PERIÓDICO TCHÊ QUÍMICA
ARTIGO ORIGINAL

MEDIÇÕES PRECISAS DE ALTURA EM PERSPECTIVA EMPREGANDO TRÊS PONTOS DE FUGA DE UMA ÚNICA IMAGEM

ACCURATE HEIGHT MEASUREMENTS IN PERSPECTIVE EMPLOYING THREE VANISHING POINTS FROM A SINGLE IMAGE

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RESUMO

Introdução: Este estudo explora a necessidade de obter medições precisas a partir de imagens únicas, aplicável em áreas como reconstrução arquitetônica e investigações forenses. A técnica usa geometria de pontos de fuga para deduzir medidas reais, a partir de referências conhecidas. **Objetivo:** O objetivo principal é demonstrar um método para medir a altura de objetos e pessoas em imagens usando três pontos de fuga, permitindo a análise de dimensões reais a partir de uma imagem. **Métodos:** Este artigo apresenta um método para medição precisa de altura em imagens usando pontos de fuga e geometria de razão cruzada. Ao utilizar três pontos de fuga correspondentes a eixos ortogonais, a técnica permite a recuperação de dimensões reais a partir de uma única imagem. Os pontos de fuga, que representam a intersecção de linhas paralelas no espaço quando projetados em um plano 2D, permitem mapeamento espacial preciso e análise dimensional. Neste estudo, foram utilizadas referências conhecidas para calibração. **Resultados e Discussão:** Os resultados demonstraram que a metodologia é confiável, produzindo estimativas de altura entre 1,86 e 1,92 metros para um sujeito com 1,91 metros de altura, com desvios dentro de margens de erro aceitáveis. Estas descobertas destacam a robustez do método, especialmente em aplicações onde medições diretas não são viáveis, como investigações forenses ou reconstruções arquitetônicas. A precisão da metodologia foi validada através de ensaios repetidos, onde 10 iterações mostraram uma concentração de resultados dentro de uma faixa estreita, reforçando ainda mais a sua confiabilidade. **Conclusões:** Esta técnica oferece uma solução prática para extrair medições precisas de imagens, com aplicações potenciais em arquitetura, ciência forense e realidade virtual/aumentada. Os resultados sugerem que, com o refinamento contínuo, a precisão desta abordagem poderia ser melhorada, tornando-a uma ferramenta valiosa em vários campos que requerem análise espacial.

Palavras-chave: *Pontos de fuga; Geometria de perspectiva; Método de razão cruzada; Medição de altura; Análise forense de imagens.*

ABSTRACT

Background: This study explores the need to obtain accurate measurements from single images, applicable in areas such as architectural reconstruction and forensic investigations. The technique uses vanishing point geometry to deduce real measurements from known references. **Aim:** The main objective is to demonstrate a method for measuring the height of objects and people in images using three vanishing points, allowing the analysis of real dimensions from an image. **Methods:** This article presents a method for accurately measuring height in images using vanishing points and cross-ratio geometry. By using three vanishing points corresponding to orthogonal axes, the technique allows the recovery of real-world dimensions from a single image. Vanishing points, which represent the intersection of parallel lines in space when projected onto a 2D plane, allow for precise spatial mapping and dimensional analysis. In this study, known references were used for calibration. **Results and Discussion:** The results demonstrated that the methodology is reliable, producing height estimates between 1,86 and 1,92 meters for a subject who is 1,91 meters tall, with deviations within acceptable margins of error. These findings highlight the robustness of the method, especially in applications where direct measurements are not feasible, such as forensic investigations or architectural reconstructions. The accuracy of the methodology was validated through repeated tests, where 10 iterations showed a concentration of results within a narrow range, further reinforcing its reliability. **Conclusions:** This technique offers a practical solution for extracting precise measurements from images, with potential applications in architecture, forensic science, and virtual/augmented reality. The results suggest that, with continued refinement, the accuracy of this approach could be improved, making it a valuable tool in several fields that require spatial analysis.

Keywords: *Vanishing points; Perspective geometry; Cross-ratio method; Height measurement; Forensics image analysis.*

1. INTRODUCTION:

With the growing ubiquity of digital imagery, the need for extracting reliable measurements from single images has increased across various domains. Architectural analysis, accident reconstruction, and even augmented reality (AR) applications all benefit from accurately determining real-world dimensions based on a single photograph. However, traditional measurement methods often require external references, such as scale bars or pre-calibration objects, limiting their practical application.

One powerful solution is leveraging perspective geometry and vanishing points to deduce accurate measurements. Vanishing points are the locations where sets of parallel lines in a 3D space appear to converge due to the effects of perspective projection (Hartley and Zisserman, 2004; Criminisi, Reid, and Zisserman, 2000). In scenes involving man-made structures or objects with defined geometries, three distinct vanishing points can often be identified: one for each of the three principal axes (X, Y, Z).

This paper explores how vanishing points can be used to determine real-world measurements from single images. By identifying three orthogonal vanishing points, we recover the object or scene's underlying dimensions with precision. We will discuss the mathematical framework, the measurement process, and practical applications, demonstrating the effectiveness of this method in various real-world contexts.

To perform 3D measurements from an image containing a cube or other similar references on the ground, the technique of determining vanishing points using three sets of parallel and mutually perpendicular lines is essential. These lines, when projected onto the image plane, no longer remain parallel but instead converge at distinct vanishing points, with each set of parallel lines producing its own vanishing point.

For instance, when observing a cube in an image, the parallel lines of each face are projected as non-parallel lines that meet at a vanishing point. The parallel lines of the cube's front face converge at the vanishing point Vx, those of the side face converge at Vy, and those of the top face converge at Vz. Since the cube's faces are mutually orthogonal, the orthocenter formed by these three vanishing points corresponds to the image's principal point, defining the central projection.

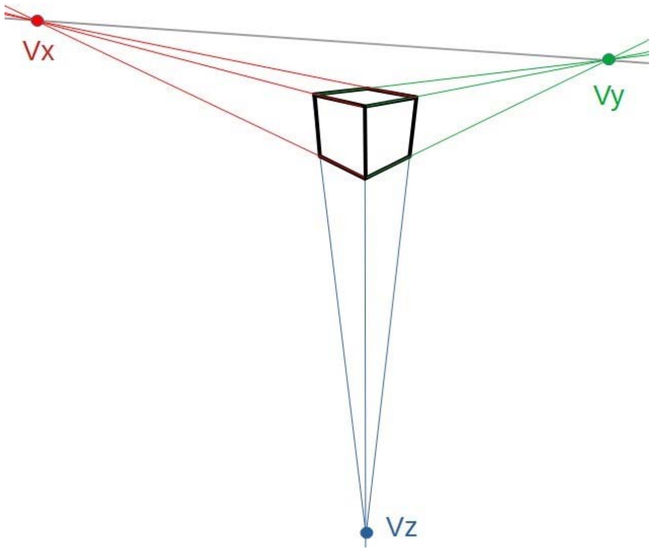

Figure 1. *Three orthogonal vanishing points.*
Source: the author.

Once the three vanishing points are established, accurate measurements in each direction can be made using the concept of the **cross-ratio**. Cross ratio is a concept from projective geometry (Beutelspacher and Rosenbaum, 1998; Kadison and Kromann, Matthias, 1996; Thomas, 2022; Shashua, 1994).

The cross-ratio allows for the calculation of real-world distances and dimensions from the image, regardless of the perspective distortion.

Practically speaking, to measure distances in a particular direction, one identifies the vanishing point associated with that direction and applies the cross-ratio to compute the real distances. This enables the accurate measurement of height, width, and depth of objects in an image, even if the perspective distorts them.

This technique is widely used in 3D reconstructions from images, such as in photogrammetry and forensic applications, where precise measurements are required from static images.

2. MATERIALS AND METHODS:

2.1. Materials

The methodology employed in this study relied on the following key materials:

1. **Photogrammetry software Niewtun:** A bespoke software application, developed using Visual Basic (VB), was utilised for the core photogrammetric processing. This software incorporates specific routines designed for accurate three-dimensional reconstruction and measurement from single perspective images. Key functionalities include automated vanishing point detection algorithms and cross-ratio calculation tools, tailored for spatial analysis.
2. **Digital camera:** Photographic data acquisition was performed using a digital camera capable of capturing high-resolution images of the subject and the surrounding environment. The specifications of the camera, including its lens characteristics and sensor size, were considered to ensure sufficient image quality for precise identification of reference points and vanishing lines.
3. **Vanishing Point Determination:** The photographic data acquired contained visual cues in the form of three distinct pairs of parallel lines, which were also mutually perpendicular. These line pairs, clearly identifiable within the image, converged towards three separate vanishing points. These vanishing points, derived directly from the perspective geometry of the scene, provided the necessary spatial information for the photogrammetric analysis, enabling the calculation of object heights and dimensions through the software's routines.

2.2. Methods

2.2.1 The nature of perspective projection

When a 3D object is viewed through a camera or a human eye, the process of projection onto a 2D plane introduces perspective distortion. Parallel lines, which in the real world would remain equidistant, appear to converge as they extend away from the viewer. This phenomenon creates **vanishing points**, which serve as key indicators of the scene's depth and orientation.

For example, in an image of a road, the edges of the road appear to converge toward a single point in the distance—the vanishing point along the road's axis. Similarly, vertical and horizontal lines (such as those of buildings) converge toward distinct vanishing points in different directions. These points reveal important geometric properties of the image.

In typical scenes containing right-angled objects or structures, such as buildings or vehicles, three primary vanishing points can often be identified, corresponding to the three orthogonal axes (X, Y, and Z) of the scene.

In this work, vanishing point locations are determined by utilizing a method based on the detection of parallel lines on the ground plane, rather than a checkerboard pattern. This approach leverages the inherent geometry of scenes where multiple sets of parallel lines exist in different directions. These lines, which are mutually perpendicular in the real world (e.g., street markings, building edges, or grid-like layouts), converge to form distinct vanishing points when projected onto the 2D image plane due to perspective.

The technique begins by manually selecting points along the parallel lines in the image, which serve as key reference points for further analysis. Once these points are chosen, they are grouped based on their directionality, corresponding to sets of lines that are parallel in the real world. The vanishing points for each of these sets are then calculated through geometric principles, using the intersection of these parallel lines as they converge on the image plane. This manual point selection allows for a more controlled and precise identification of key features in cases where automated detection algorithms may not perform as reliably, particularly in scenes with varying image quality or when dealing with complex perspectives.

For instance, in the case of an urban environment, the parallel lines along the street, the building edges, and other architectural features generate three vanishing points corresponding to the x, y, and z axes. These points are located by extending the detected parallel lines until they intersect at a point in the image.

Once these three vanishing points are found, which represent the orthogonal directions of the scene, accurate 3D measurements can be performed. This is achieved through the **cross-ratio**, a projective geometry principle that remains invariant under perspective transformations. By using the vanishing points and the known geometric relationships between the parallel lines, the true dimensions of objects in the scene can be calculated.

To establish a reference frame for the measurements, the horizon line is estimated by identifying the vanishing points lying along the plane of the ground. A regression is then applied to align the vanishing points associated with the horizontal lines (e.g., ground markings), generating the horizon line for the ground plane. This process is repeated for other planes in the scene, allowing for full 3D reconstruction.

This method is particularly useful in scenarios such as urban mapping, forensic reconstruction, and any application where 3D measurements are needed from a single image, as it provides an efficient and precise way to deduce spatial relationships from parallel structures present in the environment.

2.2.2 The role of three vanishing points projection

The three vanishing points represent projections of orthogonal lines in the scene:

- The **X-axis** represents width (horizontal lines across the scene)
- The **Y-axis** represents height (vertical lines).
- The **Z-axis** represents depth (lines receding into the distance).

2.3. Mathematical formulation

2.3.1 Identifying vanishing points

The first step in utilizing vanishing points for measurement is locating them within the image. This requires identifying at least two sets of parallel lines in each of the three principal directions (X, Y, Z).

For each set of lines, the equation of a line in a 2D image plane is represented as:

$$A.x + B.y + C = 0 \quad \text{(Eq. 1)}$$

Where A, B, and C are coefficients defining the line, and (x,y) are the pixel coordinates of points along the line. The vanishing point for that set of lines is found by calculating the intersection of two or more parallel lines. This intersection provides the coordinate of the vanishing point in the image.

Once the three vanishing points (Vx, Vy, and Vz) are found, the process of determining the position of a point along a specific axis (X, Y, or Z) can be performed using the **cross-ratio** method. This approach is based on projective geometry, which preserves the cross-ratio under perspective transformations.

2.4. Measurement process using Cross-Ratio

Some authors propose solutions for camera calibration based on the analysis of vanishing points, which are crucial for enhancing the accuracy of measurements in computer vision and photogrammetry applications (Cipolla, Drummond, and Robertson, 1999; Orghidan et al, 2012; He, Zhou, and Li, 2011; Ghosh et al, 2020). However, in this article, the solution we present for performing measurements is an innovative approach that combines this technique with the cross ratio. This combination aims to increase the robustness and accuracy of the measurements obtained, allowing for a more detailed and reliable analysis of images, which is essential for applications in various fields, including traffic safety and forensics.

2.4.1 Vanishing points and directional lines

To measure the position of a point along a given direction (X, Y, or Z), we start with the vanishing point corresponding to that direction (e.g., Vx for the X-axis). From this vanishing point, we trace lines through two projected points in the image plane that correspond to known real-world positions along the X-axis. These two points, along with the vanishing point, form the basis for calculating the cross-ratio.

2.4.2 Cross-ratio calculation

The cross-ratio of four collinear points (A, B, C, D) is defined as:

$$K_{(A,B,C,D)} = \frac{(A-C)}{(B-C)}.\frac{(B-D)}{(A-D)} \quad \text{(Eq. 2)}$$

In this case, the four points are:

- The vanishing point (Vx).
- The projections of two known points (P_1 and P_2) on the X-axis in the image Y-axis represents height (vertical lines).
- The point P to be determined.
- P1=A, P2=B, P=C e Vx=D.

Once the cross-ratio is computed using the known distances between the real-world points (P_1, P_2), it can be used to solve for the unknown point (P) in the real-world direction.

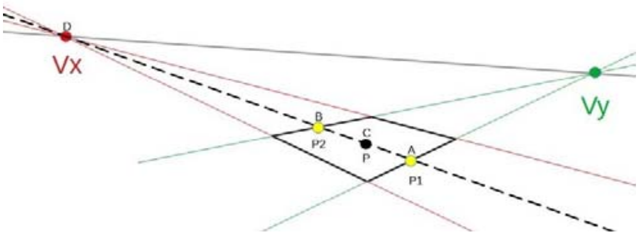

Figure 2. *Definition of the four collinear points for the cross ratio in the x direction.*
Source: the author.

2.4.3 Measuring 3D coordinates

By repeating this process for each of the three mutually orthogonal directions (X, Y, Z), and applying the cross-ratio for each set of parallel lines, the 3D position of any point in space relative to the camera can be recovered. Since the cross-ratio remains constant regardless of perspective distortion, it provides an accurate way to deduce real-world distances from image data.

When determining the position of a point using vanishing points, it's important to recognize that the distance from any specific point along the corresponding axis to its vanishing point is effectively infinite. In projective geometry, this infinite distance is represented by a very large number, as the vanishing point lies on the horizon, beyond the limits of the image space.

However, in practical terms, this "infinite" distance can be approximated by calculating pixel distances between the point of interest and the vanishing point in the image. The pixel coordinates provide a measurable reference for the relative positioning of points, and this allows for the use of cross-ratio calculations to accurately determine the 3D location of a point in relation to the vanishing point and other reference points. Thus, even though the vanishing point represents an unreachable location at infinity, its role in the projective framework is essential for reconstructing real-world distances in a 2D image.

2.4.4 Calibration and scaling

To ensure that the cross-ratio measurements reflect real-world units, a known reference length must be used for scaling. This reference object, such as a building edge or a vehicle of known dimensions, is used to normalize the calculated distances, enabling precise dimensional recovery of any measured point.

This method of using vanishing points, parallel line projections, and the cross-ratio principle allows for an efficient and accurate 3D reconstruction from a single 2D image.

For the calibration of the height measurement model based on vanishing points, two main references were used: the height of a door and the tiled floor pattern.

The first reference was the known height of the door, which is 2,09 meters. This provided an absolute vertical reference, crucial for establishing the scale of the model in relation to real-world dimensions. Given that the height of a door is a constant, easily verifiable value, it served as a reliable anchor to ensure the accuracy of the height estimation for other objects and individuals in the scene.

The second reference was the tiled floor pattern, with each tile measuring 34 cm (or 0,34 meters). This grid provided an important horizontal reference, allowing for precise calibration of distances on the ground. The consistent and repetitive nature of the grid made it ideal for aligning the geometry of the model with real-world proportions, especially in the horizontal plane.

By combining these two references—one for vertical calibration (the door) and one for horizontal calibration (the tiled floor)—the model was accurately scaled in both height and depth. Using vanishing points, this system accounts for perspective distortion and offers reliable height measurements of various elements within the image.

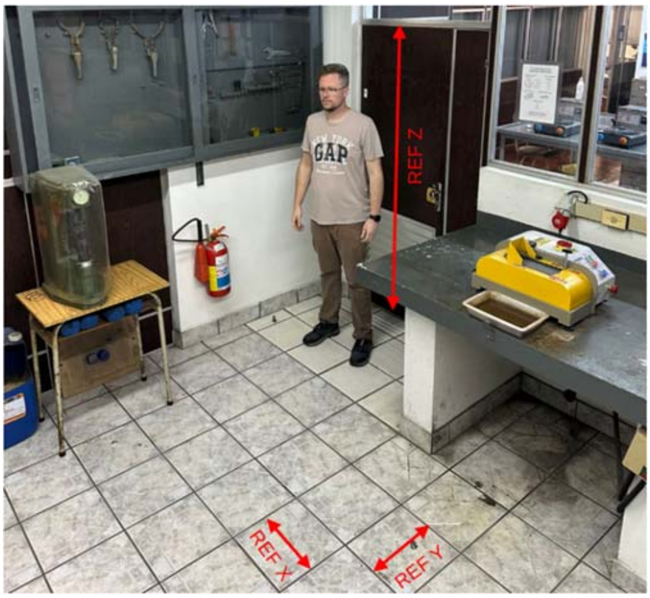

Figure 3. *Definition of the references in each direction.*

Source: the author.

2.5. Applications

2.5.1 Architectural reconstruction

Vanishing point analysis has proven to be a valuable tool in architectural reconstruction. By identifying vanishing points in photographs of buildings or structures, it becomes possible to extract precise measurements from 2D images. This technique allows for the creation of accurate 3D models without the need for complex scanning technologies, making it particularly useful in historical preservation, urban planning, and digital reconstruction of heritage sites. The ability to map parallel lines to vanishing points enables architects to determine dimensions and perspectives from a single image, significantly reducing the need for manual input.

2.5.2 Forensic analysis

Vanishing point techniques are especially useful in forensic applications, particularly when determining the height of suspects from crime scene footage or other image evidence. By using three sets of mutually perpendicular parallel lines in the environment, such as edges of walls, doors, or other known structures, vanishing points in each of the principal directions (X, Y, Z) can be identified. Once these vanishing points are determined, the position of any object or person in the scene can be measured using the concept of cross-ratio. For instance, by identifying the vanishing points and using reference points in the environment, investigators can accurately calculate a suspect's height or the relative positioning of individuals and objects in the scene.

This method is highly beneficial in crime scene analysis, where precise measurements are crucial for reconstructing the sequence of events. For example, the height of a person in a surveillance video can be estimated by projecting lines through their feet and head and comparing them to vanishing points along the vertical axis. This provides law enforcement with an accurate physical profile, even when direct measurement tools are unavailable.

2.5.2.1 Subheadings forensic analysis: A deep dive into height measurement

One particularly valuable application of vanishing point analysis in forensics is the accurate measurement of suspect height. By identifying the vanishing points of parallel lines in a scene, such as the edges of a building or the horizon line, investigators can create a virtual grid overlaying the image. This grid allows for precise measurement of the relative size of objects in the scene, including the suspect.

Key advantages of using vanishing points for height measurement:

- **Non-invasive:** Unlike traditional methods involving physical measurements, vanishing point analysis can be conducted from a distance, minimizing the risk of contamination or alteration of the crime scene.
- **Accuracy:** When applied correctly, vanishing point analysis can provide highly accurate height measurements, even in challenging lighting conditions or from oblique angles.
- **Versatility:** The method can be used in various forensic scenarios, including crime scene reconstruction, surveillance footage analysis, and mugshot comparison.

Example: In a case involving a surveillance video of a suspect fleeing a crime scene, investigators could use vanishing point analysis to determine the suspect's height relative to nearby objects, such as street signs or parked cars. This information can be crucial for narrowing down the pool of potential suspects and aiding in their identification.

2.5.3 Augmented reality and virtual reality

In the fields of augmented reality (AR) and virtual reality (VR), vanishing point analysis facilitates the integration of virtual objects with real-world environments. By mapping vanishing points from the real world, developers can ensure that virtual elements align perfectly with the user's physical surroundings, creating a seamless and immersive experience. Accurate spatial measurements obtained from vanishing point analysis improve the realism of AR/VR applications by ensuring that virtual objects maintain the correct size, scale, and perspective relative to real-world counterparts.

3. RESULTS AND DISCUSSION:

Results:

The routines necessary for pinpointing the three vanishing points and subsequently carrying out the cross-ratio measurements were successfully implemented within the Visual Basic environment, integrated into the Niewtun Photo software. The application of these functionalities demonstrated the capability to perform spatial measurements with a noteworthy degree of accuracy. Specifically, the utilisation of the vanishing points, identified from parallel and perpendicular lines within the image, facilitated an effective conversion of two-dimensional coordinates into their corresponding real-world dimensions. Furthermore, the cross-ratio analysis proved to be a valuable tool, providing accurate estimations for both the distances and the dimensions of the objects present in the scene, as illustrated in Figure 4 attached to the paper. In one particular analysis, a high-resolution image, boasting dimensions of 1200 by 1600 pixels, was employed as the basis for the height measurements. The wealth of detail afforded by this resolution aided the unequivocal identification of the crucial reference points for the process. It's worth noting that the region of interest within the image, encompassing the primary subjects of the analysis, presented itself free from any noticeable optical distortions, ensuring that any curvature or warping effects introduced by the camera lens were considered negligible and, therefore, did not compromise the precision of the measurements taken. For the calibration of the model, two references with known dimensions were utilised: the height of a door, established at 2.09 metres, and the dimensions of the tiled floor pattern, precisely measured at 0.34 metres. These references served as the foundation for the accurate scaling of both the vertical and horizontal planes within the image, effectively compensating for the distortions inherent in perspective. The height measurements of the objects and individuals present in the scene were then calculated by exploiting the geometric relationships defined by the vanishing points. The principle of the cross-ratio, a property that remains constant under projective transformations, was applied to estimate the relative dimensions of the elements in the scene, demonstrating its particular utility in accounting for the variation in depth and the effects of perspective. To assess the consistency of the method, the process of height estimation for an individual with a known height of 1.91 metres was repeated ten times. The results obtained demonstrated a remarkable convergence, consistently falling between 1.86 and 1.92 metres.

Discussion:

The implementation of the routines for determining the three vanishing points and the application of the cross-ratio methodology within the Niewtun Photo software establishes a promising approach for conducting precise spatial measurements from a single perspective image. The ability to calculate the vanishing points based on parallel and perpendicular lines allows for a robust transformation of two-dimensional coordinates into the actual dimensions of objects within the scene. The utilisation of cross-ratio analysis complements this approach, offering accurate estimations of distances and dimensions, which proves particularly valuable in contexts such as forensic image analysis and accident investigation, where precise spatial reconstruction is of paramount importance. The results obtained, demonstrating acceptable levels of uncertainty and error in the height estimation, attest to the reliability of the technique employed. The use of a high-resolution image in the analysis contributed significantly to the accuracy of the estimations, facilitating the identification of crucial details for the determination of vanishing points and the application of the cross-ratio. However, it is important to consider that images captured by surveillance cameras with lower resolutions and noticeable lens distortions can present challenges to the accuracy of measurements. The lower resolution can result in a loss of fine detail, hindering the identification of reference points, while optical distortions can introduce significant errors, particularly in the peripheral regions of the image. In these scenarios, the application of image correction techniques, such as geometric calibration or distortion rectification, may be necessary to improve the accuracy of height estimations and other spatial measurements derived from such footage. The calibration of the model using references with known dimensions, such as the height of the door and the floor tile pattern, proved to be an effective strategy for the accurate scaling of the image, compensating for the distortions introduced by perspective. The application of the cross-ratio principle proved particularly useful in dealing with the variation in depth and the effects of perspective, allowing for a more precise estimation of the relative dimensions of the elements within the scene. The consistency of the results obtained across multiple repetitions of the height estimation process for the individual of known height reinforces the reliability of the method, even in the face of minor inaccuracies in the identification of vanishing points and variations in the floor pattern. The observed margin of error remained within acceptable limits for practical applications, indicating that this methodology represents a promising tool for height estimation in situations where direct measurement is not feasible, provided that the calibration references are well-defined and properly aligned with the perspective of the image.

4. CONCLUSIONS

This study introduced a robust method for extracting accurate height measurements from images using vanishing points and cross-ratio analysis. By identifying three vanishing points associated with orthogonal axes, the technique allows for the transformation of 2D image coordinates into real-world dimensions, enabling precise spatial measurements. This method was validated through repeated height measurements of an individual using known references within the image, such as a 2,09 meters door and a 0,34 meters floor grid.

The results demonstrated that the method provided reliable height estimates, with measurements consistently falling between 1,86 and 1,92 meters for an individual known to be 1,91 meters tall. These findings highlight the method's precision, with the margins of error remaining within acceptable limits. Uncertainties were attributed to slight inaccuracies in locating vanishing points and minor variations in the floor grid's geometry.

Applications of this technique span various fields, including architecture, forensics, and augmented/virtual reality, where accurate spatial measurements are crucial. In forensic contexts, the ability to estimate the height of individuals from images or video footage presents a valuable tool for reconstructing crime scenes and assisting in suspect identification.

Future developments could focus on automating the detection of vanishing points, enhancing the accuracy of measurements in scenes with more complex geometries, and integrating this approach with other image processing techniques. These advancements would increase the utility and ease of use of this methodology, further solidifying its role in diverse domains.

In conclusion, vanishing point analysis offers a powerful tool for obtaining precise measurements from images, particularly in forensic investigations. As technology progresses, we can anticipate improvements in the accuracy, automation, and application of this technique, making it even more indispensable for law enforcement and other fields requiring spatial analysis.

5. DECLARATIONS

5.1. Study limitations

Despite the versatility of vanishing point analysis, certain limitations must be considered. The method relies on the assumption that the lines used to determine vanishing points are perfectly parallel in real-world conditions. However, small deviations from parallelism can introduce significant errors in the measurements. This limitation is particularly relevant in outdoor scenes, where structures may not be perfectly aligned due to architectural variations.

Furthermore, environments with curved or irregular surfaces do not lend themselves well to vanishing point analysis, as the underlying geometry does not support the necessary assumptions for parallelism. In such cases, alternative measurement techniques like photogrammetry or laser scanning may be required for accurate dimensional recovery.

Another challenge lies in the manual identification of vanishing points, which can be time-consuming and susceptible to human error. Automating this process through machine learning and computer vision techniques could enhance both accuracy and speed, making the method more accessible for a broader range of applications.

While vanishing point analysis offers a powerful tool for forensic investigations, it is essential to acknowledge its limitations:

- **Assumptions:** The method relies on the assumption that the lines used to calculate vanishing points are perfectly parallel in the real world. Deviations from parallelism can introduce errors into the measurements.

- **Image quality:** The accuracy of the results depends on the quality of the image. Factors such as blurriness, distortion, and occlusion can affect the reliability of the measurements.

- **Manual intervention:** The identification of vanishing points often requires manual intervention, which can be time-consuming and prone to human error.

To address these limitations, future research should focus on developing automated methods for vanishing point detection and refinement. Machine learning techniques, such as deep neural networks, can be employed to improve the accuracy and efficiency of the measurement process. Additionally, exploring the integration of vanishing point analysis with other forensic techniques, such as 3D reconstruction and facial recognition, can enhance its overall utility in criminal investigations.

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5.3. Competing Interests

The authors declare no conflicts of interest.

5.4. Open access

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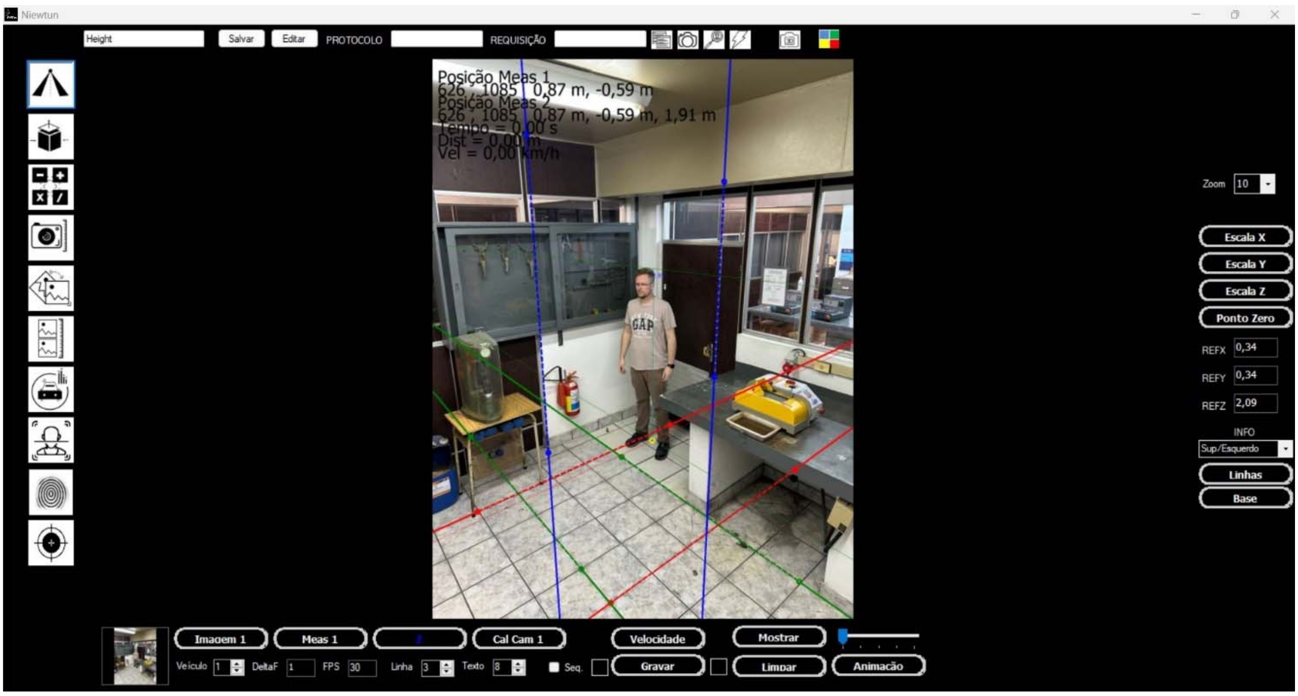

Figure 4. *Example of a figure result of height measurement, using the methodology described here.*

Source: the author.