

# A Novel of RTK Survey with TGM2017 Height Determination using IoT Device

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**Abstract**—In this paper, we propose a development method for precisely positioning Thailand's water resource management. We are developing a low-cost GNSS RTK Receiver named "IoRTK" using Ublox F9P and ESP32 that can be used on Android devices. We used the RTK protocol and calculated the Thailand-Geoid-Model (TGM) value with the TGM2017 orthometric height determination from the global standard height WGS84, which was developed to suit the area of Thailand. Our goal of application calibration for RMSE positioning accuracy should be less than 5 cm in a horizontal plane and less than 10 cm in a vertical plane. The experimental results show that RMSE positioning accuracy is 4.5 cm in a horizontal plane and 8.3 cm in a vertical plane in real-time operation.

**Keywords**—GNSS RTK, TGM2017, Ublox F9P, ESP32

## I. INTRODUCTION

The Hydro-Informatics Institute (Public Organization), known as HII [1], is an institute that develops and manages water resources in Thailand. It has collected information about water and weather. The Hydro-Informatics Institute (a public organization) aims to improve the resources of the National Hydro-Informatics and Climate Data Center in Thailand for international cooperation and share knowledge with the government, private sector, community, and people. GNSS technology is very costly. Therefore, research has been conducted to develop technologies and innovations to reduce costs. The community sector can use the equipment from GNSS RTK. If the cost is low, then they can manage the water in the community.

## II. BACKGROUND

The Hydro-Informatics Institute (a public organization) or HII aims to collect, link, integrate, and analyze water and climate data that affect water management. For the government, private sector, community, and people to use.

There are 251 CORS stations in Thailand [2], as shown in Fig. 1. We have 251 stations from collaboration with eight departments such as the Department of Lands (DOI), the Royal Thai Survey Department (RTSD), the Hydro-Informatics Institute (Public Organization) (HII), the Department of Public Works and Town and Country Planning (DPT), King Mongkut's Institute of Technology Ladkrabang, the Geo-Informatics and Space Technology Development Agency (Public Organization) (GISTDA), Chulalongkorn University

(CU), and the National Institute of Metrology (NIMT) spread all over the country. For GNSS CORS, there are more than 400 stations divided into 80 main stations and other sub-stations.

To achieve other benefits besides station information for research studies, the HII would like to extend the use of such satellite-receiving stations to local networks with which it is collaborating in different areas of Thailand [3].

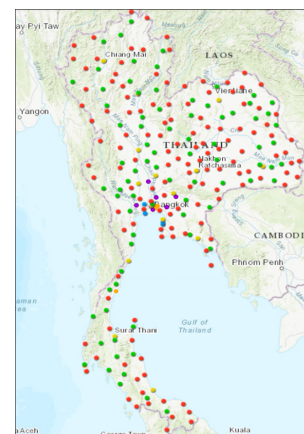


Fig. 1. CORS Stations in Thailand.

To develop a low-cost GNSS receiver satellite device. Because modern satellite receivers are genuinely expensive, their use is restricted. Developing low-cost satellite receivers will reduce costs and make the device more accessible to the public.

The HII has collaborated with the Royal Thai Survey Department and the Department of Lands for research on the Virtual Reference Station (VRS) network. Usually, the VRS network has a WGS84 reference system. It uses EGM2008 (Earth Gravitational Model) as the geoid standard. However, the Royal Thai Survey Department has developed a geoid value over TGM2017 for use on Thai territory, which makes it more correct. Therefore, we use TGM2017 (Thailand Geoid Model 2017), which typically provides a vertical accuracy of 10 cm in the general area and 2–5 cm in Bangkok and surrounding areas. VRS (Virtual Reference Station) is a

method of RTK correction and one of the methods of NRTK (Network-based Real-Time Kinematic).

The reference station sends the approximate location coordinates to the central services. The central station then computes the modified values and sends the modified values back to the receiver. We use the NTRIP protocol (Network Transport of RTCM via Internet Protocol), which means that the data is transmitted over the Internet rather than over the radio. Using the GNSS CORS Network (GNSS Continuously Operating Reference Station Network), values are transmitted back to networks that allow for highly accurate positioning. The Hydro-Informatics Institute (a public organization) provides information services in Real-Time and Post-Processing formats. The Royal Thai Survey Department and the Department of Lands must request and use the real-time format.

TGM2017 [4], or Thailand Geoid Model 2017, is a high-resolution geoid model for Thailand. Each grid is approximately 1.8 kilometers apart, with the following details: Latitude values start at 3 degrees. Longitude values start at 95 degrees. It has a spatial resolution of 1 lipda. There are 780 Columns and 1200 rows reference from a ASC file of TGM2017 program [5], as shown in Fig. 2.

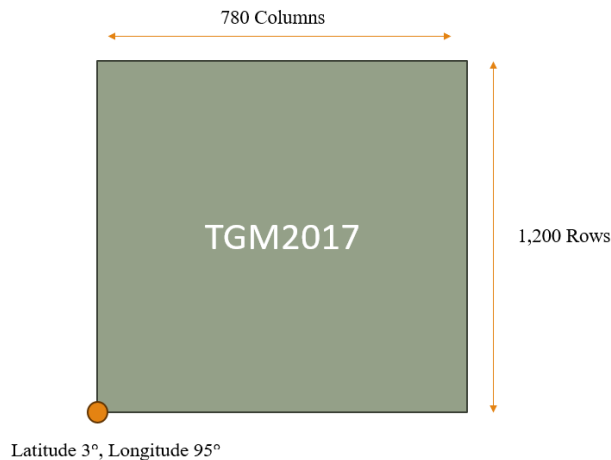


Fig. 2. Thailand Geoid Model 2017 Boundary

The primary purpose of this research, Applications of the "IoRTK," was to develop devices to be reachable for all. The HII wants to distribute the devices to most people to be accessed and used conveniently and to be able to observe the amount of water or measure other values. Meanwhile, there is continuously increasing flooding in Thailand, but the equipment used to work according to the demand is still expensive. Therefore, a large amount of equipment is needed to maintain the problem. This is why these studies are essential. The research was being done on developing an "IoRTK" application with a receiving device.

The ZED-F9P [6] is a low-cost GNSS satellite receiver board from the Comparison Study of Technical Characteristics of Low-cost Multi-band GNSS Modules in Solving the Prob-

lem of Measuring the Total Electron Content of the Ionosphere [7] and Research of the Implementation Possibility of the Precise GPS Positioning Technology [8]. Using the U-Blox ZED-F9P model as the ability of its dual-frequency GPS [9], Glonass, and Beidou reception. Also, to perform RTK (Real Time Kinematic) due to typical GPS values only in meter unit level accuracy, we need accuracy in centimeters, which increases the device's cost. Using RTK will reduce the cost of determination of accuracy.

RTKLib [10], [11] is a library developed by Takasu Tomoji and Akio Yasuda of the Laboratory of Satellite Navigation, Tokyo University of Marine Science and Technology, capable of taking measurement data from a reference station obtained from the rover's GPS. Then calculates in real time to get coordinates with centimeter accuracy, an open-source program package. It has been continuously developed since its release in 2009. The latest version is 2.4.3 b34.

### III. METHODOLOGY

In this research, there are two parts to development. The first part is the hardware development of a low-cost GNSS Receiver, and the second part is an Android application for use with the receiver. The application can get a differential correction from VRS networks using the NTRIP protocol and then process the mean sea level (MSL) height using the TGM2017 standard.

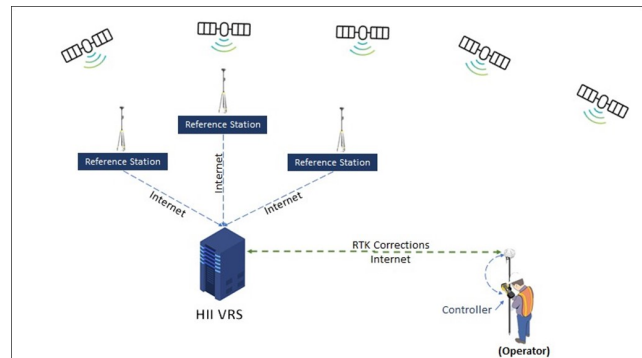


Fig. 3. System Overview

In Fig. 3, we show a system overview of the connection of HII VRS networks between the reference station and the controller application.

#### A. Hardware Development

We use the UBLOX model ZED-F9P for GNSS satellite receivers, which can receive dual-frequency GPS, Glonass, and Beidou. Also, ZED-F9P can be calculated by itself at a cheap cost of around 170 USD. For the receiver's control part, we use an ESP32 controller that supports Wi-Fi and Bluetooth, with an approximate price of around 15 USD. A Helix GNSS antenna is used to receive the GNSS signal. We also used a 6,000 mAh lithium battery to power the receiver. It can operate for 5 hours. We have named the development unit IoRTK, as shown in Fig. 4.

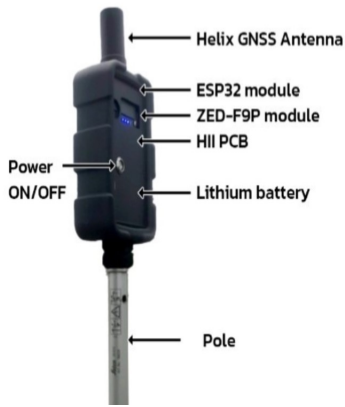


Fig. 4. IoRTK Hardware Device



Fig. 6. "IoRTK" Application connection

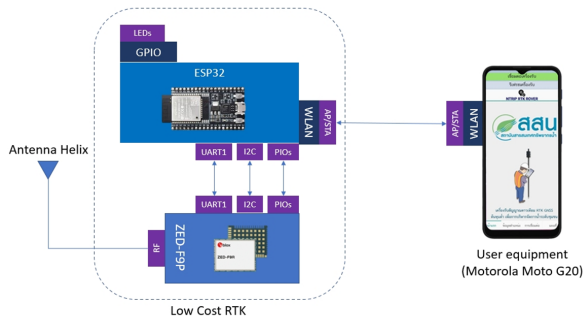


Fig. 5. System Diagram

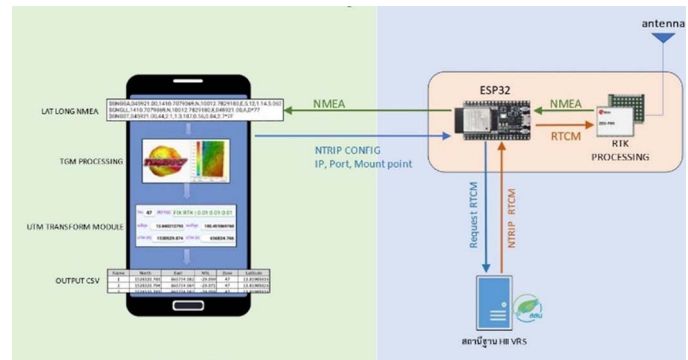


Fig. 7. System Diagram Data transmission.

The equipment we use:

- ESP32 Dual Core 160 MHz Model ESP-WROOM-32 has Wi-Fi, Bluetooth 4.2, Touch + Temp Sensor that can be developed via Arduino Ide [12]
- The Motorola Moto G20 is Android version 11, with a CPU of 1.8 GHz, a RAM of 4 GB, and a battery of 5,000 mAh.

In Fig. 5. Show how ESP32 and Ublox connect, and then ESP32 connects to the application in the same network. Satellite receivers will be connected automatically to Wi-Fi with a specific username and password.

### B. Application

The first page of the application shows the connection profile with VRS networks and satellite receivers, as shown in Fig. 6. The connection profile with the Royal Thai Survey Department and Department of Lands shows the time and data transmissions, as shown in Fig. 7.

For the connection between the GNSS RTK receiver and the VRS network, we use the Motorola Moto G20 smartphone as a controller that serves as a bridge to connect the IoRTK device to the VRS network.

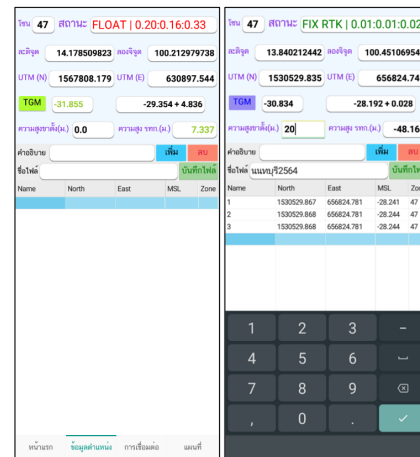


Fig. 8. "IoRTK" applications use TGM (green) and not use TGM (purple)

$$MSL = Altitude + Geoid - Pole - TGM \quad (1)$$

The MSL result of the calculation shown in the green text is 7.337, as shown in Fig. 8. Even if the TGM function is not used, the MSL function is calculated by

$$MSL = Altitude + Geoid - Pole \quad (2)$$

MSL : Mean Sea Level.

Altitude : Height above the oval

Geoid : Geoid Height TGM 2017

Pole : Pole offset from ground to receiver fixed distance.

TGM : Differential correction

We use multiple fields for this application, as shown below, which get values from the RTK messages output by NMEA, from which we compute Latitude, longitude, polar altitude, and the TGM altitude.

The TGM calculation converts the Latitude and longitude values into the UTM zone. In this zone, we find the UTM, or Universal Transverse Mercator, with Latitude and longitude given in degrees. Then, the value must be converted to decimal units to locate the zone. This is because the values will be different if it falls in different zones. Then the distance to the nearest waypoint is determined, and the nearest value of the point is sorted. If it is precisely at the point, the altitude of that point is used. If not, the distance is calculated by summing the values around the point with the current point to get the TGM altitude.

To calculate the TGM2017 [13]–[16] since the Earth's surface is not a smooth ellipsoid, we had to take the value of the ellipsoidal surface, or WGS84, to calculate the TGM2017 value to get the geoid height, which can be used to find the mean sea level. We will interpolate the value to find the Goid.

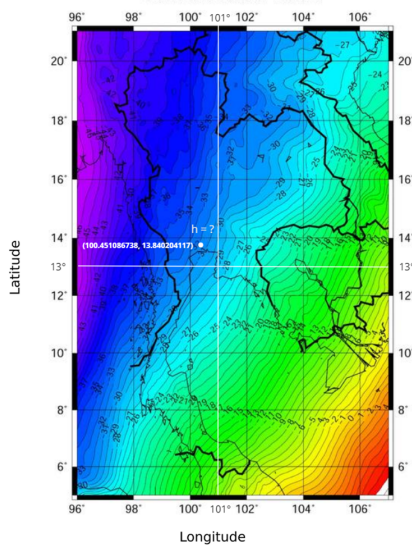


Fig. 9. Thailand Geoid Model 2017

TGM2017 is computed by the Latitude and longitude we want to find to see if it exceeds the coordinates of TGM2017. After that, we calculate it as the TGM2017 coordinate to find

the columns and rows of the desired coordinates, as shown in Fig. 9.

Find the four elevation points from the column and the rows in the TGM2017 coordinates by adding 1 to the columns and rows of TGM2017 to get the perimeter. The Latitude and longitude of all 4 points are added by Lipda to each position based on adding 1 in digits and rows.

Convert Latitude and Longitude, both initials and all 4 points, to UTM in WGS84 format using the Geodesy Library of Movable Type Scripts [17], which gets zone, E, N, hemisphere and calculates the distance between all 4 points. The initials ( $E, N$ ) are in meters.

Then, using the values ( $E, N$ ) of each one to enter the equation of the Carty formula, Latitude and longitude are transformed to UTM to find the zone of each point and the distance of each point obtained with the initiator for two points.

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \quad (3)$$

We determined all four coordinates; we will make a new virtual point coordinate by calculating the values of the first to third coordinates in the equation to make a virtual point.

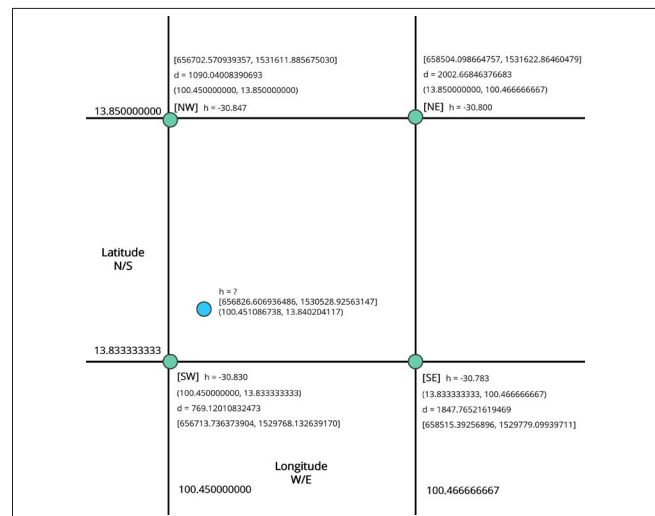


Fig. 10. Value around the starting point.

After calculating area and linear interpolation, we can summarize assuming points by the equations 4 and 5.

Once we have the coordinates ( $E_v, N_v$ ) have a virtual point. When ( $E_s, N_s$ ) are the coordinates, we want to find.

$$d_{2v} = \sqrt{(E_v - E_2)^2 + (N_v - N_2)^2} \quad (6)$$

$$d_{23} = \sqrt{(E_3 - E_2)^2 + (N_3 - N_2)^2} \quad (7)$$

$$d_{1v} = \sqrt{(E_v - E_1)^2 + (N_v - N_1)^2} \quad (8)$$

$$E_v = \frac{(((E_2 - E_3)((N_1 - N_S)E_S) + ((E_S - E_1)N_S))) - ((E_S - E_1)((N_3 - N_2)E_2) + ((E_2 - E_3)N_2))}{((N_1 - N_S)(E_2 - E_3)) - ((N_3 - N_2)(E_S - E_1))} \quad (4)$$

$$N_v = \frac{(((N_1 - N_S)((N_3 - N_2)E_2) + ((E_2 - E_3)N_2))) - ((N_3 - N_2)((N_1 - N_S)E_S) + ((E_S - E_1)N_S))}{((N_1 - N_S)(E_2 - E_3)) - ((N_3 - N_2)(E_S - E_1))} \quad (5)$$

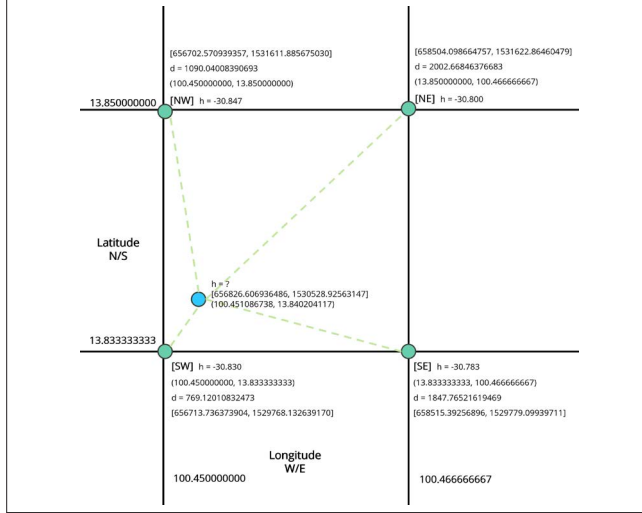


Fig. 11. Distance between all four points.

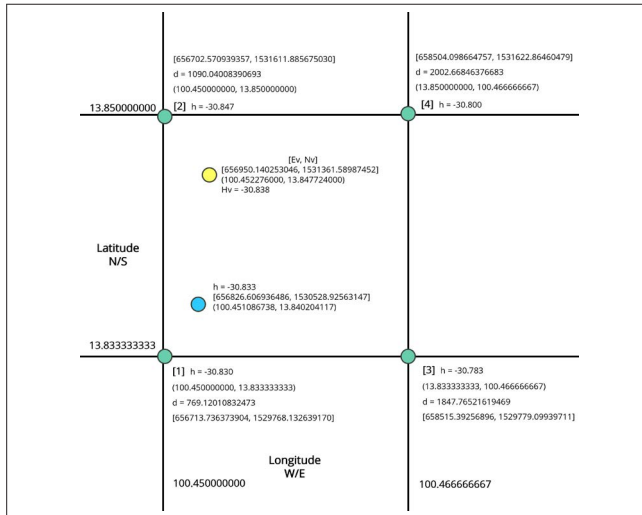


Fig. 12. Virtual point coordinates.

Then we will determine the height of the virtual point by using the equations to get the distance.

$$H_v = \left( \frac{d_2 v}{d_2 3} \times (H_3 - H_2) \right) + H_2 \quad (9)$$

After calculating area and linear interpolation, we can summarize assuming points by these equations.

Finally, we get.

$$H_s = \left( \frac{d_1}{d_1 v} \times (H_v - H_1) \right) + H_1 \quad (10)$$

#### IV. EXPERIMENTAL RESULT

To examine the performance of the IoRTK, we use the results of a 100-fold comparison between the low-cost RTK and the GNSS Leica RTK. In the Water Resources Informatics Institute (Bangkhen) building on August 18, 2021, the results of the two devices showed error differences in the horizontal and vertical. Then we use the RMSE to calculate the average.



Fig. 13. Testing between Leica Receivers and Low-Cost RTK Receivers.

The test results in Table I show that we archive 67% better than 5 cm in the horizontal plane and 100% better than 10 cm in the vertical plane compared to the static reference. These two figures are the most critical constraint on positioning accuracy for this research objective.

TABLE I  
IORTK PERFORMANCE OF ABSOLUTE ACCURACY

	ERROR (cm)				
	Performance test results	Error Horizontal		Error Vertical	
		LEICA	IoRTK	LEICA	IoRTK
1	Maximum error	6.1	6.8	5.1	8.7
2	Minimum error	1.8	1.7	0.7	1.4
3	Average deviation of RMSE	3.6	4.5	3.3	8.3

## V. CONCLUSIONS

In this paper, we have proposed the development of a GNSS RTK receiver called "IoRTK" using Ublox F9P and ESP32. This can reduce the hardware cost of GNSS RTK devices. We developed an application capable of managing the RTK protocol and TGM2017 processing that can be used on Android devices. The experimental results show that the RMSE positioning accuracy is 4.5 cm in the horizontal plane and 8.3 cm in the vertical plane. This is better than we expected. We are also sure that the developed IoRTK will be one of our tools for water resource management in Thailand.

The purpose of the IoRTK will be the development of low-cost GNSS receivers for real-time operation. The development of the application is consistent with the terrain of Thailand. It allows calculations with TGM2017, i.e., altitude values calculated from Latitude and longitude. This makes the average sea level more suitable for Thailand. It has been designed for HII staff.

## ACKNOWLEDGMENT

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