Research on Key Technologies of Robot for Visual Detection of Foreign Matter in Liquid Medicine Based on Machine Learning Algorithm

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Abstract. At present, in the pharmaceutical industry, people pay more and more attention to the quality of drugs, and therefore put forward higher requirements for the detection of drugs. In this paper, based on a large number of theories and experiments, an intelligent on-line detection system for visible foreign bodies in medicated liquor solution is designed based on machine learning algorithm. From the angle of mechanics and kinematics, the force analysis of moving objects in liquid after high-speed rotation and sudden stop is discussed, which provides an important reference standard for distinguishing visible foreign objects from random noise. The experimental results show that the algorithm can effectively eliminate the vibration interference of electromechanical system, and make the foreign body detection equipment of liquid medicine successfully migrate from single-station detection equipment to automatic online detection robot, which is of great significance to the research and development of the whole equipment.

Keywords: Machine learning algorithm; Machine vision; Drug foreign body detection

1. Introduction
Intelligent online detection of visible foreign bodies in medicinal liquor, infusion, ampoule injection and other liquids is a research hotspot in the field of machine vision and intelligent control [1]. Drug manufacturers at home and abroad have experienced a gradual development process in detecting the purity of liquid medicine. According to the "Inspection Method of Visible Foreign Matter" formulated in Pharmacopoeia of the People's Republic of China, visible foreign matter is an insoluble substance that can be observed visually under specified conditions, and its particle or length is greater than 50 microns. The manufactured liquid drugs shall not contain visible foreign matter [2-3]. The new edition of Pharmacopoeia puts forward quantitative requirements on the inspection method and the number of branches taken in Visible Foreign Matter Inspection Method, and the judgment standard is stricter, which lays a foundation for the gradual popularization and implementation of automatic detection of machines.

Under the irradiation of visible light, foreign objects can be detected by using the different reflection characteristics of foreign objects and products to light. For example, using image tag matching and network image searching methods [4-5]. In addition, some literatures show that manual
labeling is different from actual target data because it is easily influenced by subjective factors (for example, when there are multiple targets in the image). In this paper, based on machine learning algorithm, an anti-vibration machine vision detection algorithm for foreign bodies in liquid medicine is proposed. Image matching preprocessing is added before the inter-frame difference step in the traditional inter-frame difference detection algorithm for foreign bodies in liquid medicine, and the original image with vibration offset is translated to the corresponding spatial position, and then the inter-frame difference is carried out, thus overcoming the vibration interference of electromechanical system and achieving good detection results.

2. Working principle of medical detection robot

The intelligent robot system for detection and sorting in pharmaceutical automatic production line is based on machine vision detection and recognition, which can realize visual detection of foreign bodies in pharmaceutical liquids and complete real-time automatic sorting and removal without affecting the normal safe production process. The router receives the camera video data and transmits it to the industrial computer, which displays the detection results on a public display [6]. Detectors hold the top of the medicine bottle with a special clamp, take 2 to 10 bottles of liquid medicine at a time, and rotate and turn over slowly under the light of white and black background, so that the foreign matter that may exist at the bottom of the bottle enters the middle of the liquid after moving with the bottle body, and then make visual judgment. The high-speed production line must also consider the size and installation orientation of visual devices such as cameras and light sources; Matching with the production line speed of pharmaceutical enterprises; The volume requirement of the whole vision inspection system and other factors.

In this paper, the vision imaging system adopts the way of back plus top to give light, and the foreign matter information in the liquid medicine can be well reflected on the image by turning over the foreign matter in the bottle and making relative movement. After grasping the medicine by the positioning mechanism, it rotates smoothly and at high speed, and stops abruptly after a certain time. At this time, the foreign matter in the medicine liquid moves rapidly, and the servo tracking and shooting mechanism is started to obtain multi-frame sequence images. After that, the whole mechanical device returned to a static state, the liquid level in the bottle gradually tended to be flat, the liquid continued to rotate due to inertia, the foreign matter in the bottle kept moving in the flowing liquid, and finally returned to a static state due to friction after a certain time. Because of the failure of bottle breakage caused by the mismatch of various speeds, a motor is specially designed to drive the main wheel disc, and the main wheel disc is transmitted to the auger and other wheels at a fixed transmission ratio through gear meshing, thus ensuring that the speed change of the main wheel disc is consistent with other rotation changes.

3. Hardware system

It consists of three subsystems: electrical control system, visual imaging system and mechanical execution system. The overall system operation flow is shown in Figure 1.
3.1. Electrical control system

The upper industrial computer communicates with the bottom PLC through serial port to transmit the detection result signal. The mechanical part of the equipment mainly includes four parts: production conveyor belt, lead-in wheel disc, detection wheel disc and two lead-out wheel discs. In this paper, the second-generation high-speed servo tracking scheme is adopted, in which the bottle body is clamped on the master wheel and moves at a constant speed along with the master wheel, the optical imaging components such as industrial camera and light source are fixed on the slave wheel, and the servo motor drives the slave wheel to swing periodically "forward acceleration-forward uniform tracking-forward deceleration-reverse acceleration-reverse deceleration" [7]. Only in this way can a correct sub-sampled image be obtained. It is necessary to design the corresponding fixing mechanism without affecting its own rotation movement, so as to ensure that it will not be thrown out when rotating at high speed.

A plurality of bottle rotating devices sequentially drive the push-down manipulator to perform multi-stage accelerated rotation until the liquid medicine fully rotates. When the medicine bottle passes through the emergency stop area, the brake pad brakes the push-down manipulator and the medicine bottle stops rotating. The lead-in wheel is responsible for adjusting the spacing and conveying direction of the products to be inspected. Tangent connection is adopted between the lead-in wheel disc and the main wheel disc, so that products can smoothly enter the rotating groove on the main wheel disc. PLC controls the operation of conveyor belt, main wheel disc and swing arm motor through frequency converter and servo driver, and controls the baffle bottle picking device to sort products according to the detection results.

3.2. Visual imaging system

According to different optical imaging of foreign matter in liquid, two detection stations are set to detect white foreign matter and black foreign matter in liquid respectively. PLC is used as the control center to control the underlying hardware, including the control of the rail motor in and out of the bottle, the control of the servo motor of the master wheel disc and the servo motor of the slave wheel disc, the sorting operation of defective products, the triggering and photographing of industrial cameras, and the input and output of various switching values and I/O signals. Match the local features of the test image with the feature book, and get the probability histogram of the test image [8]. That is to say, the main wheel disc always rotates counterclockwise at a constant speed during the whole running process, while the tracking swing arm performs the periodic action of "accelerating-tracking at a constant speed-returning quickly" independently of the main wheel disc. The CCD camera is installed on the camera bracket of the swing arm and corresponds to the light source one by one.

![Figure 2 Schematic diagram of tracking swing arm periodic motion](image-url)
With the production rate of 300 bottles/min in the production line and the single camera acquisition mode, the vision inspection robot must complete one cycle movement within 0.2 seconds, that is, realize the acceleration, uniform tracking and accelerated return movement of the tracking swing arm. The periodic running diagram of the tracking swing arm is shown in Figure 2.

On a test image, firstly, image pyramids with different scales are constructed, and then SLBP features are extracted from different scales. Finally, SLBP features extracted at different scales are connected according to different weights to form feature vectors of the image.

3.3. Mechanical execution system
Because of the embossed scale, uneven surface, bubbles caused by liquid movement and other reasons in the filling bottle wall of the drug to be detected, there are bright spots in the gray image collected by the camera, which are very similar to foreign bodies. The slave wheel swings back and forth to track the master wheel, and collects images in the synchronous tracking area. To use vector quantization technology, the key step is to design a good feature book. This is usually determined by statistical experiments with a large number of input vectors. This process is called "training" or "learning", and its task is to build a signature book. The execution part mainly uses the learning results to process the data to be identified to obtain the corresponding recognition results, and feeds back the execution results to the learning part for further learning and improving the system performance.

The motor is started, the conveyor belt drives the detection target to enter the detection cabinet, and the twist-wheel bottle separator ensures that the wine bottles to be detected enter the star wheel at equal intervals and uniform speed. Therefore, the collected images must be processed in series, including image preprocessing, denoising, differential extraction of moving foreign bodies, foreign body segmentation, tracking and marking of targets in images, and drug defect judgment [9]. After the sample screening, for each sample, the operation, Fourier transform and high-pass filtering are performed. The results of all positive samples are the positive input of the classifier, and the results of all negative samples are the negative input of the classifier. The impact offset wheel disc is added to eliminate the impact of repeated acceleration and deceleration from the wheel disc on the system, and the consistency of each detection station and the vibration amplitude of the whole machine are evaluated, so as to guide the electromechanical engineers to further improve the accuracy of the electromechanical system.

4. Detection algorithm

4.1. Machine learning
Machine learning is a study of acquiring new knowledge and skills and identifying existing knowledge. As shown in Figure 3, it is a machine learning schematic diagram. For each input \( x \), the system predicts the output \( y \). This prediction mechanism \( h \) is obtained through a certain learning algorithm and training samples.

![Figure 3 Machine learning schematic diagram](image)

In order to associate multiple foreign objects and residual background blocks in sequence images, it is necessary to extract the invariant features of multiple objects and residual background blocks in
each frame image and identify them, then use these invariant features to match the same object in sequence images, and finally associate them into continuous motion trajectories of visible foreign objects and residual background blocks. Therefore, the real output can be used to evaluate the learning results, such as the disease category of known training samples in medical diagnosis problems and the real price of known training samples in market price prediction problems. When there are many image samples, this matching method is likely to divide different LBP features into the same word. In addition, this nearest neighbor matching method is sensitive to isolated noise [10].

4.2. Shape feature extraction

Image matching is a process of establishing the spatial position relationship between two images, determining the geometric transformation parameters between images, and geometrically transforming one image to make it align with the other image in spatial position [11]. The basic operations of gray morphology are corrosion, expansion, open operation and closed operation. The main source of static interference area is the inhomogeneity of the bottle wall and the contamination on the bottle wall, which is characterized by taking the bottle body as the reference system and no movement. Therefore, a $7 \times 7$ circular template is selected as the structural element to perform Top-hat morphological filtering on the original image, and a denoised image containing foreign objects and bubbles is obtained.

As an important feature of objects, the geometric moment invariants of images are widely used in pattern recognition, image classification, target recognition and other fields [12].

For image $f(x, y)$, its $p + q$-order geometric moment is:

$$m_{pq} = \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} x^p y^q f(x, y) \, dx \, dy, \quad p, q = 0, 1, 2, \ldots$$

The $p + q$-order central moment is:

$$\mu_{pq} = \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} (x - \bar{x})^p (y - \bar{y})^q f(x, y) \, dx \, dy$$

Among them,

$$\bar{x} = \frac{m_{00}}{m_{00}}, \quad \bar{y} = \frac{m_{01}}{m_{00}}$$

Normalized central moment is:

$$\eta_{pq} = \frac{\mu_{pq}}{\mu_{00}^\gamma}, \quad \gamma = \frac{p + q}{2} + 1$$

In the process of transformation, the distance between any two points in the image remains unchanged [13]. Non-rigid matching mainly uses projection transformation, affine transformation, nonlinear transformation and other methods to transform the original image, and the distance between any two points in the image may not remain constant. When adding a new target image, firstly extract the SIFT features of the new target image, compare the new features with the nodes of the dynamic feature word tree, and grow the dynamic feature word tree. The two-stage EM iterative method is used to dynamically update the training samples and feature words, and the updated model does not need to retrain the original classification parameters. Finally, the classification effect of the classifier is tested by a large number of test pictures. If it does not meet the requirements, according to the test phenomenon, the positive and negative samples are continuously screened, and the classifier is retrained until the classification effect meets the requirements.

4.3. Judge and give the test result

When extracting the target features in each frame of images, visible foreign objects are rotated by liquid into the bottle wall far away from the camera, or the reflective surface facing the camera changes due to the rotation of foreign objects. After determining whether to use texture classifier or
edge classifier, Fourier transform and high-pass filtering are continuously performed on the region. Avoid the defects of individual detection stations affecting the detection efficiency of the whole machine when actually detecting foreign bodies in liquid medicine. After direct normalization, it is input into the classification algorithm, resulting in a large error. Therefore, before the normalization of feature data, the incomplete data is filled by using the quantitative tolerance relation.

The detection results are determined by the number and size of blocks in the target area. In actual detection application, in order to reduce the false detection rate, the conditions given by the detection results are set as follows:

\[
\text{Result} = \begin{cases} 
0 & (N \geq 2) \text{ or } (N = 1 \text{ and } A_i > 5) \\
1 & (N = 0) \text{ or } (N = 1 \text{ and } A_i \leq 5)
\end{cases}
\]

In the formula, \(N\) is the number of blocks in the target area, \(A_i\) is the area of the first block in the target area, and 0 and 1 respectively indicate that the detection results are unqualified and qualified.

Since the image was taken when the medicine bottle was turned over 180 and stood still, it can be seen that the foreign body is moving downwards, so the centroid ordinate should be enlarged in turn. In principle, as long as the target area is not empty, the test result should be judged as unqualified. If the test finds that there is a high probability of large amplitude vibration in the vibration amplitude statistical analysis results of the whole machine, the electrical control engineer needs to readjust the relevant parameters of the electrical control system, so that the overall vibration amplitude of the system can meet the high precision requirements of visual inspection.

5. Experimental analysis

During the performance test of the system, we selected 10% glucose and 0.9% sodium chloride solution in 100ml glass bottles as the test objects. The test shows that the system has a high false detection rate for detecting foreign bodies with particle size less than 50 μm. It has high recognition accuracy for foreign bodies larger than 50μm, and the rate of false detection and missed detection is less than 5%. Table 1 shows the detection results of engineering products of a pharmaceutical factory by using this method.

**Table 1** Comparison between the test results of the system developed in this paper and the manual test results

| Drug type                        | Kind         | Existing manual light inspection results | Test results of this system |
|----------------------------------|--------------|------------------------------------------|----------------------------|
|                                  |              | Qualified                  | Disqualification | Qualified | Disqualification |
| 10% glucose injection            | Qualified    | 446                        | 17              | 488       | 12               |
|                                  | Disqualification | 6                        | 93              | 2         | 91               |
| 0.9% sodium chloride solution     | Qualified    | 1022                       | 33              | 1087      | 24               |
| injection                        | Disqualification | 11                        | 72              | 6         | 89               |

Select a frame of image after preprocessing and target segmentation, and extract the black residue, interference points and fibers in the residual image, as shown by reference numerals 1, 2 and 3 in Figure 4(a). The extracted single target images are superimposed in the column direction to form a one-dimensional signal. The signal is decomposed in five layers by db4 wavelet packets, and \(\text{diag}(\lambda_1, \lambda_2, \cdots, \lambda_{32})\) is sorted from big to small. The first eight energy spectra of wavelet packets are extracted as principal components, and the normalized energy spectrum is shown in Figure 4.
Among them, (b)–(d) respectively represent the normalized wavelet packet energy spectrum of black slag, random noise points and fibers. It can be seen from the figure that the wavelet packet energy spectrum of the same type of target is relatively fixed, whereas different types are quite different. Therefore, it is feasible to take the wavelet packet energy spectrum attribute value as the feature value of target classification.

Select 500 empty bottles without liquid medicine, and test them for 20 times at full speed of field equipment. In the first batch of tests, the detection program calls the traditional interframe difference detection algorithm for foreign matter in liquid medicine. In the second batch of tests, the detection program calls the anti-vibration machine vision detection algorithm for foreign matter in liquid medicine, and counts the number of samples coming out of the defective channel respectively. The experimental results are shown in Table 2.

**Table 2** Comparative test of anti-vibration ability of algorithms

| Detection algorithm | Traditional interframe difference algorithm for foreign body detection of liquid medicine | Anti-vibration machine vision detection algorithm for foreign matter in liquid medicine |
|---------------------|--------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
| Number of defective products (bottles) | 5882                                                                                       | 458                                                                                  |
| False detection rate | 58.82%                                                                                     | 4.582%                                                                               |

Experimental results show that, compared with the traditional interframe difference detection algorithm for foreign matter in liquid medicine, the anti-vibration machine vision detection algorithm for foreign matter in liquid medicine proposed in this paper can effectively eliminate the vibration influence of the system, and the false detection rate of the system is greatly reduced. Therefore, when
designing, processing, installing and debugging a full-automatic liquid medicine foreign body online detection robot, the requirements on mechanical design and processing accuracy, servo motor encoder accuracy and tracking accuracy are greatly reduced, and the design and manufacturing cost of equipment is significantly reduced.

6. Conclusions
With the innovation of high-speed and high-resolution cameras, and the continuous maturity of pattern recognition, image processing and computer vision technology, it is possible to detect tiny visible foreign bodies in ampoule liquid medicine based on machine vision detection technology. In this paper, based on machine learning algorithm, an anti-vibration machine vision detection algorithm for foreign bodies in liquid medicine is proposed, which overcomes the influence of vibration interference of electromechanical system on the vision detection system from the perspective of software. By using the optimized sub-pixel image matching algorithm, the computational complexity is reduced, the program's memory requirement on the computer is greatly reduced, and the computational speed is improved.

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