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ANYLYSIS ON DATA STREAM MODEL OF NETWORK IMAGE FIRE DETECTION SYSTEM

ABSTRACT

Along with the scale of IFD (Image Fire Detection) system continuously enlarging in the field of fire detection, the capturing, transfer, and processing of a large quantity of image information inevitably result in the longer response time for fire, which contradicts the early alarm requirement of fire detection. In this paper, mathematics model of data acquisition and data processing of IFD system is constructed with the guidance of queuing theory. After the calculation and analysis of the result of emulating program, appropriate scale of IFD system is determined under certain speed of data processing and transferring.

Key words: Image fire detection, Queuing theory, Model analysis, Emulator

INTRODUCTION

Typical development procedure of compartment fire characterized by the average gas temperature can be described in four stages, growth period, flashover, fully developed fire, decay period [1]. Flashoveris disastrous and has been an increasing problem because of the use of new material in buildings [2]. So the alarm of fire must be sent out in the early stage of fire, or in the early growth period. Grosshandler outlined advances in sensor technology along with intelligence that could be implemented to improve detection time while limiting the frequency of unnecessary alarms [3] so that there is enough time for people to escape or for fire-extinguishing system to put out of the fire.

Make use of the temperature measurement methods based on primary colors [4] and the technology of infrared imaging and digital image processing, the IFD system is a vigorous developing intellectualized system that includes the technology of fire

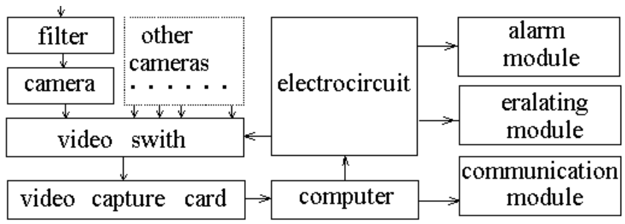


Figure 1. Hardware of IFC system

detection, recognition, alarm and control. Figure 1 gives hardware used in IFD system.

The infrared images from CCD are transferred into the central processing unit (CPU) through video cable and video card [6]. The CPU extracts the characteristic figure of the early fire flame which is distinguished from the environment, and judges whether the fire has taken place by computing the criterion of fire, then sends the command codes through I/O card to control the alert function of IFD system. If the CPU is assimilated to the brain of human, then CCD just acts as eyes.

In recent years, along with the fast development of Chinese economy, large buildings with complicated circumstance such as large spaces appear continuously, bringing forward. higher demand to the field of fire detection. Traditional fire detectors such as smoke detector, temperature detector can't be competent for the large and complicated circumstance. For its high sensitivity□high reliability and high applicability, IFD system is quickly accepted by society. Now IFD system becomes one of the development trends of fire detection and control, and has broad application prospect..

However, modern buildings tend to larger-scale, which results in the increasing of fire detection area. So the number of sub-area of fire protection becomes more and more. To meet with this requirement, the scale of IFD system must be enlarged through increasing of CCD number. Consequently, in a certain interval, the number of infrared images transferred to CPU for processing increases greatly. The speed of image processing relies on frequency of CPU and time complexity of image processing algorithm. Therefore, the increase of image number conduces to overtime of image processing, which will affect the early alarm of fire detection. so as to limit the scale of IFD system.. Given the speed of image capturing, data transferring and data processing, the mathematics model is be constructed with the guidance of queuing theory in this paper. Appropriate scale of IFD system is then gained through analyzing of model.

BASIC QUEUING THEORY

2.1 Model and key points of queuing system [7]

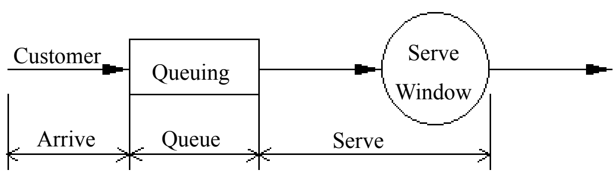


Figure 2. Simple model of queuing system

Figure 2 gives the simple model of queuing system□Key points of queuing system:

1. λ □Average arrival rate of customer (average arrival number per second);

The arrival interval between two contiguous customers t_i is a random variable, and the statistical mean of t_i is called average arrival interval, expressed as $\bar{t} = E(t_i)$. The average arrival rate is given by

$$\lambda = \frac{1}{\bar{t}} \quad □2□$$

2. μ □Service rate of system, which is a parameter to express the number of customer served by system every second. Define

$$\mu = \frac{1}{\bar{\tau}} \quad □3□$$

here $\bar{\tau}$ is called average service time. It is the statistical mean of service time per custom, τ_i. And w_i is the queuing time of every customer.

3. m It is named number of window or server, showing the number of system resource.

It is called single window queuing system when $m=1$, and called multi-window queuing system when $m>1$.

2.2 Service and queuing principle

1. Service principle:

The service principle is classified as FCFS (First Come, First Served), LCFS (Last Come, First Served), SIRO (Stochastic Served) and PRI (Priority)

2. Queuing principle:

It is defined as waiting mode and cut-off mode. Waiting mode means arrival will queue in turn until being served, while cut-off mode means arrival will be refused to serve if necessary.

2.3 Primary parameter of queuing system

1. Queue length k

It points out the number of customers who are held up in system at a certain time, which includes the one who is being served. The average queue length is given by $\bar{t}=E(t_i)$.

2. Queuing time w

It means the time length from arrival to beginning to be served, with average queuing time marked as $\overline{w}$.

3. Service time τ

It is the time while a customer is being served, and $\bar{\tau}$ is called average service time.

4. Standing time T

The whole interval, from the time when customer arrives to the time when he leaves the system, is known as standing time. And it is given by $\overline{T}=\overline{w}+\bar{\tau}$.

5. Little formula

For a queuing system with average arrival rate of customer λ, the equation

$$\overline{k} = \lambda \cdot \overline{T}$$

(4) is presented in the meaning of average, and it is called Little formula.

6. System efficiency

For multi-window queuing system with *m* windows, the acquisition probability is *r/m* when *r* windows are engrossed. The system efficiency can be expressed as

$$\eta = E(r/m) \tag{5}$$

7. Stability

The expression $\rho = \lambda / \mu$ (6) is

entitled system strength. For waiting mode system, the system is stable when $\rho < m$, and it is unstable when $\rho \geq m$.

8. Sign for queuing system: *A/B/m (N, n)*

where *A* signifies arrival principle of customer, *B* signifies service principle, *m* is the number of windows, *N* indicates the number of potential customer (It can be omitted when $N \to \infty$) and *n* means queue length of cut-off system (It indicates waiting mode when $n \to \infty$, and here *n* can be omitted).

MATHEMATICS MODEL

3.1 Two common characteristic distribution

1. Poisson distribution

Poisson distribution can describe the probability that there are *k* customers arriving in *t* seconds, which is expressed as

$$P_k(t) = \frac{(\lambda t)^k}{k!} e^{-\lambda t}, \quad k = 0,1,2,\cdots \quad (t > 0) \tag{7}$$

And this distribution must satisfy three characteristics mentioned as follows:

- Stationarity: The probability $P_k(t)$ only depends on the time interval *t*, while it is independent on start point of this time interval.

- No hereditary characteristic: The number of customers who appear in the two mutually disjoint interval (t_1□t_2) is mutually independent.
- Sparse characteristic: The maximum number of customer should be 1 in an infinitesimal interval Δt.

2. Negative exponential distribution

When the arrival of customer satisfies Poisson distribution, it can be proved that the arrival interval between two contiguous customers t submits negative exponential distribution. The procedure is described as following.

Prove: The probability that there is no arrival (k=0) in time interval t can get from equation (7)

$$P_0(t) = e^{-\lambda t}$$

The probability that there is arrival in t is given by

$$P(t) = 1 - P_0(t) = 1 - e^{-\lambda t}$$

The density function probability of t is negative exponential distribution

$$f(t) = \frac{dP(t)}{d\tau} = \lambda e^{-\lambda t} \qquad □8□$$

The same result can be got from the analysis of service procedure.

3.2 Construction of mathematics model

In IFD system, the frame number of image that transfers from CCD to central processing unit is affected by distance of data transfer, delay of video switchover and other delay caused by hardware. So, the frame number of image isn't a simple direct ratio of time. Instead, it has a certain characteristic distribution. On the other hand, the time for image data processing varies along with the change of circumstance. For example, the quantity of characteristic information drawn from image varies as the background light intensity changes, and the area of the fire can't always be the same. Thereby, the time for digital image processing based on certain time complexity of algorithm is fluctuant. In another word, the frame number of image data which is processed in a given interval submits a certain distribution character.

According to the queuing theory, the frames of image can be considered as customers while the recourse such as video card and CPU can be regarded as window. Studying the distribution characteristic of arrival frame number of image and that of processing procedure in a given interval, it can be concluded that the two distributions are provided with the three characteristics of Poisson distribution. Therefore, the negative exponential distribution can be expressed as the model of arrival interval of image frame and the processing interval.

3.2.1 Mathematics model about arrival of image frame

The time of fire growth period can defined by

$$t_{ia} = \frac{1}{4\sqrt{2}b(1-\varepsilon_K)}\left[\ln\frac{1+b^4\theta_i^4}{(1+b^2\theta_i^2+\sqrt{2}b\theta_i)^2} + 2\pi - 2\tan^{-1}\frac{\sqrt{2}b\theta_i}{1-b^2\theta_i^2}\right]$$

where ε_K is a dimensionless characteristic of the radiation heat flux from the zone to the upper fire bed, θ_i is dimensionless temperature, and b is given by

$$b = [\varepsilon_K/(1-\varepsilon_K)]^{1/4}.$$

It is easy to conclude that ε_K is different as for different circumstance and fuel, which result in different growth period of fire. The destination goal of fire detection and alarm is to reduce loss as can as possible, then if fire occurs, enough time should be provided for human to escape and for fire-extinguishing system to work. So fire detection and alarm should give alarm as early as possible.

In IFD system, the image data acquisition is finished by circulation detection. To satisfy the require of early fire detection, all CCD in the system should be circulation detected in a relative short time. In the same time, a single CCD should capture several continuous frames of image to implement the image comparison, which will extract the dynamic characteristic to detect the fire.

Suppose that there are *n* CCD cameras for detecting in one system, every circulation detection time is 1 minute, and every CCD camera will continuously shoot 6 frames image, then, the average arrival interval between two contiguous frames image is given by

$$\bar{t}_A = 60/6n = 10/n(s)$$

It can be concluded from formula (2) that the arrival interval between two contiguous frames of image submits the negative exponential distribution

$$f(t_A) = \lambda_A e^{-\lambda_A t_A} = \frac{n}{10} e^{-\frac{n}{10} t_A} \qquad \square 9 \square$$

where $\lambda_A = 1/\bar{t}_A = n/10$ means average arrival rate of image.

3.2.2 Mathematics model about processing procedure

In my IFD system, the basic frequency of CPU is 300MHz, and high-velocity colorized video card DH-VRT-CG200 is used. Based on PCI bus, video card can control the speed of image data transferring without the help of CPU, and the highest picking rate is 40MB/s. The image resolution ratio picked by video card is 640×480×24bit in NTSC standard[9], so the date size of one frame of image is $q_0 = 0.88MB$.

The digital image processing time of CPU should consider the factors such as the speed of data transferring of video card, CPU clock period and time complexity of digital image processing algorithm. All the factors mentioned here will be regarded as parts of service procedure, in which digital image processing algorithm manly includes write-read process of memory, extracting the infrared image characteristic of early fire. The extracting procedure are made up by threshold comparison, flame area calculating and comparing and series of fire pattern recognition such as development of flames' edge, orderliness of flames' twinkle, that of flames' layers and that of flames' movement [5]. It is quite complex to determine the processing time for every frame of image from the analysis of time complexity of algorithm. Therefore, in this paper, it is provided by the mean of computer processing time from the results of multiple tests, which is about 0.347s. Then the average service time of service model is given by

$$\bar{\tau}_S = \frac{q_0}{40} + 0.347 = \frac{0.88}{40} + 0.347 = 0.369s$$

It can be concluded from formula (3) that the service interval time for one frame of image submits the negative exponential distribution

$$f(\tau_S) = \lambda_S e^{-\lambda_S \tau_S} = 2.710 e^{-2.710\tau_S} \qquad \text{(10)}$$

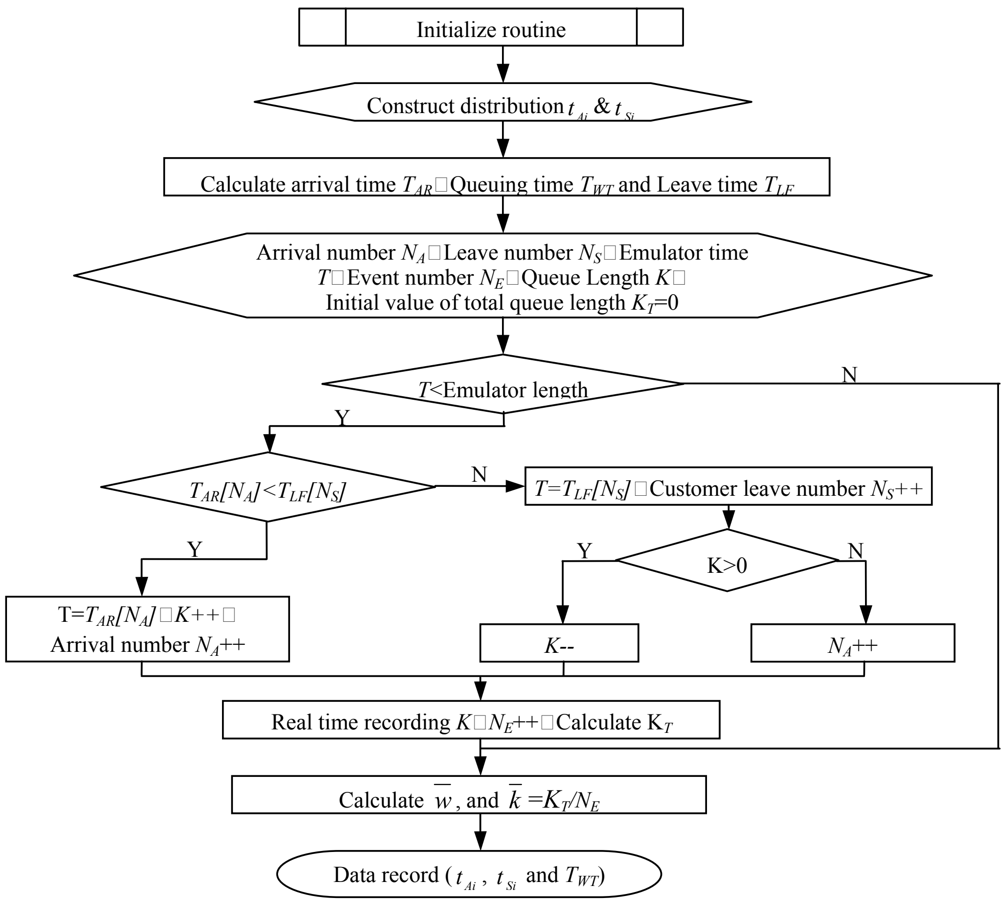
where $\lambda_S = 1/\bar{\tau}_S = 2.710$ means average arrival rate of image.

From the analysis described above, it can be concluded that the IFD system can be simply modeled as ideal *M/M/*1 queuing system with single queue, whose service principle is FIFS.

STUDYING AND ANALYZING

4.1 Emulator program

In order to study the relation between the average queuing time for each image and the scale of IFD system, emulator program for data stream of IFD system



is designed based on queuing theory. Figure 3 shows the program flow diagram.

Figure 3. Queuing model emulation floe process chart of IFD system

4.2 Analyzing of result

According to the queuing theory, the average queuing time $\overline{w}$ can be theoretically deduced.

$$\rho = \frac{\lambda_A}{\lambda_S} = \frac{\overline{t}_S}{\overline{t}_A} = \frac{0.369}{10/n} = 0.0369n \tag{11}$$

$$\overline{k} = \frac{\rho}{1-\rho} = \frac{0.0369n}{1-0.0369n} \tag{12}$$

$$\overline{w} = \frac{\rho \bar{t}_s}{1-\rho} = 0.369 \times \frac{0.0369n}{1-0.0369n} = \frac{0.0136n}{1-0.0369n} \qquad (13)$$

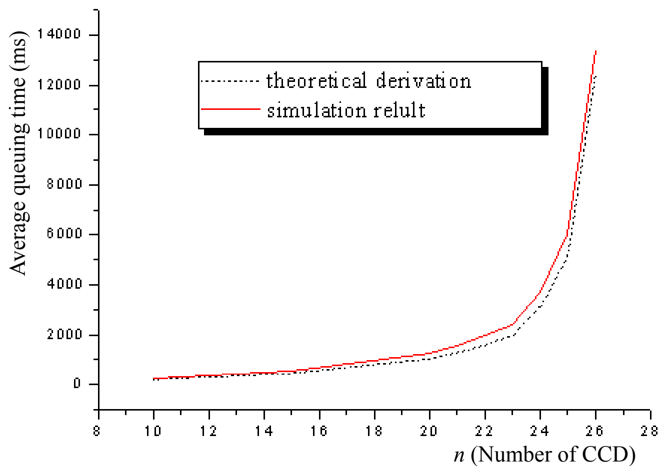


Figure 4. Comparison of theoretical derivation and simulation result

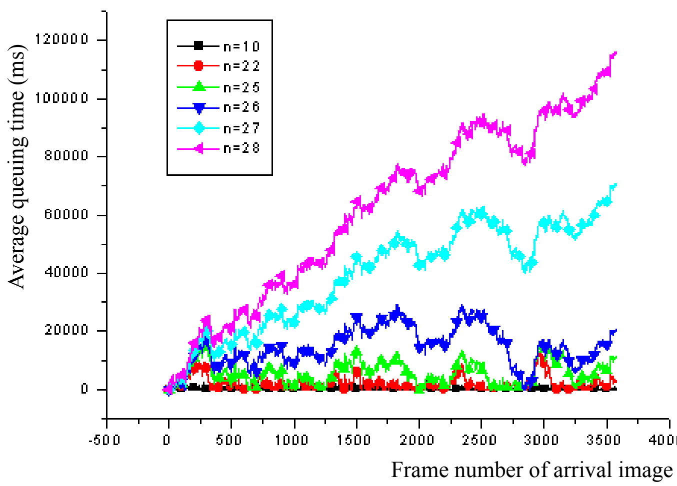


Figure 5. Average queuing time tendency against different n

Therefore $\overline{w}$ can individual gained from theoretical derivation or emulator program. The comparison of these two results is showed by figure 4. It can be concluded that the two comparison curves are both indicate the relation between $\overline{w}$ and n, and the different calculation methods can get almost the same tendency. So, the result of emulator program can be considered right. That's to say, emulator program can be used to study the problem of data stream of IFD system.

Figure 5 clearly shows the different tendency of $\overline{w}$ relative to variant n. If $n = 28$ □ $\rho = 1.259 > 1$ is got from equation (11). So the mathematics model is unstable, the curve $n = 28$ visibly expresses the instability of the model. The curve $n = 27$ in the figure seems unstable while it is theoretical stable for $\rho = 0.997 < 1$ got from equation (11). And $\overline{w} = 122508(ms)$ can be calculated from equation (13). The reason is that the emulator time is not long enough to reflect the stability in the end. It can be predicted that this curve will be stable where $\overline{w} = 122508(ms)$.

However, what should be paid more attention is that it is not inevitable to reach the request if the model is stable. For example, the result of model analysis trends stable when $n < 28$. But considering the early alarm require of fire detection, it is not permitted if the queuing time is too long. Suppose that the IFD system does not confirm to early alarm require for fire detection if the queuing time is more than 10 second. Then the suitable scale is $n < 22$, for there are some frames of image whose queuing times are more than 10 second if $n \geq 22$.

DISCUSSION AND CONCLUSION

The data stream of IFD system is simulated using the emulator program based queuing theory, which is more progressive than traditional analysis method in that only the mean image processing time and that of image frame arrival interval. In traditional opinion, the scale of the IFD system is appropriate as long as the mean time of image processing is shorter than that of image frame arrival interval. However, it is not always right from the opinion of queuing theory, which has been analyzed clearly hereinbefore.

One second thoughts, it will be found that the simple theoretical analysis based on queuing theory can get nothing but the average data. Obviously, this is still not enough. However, the emulator program will solve this problem easily. The queuing time of each frame of image can be obtained through the simulation process. More dynamic curves could be achieved if necessary, which express queue length k, service time τ, standing time T and so on.

In a word, the analysis method introduced in this paper can exactly guide the scale of IFD system.

EXPECTATION

From the analysis result described above, the conclusion is that the IFD system based on a single CPU can not meet the requirement put forward by larger and larger buildings.

The usage of distributed processing system (DPS) may be a feasible way to solve this problem. That is to say, every sub-area of fire protection will be collocated a distributed processor. So the digital image processing task could be decentralized into each distributed processor. Every distributed processor will send information to central processing unit after the digital image processing has finished. Of course, the quantity of information here is much fewer than image data.

With the development of fire detection technology, micro-treatment technology, the point intelligentized image detector based on digital image processing will come into being, which is an integrated module of data acquisition components and distributed processor components. This kind of detector can realize the communication with central processing unit usage 2-bus mode. The advantage is that it thoroughly solves the overtime problem that comes with the enlarging of IFD system. And based on the existing integration technology [10], it can completely integrated with the traditional detectors such as smoke detector, temperature detector that is widely used in fire detection.

The signal of temperature, smoke and acoustic signal can be introduced into fire image recognition technology. The compound detector will be formed in the future, which holds the sensor of sight, feeling, taste, and hearing, just as human being. It also holds “brain” (processor) for processing and recognizing. It can be predicted that the new detection detector will greatly improve the accuracy and early-stage of fire detection.

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