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Indoor Positioning Technology Based on Pseudo Satellite

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

With the increasing demand for indoor positioning, traditional GPS positioning technology can no longer meet people's needs, and pseudo satellite indoor positioning technology has become a new method to solve indoor positioning problems. Pseudo satellite indoor positioning technology can improve positioning accuracy through the collaborative positioning of multiple signal sources and meet the positioning needs of different scenarios. Pseudo satellite indoor positioning technology can be applied to the field of smart home to achieve a more intelligent home environment and improve the quality of life; Pseudo satellite indoor positioning technology can be applied to the construction of smart cities, improve the efficiency and quality of urban management and services, and provide people with more convenient life services [1]. The research and application of pseudo satellite indoor positioning technology has important practical significance and value.

This paper describes in detail that in the indoor complex environment, GNSS signals are easily occluded, so that the GNSS system cannot complete positioning services, and GNSS signals can be simulated through the establishment of pseudo satellite base stations to provide positioning services. In this project, the layout settings of indoor ground-based pseudo satellites and the calculation of HDOP values are studied, and the HDOP values under different pseudo satellites and layout modes are compared.

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Experimental properties include: Positioning accuracy evaluation: Through simulation, it is possible to evaluate the positioning accuracy of pseudo-satellite systems in different configurations and environments. The smaller the HDOP value [2], the higher the positioning accuracy. System optimization design: Simulation can help researchers analyze and optimize pseudo-satellite layout schemes to reduce HDOP values and improve positioning accuracy. Environmental impact study: By simulating HDOP values in different environments (such as cities and mountains), the performance of pseudo-satellite positioning in complex environments can be studied [3].

Keywords: Pseudo satellites; GNSS signal; indoor positioning; HDOP values.

1. INTRODUCTION

In recent years, with the rapid development of wireless communication technology and Internet of Things, indoor positioning technology has become a research hotspot. Traditional satellite navigation systems (such as GPS) perform well in open outdoor environments, but in complex indoor environments, the signal is blocked and the accuracy is greatly reduced, and it is difficult to meet the needs of high-precision positioning. In order to solve this problem, Pseudolite technology has gradually become the focus of research [4]. Here are two simple facts to prove it: New GNSS equipment allows mask resolution, which helps in forest surveys: Trimble's R10 GNSS receiver, for example, uses adaptive signal filtering technology to efficiently process canopy masks, providing more accurate location results and helping in forest resource measurement and management [5]. The new device takes into account the rover's inclination Angle: The new GNSS device incorporates an IMU (Inertial Measurement Unit), which detects the inclination of the device in real time and compensates for it in positioning calculations. For example, Leica Geosystems' GS18 T GNSS receiver incorporates IMU technology to maintain high-precision positioning even when the device is tilted, which is very helpful for mapping work on uneven terrain [6].

Pseudo-satellite technology simulates satellite signals by installing pseudo-satellite signal transmitters on the ground or inside buildings, thus achieving high-precision positioning in a specific area. Compared with traditional satellite navigation systems, pseudo-satellites have the advantages of low cost, flexible deployment and stable signal, so they show great application potential in the field of indoor positioning [7].

The purpose of this study is to discuss the indoor positioning technology based on pseudo satellites, analyze its principle and implementation method, and evaluate its performance in practical applications. Through experimental verification, this study will provide theoretical support and practical reference for the development of high-precision indoor positioning technology, and provide technical support for the application of smart home, medical monitoring, storage management and other fields.

2. PSEUDO-SATELLITE POSITIONING PRINCIPLE

In the process of designing the scheme of indoor positioning system for pseudo-satellite, the first thing to be determined is the positioning method used in indoor positioning, which determines the cost, layout and performance of pseudo-satellite, and also determines the information carried by the pseudo-satellite signal. Therefore, the advantages and disadvantages of several positioning methods are discussed in this section, and the positioning algorithm which can be used in the pseudo-satellite system in this paper is determined by comparison [8]. Here's how it works:

1. Pseudo satellite signal transmission: Pseudo satellites are installed at specific locations in the room and transmit positioning signals similar to GPS. These signals usually use GPS bands or other suitable frequencies. 2. Receiving signals: Indoor positioning devices (such as mobile terminals with pseudo satellite receiving modules) receive signals from multiple pseudo satellites. 3.Distance measurement: By calculating the transmission time difference (i.e., pseudo distance) of the received pseudo satellite signal, the relative distance to each pseudo satellite can be measured. 4.Position calculation: Using triangulation, the device calculates its own position based on the received pseudo satellite signal and its pseudo distance. This is similar to traditional GNSS positioning, except that the signal source is from an indoor pseudo-satellite instead of a satellite in the sky. 5. Error correction: Due to the complex indoor

environment, such as reflection and multipath effects, pseudo-satellite positioning systems usually combine other sensors (such as IMUs) for error correction to improve positioning accuracy [9].

2.1 Overview of the Basic Methods of Indoor Positioning

At present, indoor positioning algorithms can be divided into three types, namely geometric positioning, scene analysis positioning and approximate perception. Geometric positioning is the most widely used positioning algorithm at present. These methods include signal strength based positioning (RSS), Angle of arrival based positioning (AOA),arrival time based positioning (TOA) and arrival time difference based positioning (TDOA),etc. Among them, TDOA is the main positioning algorithm for pseudo-satellites to complete indoor positioning in this paper.

TOA ranges the carrier by signal arrival time, which means that TOA can accurately measure in both line-of-sight and non-line-of-sight environments. At the same time, the principle of TOA technology is relatively simple, without too many external devices. If the distance between the base station 1 and the receiver 2 needs to be measured, taking the two-dimensional coordinate system as an example, assuming the time synchronization of the devices at both ends, and the coordinates of the two are respectively (x_1, $y1$) and ($x2$, $y2$), the relationship between the two is expressed as follows:

$$\sqrt{\left(x_2 - x_1\right)^2 + \left(y_2 - y_1\right)} = \mathrm{ct}_{21}$$

Where, c is the speed of light, $t21$is the signal from the base station 1 to the receiver 2 time, without considering other errors, if the specific location of at least two base stations is known, and measured each base station signal from the time to receive, you can solve the receiver 2 position coordinates of the equation [10].

The principle of TOA is simple, the calculation is low, and the positioning accuracy is seemingly high, but the premise is to achieve complete synchronization of the time at both ends of the transceiver, which requires great hardware and is difficult to achieve in practical engineering applications [11]. TDOA technology is aimed at the shortcomings of TOA technology and proposes an improved method. The difference between TDOA and TOA is that the technology does not need to know the signal arrival time directly, but obtains the arrival time difference through the way of difference, and uses it as the observed value for ranging positioning. In actual measurement, the clock difference caused by time synchronization or hardware reasons will be included in the signal arrival time, but the difference can be offset by the partial minute difference in the measured value, effectively reducing the system's demand for time synchronization, and compared with TOA, TDOA only needs to install one more observation base station [12].

TOA technology Calibration process: Because the signal may be affected by reflection or attenuation of obstacles in the environment, the actual measured arrival time may be longer than the time of the straight path, resulting in a false distance greater than the actual distance. In order to correct this error, the system can combine the TOA data of multiple pseudo-satellites to solve the positioning problem through geometric relationship, so as to find an optimal solution to minimize the error [13].

TDOA technology Calibration process: Imagine that the receiver receives a signal from two pseudo-satellites and measures their arrival time difference (Δt). Because the signal propagation speed is known, the pseudo distance difference between the two pseudo satellites can be calculated from the time difference Δt, thus determining that the receiver is located on some equal circle or ellipse of the pseudo satellite. By TDOA measurement between multiple pairs of pseudo satellites, multiple elliptic intersections can be formed, and the solution of these intersections can be used to accurately determine the receiver position and correct the pseudo range error [14].

2.2 Principles of TDOA Technology

TDOA compares two base stations to two focal points, and the distance difference is the arrival time difference, and the distance difference is the corresponding constant. Therefore, the essence of TDOA is a hyperbolic equation formed between a reference base station and each other observation base station, and the focus in each hyperbolic equation is the reference base station, so these hyperbolic curves will intersect. At this time, by combining these equations, the intersection point can be obtained, and the intersection point is the coordinate of the user (carrier) [15], as shown in Fig. 1:

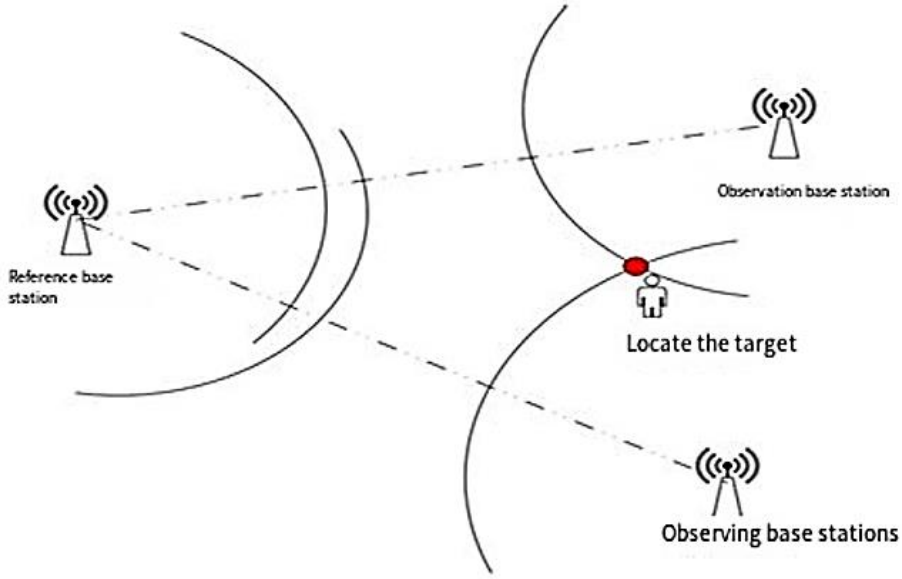

Fig. 1. Locating the TDOA

Suppose there are n coordinates, the coordinates of the reference base station are (*x1, y1*). (*xn, yn*), the coordinate of the target to be measured is (*x, y*), then the distance difference between the reference base station and the *i* observation base station and the target is as follows:

$$\sqrt{(x_i - x)^2 + (y_i - y)^2} - \sqrt{(x_1 - x)^2 + (y_1 - y)^2} = ct_{i,1}$$

Where *ti* is the time difference between the arrival of the reference base station and the arrival of the base station *i*. Command: $d_i = \sqrt{(x_i - x)^2 + (y_i - y)^2}$ *di* represents the linear distance between the target and the base station *i*, referring to the difference of the arrival distance between the base station and the base station *i di,1=di-d1*, the simultaneous equation of TDOA can be obtained according to formula [16].

$$\begin{cases} d_{2,1} = \sqrt{(x_2 - x)^2 + (y_2 - y)^2} - \sqrt{(x_1 - x)^2 + (y_1 - y)^2} \\ d_{3,1} = \sqrt{(x_3 - x)^2 + (y_3 - y)^2} - \sqrt{(x_1 - x)^2 + (y_1 - y)^2} \\ \cdots \\ d_{n,1} = \sqrt{(x_n - x)^2 + (y_n - y)^2} - \sqrt{(x_1 - x)^2 + (y_1 - y)^2} \end{cases}$$

In the pseudo-satellite system, the pseudo range or carrier phase ranging can be used to determine the value of the arrival distance difference *di, 1*, and the excess equations in the equation can improve the positioning accuracy. TDOA has the advantages of relatively high precision technology, low accuracy requirement for time synchronization and easy layout, which is just in line with the design of indoor pseudosat system. Therefore, the pseudosat system studied in this paper adopts the algorithm based on TDOA for indoor positioning [17].

3. PRECISION FACTOR DOP

Dilution of Precision (DOP) is an important index to evaluate the positioning accuracy of satellite navigation system. It reflects the amplification effect of the geometric distribution of navigation satellites on the positioning error, that is, the positioning error increases due to the unsatisfactory geometric layout of the satellite [18]. The smaller the DOP value is, the more ideal the satellite geometric distribution is and the higher the positioning accuracy is. On the contrary, the larger the DOP value, the lower the positioning accuracy.

3.1 DOP Principle

In order to construct a model corresponding to the definition of DOP values, it is assumed that the ranging errors of each observation are equal in magnitude and do not affect each other. Such ranging errors are usually expressed as User Equivalent Range Error (UERE) σuere, i.e:

$$\mathrm{cov}(\mathrm{dp}) = I_{n*n}\sigma_{\mathrm{uere}}^2$$

Where *In*n* represents the n-order identity matrix, according to the law of cofactor propagation:

$$\mathrm{cov(dx)} = \left(\mathrm{H^T H}\right)^{-1} \sigma_{\mathrm{uere}}^2$$

Therefore, the precision attenuation factor is the ratio of the geometric error *σG* to the ranging error *σuere*:

$$\mathrm{GDOP} = \sigma_G \setminus \sigma_{\mathrm{uere}} = \sqrt{\mathrm{tr}\left[\left(H^T H\right)^{-1}\right]}$$

GDOP (Geometric Dilution of Precision), also known as geometric dilution of precision, expands the matrix H^TH^{-1} as follows:

$$\mathrm{H^T H^{-1}} = \begin{pmatrix} D_{11} & D_{12} & D_{13} & D_{14} \\ D_{21} & D_{22} & D_{23} & D_{24} \\ D_{31} & D_{32} & D_{33} & D_{34} \\ D_{41} & D_{42} & D_{43} & D_{44} \end{pmatrix}$$

The value of GDOP can also be expressed as:

$$\mathrm{GDOP} = \sqrt{D_{11} + D_{22} + D_{33} + D_{44}} = \sqrt{\mathrm{tr}\left[\left(H^T H\right)^{-1}\right]}$$

Similarly, there are other error related precision factors, such as: Position Dilution of Precision (PDOP) related to position error, Horizontal Dilution of Precision (PDOP) related to horizontal error: HDOP, the error related to the Vertical height is called Vertical Dilution of Precision (VDOP), and the error caused by the difference with the receiver clock is called Time Dilution of Precision (Time Dilution of Precision), referred to as: TDOP). Because this paper studies the installation layout and positioning of the pseudo-satellite in the room, and the carrier does not move relative to the pseudo-satellite in space, the HDOP value is compared to design the layout [19].

$$PDOP = \frac{\sigma_p}{\sigma_{uere}}$$

$$HDOP = \frac{\sigma_{\mathrm{h}}}{\sigma_{uere}}$$

$$VDOP = \frac{\sigma_v}{\sigma_{uere}}$$

$$TDOP = \frac{\sigma_t}{\sigma_{uere}}$$

Because the pseudo-satellite is stationary under indoor installation, and the user only does horizontal movement indoors, the user and the pseudo-satellite have no relative movement in the vertical direction indoors [20], and only do horizontal movement. Therefore, the equation for calculating the user's location is:

$$\Delta\rho_i = a_{xi} + a_{yi}\Delta y_u - c\Delta t_u$$

Where, $\Delta \mathrm{x_u} = \mathrm{x_u} - \bar{\mathrm{x}}_\mathrm{u}, \Delta \mathrm{y_u} = \mathrm{y_u} - \bar{\mathrm{y}}_\mathrm{u}, \Delta \mathrm{t_u} = \mathrm{t_u} - \bar{\mathrm{t}}_\mathrm{u}, \mathrm{x_u}$、$\mathrm{y_u}$ is the real position of the user, t_u is the deviation between the system time and the user's clock, $\bar{x}$、$\bar{y}$ is the approximate position of the user, is the estimate of the time deviation, *c* is the speed of light, a_{xi} and a_{yi} represent the direction cosine of the unit vector pointing from the approximate position of the user to the *i* pseudo satellite. The matrix *H* is thus:

$$\mathrm{H} = \begin{pmatrix} a_{x1} & a_{y1} & 1 \\ a_{x2} & a_{y2} & 1 \\ a_{x3} & a_{y3} & 1 \\ a_{x4} & a_{y4} & 1 \\ a_{x5} & a_{y5} & 1 \end{pmatrix}$$

This formula can represent the geometric relationship between the user and the satellite, from which HDOP can be obtained [21].

3.2 Influencing Factors of Pseudo-satellite Indoor Positioning

Although the principle of pseudo-satellite indoor positioning system and GNSS system is similar, due to different positioning methods and different scope of application, there are quite differences in error sources and key problems: (1) because the cost is too high; It is difficult for pseudo-satellites to use atomic clocks to achieve high precision time synchronization with GPS systems; (2) The signal propagation distance is short, the amplitude of the received power varies greatly, and the near-far effect is significant; (3) In the room with many reflective surfaces, the multipath effect is significantly enhanced, so the receiver should ensure the stability of signal tracking, otherwise it is easy to cause significant errors [22].

The near and far effect means that when the base station receives signals from two different carriers during the carrier's movement, the carrier signal closer to the base station is stronger, while the mobile station signal farther away is weaker. Therefore, the strong signal of the carrier closer to the base station will cause serious interference to the carrier signal farther away. As shown in the Fig. 2, MS1 sends a stronger signal to the base station than MS2, and the stronger signal will interfere with the weaker signal.

In practice, HDOP values are usually between 1 and 10. If the HDOP value is greater than 10, it indicates that the GPS receiver has low positioning accuracy and may not be able to provide accurate location information. On the contrary, if the HDOP value is less than 1, it means that the positioning accuracy of the GPS receiver is very high and the position information provided is very accurate [23]. The HDOP value studied in this paper is required to be less than 2.

HDOP is a very useful measurement that can help users determine the positioning accuracy of a GPS receiver. When using GPS receivers, knowing the value of HDOP can help users make better use of GPS technology to obtain more accurate location information [24].

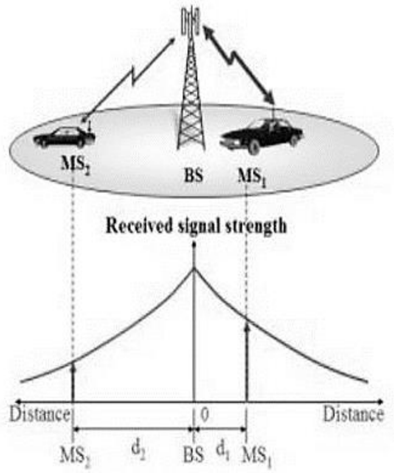

Fig. 2. MS1 sending

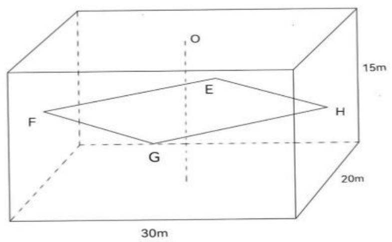

Fig. 3. A1 layout

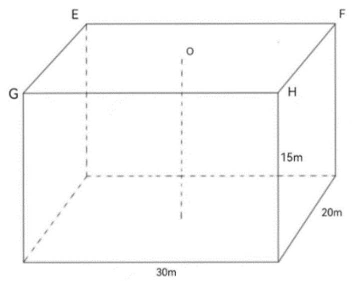

Fig. 4. A2 layout

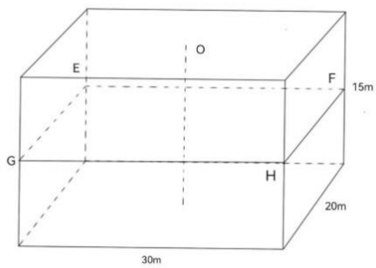

Fig. 5. A3 layout

4. THE LAYOUT DESIGN OF PSEUDO SATELLITE POSITIONING IN A CERTAIN AREA

Assume that the motion in this scenario is in a room with a length of 30m, a width of 20m, and a height of 15m The indoor ground area moves through pairs of radio carrier signals transmitted by five pseudo-satellites. A carrier with a receiver is installed for positioning. The satellites were placed on the ceiling and four walls. Somewhere in the corner.

Layout scheme: Use 5 pseudo satellites to achieve indoor positioning, arrange one satellite in the center O of the ceiling, and the other four pseudo satellites are arranged in the intersection line of the four walls in the room or arranged in the center of the wall, represented by EFGH. The layout of these four pseudo-satellites can be divided into three scenarios: (1) Four pseudo-satellites are placed in the center of the four walls, which is called the A1 layout; (2) The four satellites are located at the four corners of the ceiling, that is, 15m above the ground, which is called the A2 layout; (3) The four satellites are arranged at the midpoint of the four wall lines, that is, 7.5m from the ground, becoming an A3 layout.

Since the precision factor (DOP) is related to the volume V of the polyhedron composed of satellite and user, the larger the volume V, the smaller the precision factor DOP. In these three layouts, the volume of the polyhedron composed of pseudo-satellites on the wall intersection is significantly smaller than the volume of V in the A2 and A3 layout. Therefore, A1 scheme can be directly excluded when considering the layout of pseudo-satellites. The following describes the layout in the A2 and A3 scenarios.

With the indoor point K as the coordinate origin, the edge parallel to EF is the x axis, the edge parallel to EG is the y axis, and the edge parallel to EK is the z axis. A rectangular coordinate system is established. The HDOP value distribution of pseudo-satellites under the two layouts of A2 and A3 is simulated by matlab, as shown in the Fig .6 below:

By comparing the two sets of data, it can be seen that when the carrier moves in the center of the movement area, the HDOP value of the four surrounding pseudo-satellites located at 7.5m is about 1.2257, and the HDOP value located at 15m is about 1.4786. In terms of HDOP value, the HDOP value in the A3 layout is significantly smaller than that in the A2 layout. Therefore, this layout of A3 is more accurate and more suitable for indoor positioning of pseudo-satellites.

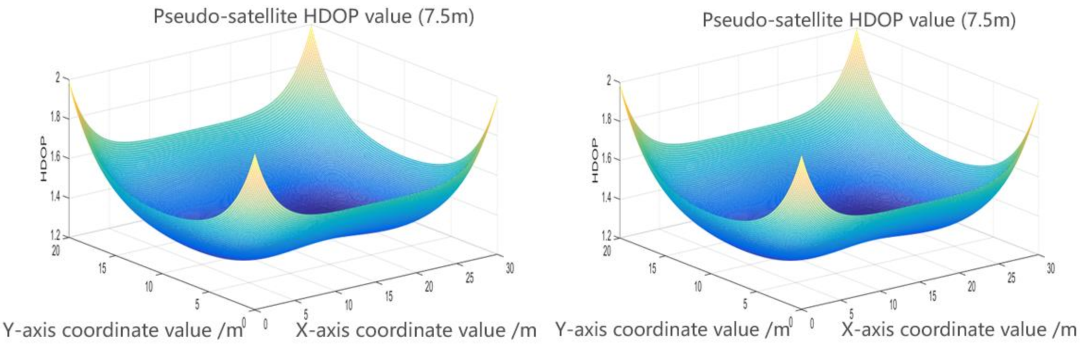

Fig. 6. Graphical presentation showing pseudo-satellite HOOP value

Table 1. A comparison of HDOP values for a location in two layouts

The distance of the carrier from the center of motion /m	A2 Specifies the HDOP value	A3 Specifies the HDOP value
0	1.4786	1.2257
2	1.4886	1.3664
4	1.4920	1.3725
6	1.4944	1.3857
8	1.5048	1.3918
10	1.5096	1.4047

5. CONCLUSION

Independent networking of ground-based pseudo-satellites can provide positioning services in certain indoor areas without GNSS positioning. In indoor positioning, the horizontal accuracy factor HDOP can reflect the influence on positioning accuracy to a certain extent. In practical engineering applications, it can solve the complex indoor situations where GNSS signals cannot reach. In this paper, the number of pseudo-satellites and the layout of the pseudo-satellites are discussed and studied, and through simulation, the most effective location is obtained. Mainly completed the following work:

1. Firstly, the positioning principle of ground-based pseudo-satellite with independent networking is introduced, and the influencing factors such as near and far effect and multipath effect are analyzed.

2. The formula can be used to calculate the HDOP value when the carrier is located at any point under any layout of the pseudo-satellite. Meanwhile, this paper simulates the schemes in different layouts and different areas, and obtains the HDOP value distribution mesh diagram in the positioning area. The scheme of rectangular arrangement of five pseudo satellites and four pseudo satellites in the middle point of the wall is ideal, which can meet the requirement of HDOP value less than 2, and can be used in practical engineering.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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