually monitoring and measuring the stere volume of logs stacks in sawmill yards, in this case, Madeflona, at Itapuã do Oeste, Rondônia state. Even individual logs spread around the yard were identified with the orthomosaic and had their volume estimated using the respective DEM data.

The short time used for the survey and analysis, and the low number of people needed to perform this measurement (between 2 and 3 technicians/analysts involved, including operating the RPAS) is an important and very positive differential to the SFB. With approximately 20 minutes of flight, plus a 30-minute processing time (using a commercial software for 3D analysis), it was possible to obtain all the necessary data to estimate the volume of wood stored in the evaluated sawmill yard.

If a conventional volume measurement method was used (such as metric tape), the estimated time to complete the task in the same area would be at least one day, with the necessary presence of several inspectors in field (more than the two analysts involved in planning and operating the RPAS in this experiment). Although only one test was performed, the results suggest a large potential of the technology to support the monitoring of forest production areas with a SFB concession, above all in the Amazon region, a notable illegal logging area. Other agencies that would benefit from it are IBAMA, ICMBio and State Environmental Agencies, responsible for similar inspections in private areas.

The conduction of more robust surveys, incorporating more detailed field information, such as a larger sample of stacks, and the incorporation of data from the new SCC should be considered in a continuation of this research. The identification of wood species in stacks by high-resolution spatial and spectral imaging as a way to estimate its commercial value may also prove to be a further application of this method.

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