

# Theory of Relativity for GPS and Its Application to Determining the Geographical Location of Students' Address

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**Abstract:** This study aims to determine the working principle of the Global Positioning System (GPS) as a technology that applies the concept of relativity, and its application to determine the geographic location of students' addresses. This type of research is a literature study. In general, the GPS system has three main components, namely the ground segment (control station), the space segment (satellite), and the user segment (receiver device). GPS determines the receiver's position using the trilateration method from a minimum of four satellites that are always visible from any point on Earth at any time. The results of the study state that information from three satellites is needed to determine location, while the fourth signal is needed to determine time accurately. Relativity causes the GPS system to experience a time lag. The relative motion of the satellite to the earth causes the time on the satellite to be slower than earth time, while earth's gravity makes the satellite time move faster than earth time. The novelty of the results and discussion of the study conducted is to find the coordinates of student addresses, thus facilitating mapping of student residences in the city of Lubuklingau and its surroundings.

**Keywords:** General relativity; Global positioning system; Special relativity; Student addresses

## Introduction

Physics is a branch of science, and the beginning of the revolution in science was marked by important discoveries by scientists. One of the main consequences of this revolution was a significant change in the way scientists view and carry out scientific activities. In addition, the scientific revolution has also fundamentally changed humanity's view of the universe (Hartini, 2019). Paradigms act as the main reference in the development of science, both in the research process, problem solving, and determining topics that are worth studying. Paradigm shifts have a major impact on how scientists view the world. Paradigms in science are born from mutual agreement among scientists. The process of developing science also takes place in a revolutionary

manner, and continues through the contributions of individuals in the scientific community. One example of a scientific revolution in physics is the transformation of Newton's classical mechanics into relativity mechanics introduced by Einstein. Newton's theory of space and time leaves a number of questions that trigger the curiosity of scientists to continue digging deeper. In the 19<sup>th</sup> century, a famous phenomenon known as the twin paradox emerged: two separated twins, one of whom traveled into space, then returned to earth looking younger than his brother who remained on earth. This phenomenon cannot be explained by Newton's theory which assumes that time is absolute wherever it is. Therefore, new thinking about space and time and a new view of the structure of the universe are needed. Einstein's special theory of relativity on the expansion of

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time has provided the view that the quantities of time, length, and mass are relative or dynamical quantities (Kurnia, 2021).

Einstein's theory of relativity is divided into special and general relativity. Special relativity appeared first and discussed the speed of light which is constant for everyone. This theory seems simple, but it turns out to have profound consequences. Einstein concluded this theory in 1905 after experimental evidence emerged showing that the speed of light does not change as the earth orbits the sun. This result was quite surprising to the world of physics because it still assumed that the speed of almost all objects depended on the direction of observation of the observer. If someone were to drive a car next to a railroad track, that person would realize that the train would move much faster if the car was moving against the direction of the track than if the car was moving in the same direction as the train.

According to Einstein, every observer would measure the speed of light at 299,792,458 m/s regardless of how fast the observer was moving or in what direction the observer was moving. However, various questions arise, such as what if someone were in a spaceship moving at the speed of light, and turned on the lights. Some physicists answer that the lights would still be on as usual, but only from the perspective of someone inside the spaceship. If someone outside observed how the spaceship was moving, the lights would not come on. It would take a very long time for the lights to come on for someone outside the spaceship. However, this answer is controversial. If the speed of light is considered constant as Einstein said, then space and time are not absolute. They must be relative. In addition to space and time, mass will also change. The faster an object moves, the heavier the mass of the object. In fact, no spaceship can reach 100% of the speed of light. If this happened, the mass of the spaceship would soar to infinity. The relationship between mass and velocity is often expressed in the equation  $E = mc^2$ , where  $E$  is energy,  $m$  is mass, and  $c$  is the speed of light. The equations of general relativity successfully predict a number of phenomena, some of which have been proven, such as: the bending of light in giant objects, the evolution of the orbit of the planet Mercury, the acceleration of the rotation period of binary stars and pulsars, gravitational waves caused by cosmic explosions and the existence of black holes that can pull everything without leaving it, including light and the bending of space-time around black holes that is much larger than anywhere else (Haruyama et al., 2021).

There are the most striking developments in Physics in the 20<sup>th</sup> century, namely relativity by Albert Einstein in 1905 and quantum theory by Max Planck in 1900. Both of these developments are examples of scientific

revolutions that have fundamentally changed the way humans view the universe. Khun stated that science develops through paradigm shifts, namely fundamental changes in assumptions, theories, and methods within the framework of the old paradigm towards assumptions, theories, and methods within the framework of the new paradigm. New ideas in the scientific revolution of Einstein's theory of relativity include the special theory of relativity and the general theory of relativity. The laws of physics contained in the theory of relativity can be found in everyday life. One of them is the Global Positioning System (GPS). GPS is the only global navigation satellite system for determining location, speed, direction, and time that has been fully operational in the world today. GPS is empirical evidence of the theory of relativity as part of the scientific revolution. GPS stands for Global Positioning System, which is a navigation system that uses satellite technology that can receive signals from satellites.

The development of information technology is increasingly growing, one of which is in the creation of applications that can be developed on Android-based smartphone devices that can be easily used and can provide information quickly and efficiently. One of the features found on smartphones is internet services and is equipped with a GPS (Global Positioning System) feature, namely a navigation system that uses satellite signals in its use. With GPS, smartphone users can find out the user's coordinates, namely latitude and longitude data. GPS can calculate information, such as speed, direction, route, travel destination, distance traveled, sunrise and sunset and others (Perkasa, 2019). The signal sent by the satellite to GPS will be used to calculate travel time. The application of location with Location Based Services (LBS) or location-based services that are able to detect user location can also provide the information services needed according to the user's location. This LBS also utilizes the GPS technology function and cell-based location from Google. In measuring position, LBS uses latitude and longitude to determine geographic location (Rudiarto, 2023).

Global Positioning System (GPS) is a tool or system that can be used to determine a person's position (globally) on the earth's surface based on satellites (Cheng et al., 2024). Data sent from satellites are in the form of radio signals with digital data. This system was first used by the United States Department of Defense in 1978 and in 1994 had used 24 satellites. GPS is the only global navigation satellite system to determine location, speed, direction, and time that has been fully operational in the world today. GPS has three main components, namely: satellites, controllers, and receivers/users. The satellite functions to receive and store data sent by the control station. Store and maintain time information

with high accuracy (determined by the atomic clock on the satellite), and send signals and information continuously to the receiver from the user. Furthermore, a systematic approach is proposed for incorporating these effects within an algorithmic framework, offering a structured contribution to a topic that has been only marginally covered in previous studies. The controller functions to control and control the satellite from earth both to check the health of the satellite, determine and estimate the time orbit, synchronize time between satellites, and send data to the satellite. Receiver functions to receive data from satellites and process it to determine the position (three-dimensional position, namely coordinates on earth plus altitude), direction, distance, and time required by the user. Receivers are of two types, namely navigation type and geodetic type.

## Method

This study uses a literature study method combined with a field survey. Literature study by reviewing several journals related to the theory of relativity and GPS. A field survey to collect address coordinate data for 17 students was conducted on December 2, 2024 while giving a Core Physics lecture for seventh semester physics education students at UNPARI. To be more accurate, student address data was created at home, to collect a number of geographic locations of student addresses in Lubuklinggau City. Data analysis was carried out descriptively qualitatively (Mayningrum & Muhtadi, 2021).

Coordinate points are the position of a particular point on a map where the point meets the vertical and horizontal lines on the map (Yacob & Peter, 2022). There are two types of coordinates, namely geographic coordinates and grid coordinates/UTM. Geographic coordinates have longitude (west longitude and east longitude) perpendicular to the equator and latitude (north latitude and south latitude) parallel to the equator. Coordinate point codes are expressed in degrees (°), minutes (′), and seconds (″), while grid coordinates are expressed in the X and Y axes. The position of a point in these coordinates is expressed in terms of the distance of a reference point. The X axis is named from west to east/left to right, while the Y axis is from south to north/bottom to top. By using GPS latitude and longitude coordinate points, you can easily search for a place through the Google Maps application. These coordinate points will help you to find travel routes with maps that appear in the Google Maps application (Zhao et al., 2021). If you have difficulty getting the coordinates of a place on this application, you can follow these steps: Open the Google Maps application; Long tap on a specific area that is not

labeled; A red pin will appear; In the search box at the top, a coordinate point will appear.

UNPARI physics education students are guided to determine the coordinate point of their residence (home address), with the following steps: First, activate the location in the settings on your cellphone; Open Google Maps; Click on your profile photo; Select Settings; Select Start Maps on the display (activate); Press the blue round dot (home location), until a red pin appears; Then click the number in the search column; Then select Map; Slide the red pin until it is exactly above the blue round color (zoom in the blue round location first), so that the red pin is exactly on the blue round dot.; Click Ok; Then copy and share via WA (Andari et al., 2023).

Students are also guided by using coordinate points to search for addresses, how to enter coordinate points in the Google Maps application with the following steps: Open the Google Maps application; Type the coordinate point in the search contact; Can be done by typing degrees, minutes, and seconds (DMS); For example 42°24′13.2″N 3°11′27.2″N; Or with the format of degrees and decimal minutes (DMM); For example 25.2126, 11.3327; Can also be with the format of decimal degrees (DD); For example 43.41289, 5.18902; The pin will appear at the coordinate point being searched for.

## Result and Discussion

Table 1 shows the geographical coordinates and Google Maps (route from the home of a seventh semester UNPARI physics education student to the UNPARI campus).

Determining the geographical coordinates of student addresses in Lubuklinggau City and its surroundings is very important for student administration data purposes, as well as for other purposes. Figure 1 shows one of the routes from a physics education student's house to the UNPARI campus, with the house coordinates-3.2752162,102.9092237, a distance of 650 meters, and a travel time of only 2 minutes by vehicle (Vuorikari et al., 2022).

GPS provides accurate data on the geographic coordinates of students. The GPS navigation system consists of three main components, namely the ground segment which is a station on earth as a satellite controller, the space segment in the form of a satellite orbiting the earth, and the user segment in the form of a GPS receiver device (Han et al., 2021). Until 2012, there were 32 GPS satellites orbiting the earth at an altitude of about 20,200 km. GPS satellites orbit with a period of 11 hours 58 minutes (Han et al., 2021). With an orbital period of twice a day and a radius of about 26,600 km, each satellite has an orbital speed of about 3874 m/s.

GPS satellites are also equipped with booster rockets to keep the satellite in orbit, and have batteries as a power source when there is no sunlight or when a solar eclipse

occurs (Hartini, 2019). The GPS satellite orbit configuration is as shown in Figure 2.

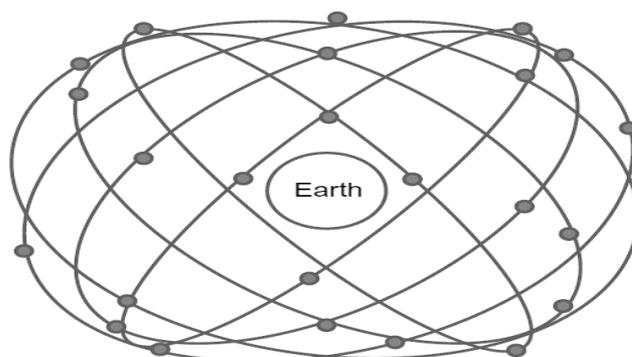
**Table 1.** Student address coordinates

Student Name	Student Address	Student Address Coordinate Point Student Address	Google Maps Link Route Home to UNPARI
Sayyidatur Rafifah	Jln. Majapahit Lubuklinggau timur 1 gang sekundang II	-3.276555, 102.909073	<a href="https://maps.app.goo.gl/C14v3L6goPSv2J1D6">https://maps.app.goo.gl/C14v3L6goPSv2J1D6</a>
Nurul Istanti	Jln Majapahit Lubuklinggau timur 1 gang sekundang II	-3.276640, 102.909042	<a href="https://maps.app.goo.gl/iNeK9vn3z1JwXTVM8">https://maps.app.goo.gl/iNeK9vn3z1JwXTVM8</a>
Kurnia Maratus Sholehah	Jln Majapahit Lubuklinggau timur 1 gang sekundang II	-3.276531, 102.909088	<a href="https://maps.app.goo.gl/ffJvjgu4fBVzZB469">https://maps.app.goo.gl/ffJvjgu4fBVzZB469</a>
Dyah Ayu Agustin	Jln Majapahit Lubuklinggau timur 1 gang sekundang II	-3.277203, 102.908647	<a href="https://maps.app.goo.gl/tF1TMmA53Yk65L3o8">https://maps.app.goo.gl/tF1TMmA53Yk65L3o8</a>
Citra Nadia Arini	Jln. Pattimura RT 01 no. 55 Mesat Jaya, LubukLingg	-3.2994015,102.8653023	<a href="https://maps.app.goo.gl/y9YBCkMzTbSEawdG7">https://maps.app.goo.gl/y9YBCkMzTbSEawdG7</a>
Isnain Janah	In Majapahit Lubuklinggau timur 1 gang kamandanu lorong kelapa	-3.2754629, 102.9096613	<a href="https://maps.app.goo.gl/GFad1sPW36BnbnsGA">https://maps.app.goo.gl/GFad1sPW36BnbnsGA</a>
Dwi Irawati	Jln Majapahit Lubuklinggau timur 1 gang kms. Aji	-3.2752162,102.9092237	<a href="https://maps.app.goo.gl/RGK7jusDiuqFkCzy6">https://maps.app.goo.gl/RGK7jusDiuqFkCzy6</a>
Indah Maghfiroh Ayu Wandira	Jln Majapahit RT 05 Lubuklinggau Timur I Jln Raden Wijaya, Timur 1, RT.4 ,No.43 Maja Pahit.	-3.2754558,102.9097447 -3.2753986,102.9098520	<a href="https://maps.app.goo.gl/UPmLCP3Ao1k2Chzy9">https://maps.app.goo.gl/UPmLCP3Ao1k2Chzy9</a> <a href="https://maps.app.goo.gl/WdKlJjH3oH4tYEgh9">https://maps.app.goo.gl/WdKlJjH3oH4tYEgh9</a>
Nurul Latifah	Jln Majapahit lorong kamandanu jln kelapa Lubuk Linggau timur 1	-3.2753437,102.9097751	<a href="https://maps.app.goo.gl/D8v8RFUP4YGmqfnW8">https://maps.app.goo.gl/D8v8RFUP4YGmqfnW8</a>
Oshea Miranda	Jl. Gentayu No.021 rt.02 kel.keputraan kec.Lubuklinggau Barat II	-3.2949447,102.8579827	<a href="https://maps.app.goo.gl/rfh6uLZ61hBVAptFA">https://maps.app.goo.gl/rfh6uLZ61hBVAptFA</a>
Selvi Karlina	Ulak Surung RT 6, Kec. Lubuk Linggau Barat II, Kota Lubuklinggau.	-3.281488,102.856877	<a href="https://maps.app.goo.gl/GXgeA8xYLRiZ4q9BA">https://maps.app.goo.gl/GXgeA8xYLRiZ4q9BA</a>
Rahayu Premesti	Jln kenanga II, Permai 16,Blok B1,RT 08, no 17, Lubuklinggau Utara II.	-3.2768868,102.8811311	<a href="https://maps.app.goo.gl/aGRLrYqMjDhtcE7J6">https://maps.app.goo.gl/aGRLrYqMjDhtcE7J6</a>
Tarisa Juwa Mey Pranata	Jln Dempo raya perumahan Niken 2 Air Kuti, Kec. Lubuk Linggau	-3.281073,102.91135	<a href="https://maps.app.goo.gl/GFad1sPW36BnbnsGA">https://maps.app.goo.gl/GFad1sPW36BnbnsGA</a>
Putri Annisa Cahyarani	Jln. Gentayu lorong gelatik No 051 rt. 02 kel. Keputraan kec. Lubuklinggau Barat II	-3.2955008,102.8575200	<a href="https://maps.app.goo.gl/yYuhG2VthT7BXBFs5">https://maps.app.goo.gl/yYuhG2VthT7BXBFs5</a>
Elka Vanesa	Jln. Kali Serayu RT. 04 Kel. Kali Serayu Kec. Lubuklinggau Utara II	-3.279786, 102.860486	<a href="https://maps.app.goo.gl/skLPt1BP8qUegzHA9">https://maps.app.goo.gl/skLPt1BP8qUegzHA9</a>
Eva Juwita	Jln Majapahit lorong kamandanu No 27, Lubuklinggau timur 1	-3.2753437,102.9097751	<a href="https://maps.app.goo.gl/D8v8RFUP4YGmqfnW8">https://maps.app.goo.gl/D8v8RFUP4YGmqfnW8</a>



2 mnt (650 m)

**Figure 1.** Route from student house to UNPARI campus



**Figure 2.** GPS satellite orbit configuration

The ground segment or control segment can be divided into four parts, namely the central control station, alternate control station, antenna, and monitoring station. This segment is tasked with monitoring the satellite orbit path to synchronize atomic clocks, correct satellite orbit model errors, update navigation, space weather information, and so on (Demyanov & Yasyukevich, 2021; Némethová & Zýka, 2024). In general, GPS devices measure the travel time of electromagnetic waves to the receiver from at least four different satellites to obtain the distance between the receiver and the satellite. The comparison of the distances of several satellites is then translated into the earth's coordinate system or digital map (Youngu et al., 2022). The GPS system can determine the distance from the satellite to the receiver through the following equation:

$$d = v \cdot \Delta t \quad (1)$$

where  $\Delta t$  is the difference in time when the signal is received by the receiver and the time when the signal is transmitted by the satellite, and  $v$  is the speed of propagation of electromagnetic waves.

The General Theory of Relativity (GRT) was developed by Einstein to handle the framework of systems with acceleration and gravitational systems that cannot be resolved by GRT (GRT is limited to relative motion with constant velocity). GRT defines gravity as the effect of curvature of space-time due to the distribution of mass and energy in that space-time (Ghosh, 2023). The main difference between GRT and GRT is that special relativity deals with "flat" space-time, while general relativity deals with "curved" space-time (Zakharov, 2024). Some implications of the concept of space-time that can be curved due to objects with mass include: the deflection of light passing through massive matter such as the sun, the idea of gravitational waves, the idea of black holes and white holes and wormholes, to the idea of time machines and time travelers.

One implication of the curvature of space-time in TRU is that gravity causes time dilation (Forrington, 2023; Rybicki, 2022). Light takes longer to travel the distance between the two shortest points in a curved geometry (geodesic) so that time dilation occurs which is known as Gravitational Time Dilation. Time in an area with a large gravitational field will move slower than time in an area with a smaller gravitational field (Forrington, 2023; Okołów, 2020). The ratio of time in the gravitational field satisfies the equation (Rezzolla, 2023; Li 李 & Wang 王, 2023).

Based on the theory of relativity, objects in different positions can experience different times. Based on the general theory of relativity, objects that are further from the center of gravity will experience longer times. So, a

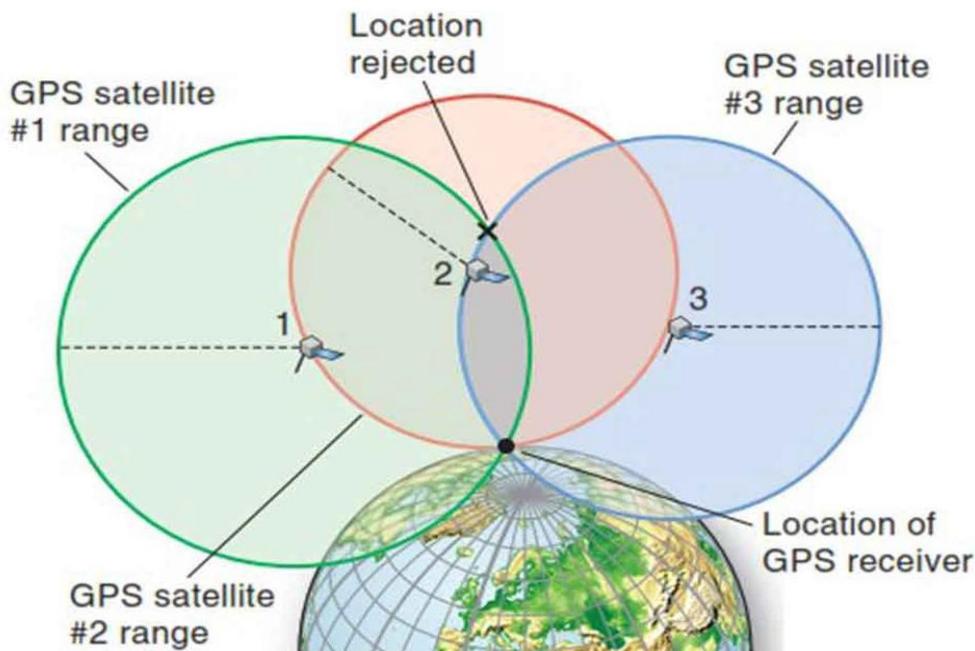
football match that usually lasts for 90 minutes feels like 200 minutes if we watch it from space. That means, satellites orbiting the earth experience different times than we do on earth. The time difference between us on the earth's surface and satellites orbiting the earth is 38 microseconds. Meanwhile, based on the special theory of relativity, objects moving at high speeds will experience longer times. Just like the football match earlier, for example, if we were still on Earth but we were on a very fast plane, the match could feel like 200 minutes. This also happens to GPS satellites that move at a speed of 1400 kilometers per hour. This satellite will experience a time difference with us on Earth of 7 microseconds. This time difference must always be included in the calculation of distance. Because if it is not taken into account, there will be an error of up to 10 kilometers. Therefore, it is very important for us to be able to know all the processes that may occur. In terms of using GPS, it is impossible for this technology to work if we do not know about relativity and its applications. The use of GPS in everyday life also makes us aware that the theory of relativity can occur anywhere.

GPS determines the receiver's position using the trilateration method from at least four satellites that are always visible at every point on earth at any time (Skone et al., 2001). Trilateration is a method for determining the spatial coordinates of an unknown point based on distance information between that point and at least three coordinates (Luo et al., 2022; Farooq-I-Azam et al., 2020; Kuptsov et al., 2020). Each GPS satellite transmits a signal containing information about the satellite's position, time, and general system conditions. The receiver then uses the signal to calculate the distance to the transmitting satellite by multiplying the time traveled by the signal and the speed of the signal (the speed of light). The receiver can determine its location as a point obtained from the intersection of the four imaginary spheres shown in Figure 3. The three spheres are needed to determine the location, and the fourth signal is needed to determine the exact time used in the calculation. In this way, the receiver can determine its position quite accurately and quickly (Rahemi & Mosavi, 2021).

To achieve a high level of accuracy, GPS must use very precise information including very precise time markers. Therefore, each GPS satellite carries an atomic clock that uses cesium-133 with one movable valence electron so that it can undergo transitions with very specific energy and frequency. This transition is used to produce a vibration resonance at 9192631770 Hz which is very sensitive to frequency variations and thus produces very accurate time measurements (Dias et al., 2022; Wang et al., 2019). In the GPS system, there is a time deviation caused by the relative motion of the

satellite to the earth (TRK) and due to the earth's gravity (TRU). The relative motion of the satellite causes the time on the satellite to lag  $7.2 \mu\text{s}$  behind the time on earth, while the earth's gravity makes the satellite time move  $4.5 \mu\text{s}$  faster than the time on earth. With the accumulation of time differences due to these two factors of  $37.8 \mu\text{s}$ , there is a deviation in the GPS system's position measurement (navigation) of about 11.33 km per day. Therefore, the GPS system needs to make

corrections related to relativistic effects as an effort to achieve a high level of accuracy. Efforts to make the GPS system precise are by adjusting the frequency of the atomic clock beats that are slowed down before the satellite is launched, so that after being in orbit, the atomic clock will beat in harmony with the clock on earth. Other efforts are to synchronize the atomic clocks of the GPS satellites and other correction efforts that can be done from the control station.



**Figure 3.** Determining the position of the GPS system using the Trilateration method (Dias et al., 2022)

The way GPS works simply consists of five steps, namely: Using triangulation calculations from satellites; GPS measures distance using radio signal travel time through triangulation calculations; GPS requires high time accuracy in measuring travel time; Knowing the position of the satellite and its orbital height precisely to calculate the distance and Correcting signal delays during travel time in the atmosphere until received by the receiver (Santerre et al., 2017). GPS satellites in sending time information are very precise so that they can determine user location information accurately.

After it was proven that the scientific revolution had fundamentally changed the way humans view the universe. The new paradigm is Einstein's theory of relativity which includes the special theory of relativity and the general theory of relativity. The laws of physics contained in the theory of relativity can be found in everyday life. One of them is GPS which is currently widely used in the military, knowing accurate navigation routes on cars and planes, geographic information systems, and earthquake monitoring. The role of the theory of relativity is very large in GPS

technology to improve the accuracy of measuring the position of objects on the earth's surface. In measurements using GPS, the level of accuracy of the data obtained is relatively more precise compared to using Google Earth and Navigation.net (Cheng et al., 2022). Without the role of the special and general theories of relativity, it is likely that GPS technology cannot be used.

This research combines two main areas in a practical and applicable way, namely: Utilization of GPS for precise acquisition of student geographic data, especially in the Lubuklinggau area and its surroundings for educational administration purposes, and application of understanding of relativity theory in the context of time correction in the GPS system, to ensure the accuracy of the location data obtained. The specific novelties are: direct application of the principle of relativity in the local educational administration system which is a rare approach, especially on a city or regional scale, Integration of GPS time adjustment due to relativistic effects (general and special relativity) in a non-technical context (student administration), demonstrating the use of advanced physics in everyday

life, and a local case study (Lubuklinggau) that provides contextual contributions in mapping and managing location-based educational data.

The contributions of this research to the development of knowledge in the field of education include: the use of GPS technology in education, the efficiency and accuracy of school administration, the integration of physics in practical education, the enhancement of geospatial literacy in education, and local case studies that provide replication models.

## Conclusion

Determining the geographic coordinates of student addresses in Lubuklinggau City and its surroundings is very important for student administration data purposes, as well as for other purposes. GPS provides accurate student geographic coordinate data. The GPS system has satellites orbiting the earth at a certain altitude and orbital speed. Each satellite carries an atomic clock and plays a major role in determining the location/position of GPS users. Based on the theory of relativity, satellites moving relative to the earth and the earth's gravity factor cause deviations in satellite time from earth time. This time deviation will affect the accuracy of the GPS system. To overcome the effects of relativity on the GPS system, the atomic clock on the satellite is slowed down before being launched into orbit. This aims to ensure that the beat of the satellite's atomic clock is the same as the time on earth when orbiting so that there is no time difference between the earth and the satellite.

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## Author Contributions

This article was written by three individuals, A.A., A.Y., and A.R., who have read and approved the published version of this manuscript. A.A., A.Y., and A.R. designed the study and analyzed the data, while A.A., and A.R. performed the laboratory work; A.Y. wrote the manuscript. They drafted the original manuscript, prepared the introduction, results, discussion, methodology, and conclusion; A.Y., and A.R. also contributed ideas to the research process, data processing, translation into English, review, and editing. All members of the research team collaborated at every stage until this article was completed.

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## Conflicts of Interest

This research is conducted to provide information to the public regarding the research that has been conducted so that it can be used for educational purposes. In addition, this research is used by researchers for lecturer performance loads and accreditation needs of study programs and institutions.

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