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# Rotation rate measurement of a microfluidic biodisk spinner and automatic adjustment for the pulsed light source

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**Abstract**

This study presents a design for a light field inspection system of a biodisk and spinner, which uses a digital camera attached a light filter below to inspect the fluorescence from the biodisk. The pulsed light is a single frequency-controllable light source that is spread over the biodisk. When the frequency of pulsed light is equal to the rotation rate of the spinner, the rotating biodisk would appear to be static due to the persistence of vision effect. The excitation light source (same as the pulsed light) is used to excite the reaction area in the biodisk, and the biochemical reaction emitted fluorescence is recorded in the monitor. Using the continuous image sequence calculation and measuring the variation of the rotating rate for the spinner, and by adjusting the frequency of pulsed light source, the rotational speed of the biodisk and the pulsed light frequency can be synchronized. We also propose a rule for high-speed image processing and low consumption of memory space. By properly judging the rotational speed of the biodisk spinner and quickly inspecting the biodisk, very large amounts of data can be handled. If the images acquired from the camera are processed individually, there will be drawbacks such as slow image acquisition speed and loss of image information. Therefore, we take a multi-task mechanism to use sufficient image buffer areas to increase the speed of acquiring images while processing the images with adjusting the memory spaces efficiently.


*Keyword:* Spinner; Fluorescence; Biodisk; Pulsed light Frequency; Synchronous

## 1. Introduction

The biodisk technology is mainly used in disease analysis. Since over 60% of human diseases are closely correlated with gene defects or abnormalities, comprehending gene function will advance in diseases mechanism and determining treatment [1]. The pathogen can be obtained from a series of complex procedures such as blood sampling, cleanup, braking, screening, and magnification, and these genes or protein as biological material can be used to make the biodisk (simulating pathogen) for medical testing. For the biodisk test, the defective gene or protein is marked with fluorescent liquid during the biodisk making process to easily observe the test results. A test specimen such as blood or urine is dropped on the biodisk to check whether there is a fluorescence reaction, or the gene in the specimen contains pathogens similar to the biodisk. Thus medical technicians can judge the conditions more easily [2–5].

Fig. 1 shows the structure of this microfluidic biodisk. Blood is first separated into corpuscles and serum, which then pass through the microfluid channel initiating the biochemical reaction. The results are displayed in the testing zone.

The biodisk includes one set of disk-sharp pedestal and multiple test lines and boundary marks designed for easily measuring the rotational speed, the frequency adjustment of pulsed light, and the position calculation

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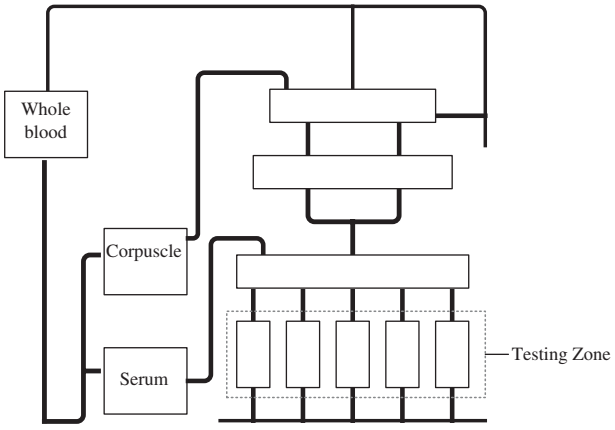


Fig. 1. Microfluidic biodisk.

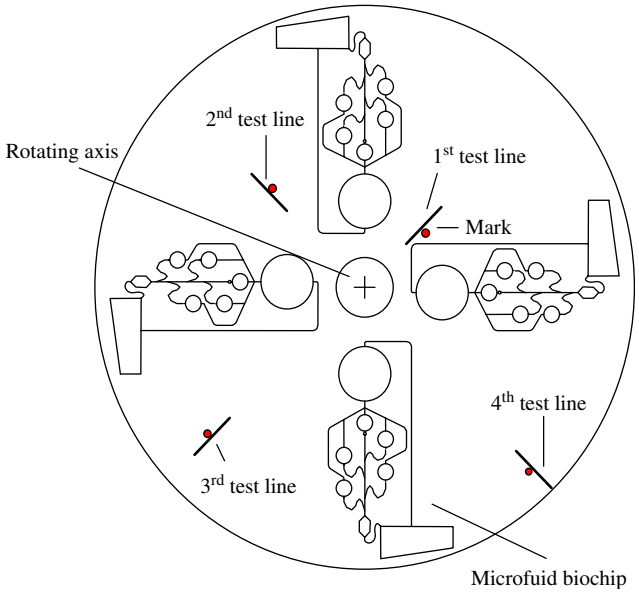


Fig. 2. Layout of the microfluidic biodisk.

of biodisks. Besides, each biodisk has one test line to identify the microfluidic biodisk and its position. For example, the *n*th test line is used to identify the *n*th testing zone. Fig. 2 shows the layout of microfluidic biodisk, where there are many microfluidic testing zones with the function of biochemical reaction in the pedestal. Every testing zone has one testing-fluid storage tank, one waste-fluid storage tank, multiple biochemical reaction areas, one test zone, and many microfluid channels. When the testing zone is illuminated with a wavelength $\lambda_1$, it will generate a fluorescence light a wavelength of $\lambda_2$. The reading device in the biodisk simultaneously reads the fluorescent signal and the corresponding signal from the disk data layer out, and the address, which is homologized in the data format of the signal of data layer corresponding to the fluorescent single. These data pass through the data processor to

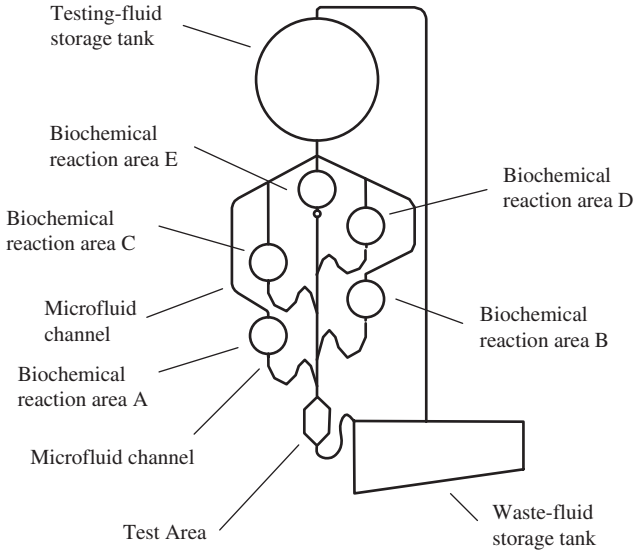


Fig. 3. Structure of testing zones in the microfluidic biodisk.

rebuild the binary format of the biodisk's fluorescent signal, so that the biodisk can be inspected successfully. Fig. 3 shows the structure of the testing zone in the microfluidic biodisk. The axiom for the flowing fluid is based on the capillarity of fluid and the centrifugal force of spinning disk, assuming that the centrifugal force is larger than the resistance from the microfluid channel or valve and then the liquid will run along the microfluid channel. When the centrifugal force is directly proportional to the rotational radius and speed, the testing fluid will run into a different position with a different rotational speed.

The processing procedures are listed as follows:

1. At rotational speeds 1–5, the microfluid valve will be opened due to the centrifugal force of the testing liquid. At each individual speed, the testing fluid passes the microfluid channel and causes the reaction in the biochemical reaction areas A–E, respectively.
2. At rotational speed 6, the microfluid valve will be opened due to the centrifugal force of the testing liquid and the testing fluid passes the microfluid channel to the test area. The results are shown in different colors, which can be checked by the mechanical vision system.
3. At rotational speed 7, the reacted fluid runs into the waste-fluid storage tank.

## 2. Algorithm for the rotation rate measurement of microfluidic biodisk and automatic adjustment for pulsed light

For detecting the rotating biodisk, the spinner is illuminated with pulsed light. When the frequency of

pulsed light source equals the rotational speed of the spinner's motor, the rotating biodisk would appear stationary due to the persistence of vision effect. Moreover, the quality of the biodisk is hard to control precisely, so that the testing fluid does not always run to the preset position under a stable preset rotational speed, and sometimes the rotational speed of motor has a drift that causes the static image of the biodisks roll slowly, so that inspection becomes more difficult. The motive of this research is a to make use of the continuous image sequence calculation with the variation of motor speed measurment, and through a controller to adjust the frequency of pulsed light, to maintain the biodisk images stationary and use a mechanical vision system for automatic inspection and recognition of the bioreaction. Following is the algorithm for the speed measurement of the biodisk spinning machine and the frequency adjustment of the pulsed light.

(1) Search the positions of all boundary marks in an entire biodisk image.
(2) Use multiple dynamic searching frames to lock and confirm the test lines and their positions, e.g. as shown in Fig. 4. The central point of dynamic searching frame will lock the mark and move with it to distinguish the test line in the frame.
The shift principle for the dynamic searching frame is shown in the following:
(i) Search the positions of all boundary marks in an entire biodisk image.
(ii) The central point of dynamic searching frame moves to the new position, and calculate the angular displacement, as shown in Fig. 5.

$$\vec{A} = [X_c - X_t,\ Y_c - Y_t], \tag{1}$$

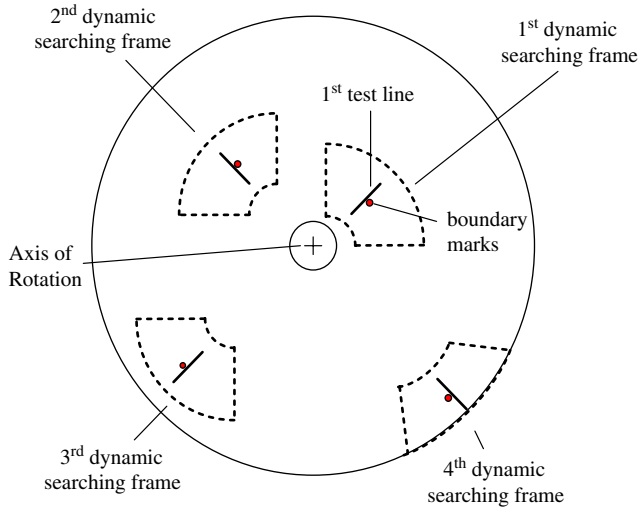


Fig. 4. Use of multiple dynamic searching frames.

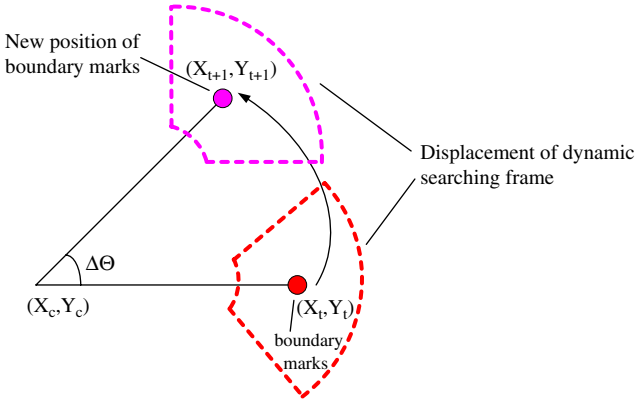


Fig. 5. Displacement of dynamic searching frame.

$$\vec{B} = [X_c - X_{t+1},\ Y_c - Y_{t+1}], \tag{2}$$

$$\Delta\theta = \cos^{-1}\frac{||\vec{A}||^2 + ||\vec{B}||^2 - \vec{A}\,\vec{B}}{2||\vec{A}||||\vec{B}||}, \tag{3}$$

where $(X_{t+1}, Y_{t+1})$ is the boundary marking position in the next time point $(t+1)$, $(X_t, Y_t)$ is the boundary marking position in the present time point $(t)$, and $\Delta\theta$ is the angular displacement. Fig. 5 shows the displacement of dynamic searching frame.

(iii) Pick the traits of a test line such as the specific points on the test line and the distance to rotating axis.
(iv) Differentiate each frame by the traits of test lines.
(3) Use multiple test lines to calculate the position of the rotating axis:
(i) Calculate every linear formula of each test line.

$$Y = a_i X + b_i, \quad i = 1, 2, \ldots, n.$$

(ii) Find the rotating axis from multiple linear formulas.
(4) Rectify the inaccuracy of the axis position due to motor vibration or other reasons:

$$P(X', Y') = P(X + \Delta X, Y + \Delta Y), \tag{4}$$

where $P(X', Y')$ is the coordinate after the pixel correction and $P(X, Y)$ is the coordinate before pixel correction. $\Delta X$ and $\Delta Y$ are the displacement values for the rotating axis along horizontal and vertical directions, respectively.
(5) Calculate the angular displacement:

$$\Delta\theta = \tan^{-1}\frac{Y_t - Y_{\text{center}}}{X_t - X_{\text{center}}} - \tan^{-1}\frac{Y_{t-1} - Y_{\text{center}}}{X_{t-1} - X_{\text{center}}}, \tag{5}$$

where $(X_t, Y_t)$ is the coordinate on the specific point in the test line at time $t$, $(X_{t-1}, Y_{t-1})$ is the coordinate on a specific point in the test line at time $t+1$ and $(X_{\text{center}}, Y_{\text{center}})$ is the coordinate of the spinning axis. The angular displacement could be the basis to correct the frequency of pulsed light.

(6) Calculate the angular velocity:

$$\omega = \Delta\theta/\Delta t, \tag{6}$$

where $\omega$ is angular velocity, $\Delta\theta$ is angular displacement, and $\Delta t$ is the variation value of time.

(7) Calculate the angular acceleration:

$$\alpha = \Delta\omega/\Delta t, \tag{7}$$

where $\alpha$ is angular acceleration, $\Delta\omega$ is the variation value of angular velocity, and $\Delta t$ is the variation value of time.

(8) Adjust the frequency of pulsed light: the spinning biodisk with pulsed light projected on whole image will appear motionless when the frequency of pulsed light is synchronized with the rotating rate of the spinner's motor. If not, the biodisk image spins slowly in the same direction as the motor, the frequency of pulsed light is lower than the rotational speed of the motor, and the frequency of pulsed light must be increased. Or if the biodisk image spins slowly in reverse direction from the motor, then the frequency of pulsed light is higher than the rotational speed, and the frequency must be decreased.

Then the adjusting value for the frequency of pulsed light can be obtained as follows:

$$\Delta f = \frac{\theta \times f_S}{2\pi - \theta}, \tag{8}$$

$$\Delta f = f_D - f_S, \tag{9}$$

where $f_D$ is the frequency of spinning biodisk, $f_S$ is the frequency of pulsed light, and $\theta$ is the value of angular displacement.

Fig. 6 shows the flow chart of this algorithm.

## 3. Rules for rapid image processing and adjusting memory spaces

There is a very large amount of data needed for estimating the rotating speed of the spinner accurately and inspecting the biodisk rapidly. If the images acquired from the camera are processed one by one, there are some disadvantages such as slower image acquisition speed and lost image information. To take a multi-task mechanism by using multi-image buffer areas to acquire and handle images simultaneously can upgrade the images acquisition speed but may take up a large amount of memory. Figs. 7 and 8 show the rules to rectify the rapid image processing and memory space adjustment problems. The principles are given in the following:

1. Multi-task synchronization of acquiring images with processing images [6].
2. Calculate the minimum required numbers of the buffer [7].
   (1) To acquire one new image with no empty buffer area, it must be added buffer area dynamically to store the image data [8,9].
   (2) To acquire one new image with the above two empty buffer areas, one buffer area must be reserved to store the image data and additional buffer areas after the first buffer area must be deleted.
   (3) To acquire one new image with just one empty buffer area, the system stores the new image data, and the number of buffer areas remains the same.

## 4. Experiments

For the hardware design of the microfluidic biodisk, the following five considerations are necessary to ensure better performance and prompt monitoring of the biochemical reactions.

1. The biodisk provides power for the fluid in microfluid channels to run by spinning.
2. An excitation light source is necessary to make the biochemical reactions on the biodisk, which can help identify the test result.
3. The biochemical reactions are monitored in real time for the spinning bioidisk.
4. A protective device for the biodisk spinner is necessary.
5. A stable spinning condition of the biodisk is necessary.

According to these principles, we design the inspection system of the biodisk disk and the spinner, which uses a digital camera attached to a light filter below to inspect the fluorescence from the biodisk. The pulsed light is one frequency-controllable light source and its beam is spread evenly over the biodisk. When the frequency of pulsed light is equal to the rotation rate of the spinner, it will cause the persistence of vision effect, and the rotating biodisk would seem to be stationary. The excitation light source is used to excite the reaction area in the biodisk, which can emit the fluorescence to be recognized due to a particular biochemical reaction.

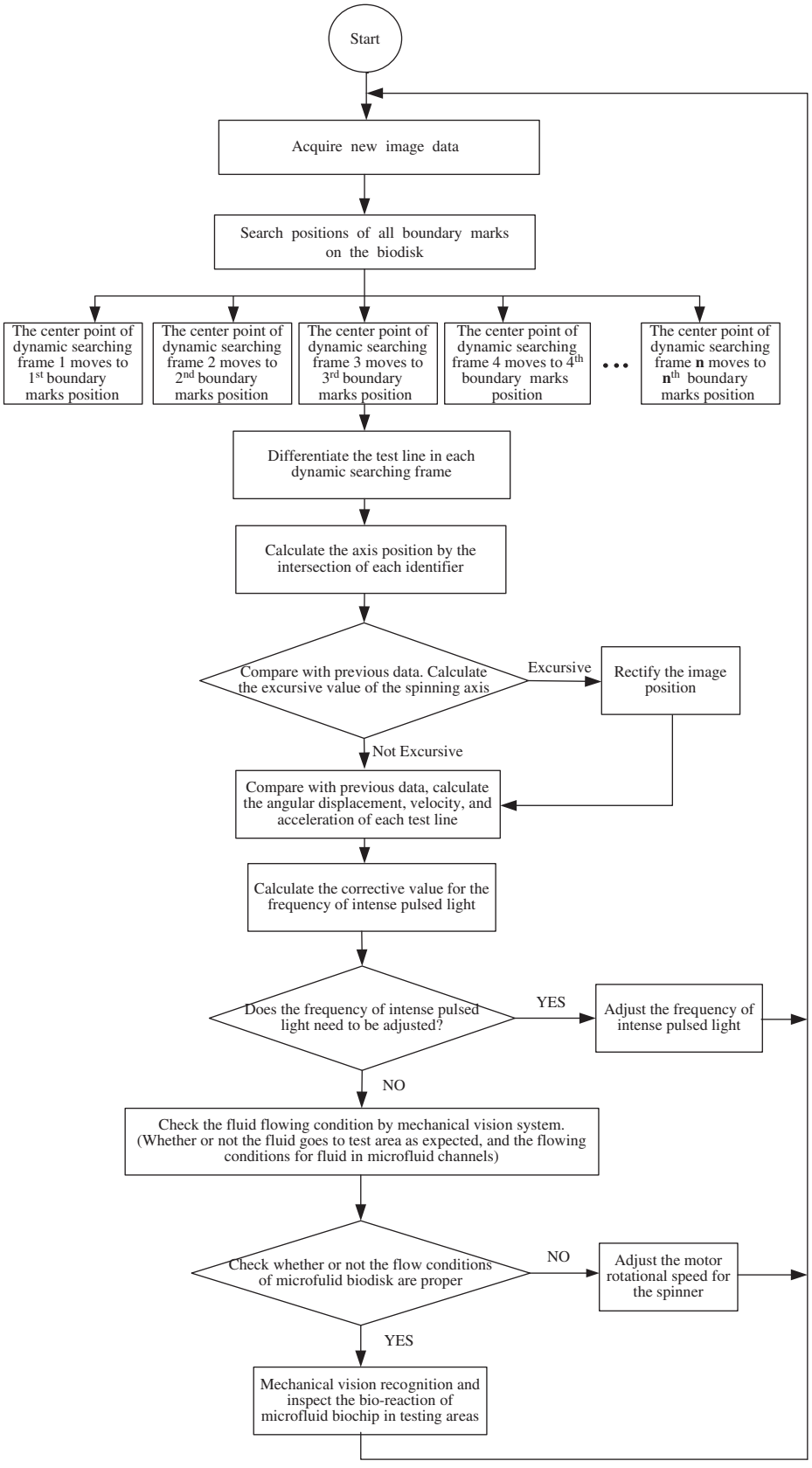


Fig. 6. Flow chart for the algorithm of mechanical vision system in the biodisk.

In addition, all aspects of structural design of the spinner are considered for maintaining a stable condition for the spinning biodisk. Figs. 9–10 are the structures and flow charts for the light field inspection system of the biodisk and spinner.

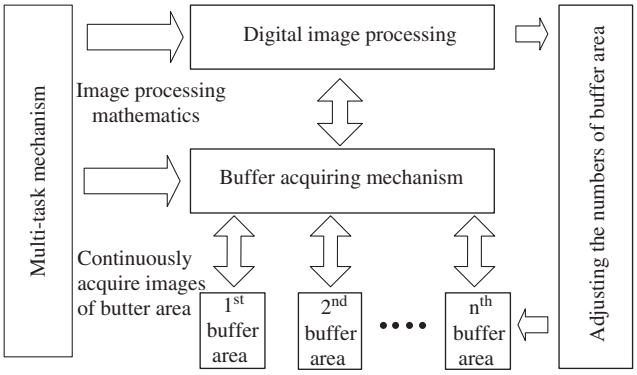


Fig. 7. Diagram for the rules of rapid image processing and adjustment of memory spaces.

The image processing steps are listed as follows:

1. Find the positions of all boundary marks for the entire image of biodisk in this experiment.
2. Use multiple dynamic searching frames for locking and checking the test line and its position.
3. Calculate the position of axis by multiple test lines.
4. Calculate the angular displacement and angular velocity.
5. Adjust the frequency of pulsed light.

As shown in Table 1, the system can reach the goal of synchronizing the rotational speed of biodisk with the frequency of pulsed light and then acquiring the static image.

## 5. Conclusions

This study proposes an automatic measurement system for measuring the rotational speed of microfluidic biodisk

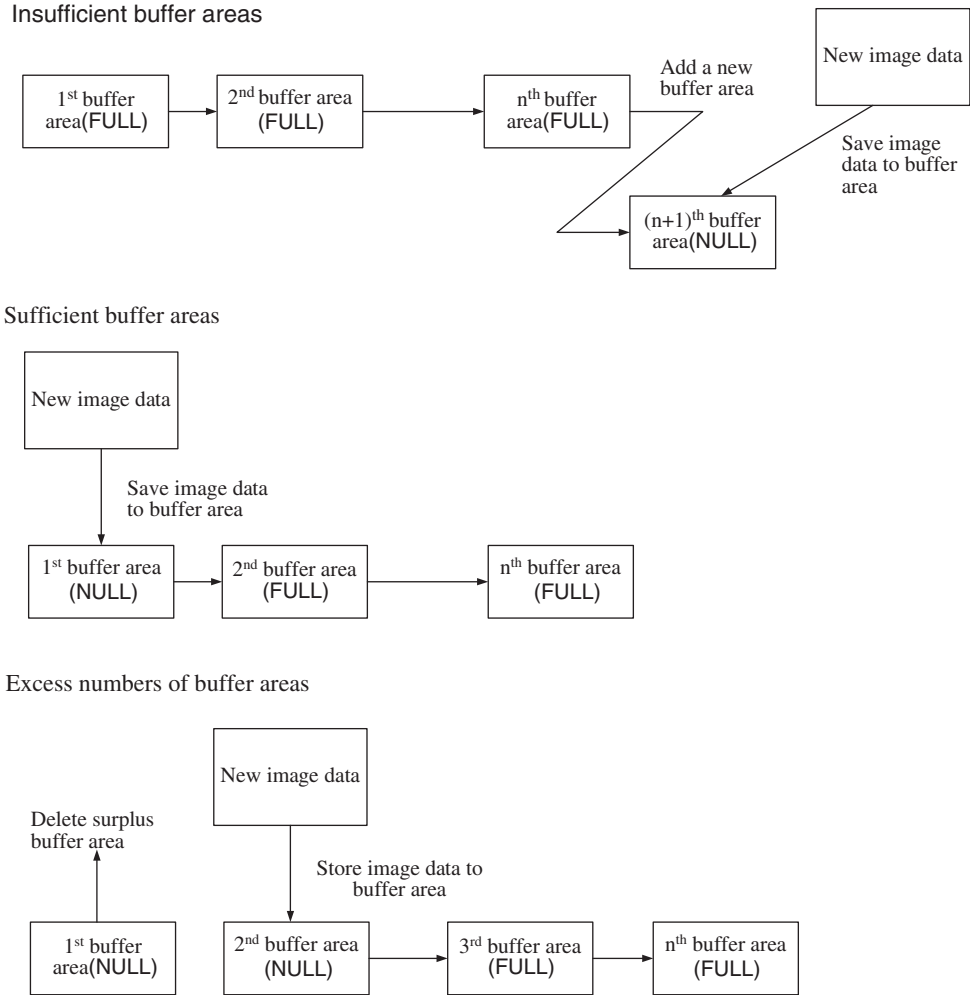


Fig. 8. Buffer areas.

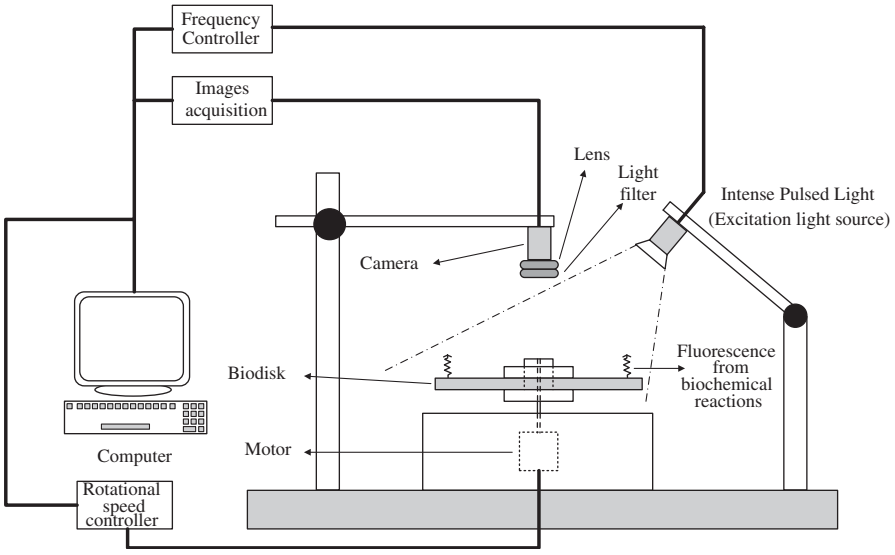


Fig. 9. Structure for the light field inspection system of the biodisk and the spinner.

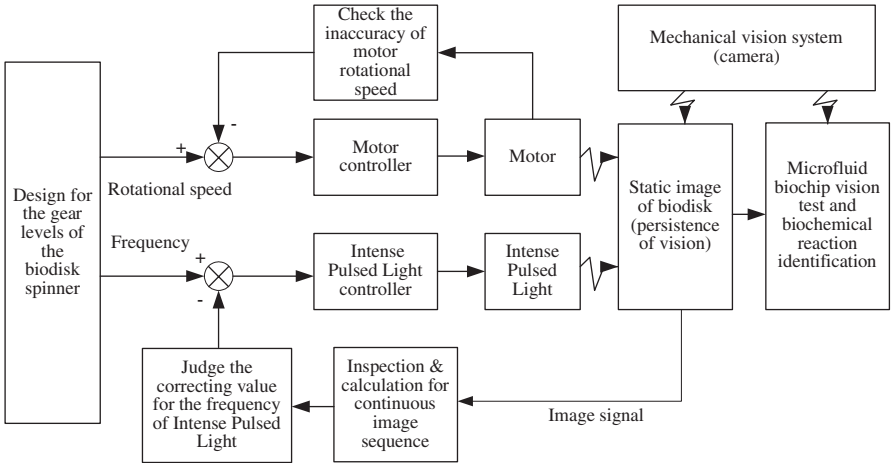


Fig. 10. Flow chart for the light field inspection of the biodisk and the spinner control.

Table 1
Expermental results in the speed adjustment of the biodisk and pulsed light by using image processing technology

| Experiment | Initial angular velocity of test line (rad/s) | Number of adjustment to the frequency of pulsed light | Frequency of pulsed light (Hz) | Simultaneous situation |
|---|---|---|---|---|
| Sample1 | 0.12 | 1 | 1206 | Synchronizing |
| Sample 2 | 0.51 | 2 | 1123 | Synchronizing |
| Sample 3 | 0.23 | 1 | 1025 | Synchronizing |
| Sample 4 | 0.06 | 1 | 924 | Synchronizing |

spinner with automatic adjustment for the frequency of pulsed light. The spinning machine turns the biodisk, which is connected to a computer. Furthermore, the pulsed light emitted from the image-acquiring device also acquires the fluorescence from the biodisk and the biodisk images are transmitted to the computer. This computer measures the rotational speed of the spinner, the frequency adjustment of pulsed light, the memory space management, and the images work, which can reach a simultaneous result between the frequency of pulsed light and the rotational speed of the spinner, and accelerate the image processing. Therefore, the image-

acquiring device can capture the motionless images to identify the biochemical reactions on the biodisks.

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