DSP Homework 08

Wang,Yaqi 10

October 18,2022

Contents

Nice and clear.

Abstract

There are three topics in this assignment:

In question 1, I summarized the relevant videos about the introduction of robots and bones I watched this week, learned about the pros and cons of robots in military applications and the development of quadruped robots and bipedal robots, and learned how to achieve color recognition through coding.

In question 2, I analyzed and compared Shannon's sampling theorem and Wan sampling theorem from three aspects: sampling frequency determination, sampling reconstruction and reconstruction error, and in order to make the explanation clearer, the actual sampling reconstruction explanation was carried out using the $\sin(2\pi t)$ as an example.

In question 3, by looking up relevant information, I have a certain understanding of the separation transmission of USB hubs, and based on this theory, I can design an irrigation system that can work more efficiently.

1 Write a summary of this week's video(s) and your further thoughts on the content.

1.1 The summary of the videos

1.1.1 Robot

The first video explains the current development results of robots and their application scenarios: at present, quadruped robots can still maintain balance under weight and can adapt to cold, hot, dry and wet working environments. Some quadruped robots can also realize functions such as opening doors, picking up garbage, climbing steps, and handling materials, which can provide great help for people's production and life. Bipedal robots have also developed greatly, from the initial only smooth walking to today's difficult human behavior such as climbing steps, jumping, and backflipping.

Our expectations for robots are more reflected in their military application space, and the robots currently used for military use are mainly divided into three categories: robots that respond to the external environment through machine input, robots that operate according to the instructions that have been written, and robots that are programmed to make different choices in different environments.

The military use of robots has its drawbacks: the advantage is that we can send robots to dangerous environments such as extreme cold and nuclear pollution that humans do not want to set foot in; The disadvantage is that most of the robot's activities are carried out through programming, and if it is hacked, it is likely to be reversed, and there are some moral and ethical problems in the use of robots.

1.1.2 Bone

Exercise has an important impact on our bones, and it will change with changes in the external environment. For example, astronauts reduce their bone density by about 20% after the return to outer space due to long-term zero gravity, and the changes are mainly reflected in the shape and internal structure. Bones are mainly composed of bone tissue and sponge tissue, and the substance that has a greater influence on it is hydroxyapatite, and the synthesis of this substance is related to the calcium content of the human body, so the intake of foods with higher calcium content such as milk is conducive to the development of bones. We can achieve the effect of pushing and pulling bones and promoting the development of bones by running, jumping, resistance training, etc.

1.2 My further thoughts

In the video study about robots, I noticed that both robots capable of garbage disposal and robots that carry out cargo handling have a common characteristic, that is, they can recognize objects and perform corresponding operations on the recognized objects, such as picking up garbage, carrying goods, and so on. Real-time video processing plays an important role in this, and I also became very interested in this technology, so I wanted to program an color recognition processing. The specific processing process is as follows:

1. Read the picture for grayscale processing and layer the three RBG colors in the picture.
2. Set the extraction threshold for red, green, and blue.
3. If the difference between the R component and the G and B components is greater than the set threshold, it is extracted as red, and the non-red area is gray.

The results of the red identification run are as follows:

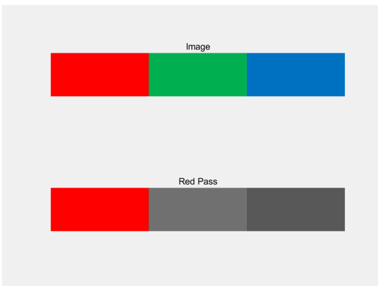


Figure 1: Color recognition

2 Comparison between the Shannon/Nyquist sampling method and the Wan sampling method.

2.1 Sampling frequency

2.1.1 Shannon sampling method

To determine the sampling frequency f using Shannon's theorem, we need to determine the bandwidth W of the signal,which requires us to perform a Fourier transform on the signal, and then select $f_0 > 2W$ according to the signal bandwidth.

2.1.2 Wan sampling method

Wan sampling theorem is based on Taylor series expansion,as shown in the figure below, take a signal x(t) with an interval length of T.

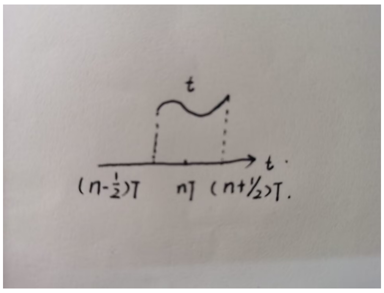


Figure 2: Sampling interval

For any sufficiently smooth function x(t), take $t \in [(n-\frac{1}{2})T,(n+\frac{1}{2})T]$, $|x''(t)|<\eta_2$, then from Taylor series expansion,we can get that

$$x(t) = x(nT) + x'(nT)(t-nT) + \frac{x''(t')}{2}(t-nT)^2$$

Thereinto,nT is any point in the interval,and $t' \in [(n-\frac{1}{2})T,(n+\frac{1}{2})T]$.

Take $\widehat{x}(t) = x(nT) + x'(nT)(t-nT)$,the error will be $|x(t) - \widehat{x}(t)|$,set the error $<\epsilon$.

Then,

$$\begin{aligned}|\widehat{x}(t) - x(t)| &= \frac{x''(t')}{2}(t-nT)^2 \\ &< \frac{\eta_2}{2}(\frac{T}{2})^2 \\ &< \epsilon\end{aligned}$$

We can get that,

$$T < 2\sqrt{\frac{2\epsilon}{\eta_2}}$$

That is, by finding the minimum of the second derivative value η_2 and the maximum error amount ϵ, the sampling frequency f can be determined,which is $f = \frac{1}{T} > \frac{1}{2}\sqrt{\frac{\eta_2}{2\epsilon}}$.

2.2 Refactoring error

2.2.1 Shannon sampling method

1. **Sampling recovery $\widehat{x}(t)$:**The method of achieving signal recovery by the sampling theorem has been discussed in the previous work, and the specific inference process will not be repeated, and the recovery result formula will only be shown as follows.

$$\widehat{x}(t) = T_0 2f_c \sum_{n=-\infty}^{\infty} x(nT)Sa(2f_c(t-nT_0))$$

where T_0 is the sampling period of the signal and f_c is the low-pass filter setting parameter.

2. **Recovery error:**Since the time-domain finite signal becomes a frequency-domain infinite signal after being changed by Fourier, the low-pass filter cannot filter out all signals in the frequency domain, which will cause distortion of the recovery signal.The reconstructed signal will continue to approximate the real signal as the sampling frequency increases, but we cannot control the error ϵ in advance,which is the Gibbs phenomenon.

2.2.2 Wan sampling method

1. **Sampling recovery $\widehat{x}(t)$:**For each t interval function,expand by Taylor series $x(t) = x(nT)+x'(nT)(t-nT)+\frac{x''(t')}{2}(t-nT)^2$, stipulate that the recovery signal $\widehat{x}_{nT}(t) = x(nT) + x'(nT)(t-nT)$.Where T is not a fixed length,it is necessary to meet $\sum nT$ coverage signal x(t) all intervals.

2. **Recovery error:** For each T interval function,

$$\begin{aligned}x_{enT}(t) &= |x_{nT}(t) - \widehat{x}_{nT}(t)| \\ &= \frac{x''_{nT}(t')}{2}(t-nT)^2 \\ x_e(t) &= \sum x_{enT}(t) \\ &= \sum |x_{nT}(t) - \widehat{x}_{nT}(t)| \\ &= \sum \frac{x''_{nT}(t')}{2}(t-nT)^2\end{aligned}$$

2.3 Example

In order to better compare the two sampling methods, x(t) = sin($2\pi t$),$t \in [-1,1]$ is taken and the signal sampling and recovery process is carried out using Shannon sampling and Wan sampling respectively as follows.

2.3.1 Shannon sampling method

1. Since x(t) is a limited signal in the time domain, the spectral signal is infinite.Therefore, before proceeding with the design, the Fourier change is first carried out to observe its spectral situation, as shown in "frequency xF(w)" in the figure below.
2. It is not difficult to see that when w = 40, the spectral signal approaches 0, so the sampling frequency $f_0 > 2W = \frac{80}{2\pi}$ can approximate the Shannon sampling condition.So we take $f_0 = 80$,the sampling results are shown in figure "sampling at 80Hz" below.
3. Bringing in the signal recovery formula introduced in 2.2.1, the signal recovery result of Shannon sampling can be obtained as shown in figure "SHANNON signal recover".

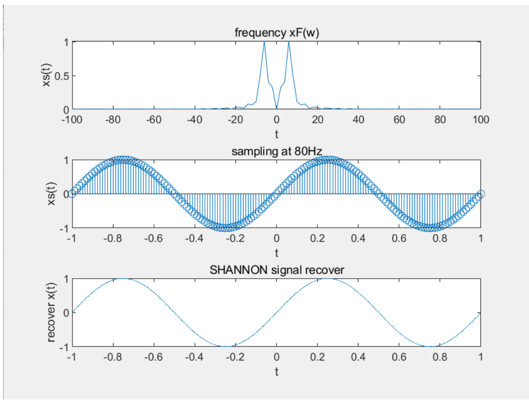


Figure 3: Shannon sampling method

2.3.2 Wan sampling method

1.
$$x(t) = sin(2\pi t)$$
$$x'' = -4\pi^2 sin(2\pi t)$$
$$|x''| < 4\pi^2$$
considering that,
$$T < 2\sqrt{\frac{2\epsilon}{\eta_2}}$$
To make the value easier to calculate, let's take $\epsilon = 0.02$. then $T < \frac{1}{5\pi}$,take T = 0.05.The sampling results are shown in figure "WAN sampling signal" below.
2. The [-1,1] interval is divided into 40 segments and reconstructed separately, and then merged to obtain $\widehat{x}(t)$.That is, for each segment $\widehat{x_n}(t) = x(nT) + x'(nT)(t-nT)^2$,$\widehat{x}(t) = \sum_{-20}^{20}\widehat{x_n}(t)$.The part of the segmented calculation that exceeds the interval is then proposed.The signal recovery results are shown in figure "WAN recover signal" below.

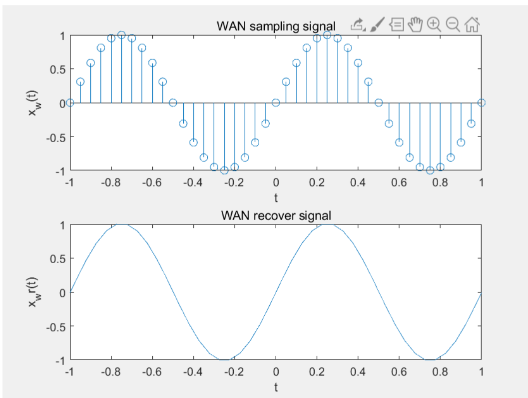


Figure 4: WAN sampling method

Fair comparison?

The error analysis of the original signal and the recovery results of the two samples is as follows.And by comparison, we find the following differences:

1. The WAN sampling method can specify the reconstruction error before sampling, which can ensure that we use the least sampling point to achieve the reconstruction value required by the error.
2. The sampling frequency of the signal does not need to be obtained by Fourier transform, and a suitable sampling frequency can be found in the time domain alone.

3. The Wan sampling theorem only requires that all the intervals for Taylor expansion are superimposed to be exactly the original interval to satisfy the condition, and there is no need for equidistant sampling.

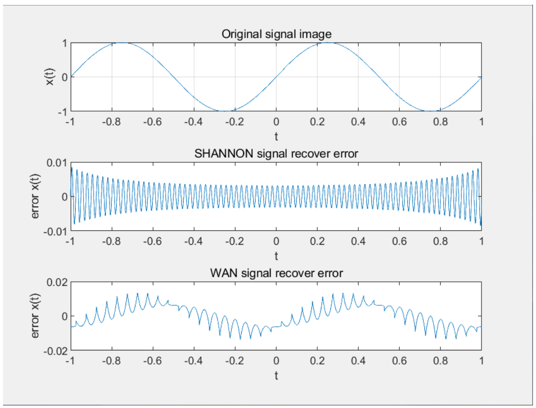


Figure 5: signal process compare

3 Describe how a USB hub works, then propose an invention using similar idea.

3.1 Structural system

The upstream port of the hub is facing the host, and the downstream port is facing the device. On the downstream port, the hub provides the ability of device access detection and device removal detection, and supplies power to the downstream port. The hub can enable each downstream port separately, and different ports can operate at different speeds (H/F/L).The relationship between hosts, hubs, and devices is shown in the following figure.

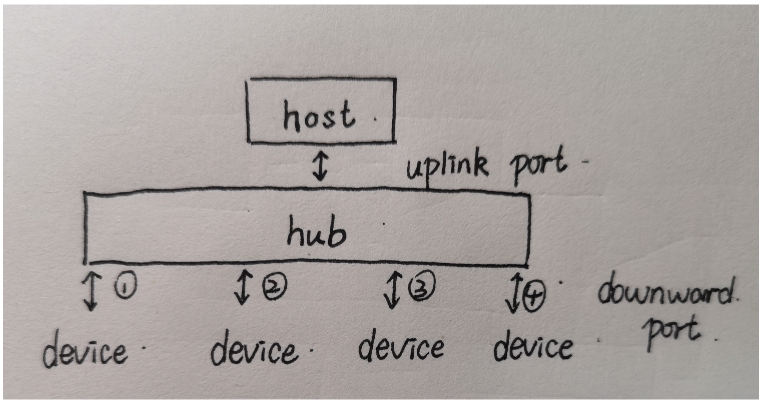


Figure 6: Structural system

As we can see from the diagram, devices and hosts are connected through hubs that act as intermediate hubs for information transfer.

3.2 Detach the transport

3.2.1 Why do we need it?

In the process of information transmission, high-speed bus is used between the upstream ports, while the downstream port uses full-speed or low-speed bus. If a full transaction is used for delivery each time, the upstream port will wait too long, resulting in lower utilization of the high-speed USB bus. Therefore, it is proposed to divide the transmission of the uplink port into two, that is, the transmission of token and data, the transmission of response data and handshake, and insert other high-speed transmissions in the middle, which is called separation transmission.

3.2.2 How does it work?

The core summary of the working principle of hub is time division multiplexing, and its specific working process is as follows:

As shown in the following figure, the split transport splits a complete IN request transaction into two transaction transfers, namely the SSPLIT transaction transmission that sends the token packet and the CSPLIT transaction transfer that receives the packet. Between SSPLIT and CSPLIT, an IN request from another device can be inserted. That is, separating a transfer allows additional transport transactions to be appropriately inserted between two separate transfers without exceeding the maximum response time, improving bus utilization.

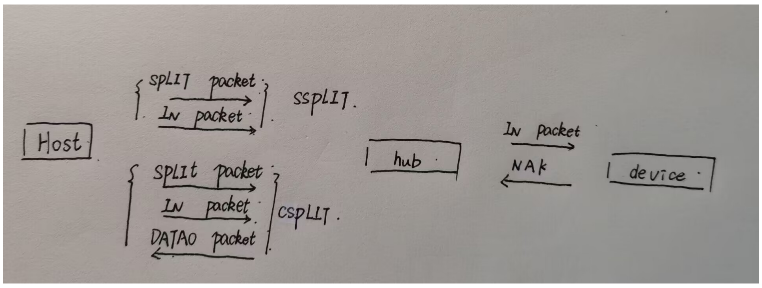
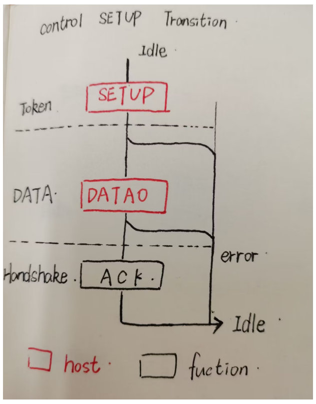


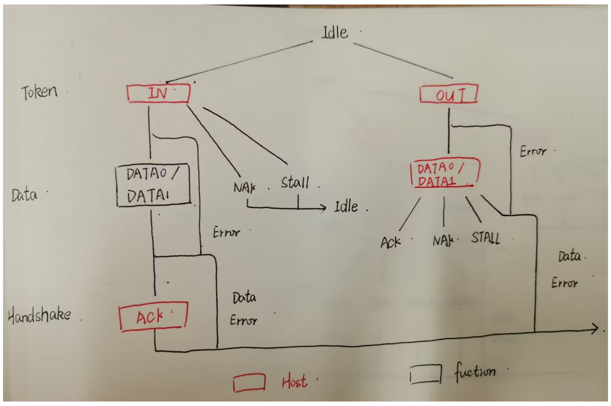
Figure 7: Detach the transport

Regarding the four data transmission modes of the system, this is the function that all USB interfaces can run, and it is not a unique function of the USB hub, but considering that data transmission is also an important part of its work, the main application environment of the four transmission methods and their specific workflow are shown as follows:

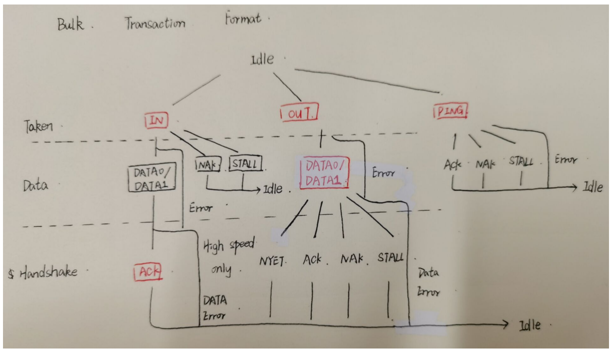
1. **Control Transfer:**Control transfer is a two-way transfer, the amount of data is usually small, mainly for querying, configuring and sending common commands to USB devices.
2. **Interrupt Transfer:**Interrupt mode transmission is mainly used to regularly query whether the device has interrupt data to be transmitted, and keyboards, joysticks and mice belong to this type of interrupt mode.
3. **Bulk Transactions:**The main application is in the transmission and reception of data in large quantities, and there is no bandwidth and interval time requirements, requiring guaranteed transmission, printers and scanners belong to this type, this type of equipment is suitable for transmitting very slow and large amounts of delayed transmission, can wait until the transmission of all other types of data is completed before transmitting and receiving data.
4. **Isochronous Transfer:**Isochronous transmission provides a defined bandwidth and latency, which is used for time-critical and fault-tolerant streaming data transmission, or for immediate applications that require constant data transfer rates.



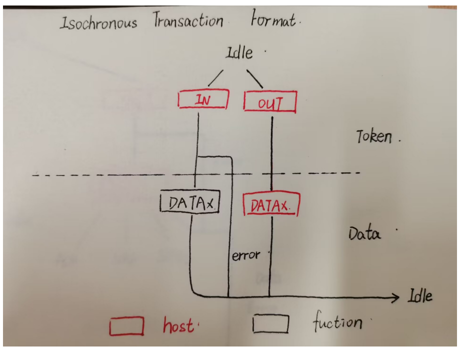
(a) Control Transfer



(b) Interrupt Transfer



(c) Bulk Transactions



(d) Isochronous Transfer

Figure 8: the four data transmission modes

3.3 My invention

3.3.1 Principle application characteristics

First of all, consider the application characteristics of hub separation transmission:

1. **A device is responsible for multiple components.** For example, a computer can only process one request at a time, and a hub can only interact with one device at a time.

2. **With a certain waiting time.** the speed between the hub and the device is relatively slow due to the high-speed transmission between the hub and the host, so in order to avoid the waste of the high-speed bus, SSPLIT and CSPLIT are added to the IN requests of other devices.

3.3.2 Design inspiration

The design was inspired by the school's irrigation equipment.There are many sprinkler machines used for irrigation and sprinkling in front of the second school building, although they are 360° rotating spraying, but the sprinkling time is very long, I often wonder if there is a hidden danger of overwatering and causing the death of flowers and plants.So I wanted to design a movable irrigation sprinkler as shown below.

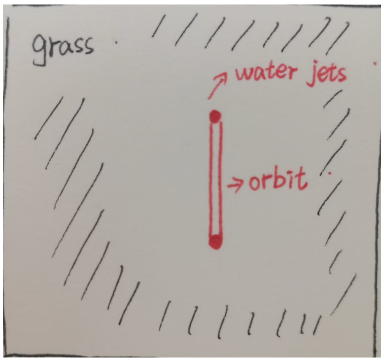


Figure 9: Scenario diagram of irrigation equipment

Although this design scenario does not seem to have any connection with the hub device, we put forward two requirements for the device compared to the design principle:

1. The equipment does not work in a fixed position, that is, it is not only responsible for the irrigation of one area, it has two working points, and when certain conditions are met, the position is switched to irrigate another area.

2. Considering the problem of excessive irrigation time we just raised, we find a suitable irrigation time t from factors such as water spray water v and irrigation area s, which can ensure that the water source can penetrate the soil, but will not lead to excessive irrigation. After the irrigation time reaches t, it is not possible to irrigate the area, but if the equipment is idle, the utilization rate will decrease, which is why we propose to move the equipment to another section to irrigate another area.

3.3.3 Design ideas

1. **constituent:**As shown in Figure 9 above, the system is mainly composed of two parts, the track and the water jet, the water jet can slide in the track to achieve the purpose of moving, in order to ensure the stability of the water jet at the working point, you can consider adding a card slot to fix the water jet.

2. **How to move:**As shown in the figure below, there are support rods at the bottom of the track at both ends, and when the calculated irrigation time t is reached, the support rods pop up, and after reaching a certain angle, the water jet begins to move to the other side.

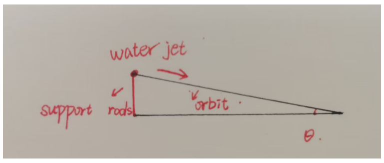


Figure 10: Equipment side planing

3. **In order to ensure the maximum use of equipment,** the maximum number of equipment fixed points can be obtained according to $\lfloor \frac{t_i}{t} \rfloor$ according to the sprinkler irrigation interval time of t_i and irrigation time t of an area.

3.3.4 Problems of the invention

Good.

1. Although it can achieve the purpose of saving water resources and preventing over-irrigation, **the cost of this irrigation system will be much greater than the cost of the original system.**

2. **What kind of material should be used to support the track of the water jet to ensure the maximum service life,** if metal materials are used, it will be easily eroded due to excessive ambient humidity, but the use of plastic materials will not bear weight.

3. Since the irrigation equipment needs to be connected to the water pipe, and the length of the water pipe is limited, our system **has a certain limit on the distance** from the activity when it achieves more than 4 fixed irrigation points.

Reference

[1]基于matlab的颜色识别与提取https://blog.csdn.net/Jessaly/article/details/111352699
[2]USB HUB简述:https://blog.csdn.net/dkmknjk/article/details/115127909
[1]USB 四种传输方式详解:https://blog.csdn.net/shenjin_s/article/details/86229307

Appendix A Code Listings

```
%%Color recognition
Image=imread("Image.jpg");
Gray=rgb2gray(Image);
R=Image(:,:,1); G=Image(:,:,2); B=Image(:,:,3);
diff_R=110;
Image_R=Image;
RP_R=Image_R(:,:,1); RP_G=Image(:,:,2); RP_B=Image(:,:,3);
XYR=~((R-G)>diff_R&(R-B)>diff_R);
Mask=Gray(XYR);
RP_R(XYR)=Mask; RP_G(XYR)=Mask; RP_B(XYR)=Mask;
Image_R(:,:,1)=RP_R; Image_R(:,:,2)=RP_G; Image_R(:,:,3)=RP_B;
figure(1);
subplot(2,1,1),imshow(Image); title('Image');
subplot(2,1,2),imshow(Image_R); title('Red Pass');

clear;clc;
%% Original signal
t = [-1:0.001:1];
x = sin(2*pi*t);
figure(1);
subplot(3,1,1);
plot(t,x);
grid on
xlabel('t');
ylabel('x(t)');
title('Original signal image');
%% Shannon signal process
Nsampling = 1/80;
t1 = -1:Nsampling:1;
f80Hz = sin(2*pi*t1);
figure(2);
subplot(2,1,1); stem(t1, f80Hz);
xlabel('t');
ylabel('xs(t)');
title('sampling at 80Hz');
%% Shannon signal recover
n = -100 : 100;
Nsampling = 1/80;
nsam = n * Nsampling;
funcovery = sin(2*pi* nsam);
t = -1:0.001:1;
fcovery = funcovery * sinc((1/Nsampling) * (ones(length(nsam), 1) * t - nsam' * ones(1, length(t)
subplot(2, 1, 2); plot(t, fcovery);
xlabel('t');
ylabel('recover x(t)');
title('SHANNON signal recover');
xes = x-fcovery;
figure(1);
subplot(3,1,2);
plot(t,xes);
xlabel('t');
ylabel('error x(t)');
title('SHANNON signal recover error');
%% Wan signal process; Wan signal recover
N = -20;T = 0.05;
xsum = 0;
xwan = 0;
m = 0;
```

```
while(N<21)
    t = (-1/2+N)*T:0.001:(1/2+N)*T-0.001;
    xrNT = sin(2*pi*N*T)+2*pi*cos(2*pi*N*T)*(t-N*T);
    xsum = [xsum,xrNT];
    xsamp = sin(2*pi*N*T);
    xwan = [xwan,xsamp];
    m = [m,N*T];
    N = N+1;
end
    [h,p] = size(xsum);
    xsum = xsum(26:p-25);
    t = -1:0.001:1;
    figure(3);

    subplot(2,1,1);
    m = m(2:42);
    xwan = xwan(2:42);
    stem(m,xwan);
    xlabel('t');
    ylabel('xw(t)');
    title('WAN sampling signal');
    subplot(2,1,2);
    plot(t,xsum);
    xlabel('t');
    ylabel('xwr(t)');
    title('WAN recover signal');
    xew = xsum-x;
    figure(1);
    subplot(3,1,3);
    plot(t,xew);
    xlabel('t');
    ylabel('error x(t)');
    title('WAN signal recover error');
```