Design of analog electromagnetic launcher based on STM32

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Abstract. In order to improve the accuracy of the electromagnetic launching system, this paper designs a simulated electromagnetic launching device based on STM32 MCU, which takes the steering gear pylons as the motion system, the solenoid coil as the launching system, and the capacitor as the energy storage element. After collecting data, the microcontroller controls the deflection of the pylon steering gear to adjust the launching Angle or the control transformer to adjust the launching voltage, and then controls the charging or discharging of the capacitor to provide energy for the launching device to launch the projectile. Two modes, automatic and manual, are designed. The former takes OpenMV as the target identification and ranging device, and transmits data to SCM through serial communication. The latter can be displayed on the OLED screen by entering the target position through a manual key. The launcher simulates the real electromagnetic launcher and realizes the automatic and accurate launch of the projectile.

1. Introduction
Electromagnetic gun is an advanced kinetic energy killing weapon made of electromagnetic launch technology. The research on electromagnetic coil launching technology in China is becoming more and more mature, and many scientific research institutions have achieved successful launching. The achievements of these work have accumulated rich theoretical and practical experience for the research of electromagnetic coil launching measurement and control system. However, there is still a certain gap between the actual application, and the most critical problem is that the firing speed of the electromagnetic coil gun is still low, which cannot meet the requirements of precision and service life.
2. General structure and Key components

2.1. General structure

![Range identification device](image1)

2.2. Motion mechanism

In order to facilitate the control system to control the launcher, the electromagnetic launcher is fixed on the pylon of the double steering gear. Dual steering gear head has two degrees of freedom, which can adjust the launching Angle in both the upper and lower directions and the left and right directions at the same time. At the same time, the identification device bracket is fixed on the middle bracket of the head, which can make the identification device rotate synchronously with the head in the horizontal direction, and has a wider range of motion and scanning vision. The overall structure of the mechanism is shown in Fig. 2.

![Overall structure of the mechanical device](image2)

2.3. Energy storage mechanism

As the energy storage element of the whole electromagnetic launcher, the capacitor must provide sufficient charge for the launcher at the moment of launch to generate a large transient magnetic field in the barrel. The capacitor used in this design is $C=0.01$F.

2.4. Launching mechanism

The transmitting mechanism consists of coils, capacitors and relays. Because the coil wrapped around the barrel of the electromagnetic gun can be equivalent to the inductance, the equivalent circuit diagram of charging and discharging of the electromagnetic launching device is drawn through Simulink, and the discharge circuit is simulated. The transmitter circuit is shown in Fig.3. The simulation circuit is shown in Fig.4.
The voltage change results of the inductance at both ends of the simulation circuit can be observed through SCOPE, as shown in Fig. 5.

As can be seen from the simulation results, when the discharge time is 20ms, the voltage tends to be stable, that is, the amount of charge in the capacitor is basically released, and the whole transmitting process is over. So set the discharge time to 20 ms.

3. Projectile dynamics analysis

3.1. Stress analysis
The force analysis and motion analysis of the projectile fired by this small simulated electromagnetic gun in the process of motion. When the projectile is launched in the barrel, the force diagram is shown in Fig.6, and in the process of motion, the force diagram is shown in Fig.7.

F: The frictional force; Fz: support; mg: gravity; Fc: electromagnetic force; F: Air friction

mg; gravity; v: Movement speed

Fig. 6 Projectile launching force diagram

Fig. 7 Force diagram in motion
3.2. Emission motion model

3.2.1. Model

Through the force analysis of the projectile, the formula can be known as:

$$m \frac{d^2x}{dt^2} = m \frac{dv_x}{dt} = -F_x = -\mu \frac{dx}{dt} = -\mu v_x$$  \hspace{1cm} (1)

Where $m$: mass of projectile, $x$: displacement of projectile in horizontal direction, $t$: time, $v_x$: horizontal component of projectile velocity $v$, $F_x$: component of air resistance in horizontal direction, $\mu$: friction coefficient of air.

When $t=0$, the component velocity of the projectile velocity $v$ in the horizontal direction $v_x = v_0 \cos \theta$; the partial velocity in the vertical direction $v_y = v_0 \sin \theta$.

Therefore, integrate Formula 2:

$$\int_{v_0}^{v_x} \frac{1}{v_x} dv_x = - \int_0^t \frac{\mu}{m} dt$$  \hspace{1cm} (2)

Integrate both sides to get:

$$v_x = v_0 \cos \theta e^{-\frac{\mu}{m} t}$$  \hspace{1cm} (3)

When $y$ is equal to 0, the projectile lands.

So when the projectile moves in the air:

$$t_{end} = \frac{v_0 \sin \theta}{g} + \left[ \left( \frac{v_0 \sin \theta}{g} \right)^2 + \frac{2h}{g} \right]^{0.5}$$  \hspace{1cm} (5)

The air resistance is given by the formula:

$$F = \frac{1}{2} c \rho v^2 = \mu v$$  \hspace{1cm} (6)

So: $\mu = \frac{1}{2} c \rho v$, By calculation: $\mu = 0.065$.

Where $F$: air resistance, $C$: air resistance coefficient, $\rho$: air density, $S$: windward area of the object, $V$: motion speed of the object.

By substituting the initial conditions into Formula 3-8, the relationship between the emission distance $x$ and the emission Angle $\theta$ can be obtained:

$$x=v_0 \frac{m}{\mu} \cos \theta(1-e^{-0.65[0.594\sin \theta + (0.353\sin \theta + 0.027)^{0.5}]})$$  \hspace{1cm} (7)

When the firing Angle $\theta=0^\circ$, the firing voltage $U=27V$, the height of the turret $H=0.13m$ and the mass of the projectile $M=0.01kg$, the initial velocity of the projectile $v_0=5.817m/s$ can be measured by high-speed camera.

3.2.2. Model analysis

Since the launch distance is related to the launch Angle, the launcher Angle should be adjusted according to the distance between the target position and the launcher.

By substituting the initial conditions into Formula 3-8, the relationship between the emission distance $x$ and the emission Angle $\theta$ can be obtained:

$$x=8.949 \cos \theta(1-e^{-0.65[0.594\sin \theta + (0.353\sin \theta + 0.027)^{0.5}]})$$  \hspace{1cm} (8)
3.2.2.1 Actual measurement data
Under the above initial launch conditions, the launch distances measured according to different launch angles are shown in Table 1:

Table 1 The launch distances measured at different launch angles

| Launch Angle /° | distance /cm first | second | third | fourth | The fifth | average |
|-----------------|---------------------|--------|-------|--------|----------|---------|
| 0               | 105                 | 100    | 99.5  | 102    | 103      | 101.8   |
| 5               | 127                 | 130    | 131   | 125    | 127      | 128     |
| 10              | 185                 | 169    | 170   | 172    | 170      | 173.2   |
| 15              | 250                 | 230    | 234   | 226    | 220      | 188.4   |
| 20              | 250                 | 230    | 234   | 226    | 220      | 232     |
| 25              | 251                 | 254    | 252   | 251    | 254      | 252.4   |
| 30              | 260                 | 253    | 270   | 268    | 272      | 264.6   |
| 35              | 269                 | 276    | 271   | 273    | 273      | 272.4   |
| 40              | 282                 | 285    | 279   | 276    | 279      | 280.2   |
| 45              | 270                 | 274    | 270   | 273    | 270      | 271.4   |

The average values of the launching distances corresponding to different launching angles were input into MATLAB, and the curve fitting function of the MATLAB software toolbox was used to fit the relationship between the launching Angle and the launching distance. The fitting formula is:

\[ x = 2.807e^{-\left(\frac{\theta - 38}{37.63}\right)^2} \]  (9)

The Gaussian fitting curve is shown in Fig.8.

![Fig.8 Gaussian fitting curve](image)

The function formula obtained by Matlab fitting is put into the program to compare with the calculation results obtained by theoretical calculation. The actual calculation obtained by Matlab shows that under the same emission conditions, the error of the emission distance obtained by Gaussian fitting and that obtained by kinematics analysis is within 5cm, which meets the design requirements.

3.2.2.2 Relation between launch Angle and target range
The relationship between firing Angle and firing distance of electromagnetic gun is obtained by using Gaussian fitting formula in Matlab:

\[ \theta = \frac{3763 + 100 \log_{10} \left( \frac{1000}{x} \right)^{0.5}}{100} + 38 \]  (10)

Therefore, by inputting the above formula into the STM32 microcontroller program, the launching Angle can be obtained according to the target distance, and the electromagnetic gun can be controlled.
by controlling the corresponding Angle of the deflection of the steering gear head through STM32 to achieve accurate attack on the target object.

4. The program design

4.1. SCM program design

4.1.1. The program design

The program design should be set up in two working modes, one is through the camera to automatically collect the target position information, the other is a manual way to directly input the target position and position to the microcontroller. You can enter different working modes by pressing the button.

MCU should first accept the distance value and orientation returned by OpenMV or other ranging recognition devices, and then process the data and display it through the OLED display screen. According to the returned distance value, the Angle is calculated by the formula:

\[ \theta = \frac{3763 \times (\log_{1000} x^2 + 2807)}{100} + 38 \]

Calculate the launching Angle of the cradle head, control the corresponding deflection Angle of the cradle head, adjust the launching Angle, control the relay to charge and discharge the capacitor, so as to provide energy for the launching device and control the launching of the electromagnetic gun.

4.2. OpenMV programming

4.2.1. The principle of OpenMV implementation

Considering the program for the memory usage, to ensure that the identification accuracy at the same time, should have maximum reduce the running program for chips and memory resources consumption, so we used at the same time in RGB565 color map mode shape recognition and color recognition, first run hoff circle detection algorithm in the image recognition in the image circle, Then, the color value of the pixel is obtained according to the coordinate region returned by the recognized circle. If it is the color set by the target threshold value, the target is marked. Then, the distance between the target object and the camera is calculated according to the diameter pixel, and the distance and azimuth are transmitted to the single chip microcomputer\(^3\). Target recognition by OpenMV is shown in Fig.9, and the color distribution of red, green and blue is shown in Fig.10.

![Fig.9 Target recognition by OpenMV](image)

![Fig.10 OpenMV recognition target red, green and blue color distribution](image)
4.2.2. Other ranging schemes
In addition to target identification and ranging through the camera, laser ranging, infrared ranging and other methods can also be used to detect the location of the target, reducing the error caused by a single ranging device in the measurement.

4.3. The program runs
The program flow chart is shown in Fig.11.

5. System test results and analysis
Connect the whole launching system according to the line, download the program to STM32 microcontroller and OpenMV identification device respectively, and then test the whole system on the ground.

5.1. The test results
Tools required for testing: ruler, 30cm diameter annular target, red disc (target), 220V AC power supply. The higher the number of rings the projectile hit on the ground, the higher the accuracy.

5.1.1 Automatic mode
First of all, test the automatic identification target to launch, place the target in different positions, and enter the automatic mode by pressing the button. Test results in automatic mode are shown in Table 2.

| Distance /m | first | second | third | fourth | fifth | sixth | seventh | eighth | ninth |
|-------------|-------|--------|-------|--------|-------|-------|---------|--------|-------|
| 2           | 9     | 9      | 8     | 8      | 9     | 7     | 10      | 7      | 9     |
| 2.4         | 10    | 7      | 9     | 8      | 8     | 9     | 10      | 7      | 8     |
| 2.8         | 8     | 10     | 7     | 8      | 7     | 8     | 9       | 7      | 8     |
5.1.2 Manual mode

In manual mode, the target distance and Angle were input to launch, and the target was placed in different positions for testing. Enter the manual mode by pressing the key, and then enter the distance and Angle of the target by pressing the key. Test results in manual mode are shown in Table 3.

| location /m/° | The test results / ring |
|--------------|-------------------------|
|              | first | second | third | fourth | fifth | sixth | seventh | eighth | ninth |
| 1.8/15       | 8     | 10     | 9     | 9      | 9     | 10    | 8       | 9      | 9     |
| 2.5/30       | 9     | 9      | 9     | 8      | 10    | 10    | 9       | 8      | 9     |
| 2.8/-30      | 9     | 8      | 10    | 8      | 8     | 9     | 9       | 8      | 8     |

5.2. Analysis of test results

Through the test of the system, it can be found that the final launch result is less different from the ideal value in the manual mode, and the difference between the actual landing place and the ideal landing place is within 5cm. In the automatic mode, the actual landing place differs greatly from the ideal landing place, but the deviation is also within 8cm. Meet the design requirements.

The reasons for the analysis deviation mainly include the following aspects:

1. The camera will shake when rotating with the cradle head, which will affect the ranging result.
2. With the increase of transmission times, the strong current generated during transmission will cause certain damage to the components.
3. The material of the projectile is different, and the electromagnetic force generated during the launch is also different.

6. Conclusion

The simulated electromagnetic launching device based on STM32 designed in this paper is based on the principle of electromagnetic launching, which simulates the problems that need to be solved in the launching of large electromagnetic launching device, and has good accuracy and stability. The problem of target identification and ranging can be solved by OpenMV at the same time, and the target position can also be entered by pressing the key, so as to solve the problems such as the inaccurate identification of distant OpenMV and the blocking of targets by obstacles. The OLED display system can more clearly know the operating state of the system and strengthen man-machine interaction. Through the combination of the cradle head and the launching device, the launching Angle and the initial launching velocity can be adjusted at the same time, so that the whole launching device can be more easily controlled by the control device. The device has strong versatility and can be used for launching warships at sea and on land. In addition, the launcher can also be used for other purposes such as space launcher.

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