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Research article

The application of unmanned aircraft vehicle (UAV) to monitor construction area changes

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ABSTRACT

Recently, unmanned aerial vehicles (UAV) have been applied to various fields: mapping, aerial surveying, mine monitoring, construction monitoring, etc. UAVs have many advantages, such as high flexibility, low cost, and time savings, for each survey. This article studies a monitoring construction site project using photogrammetry images collected with a UAV Phantom 4 Pro. The study area was the Viet Phu Garden residential area in Phong Phu Commune, Binh Chanh District, Ho Chi Minh City. Due to the development of computer vision, photogrammetry was used to build 3D models. The study applied the structure-from-motion method to create point clouds, digital surface models (DSMs), and orthomosaics. The author monitored the area for six months (3 times of data collection) with Phantom 4 Pro using Agisoft Photoscan software to process and create products. We measured 28 points to make ground control points and checkpoints. The author proceeded to build orthomosaic and DSM 3 times to analyze changes in the area. The resolutions of the orthomosaic and DSM are 5.5 cm/pixel and 11 cm/pixel, respectively. We used checkpoints to evaluate horizontal and vertical errors. The root-mean-square error was less than 10 cm, which demonstrated the potential of UAVs for monitoring construction. We also used the DoD method to calculate the difference in DSM between each epoch. Then, we combined the DoD method with Orthomosaic to monitor the urban growth of the area. The results are divided into 2 main groups of changes, including changes in linear and regional form. Assessing the regional changes, the author divided 18 points into four main groups: New house, Completed house, House under construction, and other. Urban growth mainly occurred in the west and center of the study area. The results demonstrated that the use of the Phantom 4 Pro is appropriate for monitoring construction changes. The author recommended improving the quality of the results by combining them with the cadastral map to make planning and management easy.

Key words: Drone, UAV, Surveying, Monitoring Construction, DSM, DoD

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INTRODUCTION

Recently, the urbanization rate in Vietnam reached more than 38% in 819 cities[1]. Although the urban system in Vietnam is developing rapidly in quantity, urban quality of life is still low, which causes many challenges. Typically, technical infrastructures and social infrastructures are not synchronous, and urban competent management does not meet the reality demanded. The problem of urban management with many variables needs to be clarified for better management.

UAV (unmanned aerial vehicle) is a type of aircraft that has no pilot in the cockpit, operates independently, and is usually controlled remotely from a central or control machine[2]. With the advantages of flexibility, convenience, time savings, and effort with low cost, UAV photometry[3] opens up many new applications due to its low cost and accuracy. High resolution for topographic mapping and ground 3D data collection. UAVs have been widely applied in many fields around the world, such as construction, mining, agriculture, surveying, real estate, and urban management[4].

In Vietnam, Đặng Trung Tú et al.[5] used multitemporal Landsat satellite images with 30 m resolution to determine the spatial development of the Da Nang urban area from 1990 to 2015. However, the spatial variation analysis method using satellites has some limitations, such as a lack of time flexibility and low resolution. It is difficult to determine the exact shape and number of buildings. Le Van Trung[6] applied photogrammetry collected by using UAV Falcon 8 to update the cadastral map in Ho Chi Minh City. The error ranged between 5 cm and 7 cm, which demonstrated that the application of high-resolution drones can be used to establish large-scale and high spatial accuracy cadastral maps. In addition, the other advantage of the UAV application was that it monitored small areas by detecting the shape and height changes of buildings.

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This study aims to evaluate the effectiveness when we monitored small construction areas by using UAV technology. We detected changes in the shape and height of buildings. The research area is the Phong Phu 4 residential area (**Figure 1**). It is located in Phong Phu commune, Binh Chanh district, Southwest gateway of Ho Chi Minh City. This area covers approximately 40 hectares and has experienced massive urban growth. Orthomosaic, digital surface models, and DEM of difference models help evaluate the change in the construction area in the period from October 2018 to June 2019.

Figure 1: **Satellite image of the research area (source: Google Earth)**

Table 1: Specification Of Phantom 4 Pro

Specification	Phantom 4 Pro
Max Flight Time	30 mins
Weight	1388 g
Max speed (P-Mode)	14 m/s
Max speed (S-Mode)	20 m/s
Max Wind Speed Resistance	10 m/s
Satellite Positioning Systems	GPS/GLONASS
Hover Accuracy Range	Vertical: ± 0,1 m (with Vision Positioning); ± 0,5 m (with GPS Positioning) Horizontal: ± 0,3 m (with Vision Positioning); ± 1,5 m (with GPS Positioning)

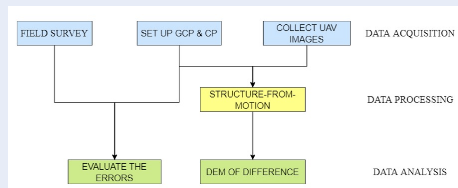

Figure 2: **Implementation workflow**

OVERALL

Equipment

The author used Phantom 4 Pro to collect images. It has a good flight time (up to 23 minutes) and a maximum speed of 70 km/h. In particular, it has a wind resistance of 10 m/s, which allows the collection of images with high stability. The technical specifications are shown in **Table 1**.

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Data acquisition

The overall process of the method is shown in **Figure 2**. We divide into three steps: data acquisition, processing, and analysis.

Data acquisition included 3 main tasks: field survey, set up GCP and CP, and collect UAV images.

The field survey includes observing the status of the area and recording the height of buildings under construction.

The author set up ground control points (GCPs) to align the image to the appropriate position. In addition, the author also set up some checkpoints (CPs) to evaluate the accuracy of the results. The author measured the coordinates and elevation of the GCP and CP by a GNSS V30 Hi-target device.

Collecting UAV data consisted of 2 main tasks: designing a flight plan by DJI GS Pro software and automatic flying. There are two key parameters: the flight altitude and the overlap.

The flight altitude determined the resolution of the images, which was calculated by formula 1:

$$H = \frac{f \times GSD}{S} \quad (1)$$

where:

H is the flight altitude of the UAV (m);

GSD is Ground Sample Distance (m);

f is the focal length of the camera (m);

S is the size of the pixel (m);

The overlap is the ratio of overlapping images in two directions: front and side. The higher the overlap is, the more accurate the data and the longer the time

Table 2: Parameters Of Flight Planning

Parameter	Oct-18-2018	Dec-04-2018	Jun-21-2019
Covered area	52.5 (ha)	51.3 (ha)	43.6 (ha)
Time	22 mins	20 mins	19 mins
Forward overlap	90%	90%	90%
Side overlap	80%	80%	80%
Number of photos	136 (img.)	137(img.)	148 (img.)
Flight altitude	200 m	200 m	200 m
Resolution	5.5 cm/pix	5.5 cm/pix	5.5 cm/pix

process. The flight planning parameters are shown in **Table 2**.

Data Processing

Data collected by UAVs were used to build a point cloud, which was created by the structure from motion method. Then, it is used to build DSM and orthomosaic.

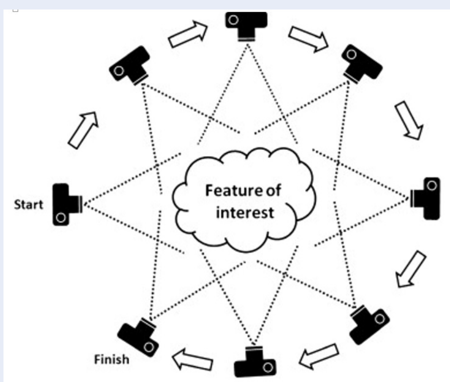

Figure 3: Structure-from-Motion (SfM). Adapted from "'Structure-from-Motion' photogrammetry: A low-cost, effective tool for geoscience applications," by Westoby, et al, 2012, Geomorphology, 179, p. 301. Copyright 2012 by Elsevier.

The SfM method has the same basic principle as stereoscopic map projection and builds a 3D model by overlapping images (**Figure 3**). The SfM method does not need to determine the location before capturing images. This method automatically recognizes and detects the image location. Features are tracked from image to image, from which initial estimates of camera position and object coordinates are obtained. Based on a repetitive process, a dataset such as x, y, z, and the color are automatically extracted from the overlapping images[7]. This method is most suitable for sets of images with high overlap that capture the entire three-dimensional structure, especially those taken at high altitudes following predesigned flight routes[8]. The method simultaneously reproduces camera location and scene geometry through the automatic matching of suitable features in multiple images. These features are tracked from image to image, allowing an initial estimate of camera position and object coordinates, which are then iteratively refined using the nonlinear least-squares method (since many solutions are available from many features in the image database).

The author used Agisoft Photoscan to process the data. Image processing by Agisoft[9–11] included 2 steps: align, optimize data, and process data (**Figure 4** shows the processing workflow on Agisoft).

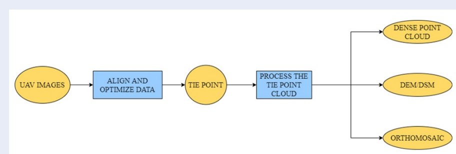

Figure 4: Workflow processed on Agisoft software

First, images were imported into the software. It was adjusted for appropriate brightness and used coordinates of the center of the image (according to the GPS coordinates of the UAV) to orientate the relative image. Next, the author imported and marked GCP's location on the images (external orientation) to increase accuracy. Finally, the author optimized the camera parameter used to align the entire area again, and we removed outliers affecting the final result. The tie point is used to build a dense point cloud and then create a DEM and orthomosaic.

Data Analysis

The technique of the DoD method is to overlap different thematic maps to achieve the goal of studying the influence of a certain object on the surrounding environment [12].

The author uses an overlaying raster called the DEM of difference (DoD) method. The DoD method is derived for the purpose of detecting geomorphological changes [13]. The author subtracted the DEM in 2 periods to evaluate the morphological changes (**Equation (2)**):

$$\triangle DEM = DEM_2 - DEM_1 \quad (2)$$

where ΔDEM represents the height change, DEM_1 is the DEM in period 1, and DEM_2 is the DEM in period 2.

The root-mean-square error is defined as the square root of the mean square, commonly used to measure the difference between values predicted by a model or an estimator and observed values [14]. The author evaluates the accuracy by calculating the coordinate error at the test points (**Equation (3)** and **Equation (4)** are for horizontal evaluation, and formula 5 is for vertical evaluation).

$$m_N = \sqrt{\frac{\sum_{i=1}^{n}\left(N_i - N_i^0\right)^2}{n}} \quad (3)$$

$$m_E = \sqrt{\frac{\sum_{i=1}^{n}\left(E_i - E_i^0\right)^2}{n}} \quad (4)$$

$$m_Z = \sqrt{\frac{\sum_{i=1}^{n}\left(Z_i - Z_i^0\right)^2}{n}} \quad (5)$$

where m_N, m_E, m_Z is the root-mean-square error in each direction (m); N_i^0, E_i^0, Z_i^0 is the coordinate at point i of the RTK method (check point) (m); N_i, E_i, Z_i are coordinates at point i exported from orthomosaic (m); and n is the total number of points used to evaluate the accuracy.

RESULTS

Ground Control Point and Check Point

The total number of measurements was 28 points (**Table 3**). The author divides 28 points into two categories: Ground Control Points and Check Points (yellow triangle points and red circle in **Figure 4**).

Orthomosaic and Digital Surface Modeling (DSM)

The orthomosaic was created with a resolution of 5.5 cm/pixel at three times (**Figure 5** shows the June 2019 orthomosaic). The author uses the ground control points to reproject the orthomosaic to the VN-2000 coordinate system and uses the control points to check the error of the image. In the image, objects such as buildings, trees, vacant land, and construction areas can be clearly identified.

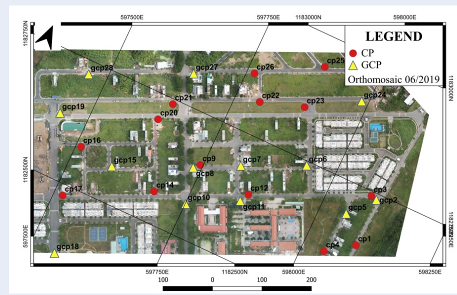

Figure 5: **Orthomosaic in June 2019**

The DSM of the area was built with a grid size of 11 cm × 11 cm three times, and the locations of the GCP and CP points are shown in **Figure 6**. Similar to the orthomosaic, the author uses control points to correct the model to the VN-2000 coordinate system and uses the control points to check the accuracy of the terrain background elevation. The DEM makes it possible to identify buildings from the ground due to the height difference. Points with an altitude of 0 m correspond to yellow, and those with an altitude of 30 m correspond to green. Points with a range of altitudes 15 m to 20 m are high-class villa blocks and the public infrastructure of residential areas (schools, medical stations). Phong Phu Junior High School, and several independent buildings have heights ranging from 25 m to 30 m.

The author used checkpoints to calculate the error. The results of the error in the N, E, and Z directions are presented in **Table 4**.

The mean error in the N-direction is 0.055 m. The mean error results in the E-direction are 0.065 m; the mean error in the Z-direction is 0.092 (**Table 4**). The result demonstrates that UAV images combined with GCPs measured by RTK can build large-scale maps.

DEM of Difference

The height change of buildings is evaluated by the DoD model. The result includes two phases: the first

Table 3: Ground Control Point And Check Point

Code	N	E	Z
CP1	1182637.254	598098.4788	2.5782
GCP2	1182737.828	598097.1528	2.7102
CP3	1182740.898	598084.8073	2.5247
CP4	1182598.815	598045.0029	2.3801
GCP5	1182686.674	598053.7112	2.552
GCP6	1182741.322	597940.2088	2.3933
GCP7	1182684.657	597819.5146	2.3452
GCP8	1182640.471	597733.8416	2.196
CP9	1182651.368	597744.5863	2.3457
GCP10	1182567.222	597750.9911	2.1933
GCP11	1182619.647	597848.4331	2.2109
CP12	1182638.363	597857.9265	2.2357
CP13	1182435.176	597813.7292	2.1665
CP14	1182563.371	597682.5934	2.1765
GCP15	1182573.148	597583.6155	2.4417
CP16	1182582.801	597510.473	2.4362
CP17	1182477.852	597518.3404	2.2473
GCP18	1182365.267	597552.5643	2.3515
GCP19	1182627.056	597443.028	1.951
CP20	1182699.186	597628.079	2.352
CP21	1182739.691	597642.1457	2.0089
CP22	1182817.961	597799.6887	2.1235
CP23	1182846.785	597886.3822	2.3619
GCP24	1182906.174	597985.9361	2.161
CP25	1182937.806	597888.9585	2.0715
CP26	1182865.89	597765.4484	2.226
GCP27	1182813.379	597654.1671	2.4042
GCP28	1182722.49	597462.2536	2.0607

Table 4: Result Of Error

Epochs	RMSN (m)	RMS_E (m)	RMSZ (m)
Oct-18-2018	0.06	0.071	0.103
Dec-04-2018	0.04	0.056	0.087
Jun-21-2019	0.066	0.066	0.085
Average	0.055	0.065	0.092

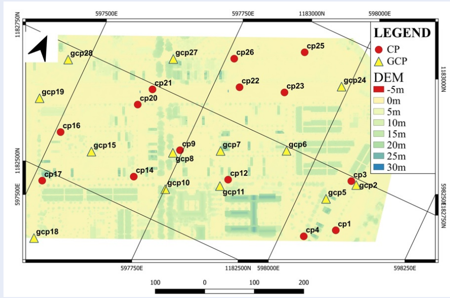

Figure 6: DEM from June 2019

Figure 8: **Unchanged height place from Phase 2: C1 is above, C4 is below**

phase lasts from October to December 2018, and the second phase lasts from December 2018 to June 2019 (**Figure** 7). Positive values (blue) represent an increase in height, and negative values (red) represent a decrease in altitude.

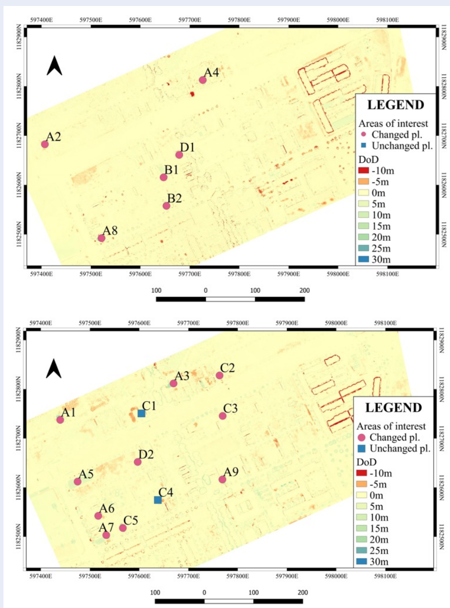

Figure 7: **A. First phase: from October to December 2018; B. Second phase: from December 2018 to June 2019.**

In the first phase, many construction activities were taking place with many new villas. In the west, six buildings were built (**Figure** 7A). In the second phase, ten new buildings appeared, and 2 of them were under construction, but the elevation remained unchanged (**Figure** 7B). In total, within only eight months, the area had a rapid change in the west, with 18 locations. Approximately two locations are under construction, with no significant change in elevation (**Figure** 8).

The author used orthomosaics at the same time for analysis. In the first phase, there are vegetation and bushes. In the second phase, there is a building under construction. The elevation did not change because the height of vegetation is equivalent to the height of the house under construction.

Two types of change

Regional Changes

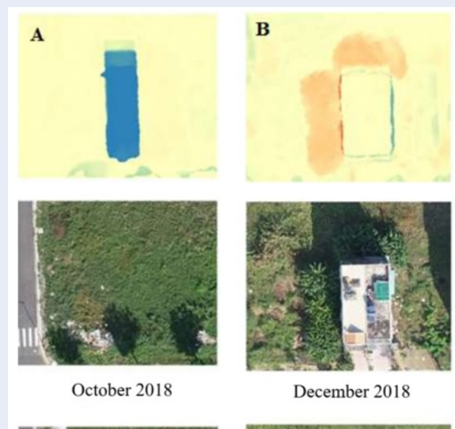

Figure 9: **A. Building under construction; B. Disappeared vegetation**

The regional change represents the appearance of new buildings, areas under construction, and changes in vegetation. They include defined geometry and undefined geometry.

The defined geometry represents the appearance of the building. **Figure 9**A shows buildings having a speed of construction of more than 15 meters during two months. In October 2018, there was vacant land, but construction works appeared in June 2019. For undefined geometry, it is planted (**Figure 9**B) and construction materials (**Figure 10**). **Figure 9**B shows the change in plants. The author found that the area had many bushes converted to vacant land between October 2018 and June 2019. Similarly, **Figure 10** shows the appearance of building materials from the original bushes.

Figure 10: **Construction materials**

Figure 11: **A. Scaffold around buildings; B. Corridor error**

Linear Changes

Linear changes are usually changes in construction scaffolds. In 2 phases, the corridor around buildings is the scaffold (**Figure 11**A). In addition, the linear shape can be confused with the error because of the offset of the image boundary. Because of flying at an altitude of 200 m with an image resolution of 5.5 cm/pixel, there is a deviation at the edge of the building, which causes the phenomenon shown in **Figure 11**B.

Monitoring Urban Changing

The author combined the DoD model with orthomosaic and field survey results to evaluate 18 changing locations. We divided them into four main groups. Group A is a 'New house': a house was built entirely from vacant land in October 2018. Group B is the 'Completed house': the house had some items unfinished in October 2018, and they had been completed in June 2019. Group C is 'House under construction': buildings were under construction in June 2019. Finally, group D is 'Other': they weren't a building. Two objects had a change on the orthomosaic, but the DoD results showed no difference in height, which we called C1 and C4. **Table 5** shows the changing assessment at 18 marked positions.

Regarding the architectural planning of buildings in the study area, the road boundaries are 12 meters, 16 meters, and 20 meters. Based on the design standards of Regulations on the architecture of semidetached houses in urban areas [15], buildings in the area are allowed to build a maximum of 7 floors (6th and 7th floors have setback), the maximum height from the pavement to the 1st floor is 5.8 meters, and the altitude between floors ranges from 3 meters to 3.3 meters.

DISCUSSION

The novelty of the paper is in the use of the DoD method. Data collected by UAVs help to build orthomosaics and DEMs, from which changes in the area can be assessed using DoD. Evaluate change with the DoD layer based on shape and intense color to identify volatile objects. Color based on elevation is considered the new appearance or disappearance of the features. Relying on the coherence of shapes and geometries will help define features such as houses, construction scaffolds, or sand yards. In addition, the author also references the standards of Regulations on the architecture of semidetached houses in urban areas to evaluate construction area changes.

The advantage of high-resolution UAV images makes it possible to survey the current status and detect changes in great detail. The error also meets the criteria for large-scale mapping. In addition, there is also the flexibility of the UAV, so it is possible to control the time when data need to be collected compared to satellite images, which are usually cyclical.

The change detection method makes it a simple and fast check of the current status. However, this method in paper is still dependent on humans and cannot be automatically applied to large areas and many complex features.

Table 5: Urban Change Assessment At 18 Marked Locations

Code	DoD (meters)	Group	Comment
A1	18.03	New house	Objects were built entirely from the vacant ground. The buildings were mainly built having the maximum height from the sidewalk to the 1st floor is 5.8 m, the height between floors ranged from 3 m to 3.3 m.
A2	10.35		
A3	18.92		
A4	19.33		
A5	5.08		
A6	6.85		
A7	19.07		
A8	19.95		
A9	16.12		
B1	3.77	Completed house	The terrace was being completed
B2	10.36		The roof and terrace were added
C1	0.93	House under construction	The ground floor was built from the bushes having the same height. There was no change in height
C2	1.52		The first floor was under construction, the construction speed was slow.
C3	5.4		The first floor was under construction, the ground floor was completed
C4	0.53		The ground floor was under construction. There were no changes in elevation
C5	19.01		The terrace under construction
D1	4.58	Other	Warehouse for materials, vehicles, etc.
D2	6.06		

CONCLUSIONS

In summary, the results include orthomosaic, DSM, and DoD models, which help more precisely assess the change in the construction area. The results of urban growth analyses classify the change objects into two main categories. Group 1 includes defined geometrical differences having prominent colors that are buildings under construction or completely new ones. The defined geometries with irregular colors often show objects such as building materials and accretion to enhance the ground or plants. Group 2 consists of corridor (linear) deviations representing scaffolding operations in buildings or corridor errors around buildings. At the same time, the error in the three directions N, E, Z are less than 10 cm, demonstrating that the results have high accuracy. The author recommends improving the quality of the results by combining them with the cadastral map to make planning and management easier. The author also proposes that the future development direction is to use AI to determine the spatial change and statistical change in the area.

LIST OF ACRONYMS

UAV: Unmanned Aircraft Vehicle

DSM: Digital Surface Model

DoD: DEM of Difference

DEM: Digital Elevation Model

GPS: Global Positioning System

GCP: Ground Control Point

CP: Check Point

CONFLICT OF INTEREST

The authors herewith declare that there are no conflicts of interest in the publication of this article.

AUTHOR CONTRIBUTIONS

Phung Ngoc Anh was involved in ideation, UAV data collection, image data processing, and manuscript writing.
Chung Minh Quan participated in assisting in collecting UAV data and proofreading the article.
Tran Anh Tu participated in giving ideas for writing articles and consulting on the analysis results.
Vo Tran The Vi assisted in designing and flying the UAV.
Nguyen The Duoc supports instructions for processing 3D data.
Le Thanh Phong supports equipment and advises on the analysis of results.

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Hình thức truy cập: Truy cập mở
Ngôn ngữ bài báo: Tiếng Việt
Tỉ lệ chấp nhận đăng 2021: 75%
Phí xuất bản: Miễn phí
Thời gian phản biện: 30-45 ngày
Lập chỉ mục (Indexed): Google Scholar, Scilit
SCAN ME

Tạp chí Phát triển Khoa học và Công nghệ - Kĩ thuật và Công nghệ
ISSN: 2615-9872
Hình thức xuất bản: In & trực tuyến
Hình thức truy cập: Truy cập mở
Ngôn ngữ bài báo: Tiếng Việt
Tỉ lệ chấp nhận đăng 2021: 61%
Phí xuất bản: Miễn phí
Thời gian phản biện: 50 ngày
Lập chỉ mục (Indexed): Google Scholar, Scilit
SCAN ME

Tạp chí Phát triển Khoa học và Công nghệ - Kinh tế-Luật và Quản lý
ISSN: 2588-1051
Hình thức xuất bản: In & trực tuyến
Hình thức truy cập: Truy cập mở
Ngôn ngữ bài báo: Tiếng Việt
Tỉ lệ chấp nhận đăng 2021: 65%
Phí xuất bản: Miễn phí
Thời gian phản biện: 45 ngày
Lập chỉ mục (Indexed): Google Scholar, Scilit
SCAN ME

Tạp chí Phát triển Khoa học và Công nghệ - Khoa học Xã hội và Nhân văn
ISSN: 2588-1043
Hình thức xuất bản: In & trực tuyến
Hình thức truy cập: Truy cập mở
Ngôn ngữ bài báo: Tiếng Việt
Tỉ lệ chấp nhận đăng 2021: 62%
Phí xuất bản: Miễn thu phí đối với tác giả là CBVC của ĐHKHXHNV, ĐHQG-HCM; Tác giả khác: 500.000 VNĐ/bài
Thời gian phản biện: 75 ngày
Lập chỉ mục (Indexed): Google Scholar, Scilit
SCAN ME

Tạp chí Phát triển Khoa học và Công nghệ - Khoa học Trái đất và Môi trường
ISSN: **2588-1078**
Hình thức xuất bản: In & trực tuyến
Hình thức truy cập: Truy cập mở
Ngôn ngữ bài báo: Tiếng Việt và tiếng Anh
Tỉ lệ chấp nhận đăng 2021: 87%
Phí xuất bản: liên hệ tòa soạn
Thời gian phản biện: 45 ngày
Lập chỉ mục (Indexed): Google Scholar, Scilit
SCAN ME

Tạp chí Phát triển Khoa học và Công nghệ - Khoa học Sức khỏe
ISSN: 2734-9446
Hình thức xuất bản: In & trực tuyến
Hình thức truy cập: Truy cập mở
Ngôn ngữ bài báo: Tiếng Việt
Tỉ lệ chấp nhận đăng 2021: 70%
Phí xuất bản: Miễn phí
Thời gian phản biện: 30 ngày
Lập chỉ mục (Indexed): Google Scholar, Scilit
SCAN ME

Tạp chí Phát triển Khoa học và Công nghệ, Đại học Quốc gia Tp.HCM
25 năm xuất bản học thuật (1997-2022)
Tòa soạn: Nhà điều hành Đại học Quốc gia Tp.HCM, P. Linh Trung, TP. Thủ Đức, TP. HCM
Email: stdj@vnuhcm.edu.vn; tcptkhcn@vnuhcm.edu.vn; Website: *http://www.scienceandtechnology.com.vn*