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A New Retail System Based on RFID and 3D Dense Face Alignment

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Abstract: Here we show a New Retail System based on Radio Frequency Identification(RFID) and 3D Dense Face Alignment(3DDFA). We found that by combining RFID and 3DDFA, goods can be located and recognized by RFID and customers can also be located through 3DDFA. For binding the goods' positions with customers' positions together, we proposed a Fuzzy Matching Algorithm. It reaches an accuracy of 0.83 without interface. Through the algorithm, the New Retail System can detect the position of goods and customers in real time even with interference like goods stacking and customers wearing masks. Additionally, customers' preference for goods is also obtained through the algorithm. We anticipate our essay to be a starting point to apply RFID and 3DDFA to New Retail. For instance, we track the location of customers and goods in real time to facilitate monitoring and straightforward settlement.

Keywords: New Retail; RFID; 3D Alignment

1. Introduction

Over the years, a lot of technologies have been applied to the field of unmanned retail, such as sensors, computer vision, QR code, NFC, and so on. In New Retail System, using computer vision to identify customers when they are moving may be invalid, and it can be challenging to identify goods when they are stacked. So there exist problems such as detecting the position of goods and customers in real time and complex settlement steps. Based on that, we proposed a Fuzzy Matching Algorithm to realize the New Retail system based on RFID and 3DDFA. We first tested the precision of the Levenberg-Marquardt algorithm to locate the RFID tags, and then that of 3DDFA to locate the center of customers' faces. Last, we bind the positions through the Fuzzy Matching Algorithm. The New Retail System we proposed can effectively address the issues of monitoring and settlement mentioned before. Apart from this, we research the relation between micro expressions or customers' actions and customers' preferences.

In this paper, in the first part, we made an introduction. In the second part, we summarize what researchers have done successfully in this field. In the third part, we gave the principle of our way to solve the problem, we adapt the LM algorithm, 3DDFA, and the Fuzzy Matching Algorithm. Finally ,the conclusion is given in the fourth part.

2. Literature Review

Liu et al.[2] designed a smart unmanned vending machine for new retail based on binocular camera and machine vision, and Zeng et al.[3] made a new intelligence retail system with a dual neural network model design. Zhou et al.[4] gave an efficient face recognition algorithm based on deep learning for Unmanned Supermarket, which solves face recognition, not in the face database. Guo et al.[5] suggested a fresh approach to comprehending consumers' behavior in unmanned stores. Zhang et al.[6] presented a product recognition algorithm based on HOG and Bag of Words Model, which has the advantages of lightweight and easy portability as well as improves the accuracy.

In unmanned stores or supermarkets, technologies like sensors, computer vision are widely used. For instance, the efficient face recognition algorithm proposed by Zhou et al.[6], or other methods to identify goods by computer vision, the issue with which is that computer vision may be invalid when stacking or under other situations. Guo et al.[5] used sensors and cameras to understand customers' behaviors, which is similar to our work. But we monitor goods' and customers' position in real time and solve the complex settlement.

3. Methodology

3.1 RFID-Technology

3.1.1 Overview of UHF-RFID technology

Ultrahigh-frequency (UHF) radio frequency identification RFID) is a low-cost, battery-free, unique identification technology that has grown powerful tool in warehouses. The perception of the position information of an RFID-tagged item may considerably increase the efficiency of goods management, and the localization method based on RFID technology is gaining popularity[7-9]. The phase-based technique has recently received much attention due to the advantageous phase sensitivity to distance.

3.1.2 New Retail System based on RFID Technology.

In this paper, we solved the tag's position using the nonlinear least-squares algorithm, and Levenberg–Marquardt (LM) algorithm is used to solve the three unknown parameters, tags' 3D coordinates[10]. For demonstration purposes, we've created the following fundamental application scenario.

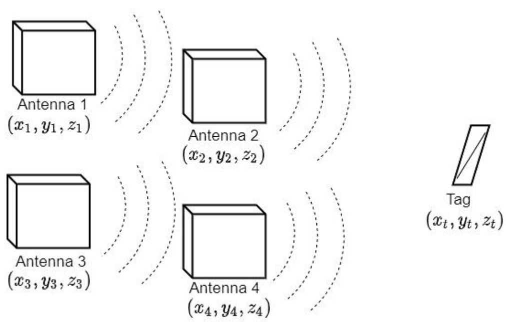

Fig. 1. Schematic diagram of tag positioning with 4 RFID antennas

In this scenario, we know the fixed positions of the four antennas (x_i, y_i, z_i), and the initial position of the tag (x_t, y_t, z_t) affixed to the goods which we know the complete information. The wavelengths produced by the antenna are all the same as λ. We will combine this initial information, using the phase-unwrapping method, nonlinear least-squares method, and LM algorithm to campaign for real-time positioning and tracking of tags. The specific methods are as follows:

Establish a goods-tags database and link the data from RFID tags to the information about the goods. In this way, we can use the ID serial number information of the tags to replace the complex goods information.

Let the reader with four fixed antennas continuously poll the RFID tag to get the RF information in the communication channel. The crucial information in this system is tag serial number and discontinuous phase. The serial number contains all the information about the item and the discontinuous phase is the key information to calculate the tag location.

Perform phase-unwrapping operation. Due to the discontinuous phase we receive, it can't be utilized to determine the distance directly. To turn the discontinuous phase value into a continuous phase value, we must execute phase unwrapping. We construct the phase unwrapping algorithm as follows:

$$\begin{cases} \theta_{initial} = \frac{2\pi}{\lambda} \times 2\sqrt{(x_i - x_t)^2 + (y_i - y_t)^2 + (z_i - z_t)^2} \\ \varphi^{(1)} = \theta^{(1)} \\ \varphi^{(k)} = \theta^{(k)} - 2\pi \cdot \left\lfloor \frac{\theta^{(k)} - \gamma^{(k-1)}}{2\pi} + \frac{1}{2} \right\rfloor, i = 2,3,4,\cdots,N \\ \gamma^{(k)} = \varphi^{(k)} - \theta^{(1)} + \theta_{initial} \end{cases} \#(1)$$

Due to the spatial sampling theory, the phase unwrapping algorithm needs to satisfy the following constraints:

$$\left| \frac{2d^{(i+1)}}{\lambda^{(i+1)}} - \frac{2d^{(i)}}{\lambda^{(i)}} \right| \times 2\pi < \pi \#(2)$$

The critical steps of phase unwrapping in the above equation system (1) are the 2nd and 3rd equations, which can provide continuous relative phases $\varphi^{(k)}$, k represents the kth detection. Equations 1st and 4th use the initial values convert the relative phase to the actual phase $\gamma^{(k)}$. In the equation system (1), $\theta_{initial}$ represents the initial actual phase of the antenna and the tag and $\theta^{(k)}$ represents discontinuous phase measurements at the kth scan. The $\gamma^{(k)}$ is linearly related to the real distance from the tag to the antenna.

Establish a mathematical model of $\gamma^{(k)}$ and three-dimensional coordinates.

$$\gamma^{(k)} = \frac{2\pi}{\lambda} \cdot 2\sqrt{(x_i - x^{(k)})^2 + (y_i - y^{(k)})^2 + (z_i - z^{(k)})^2} \#(3)$$

$\gamma^{(k)}$ is the actual phase between the tag and the antenna at the kth scan. $(x^{(k)}, y^{(k)}, z^{(k)})$ is the spatial position of the tag at the kth scan.

Build the cost function formulated as the residual sum of the squares of (3) and use the LM algorithm to find the three unknown parameters $(x^{(k)}, y^{(k)}, z^{(k)})$.

$$J = \sum_{i=1}^{4} \left\{ \gamma^{(k)} - \frac{2\pi}{\lambda} \cdot 2\sqrt{(x_i - x^{(k)})^2 + (y_i - y^{(k)})^2 + (z_i - z^{(k)})^2} \right\} \#(4)$$

When the kth polling is performed, we can obtain the information of the goods and solve the position of the RFID tag in real time[10].

Through the above method, we have realized the real-time acquisition of good information and location through RFID technology.

3.2Face Position based on 3D Dense Alignment

3.2.1 Overview of 3D Morphable Model

The 3D Morphable Model (3DMM) was presented by Blanz et al.[11], which can be described as:

$$S = \bar{S} + A_{id}\alpha_{id} + A_{exp}\alpha_{exp} \# (5)$$

where S is a 3D face, $\bar{S}$ is the mean 3D shape, α_{id} is the shape parameter and α_{exp} is the expression parameter, A_{id} and A_{exp} come from BFM and Face Ware-house, A_{id} is the shape vector and A_{exp} is the expression vector which have been trained before[12-13]. After the 3D face is constructed, it can be projected onto the image plane with scale ortho-graphic projection:

$$V_{2d}(p) = f * Pr * R * S + t_{2d} \#(6)$$

Where $V_{2d}(p)$ is the 2D projection function, f is the scale factor, $Pr = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix}$, and Pr is the orthographic projection matrix, R is the rotation matrix, and $R = [pitch, yaw, roll]$, and t_{2d} is the translation vector, so

$$p = [f, pitch, yaw, roll, t_{2d}, \alpha_{id}, \alpha_{exp}] \#(7)$$

And the $V_{3d}(p)$ is the 3D face reconstruction, which S described as:

$$V_{3d}(p) = f * [R; t_{3d}] * \begin{bmatrix} S \\ 1 \end{bmatrix} \#(8)$$

$$t_{3d} = \begin{bmatrix} t_{2d} \\ 0 \end{bmatrix} \#(9)$$

Where $[R; t_{3d}] \in R^{3\times4}$, $p = [f, pitch, yaw, roll, t_{3d}, \alpha_{id}, \alpha_{exp}]$. α_{id} has 40 dimensions and α_{exp} has 10 dimensions, p has 62 dimensions here.

3.2.2 Preliminary of Optimization Function

We first review the VDC (Vertex Distance Cost), WPDC(Weighted Parameter Distance Cost) and FWPDC(Fast Weighted Parameter Distance Cost).

The term L_{VDC} minimizes the vertex distances between the $V_{3d}(p)$ and the ground truth to optimize p:

$$L_{VDC} = ||V_{3d}(p) - V_{3d}(p^g)||^2 \#(10)$$

The term L_{WPDC} applies weights to optimize p:

$$L_{WPDC} = ||w \cdot (p - p^g)|| \#(11)$$

$$w = (w_1, ..., w_n) \#(12)$$

$$w_i = \frac{||V_{3d}(p^{de,i}) - V_{3d}(p^g)||}{Z} \#(13)$$

$$p^{de,i} = (p_1^g, ..., p_i, p_n^g) \#(14)$$

Where $n = 62$ here, $p^{de,i}$ is the i-degraded parameter, and its i-th element comes from the predicted p. Z is for regulation and Z equals the maximum of w. The term L_{FWPDC}[14]

$$L_{FWPDC} = ||w_T \cdot ([R; t_{3d}] - [R^g; t_{3d}^g])||^2 + ||w_\alpha \cdot (\alpha - \alpha^g)||^2 \#(15)$$

$$\alpha = [\alpha_{id}, \alpha_{exp}] \#(16)$$

And in this paper, we use Meta-Joint Optimization[14]. The steps of Meta-Joint Optimization are as follows:

1.Training process: sample k batches of training samples X_{train};

2.Testing process: sample one batch of X_{test};

3.Initiate the model parameters θ_i;

4.Update model parameters by k steps: get the model parameters θ_i by VPD and FWPDC on X_{train}, θ_{i+k}^v and θ_{i+k}^f are calculated;

5.Use $\nabla_{\theta_i} L_{VDC}(\theta_i, X_{train})$ and $\nabla_{\theta_i} L_{FWPDC}(\theta_i, X_{train})$ to update θ_{i+k}^v and θ_{i+k}^f;

6. Select θ_{i+k}^v and θ_{i+k}^f by using function:

$$\arg\min_{\theta_{i+k}} \left(L_{VDC}(\theta_{i+k}^v, X_{test}), L_{FWPDC}(\theta_{i+k}^f, X_{test}) \right) \#(17)$$

7.Use the result above to update θ_i.

3.2.3 Methodology

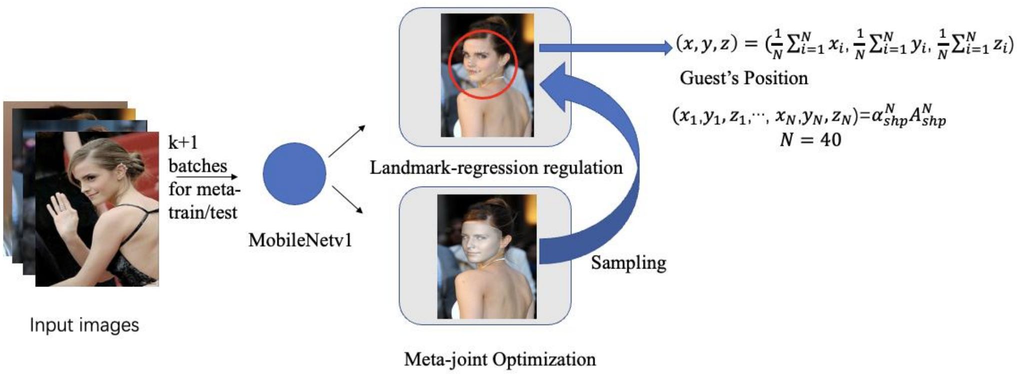

Fig. 2. The Overall of The Method

The loss function of Landmark-regression regulation is L_{rr}.

$$L_{rr} = \frac{1}{M}\sum_{i=1}^{M} ||l_i - l_i^g||_2^2 \#(18)$$

Where M = 136, here we flatten 68 2D landmarks into a 136-d vector, and we only extract the 40 parameters which symbolizes the shape vector $A_{id}\alpha_{id}$ of the face. And we calculate the arithmetic mean of $A_{id}\alpha_{id}$, which is position of the face center point.

3.3 A New Retail System Using Combination of RFID and 3D Dense Alignment

We proposed a Fuzzy Matching Algorithm for the combination of RFID and 3D Dense Alignment. Firstly, the Euclidean distance between every guest and the goods they select is calculated:

$$D = \sqrt{(x_i - x_m)^2 + (y_i - y_m)^2 + (z_i - z_m)^2} \#(19)$$

Where (x_i, y_i, z_i) is the 3D coordinate position of one guest, and the (x_m, y_m, z_m) is that of the goods. A threshold value D_0 was pre-set, and the set Ω_1 equals $\{D_i | D_i < D_0\}$ meanwhile the elements in Ω_1 are $D_i^{(1)}$. Then the elements $D_i^{(1)}$ was sorted, and the average of the elements $D_i^{(1)}$ is $\bar{D}_i$. Next, a new set Ω_2 equals $\left\{D_i^{(1)} \middle| D_i^{(1)} < \bar{D}_i\right\}$ and the elements in Ω_2 are $D_i^{(2)}$. Finally, the match function ψ_i is as follows:

$$\psi_i = \frac{\frac{1}{D_i^{(2)}}}{\sum_{i=1}^{N} \frac{1}{D_i^{(2)}}} \#(20)$$

$$\psi = \max \psi_i \#(21)$$

Fig. 3. The demonstration of the system

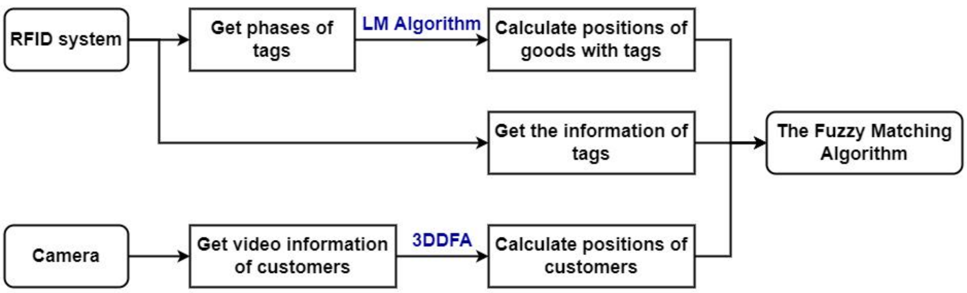

Fig. 4. The flow chart of the system

4. Conclusion and Discussion

This New Retail System gives a good way to monitor the process of shopping and solve complex settlement because RFID can obtain the information and position of the goods and 3DDFA can locate the position of customers. Through the Fuzzy Matching Algorithm, the positions could be matched.

However, there still exist something worth improving. The absolute error of RFID may accumulate as time increases. The camera may invalid when the face is out of its range. And the interface such as mask may decrease the precise of the position of the face and the Fuzzy Matching Algorithm. Apart from this, in real supermarket RFID may be affected by metal.

References

[1] Liu L,Cui J,Huan Y,Zou Z, & Zheng, L. (2021). A design of smart unmanned vending machine for new retail based on binocular camera and machine vision. IEEE Consumer Electronics Magazine,PP(99),1-1.

[2] Zeng M,Wu S, Li F, & Hu G. (2020). A new intelligent retail container system with a dual neural network model design. 2020 International Conference on Computer Engineering and Intelligent Control (ICCEIC).

[3] Xiong JA. (2018). Relating Technologies About New Retail. Technology communication (8), 2.

[4] Zhou FZ,Wan GC, Kuang YK, & Tong MS. (2018). An Efficient Face Recognition Algorithm Based on Deep Learning for Unmanned Supermarket. 2018 Progress in Electromagnetics Research Symposium (PIERS-Toyama).

[5] Guo B,Wang Z,Wang P,Xin T, &Yu Z. (2020). Deepstore: understanding customer behaviors in unmanned stores. IT Professional, 22(3), 55-63.

[6] Zhang T, & Chen E. (2019). Product Recognition Algorithm Based on HOG and Bag of Words Model. 2019 8th International Symposium on Next Generation Electronics (ISNE).

[7] Zhou J, &Shi J. (2009). Rfid localization algorithms and applications—a review. Journal of Intelligent Manufacturing, 20(6), 695-707.

[8] Dobrev Y,Vossiek M, Christmann M, Bilous I, & Gulden P. (2017). Steady delivery: wireless local positioning systems for tracking and autonomous navigation of transport vehicles and mobile robots. IEEE Microwave Magazine, 18(6), 26-37.

[9] Lu S, Chen X, & Zhong RY. (2016). An active rfid tag-enabled locating approach with multipath effect elimination in agv. IEEE Transactions on Automation Science & Engineering, 13(3), 1333-1342.

[10] Martinelli F. (2015). A robot localization system combining rssi and phase shift in uhf-rfid signals. IEEE Transactions on Control Systems Technology, 23(5), 1782-1796.

[11] Blanz V, & Vetter T. (2003). Face recognition based on fitting a 3d morphable model. IEEE Transactions on Pattern Analysis and Machine Intelligence, 25(9), 1063-1074.

[12] Zhou E, Fan H, Cao Z, Jiang Y, & Qi Y. (2013). Extensive Facial Landmark Localization with Coarse-to-Fine Convolutional Network Cascade. IEEE International Conference on Computer Vision Workshops. IEEE.

[13] Zhu X, Lei Z, Liu X, Shi H, Li SZ, Face alignment across large poses: a 3D solution. In: CVPR (2016).

[14] Guo J, Zhu X, Yang Y, Yang F, Lei Z, & Li SZ. (2020). Towards Fast, Accurate and Stable 3D Dense Face Alignment.