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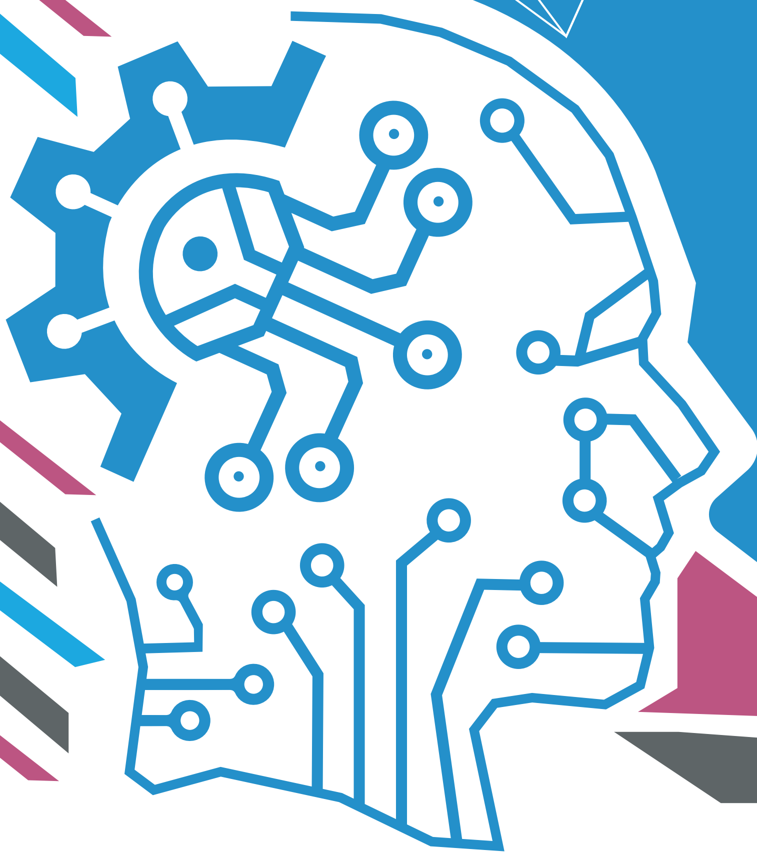
THE 14TH INTERNATIONAL INVENTION, INNOVATION & DESIGN COMPETITION 2025



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DEVELOPMENT OF LOW-COST GLOBAL NAVIGATION SATELLITE SYSTEM (GNSS) PERMANENT BASE STATION FOR EDUCATION

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ABSTRACT

This project introduces a low-cost, permanent Global Navigation Satellite System (GNSS) Real-Time Kinematic (RTK) base station system designed specifically for educational institutions. Leveraging commercially available GNSS hardware and open-source software tools, the system enables real-time centimeter-level positioning accuracy within a 15 km range. Several key technical components of this project are the development of a dedicated application layer that handles real-time data acquisition, correction transmission via Networked Transport of Radio Technical Commission for Maritime Services (RTCM) via Internet Protocol (NTRIP), and user interface interaction for both base and rover stations. The application integrates with GNSS modules through serial communication, processes RTCM data streams, and visualizes positioning outputs via a custom dashboard, enhancing usability for teaching and learning. Developed using lightweight frameworks compatible with embedded systems, the application ensures low resource consumption and high reliability. Field experiments at three locations showed the system's effectiveness in comparison to field observations using commercial GNSS equipment. The results of the field study show that the differences observed using this innovation meet the standards set by the Department of Surveying and Mapping Malaysia (JUPEM). The cost-effective nature of the system provides educational institutions the opportunity to deploy high-precision positioning infrastructure without the burden of commercial licensing, offering students hands-on experience with real-world geospatial technologies and strengthening institutional capabilities in technical education.

Keywords: Global Navigation Satellite System (GNSS), Real-Time Kinematic (RTK), internet protocol, positioning and surveying technology

1. INTRODUCTION

A low-cost permanent base station GNSS RTK system could provide a solution to these issues by making advanced GNSS equipment more accessible to educational institutions, even those with limited funding. Establishing a permanent base station at educational institutions would allow students to benefit from continuous access to GNSS RTK data, making it easier for them to gain practical experience. The proposed system would not only ensure that the base station is available to students at all times but also enable them to use it for a wide range of practical applications, from surveying and geospatial analysis to drone-based operations. Many educational institutions are constrained by limited access to GNSS RTK instruments, preventing students from using industrial standard equipment during their coursework. A permanent GNSS RTK base station would solve this problem by providing consistent access to high-quality GNSS correction data for all students. With a single base station, multiple students can simultaneously access real-time correction data, overcoming the issue of insufficient instruments.

2. METHODOLOGY

The methodology for this study will involve the following steps:

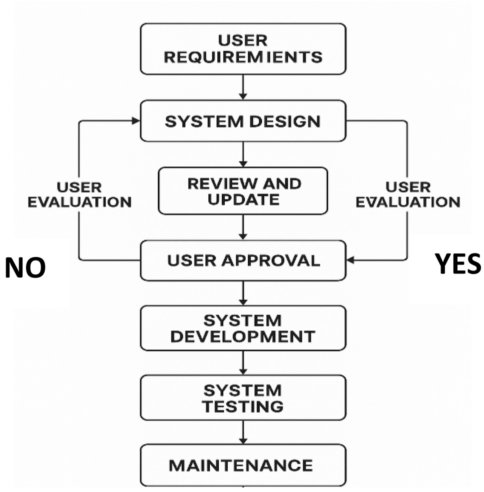

Figure 1 System development process

Figure 1 shows the system development process begins with identifying user needs, followed by system design. Next, a prototype is developed, and user evaluation is conducted to obtain feedback. If necessary, the system will go through a review and update phase before receiving user approval. Once approved, the system enters the development phase, followed by system testing to ensure complete functionality. Finally, the system will go through a maintenance phase to ensure it continues to operate properly.

3. FINDINGS

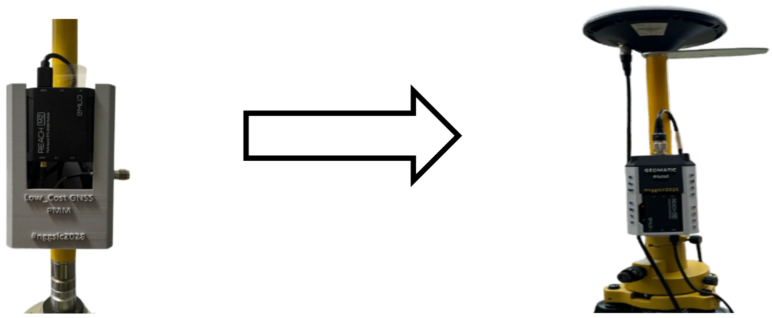

Figure 2 Low-cost GNSS RTK Base Setup Developed

Figure 2 illustrates a portable GNSS RTK receiver system composed of a multi-band GNSS antenna mounted on a survey pole, integrated with the Reach M2 RTK module. This setup was developed initiative to evaluate the performance of affordable, high-precision GNSS positioning systems. It was primarily used for field testing across various baseline distances to assess coordinate accuracy.

Table 1 Calibration results at GNSS Calibration site of JUPEM, Ayer Keroh, Melaka

Pillar	Reference Coordinate			Observed Coordinate			Difference (m)		
	Latitude	Longitude	Ellipsoid Height (m	Latitude	Longitude	Ellipsoid Height (m	Latitude	Longitude	Ellipsoid Height (m)
P002	2°16’29.06062”	102°17’11.32102”	19.219	2°16’29.06159”	102°17’11.32072”	19.1884	**-0.02910**	**0.00900**	**0.03060**
P003	2°16’28.44688”	102°17’8.80491”	17.600	2°16’28.44698”	102°17’8.80464”	17.5725	**-0.00300**	**0.00810**	**0.02750**

P006	2°16’25.39501”	102°16’56.21902”	13.660	2°16’25.39501”	102°16’56.21905”	13.6376	0.00000	-0.00090	0.02240

Table 2 Testing results at PMM Control Points

Point	Coordinate				Obs. Coordinate			Difference		
	North (N)	East (E)	Height (H)	Brand	North (N)	East (E)	Height (H)	North (N)	East (E)	Height (H)
CRM 01	-60277.4132	54454.5669	16.4802	CHC TERSUS STEC	-60277.4055 -60277.3999 -60277.4030	54454.5230 54454.5272 54454.5240	16.4080 16.4013 16.4010	-0.0082 -0.0133 -0.0102	0.0439 0.0397 0.0429	0.0722 0.0789 0.0792
CRM 02	-60409.1335	54408.7737	16.3629	CHC TERSUS STEC	-60409.1100 -60409.1141 -60409.1030	54408.75300 54408.74527 54408.75700	16.3680 16.3567 16.3690	-0.0235 -0.0194 -0.0305	0.02070 0.02843 0.01670	-0.0051 0.0620 -0.0061
CRM 03	-60284.0870	54324.716	14.8076	CHC TERSUS STEC	-60284.0740 -60284.0671 -60284.0710	54324.6940 54324.6928 54324.6840	14.7630 14.7696 14.7630	-0.0130 -0.0199 -0.0160	0.02200 0.02312 0.03200	0.0446 0.0380 0.0446
CRM 04	-59883.7648	54194.7581	18.2613	CHC TERSUS STEC	-59883.7550 -59883.7599 -59883.7590	54194.7330 54194.73918 54194.7300	18.2190 18.2092 18.2060	-0.0098 -0.0049 -0.0058	0.02510 0.01892 0.02810	0.0423 0.0521 0.0553

Table 3 Testing results for base long distance at Pantai Siring and Ayer Molek

Point	Coordinate				Obs. Coordinate			Difference		
	North (N)	East (E)	Height (H)	Brand	North (N)	East (E)	Height (H)	North (N)	East (E)	Height (H)
PMM to PANTAI SIRING: 8 KM										
M 5119	-62095.612	46161.842	5.928 (Msl)	CHC TERSUS STEC	-62095.686	46161.922	5.9108 (Msl)	0.074	-0.08	0.0172
CRM 02	-62190.301	46116.27	5.134 (Msl)	CHC TERSUS STEC	-62190.306	46116.274	5.1398 (Msl)	0.005	-0.004	-0.0058
M 0582			6.251 (Msl)	CHC TERSUS STEC	-63378.418	46939.333	2.7548 (Msl)	0.0169	-0.026	0.0182
PMM to AYER MOLEK: 10 KM										
M 0565			19.717 (Msl)	CHC	-53748.158	44702.722	19.76 (Msl)			-0.043

4. CONCLUSION

The development of a low-cost GNSS RTK permanent base station has shown significant potential to transform geospatial education by providing real-time, centimeter-level accuracy using affordable hardware and open-source software. The integration of a custom-built application layer not only enhances system functionality but also ensures ease of use in classroom and field environments. Results from field tests at multiple calibration and control points confirm the system's accuracy and reliability, with deviations well within acceptable tolerances established by JUPEM. This innovation democratises access to high-precision GNSS infrastructure, enabling students to gain hands-on experience with tools that closely simulate professional surveying workflows. It strengthens the institutional capacity to deliver technical education while simultaneously reducing dependency on expensive commercial systems.

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