The uncertainty research of visual positioning in different mediums

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Abstract. In engineering application, there existed deviation when light spreads in different mediums. At the same time miscellaneous medium and random fluctuation may lead to inaccuracy of visual positioning. It explored visual positioning technology in condition of different mediums for binocular camera. Firstly focused on medium material and impurity in real environment, the refractive index formula is derived through binocular visual positioning principle. Then considering deviation when light spreads in different mediums, deductive process of vision positioning is realized according to calculated refractive index. Because cloud model can better describe randomness and fuzziness. It was introduced to deal with problems of random fluctuation in different mediums. Finally simulation was designed to prove the accuracy improvement in different mediums. The result showed that accuracy error had decreased by 66.7% after considering transparent organic mediums. Compared with not knowing refractive index, positioning error had decreased by 49.7%.

1. Introduction

With the development of society, industrial manufacture tends to be mechanized and intelligent. Visual positioning is the key technology to provide position information of target [1-2]. Therefore it has been widely used in a variety of fields like industry, agriculture, tourism. Currently visual positioning was mainly applied in single medium. Some researches concentrated on air medium which can provide position information for industrial and agricultural manipulator. Auto-picking is an example of visual positioning in agricultural production. Especially the application was in agricultural products such as litchi [3], tomato [4] and strawberry [5]. The other researches concentrated on aqueous medium which provide position information for underwater operation. It applies to underwater fishing and submarine reconnaissance [6-7]. But visual positioning often involves the deviation in different mediums. For example, the camera obtains position information from air to water, or remote position happens in special gases. The visual positioning’s accuracy is the key to project implementation.

In addition air medium and aqueous medium usually mix with a variety of impurities. So refractive index can vary too. There is still no accurate mechanism formula to describe the situation. At the same time the light may have shape change and random fluctuations from external randomness. It would lead to inaccuracy of position information.
The research mainly includes two parts. The first one focused on refractive index calculation in real environment. The second one focused on random fluctuations from medium. Finally several experiments were designed to prove validity of the research.

2. Visual positioning in condition of different mediums

Derivation process in the paper exemplifies underwater camera. Light spreads through air, transparent organic materials and water. The refractive index of air is 1 by default. The refractive index of transparent organic materials is detected as 1.5 when they are made. The thickness $a=3$ mm. The refractive index of pure water is 1.33. Visual positioning model in condition of different mediums is shown in figure 1.

![Figure 1. Visual positioning model in condition of different mediums](image)

$C_1$ and $C_2$ are two cameras’ positions. $D_1D_2$ and $D_3D_4$ are planes between different mediums. $C_3$ and $C_4$ are projections of $C_1$ and $C_2$ in plane $D_1D_2$. $C_5$ and $C_6$ are projections of $C_1$ and $C_2$ in plane $D_3D_4$. $E_1$ is the real coordinate of target. $E_2$ is virtual coordinate of target. $E_3$ and $E_4$ are projections of target in plane $D_1D_2$ and $D_3D_4$. Refractive index is already known as $n=1.33$. According to visual positioning model in condition of different mediums, refractive index of aqueous medium is inferred in formula (1) and (2).

$$ n = \frac{\cos \angle C_1D_1C_3}{\cos \angle E_1D_1E_4} \frac{a / |D_1D_4|}{\cos \angle E_1D_1E_4} = \frac{\cos \angle C_1D_1C_3}{\cos \angle E_1D_1E_4} \frac{a / |D_1D_4|}{\cos \angle E_1D_1E_4} \tag{1} $$

$$ n = \frac{\cos \angle C_1D_1C_3}{\cos \angle E_1D_1E_4} \frac{a / |D_1D_4|}{\cos \angle E_1D_1E_4} = \frac{\cos \angle C_1D_1C_3}{\cos \angle E_1D_1E_4} \frac{a / |D_1D_4|}{\cos \angle E_1D_1E_4} \tag{2} $$

In visual positioning of binocular camera, key points coordinates are known as $C_1=(0, 0, 0)$, $C_2=(x_1, y_1, z_1)$, $E_2=(x_2, y_2, z_2)$. Assuming that material plane equation is $y=m$ and $y=m+0.3$. Therefore $C_1=(0, m, 0)$, $C_2=(x_1, y_1+m, z_1)$, $C_3=(0, m+3, 0)$, $C_4=(x_1, y_1+m+3, z_1)$, $E_3=(x_2, m+3, z_2)$ and $E_4=(x_2, m, z_2)$. $C_3, C_4, C_5$ and $C_6$ are the projections of two cameras in planes between different mediums. Because two planes of different mediums are parallel, the position of target will change in the direction of Y axis. It is shown in formula (3).

$$ \alpha = 3 - 3 \cdot \frac{y_2}{\sqrt{x_2^2 + z_2^2}} \tan[\arcsin(\frac{2 \sqrt{x_2^2 + y_2^2}}{3 \sqrt{x_2^2 + y_2^2 + z_2^2}})] \tag{3} $$

According to equations $C_1E_2$, $C_1E_3$, $D_1D_2$ and $D_3D_4$, the coordinates of points $D_1$, $D_2$, $D_3$ and $D_4$ in world coordinate are shown in formulas (4) and (5).
According to formulas (4) and (5) position information of "Virtual image" with transparent organic medium is shown in formula (6).

$$E_i = E_i + (0, \alpha, 0)$$  

(6)

The refractive index of water can be obtained through introducing formula (6) to (1) and (2). It is processed in formula (7). It can calculate formula (8) by the formula (7).

$$n = \frac{\cos \angle C_1 D_1 C_3}{\cos \angle E_1 D_1 E_3} = \frac{\cos \angle C_2 D_2 C_4}{\cos \angle E_2 D_2 E_3}$$  

(7)

$$\begin{align*}
\frac{D_2 C_2}{|E_1 D_1|} & = \frac{D_2 C_4}{|E_2 D_2|} = \frac{D_2 E_1}{|C_1 D_1|}
\end{align*}$$  

(8)

Where, 3D information of points $C_1, C_2, C_3, C_4, D_1, D_2, E_4$ are already known. There is only one unknown number for Y axis data of $E_3$. Information above is put in formula (8). The detail is shown in formula (9).

$$n = \frac{\sqrt{x_1^2 + z_1^2}}{\sqrt{x_2^2 + z_2^2} + 1} = \frac{\sqrt{(x_2 - x_1)(m - y_1))^2 + (z_2 - z_1)^2}}{\sqrt{(x_2 - x_1)(m - y_1))^2 + (z_2 - z_1)^2 + (y_2 - m_1 y_1 / m)^2 + (z_2 - m_1 z_1 / m)^2}} = \frac{\sqrt{(x_2 - x_1)(m - y_1))^2 + (z_2 - z_1)^2}}{\sqrt{(x_2 - x_1)(m - y_1))^2 + (z_2 - z_1)^2 + (y_2 - m_1 y_1 / m)^2 + (z_2 - m_1 z_1 / m)^2}}$$  

(9)

Where, $x_1, y_1, z_1, x_2, y_2, z_2, m$ are known variables. So unknown number $m_1$ can be solved. Then according to 3D information of each points, the unknown refractive index is as shown in formula (10).

$$n = \frac{\sqrt{x_1^2 + z_1^2}}{\sqrt{x_1^2 + z_1^2} + 1} = \frac{\sqrt{(x_2 - x_1)(m - y_1))^2 + (z_2 - z_1)^2}}{\sqrt{(x_2 - x_1)(m - y_1))^2 + (z_2 - z_1)^2 + (y_2 - m_1 y_1 / m)^2 + (z_2 - m_1 z_1 / m)^2}}$$  

(10)

3. The randomness description of visual positioning based on cloud model

For position information of $E_1$, wave in medium may effect on light. So position information may have deviation after interference [8]. In order to diminish the interference, cloud model is introduced to describe randomness. Each frame image can provide 3D information. The images come from underwater camera. 3D information is called $x_i, y_i$, and $z_i$. Where $i = 1, \ldots, n$. Numerical characteristics of cloud model can reflect the fuzziness and randomness. These are expectation $Ex$, entropy $En$ and super entropy $He$ respectively [9-10]. The generation algorithm of normal cloud model generator is following.

(1) Expectation of samples is calculated as shown in formula (11).

$$Ex(x_i, y_i, z_i) = \frac{1}{i} \sum (x_i, y_i, z_i)$$  

(11)

(2) Entropy can be obtained by samples in formula (12).
\[ En(x_i, y_i, z_i) = \frac{1}{i} \sum [(x_i, y_i, z_i) - E(x_i, y_i, z_i)]^2 \]  

(12)

(3) Super entropy of samples is set as formula (13).

\[ He(x_i, y_i, z_i) = 0.1 \]  

(13)

(4) Regarding \( Ex(x_i, y_i, z_i) \) and \( En(x_i, y_i, z_i) \) as expectation and standard deviation respectively, normal random numbers \((\hat{x}_i, \hat{y}_i, \hat{z}_i)\) are generated.

(5) Regarding \( En(x_i, y_i, z_i) \) and \( He(x_i, y_i, z_i) \) as expectation and standard deviation respectively, normal random numbers \( En'(x_i, y_i, z_i) \) are generated.

(6) Certainty degree is calculated as formula (14).

\[
\mu_i = \exp \left[ -\sum_{x,y,z} \frac{(x_i - \bar{x})^2}{2(En')^2} \right]
\]  

(14)

(7) Certainty degree of next frame image is calculated by iteration. Calculation process repeats steps above. The least certainty degree is obtained through comparing certainty degree \( \mu_i \) of each frame image. The \((x_i, y_i, z_i)\) with least certainty degree are the coordinates of target.

4. Experiment

The two groups of target point’s coordinates are \([2.332, -2.912, 1]\) and \([1.812, -2.849, 1]\) respectively. The coordinate of \( E_2 \) is \([1023.371, -1277.532, 2676.535]\). Transparent organic materials may lead to deviation. So distance from \( E_3 \) to \( E_1 \) is calculated through formula (1) to (10). Then \( \alpha = 2.205 \). As known variable \( m = -800 \), two points’ coordinates are respectively \( E_1 = [1023.371, -1289.737, 2676.535] \) and \( E_5 = [1023.371, -1287.532, 2676.535] \). So the refractive index of water is \( n = 1.35 \). Considering visual positioning in different mediums, there are four kinds of condition. They are ignoring the shield, including the shield, known refractive index and unknown refractive index.

The real coordinate of target is \([1023.5, -1290, 2676.5]\). 100 frame images’ errors in four conditions are compared as shown in Figure 2.

![Figure 2](image.png)

**Figure 2.** Error Comparison curve of 100 frame image in four conditions.
In the figure above, black line represents condition of ignoring the shield with \( n = 1.33 \). Blue line represents condition of ignoring the shield with unknown \( n \). Red line represents condition of including the shield with \( n = 1.33 \). Green line represents condition of including the shield with unknown \( n \). In the condition of unknown \( n \), the average error is 1mm compared with 3mm in condition of \( n = 1.33 \). The error has reduced by 66.7%. At the same time in condition of including the shield, the error has reduced by 49.7% compared with that in condition of ignoring shield. According to figures above, it is obvious that algorithm in the paper tend to be more accurate. It also fully considers thickness of transparent organic medium and unknown refractive index of water. In order to eliminate effect from random wave, further experiment is required. 100 frame images’ data is used to calculate error in the fourth conditions above. According to formula (11) to (14), trend of certainty degree curve is consistent with that of error curve. It is shown in figure 3.

![Error vs Frame Number Graph](image)

**Figure 3.** The comparison of certainty degree curve and error curve

The curve trend of error is almost consistent with uncertainty degree. And the point with least uncertainty is most close to the real value.

Repeated experiments above are implemented for a hundred times. Experimental parameters are modified in real environment. They are adjusting the camera position, mixing impurity into water, changing thickness of transparent organic materials and adjusting height of water surface. Coordinates of target are obtained through method in the paper. The conclusion is shown as follows. **Conclusion 1:** The result shows that there is better error in considering organic medium than in un-considering organic medium. **Conclusion 2:** The result shows that there is better error in considering unknown \( n \) than un-considering unknown \( n \). **Conclusion 3:** The result shows that there is better error in introducing cloud model than un-introducing cloud model. The experimental method in the paper applies to visual positioning technology in different mediums. It solves the problems of unknown refractive index and medium fluctuations. It provides an effective way for optimizing visual positioning.

**5. Conclusion**

The effect on visual positioning in different mediums is fully considered. Through deriving positioning formula of bilingual camera, it better solves the light changing problem in different mediums. The refractive index in real environment relative to that of air is worked out. At the same time cloud model can effectively describe randomness and fuzziness. It solves uncertainty problem caused by medium fluctuations in visual positioning. It provides a better way for the development of visual positioning technology in complex environment.
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