Non-contact measurement of object geometry and dimensions

"Undergraduate Course Design and University-level Innovation & Entrepreneurship Projects"

Design Requirements

This project focuses on the design and fabrication of an automated non-contact system for measuring object geometry and dimensions. The system layout is shown in the figure on the left. The measurement device is installed in the designated measurement zone, and the target object is placed in the target area. The system enables the measurement of object shape, dimensions, and the relative distance between the measurement head center and the target, while a laser beam is employed to indicate the object's center position.

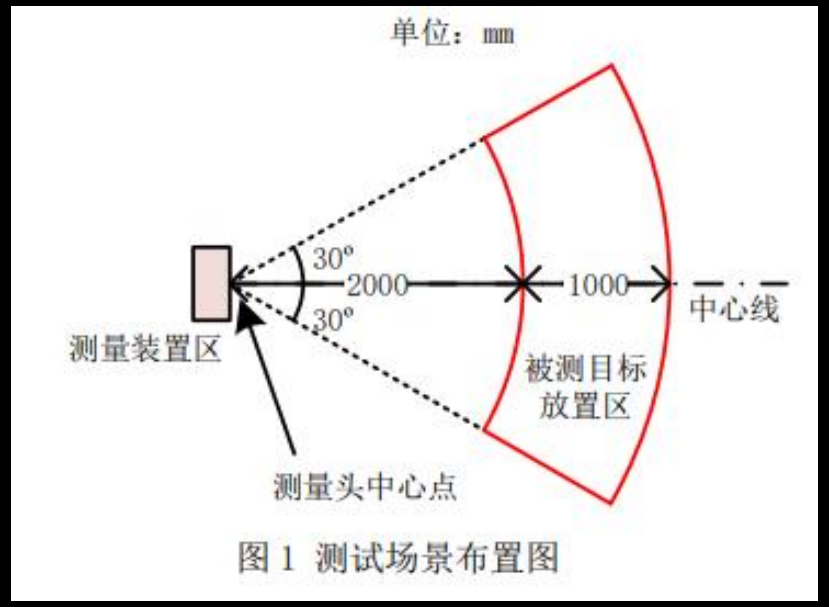
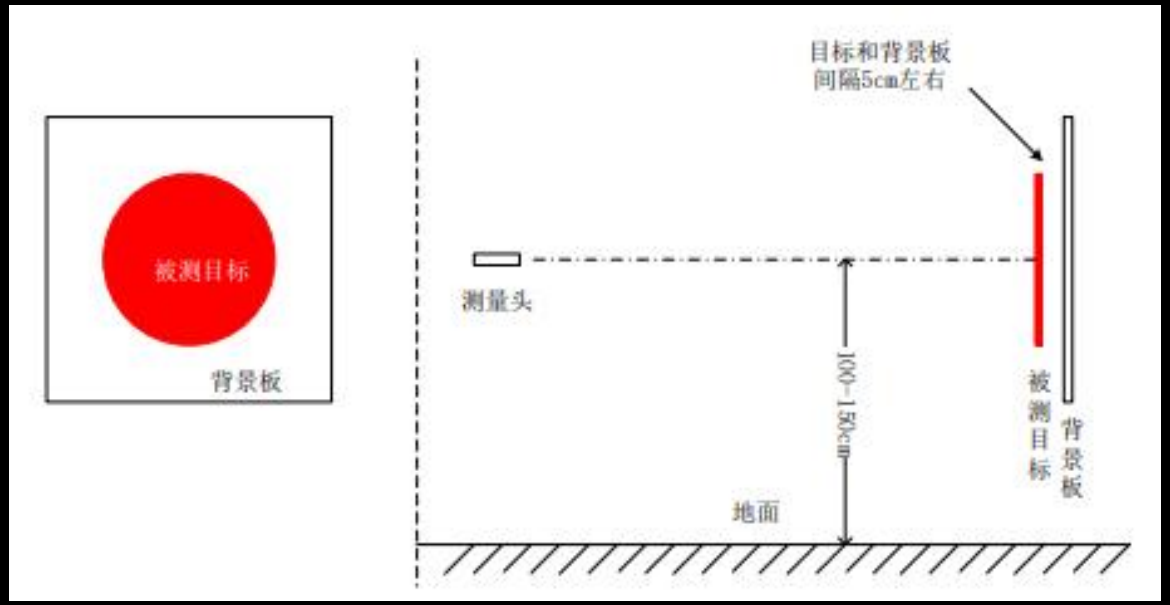
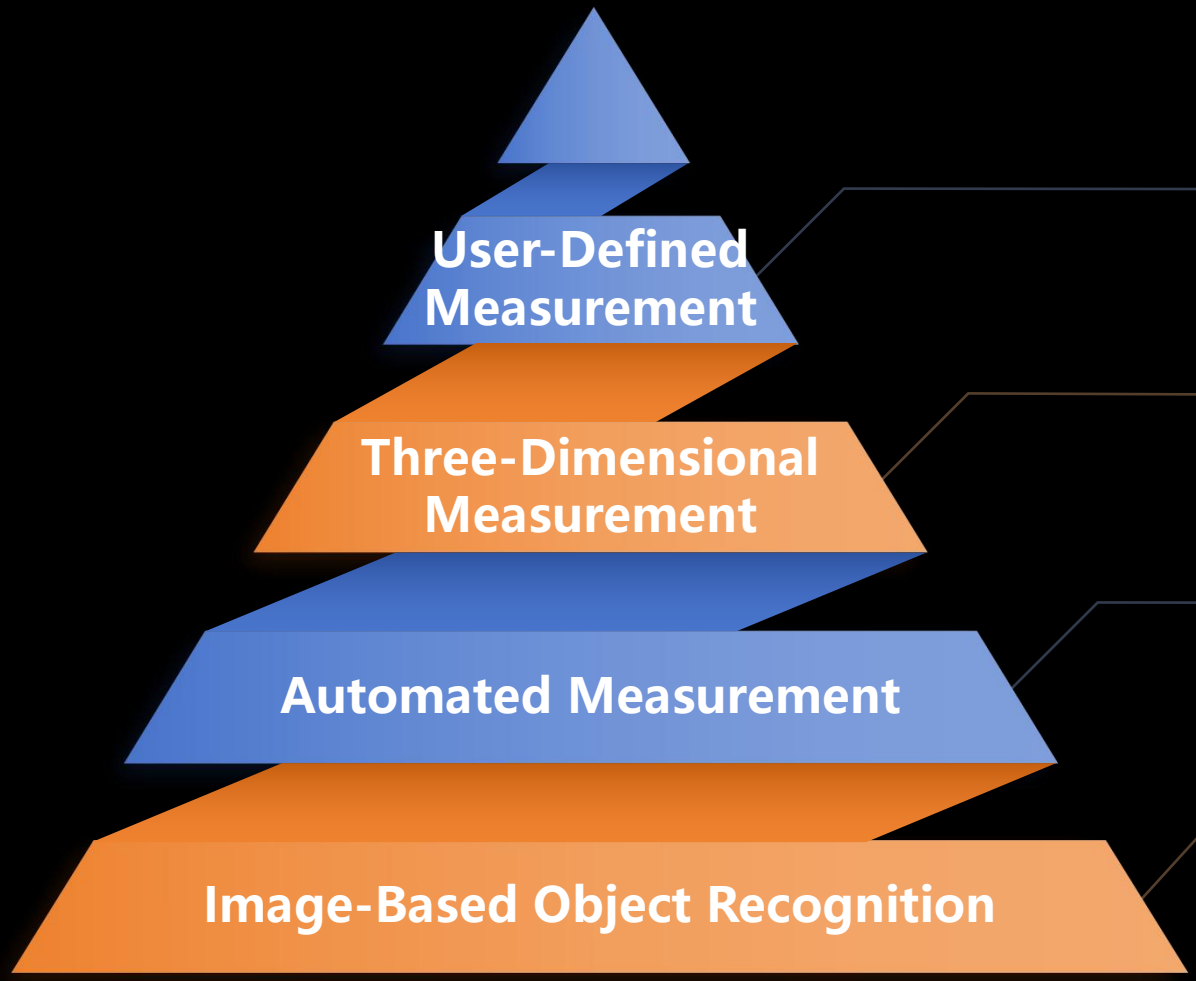


图 1 测试场景布置图



Design Requirements

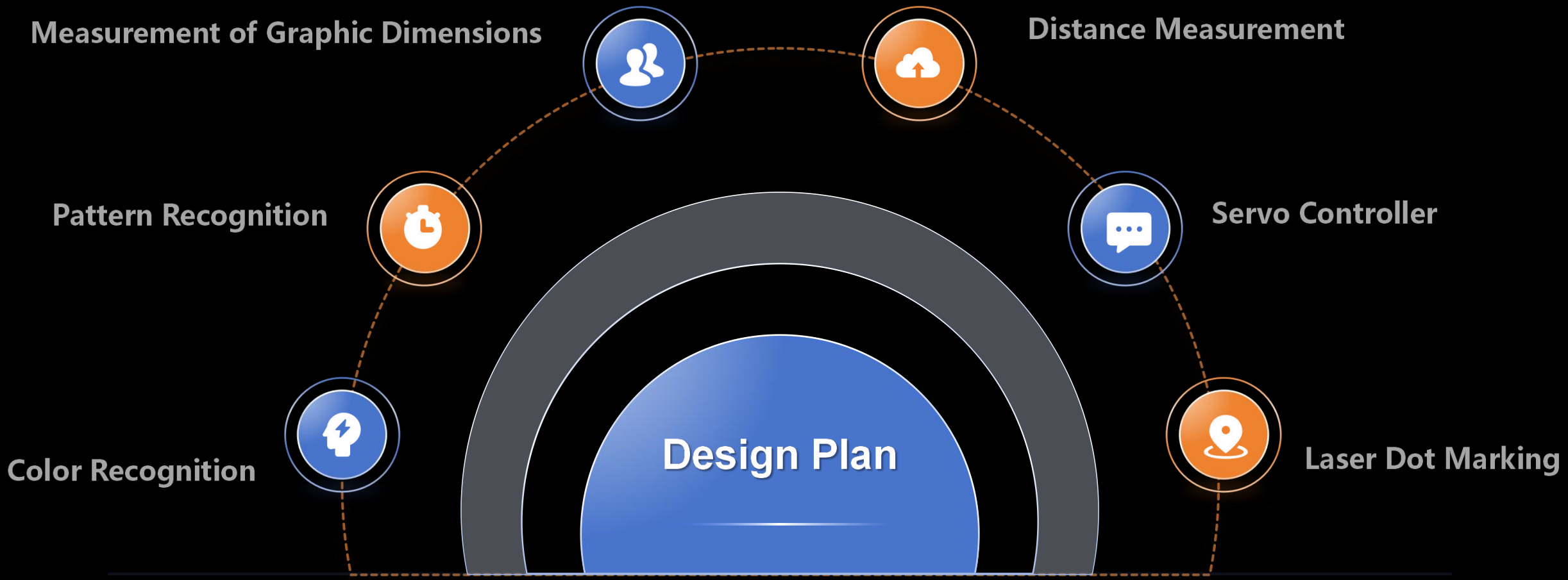


Measurement and visualization of color characteristics for arbitrary geometric objects.

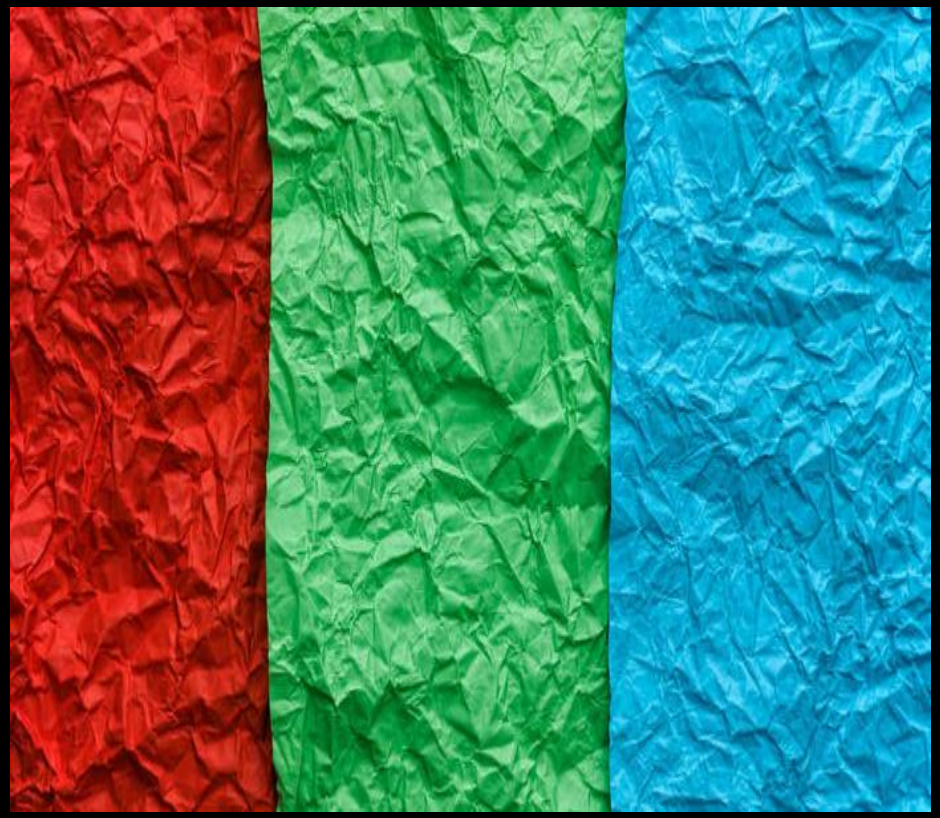
Recognition and measurement of spherical objects, including object type identification and minimum surface distance estimation.

Automated acquisition of object shape, dimensions, and relative distance, and laser-based indication of the object’ s geometric center.

Identification of planar geometric objects, with extraction of object shape, dimensional parameters, and the distance between the target and the measurement head.


Measurement of Graphic Dimensions
Distance Measurement
Pattern Recognition
Servo Controller
Color Recognition
Laser Dot Marking
Design Plan

Color Recognition



Color recognition is performed through the adjustment of color threshold values defined along the lightness, red–green, and yellow–blue axes. Probabilistic statistical analysis is employed to determine the modal values of the threshold ranges under varying illumination conditions, which are selected as the final color thresholds for the non-contact object geometry and dimensional measurement system.

Pattern Recognition

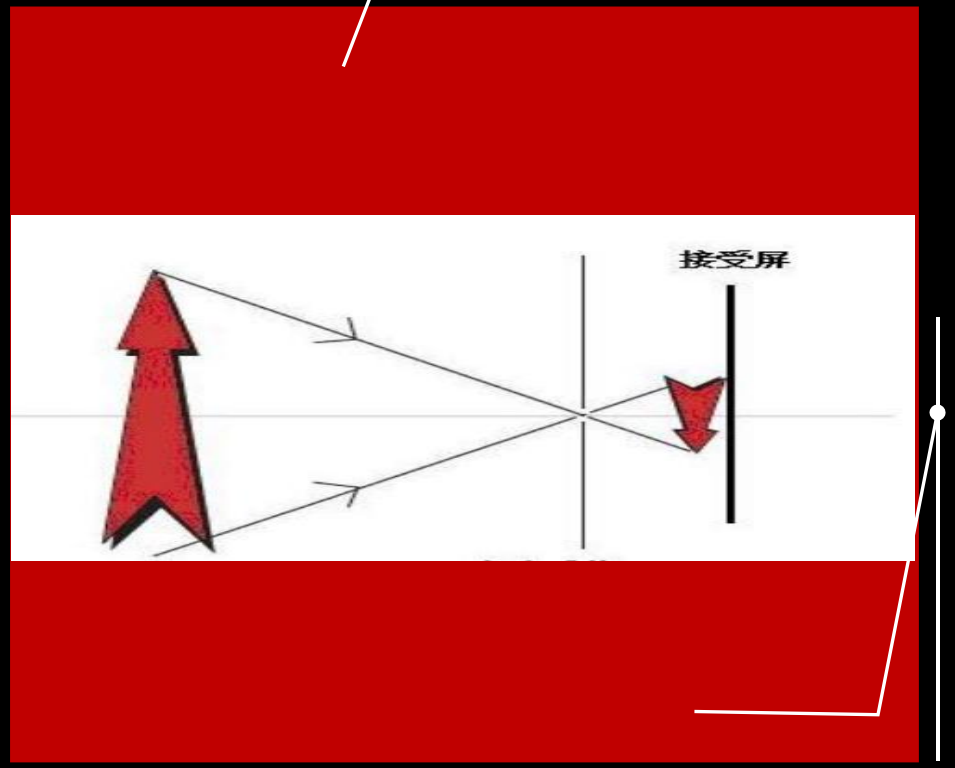
Object recognition is performed using the OpenMV module.

Circular and square objects are preprocessed and recognized using the built-in functions of OpenMV. To avoid interference from other factors, circles and squares are first discriminated using Hough circle detection and rectangle detection. The LAB values of the detected regions are compared with the LAB values of the RGB channels; if matched, a flag is set.

If no object is detected, the system searches for color blobs and evaluates multiple features—including solidity (ratio of blob area to its bounding rectangle), bounding rectangle aspect ratio, circularity, and pixel area—to determine whether the object is triangular.

Measurement of Graphic Dimensions

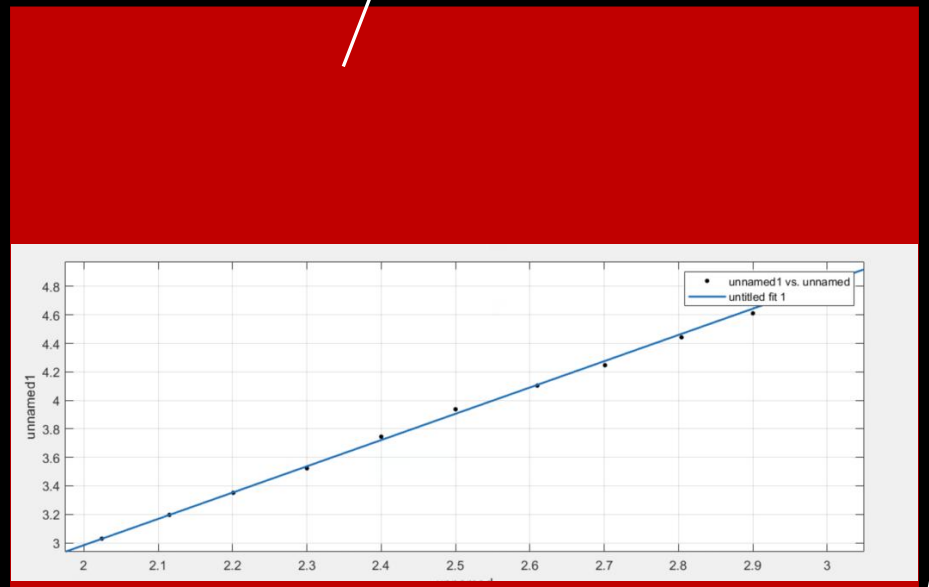
$$f = \frac{v * D}{V}$$



Here, ***f*** represents the focal length; ***v*** denotes the horizontal pixel dimension of the target image, and ***V*** denotes the actual horizontal size of the object; ***D*** is the distance between the camera lens and the target object. Prior to measurement, the relative focal length is determined through tests using objects of known length at known distances. During actual measurements, the object size is calculated using the pre-determined focal length ***f*** and the distance ***D*** measured via a laser rangefinder, according to the relation: ***V = v*D/f***. This yields the measured physical dimensions of the target object.

Measurement of Graphic Dimensions

拟合函数：f=1.845*x-0.7061



During the pre-measurement of the custom focal length ***f***, multiple measurements are performed and averaged to obtain a stable relative focal length value. Ten sets of data are collected, and the relationship between distance and ***f*** is fitted using MATLAB.

After repeated measurements and comparison with actual parameters, the focal length is verified to meet the requirements, with the measurement error of the actual object length within **2** mm.

Distance Measurement

Distance measurement is carried out using an ultrasonic module.

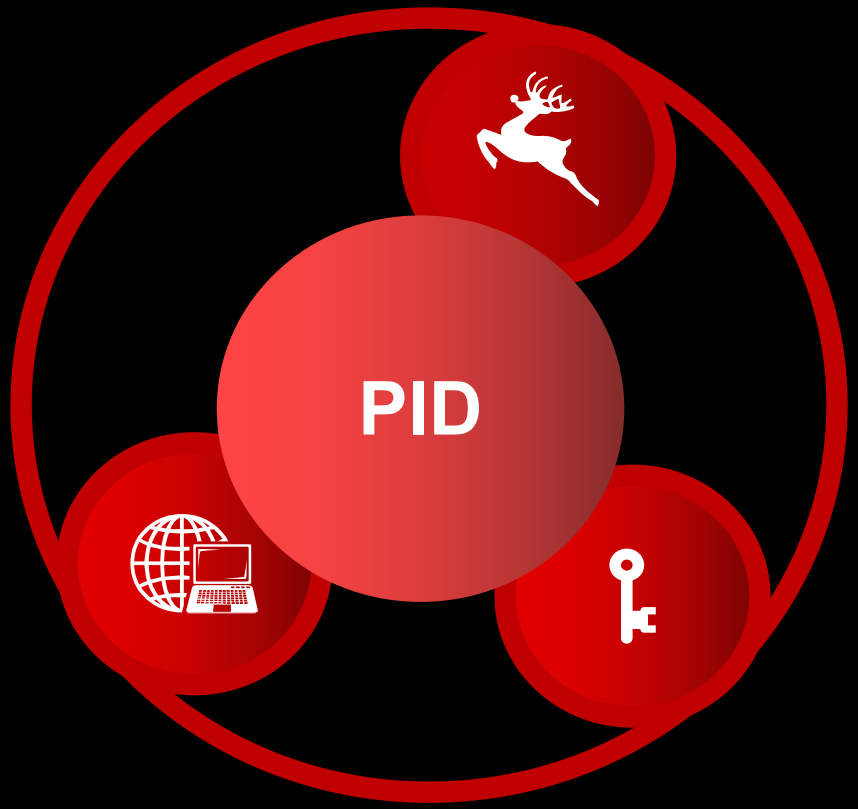
A high-level signal (***>10 μs***) is applied to the Trig pin to trigger the module to emit ***eight 40 kHz*** ultrasonic pulses.

When the pulses encounter an object, they are reflected back into the module, causing the Echo pin to output a high-level signal. The duration of this high-level signal corresponds to the time of flight of the ultrasonic wave, which is then used to calculate the detection distance:

$$dis\tan ce = \frac{high\_level\_duration \times T_c \times v}{2} = T_C(\mu s) \times 0.07cm$$

where is the pulse period and ***v = 340 m/s*** is the speed of sound.

Servo Controller



The rotation of the servo motor is controlled using a PID controller. The servo functions as a closed-loop position control system, where the input is the pulse width command and the output is the servo rotation angle. Two types of PID control are primarily employed:

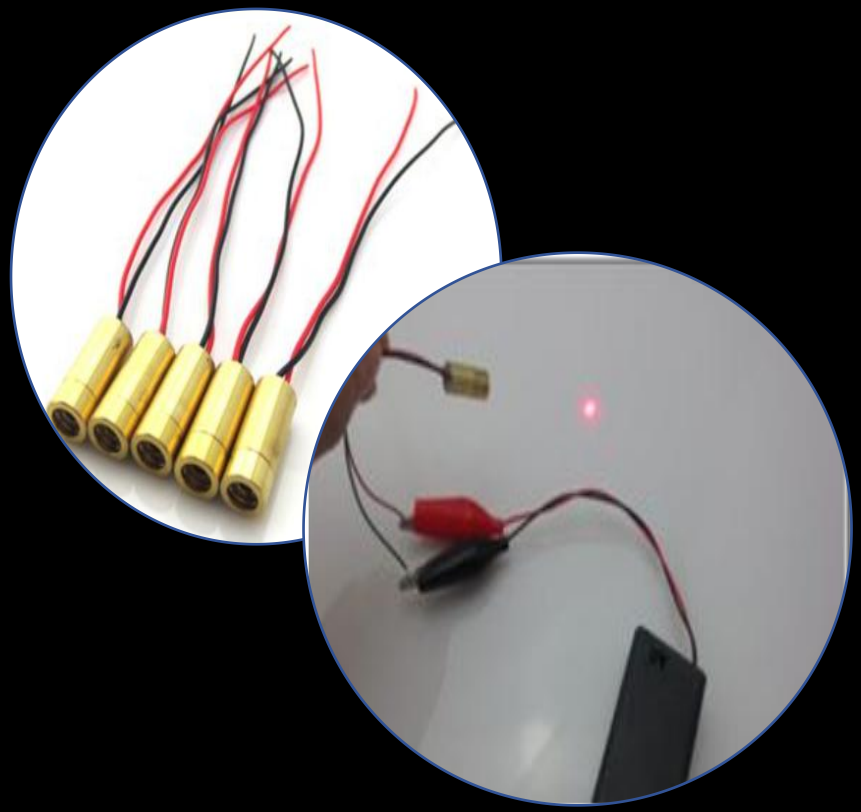
1.Position PID:

$$u(k) = k_p e(k) + K_1 e(i) + K_D[e(k) - e(k-1)]$$

2.Incremental PID:

$$\Delta u(k) = u(k) - u(k-1) = K_P[e(k) - e(k-1)] + K_I e(k) + K_D[e(k) - 2e(k-1) + e(k+2)]$$

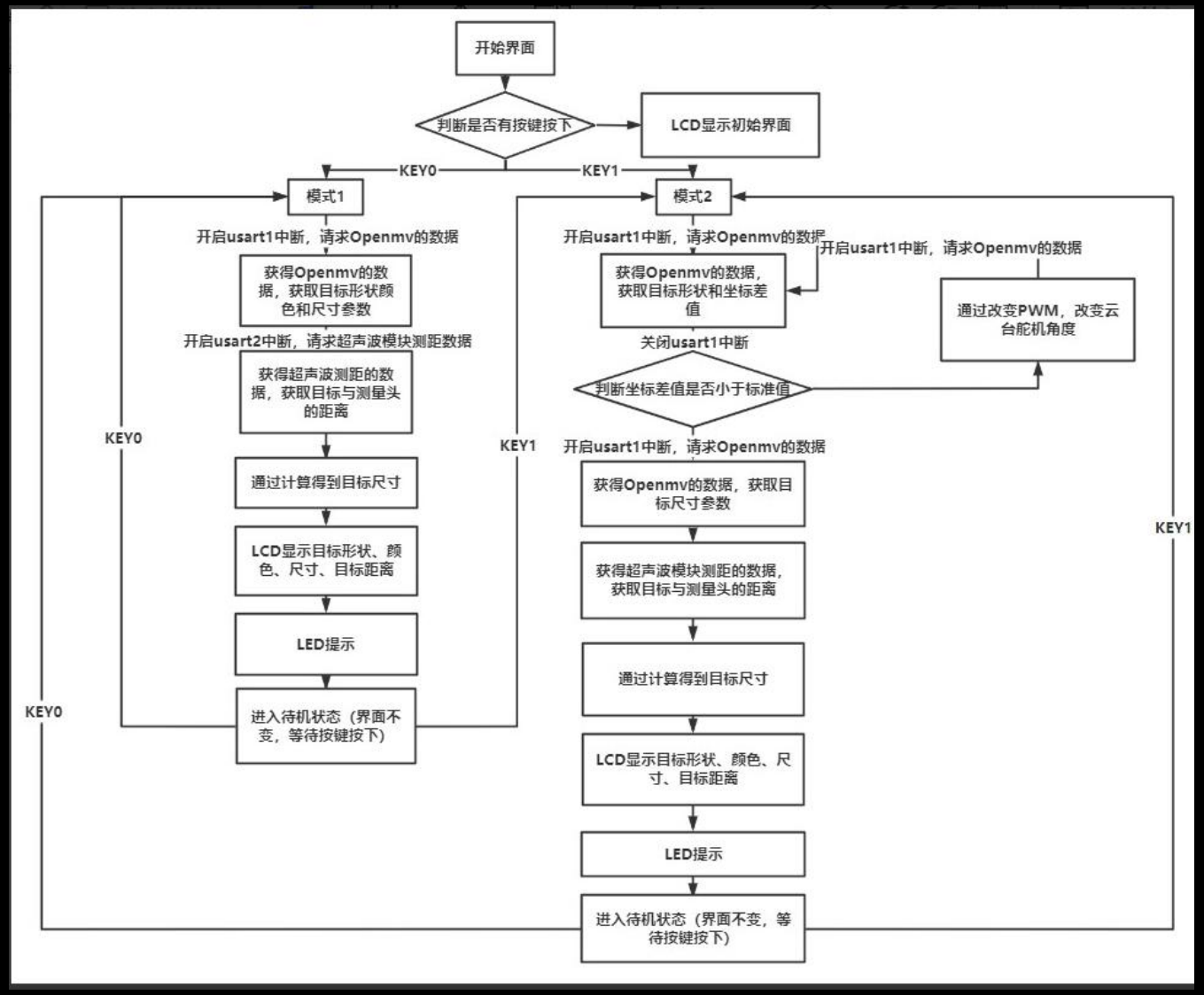
Laser Dot Marking



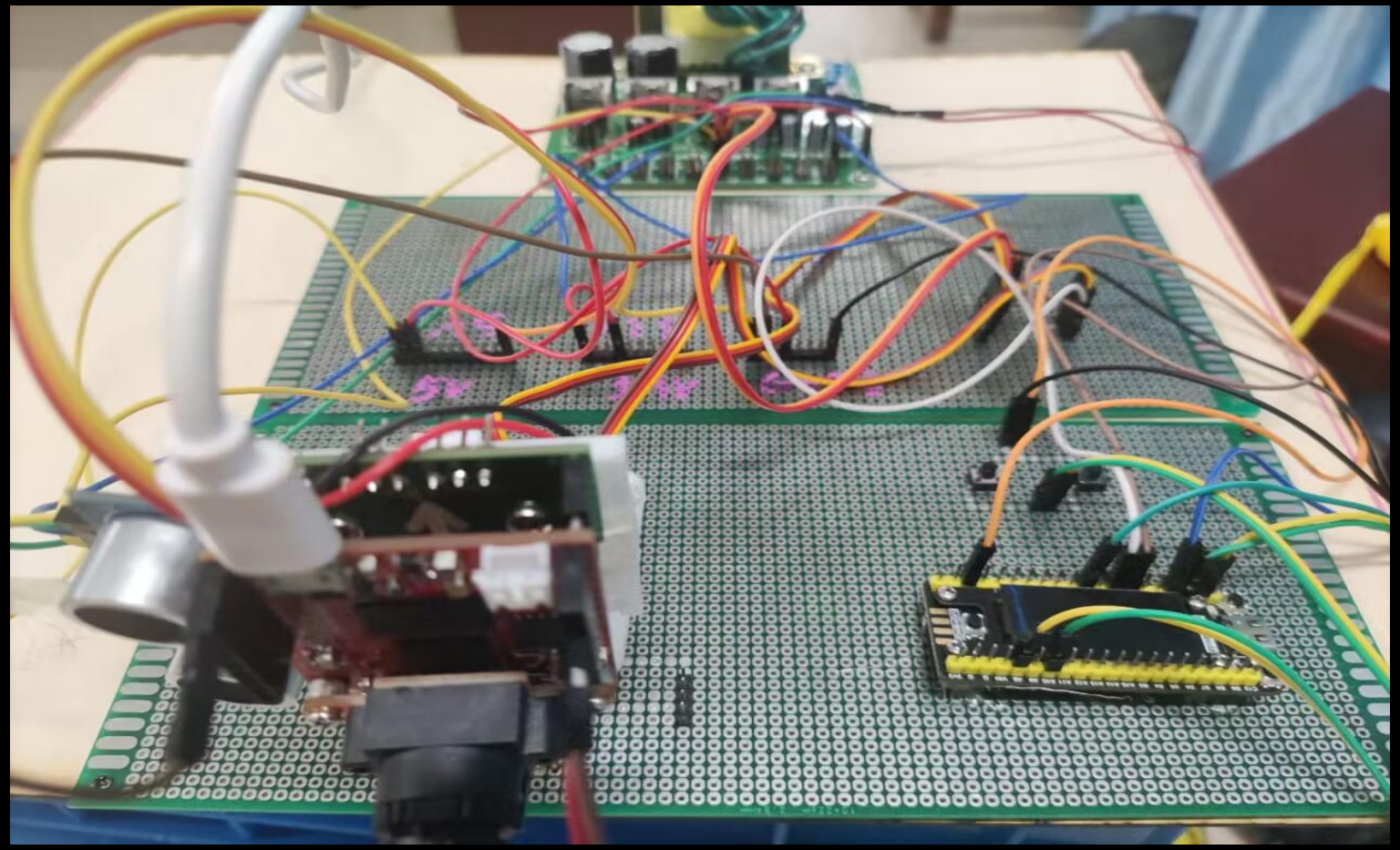
The ultrasonic module, camera, and laser pointer are aligned in **parallel**. A PID algorithm is employed to compute the angular deviation between the measurement system and the geometric center of the target object in real time, and the resulting PWM signal adjusts the servo angle accordingly. The overall system architecture is simple and easy to implement, requiring only PID parameter tuning and alignment of the ultrasonic module, camera, and laser pointer during setup. A limitation is that the PID controller may exhibit overshoot during continuous adjustment, necessitating environment-specific tuning to achieve optimal performance.

In summary, the **PID algorithm** is adopted to track the geometric center of the target object.

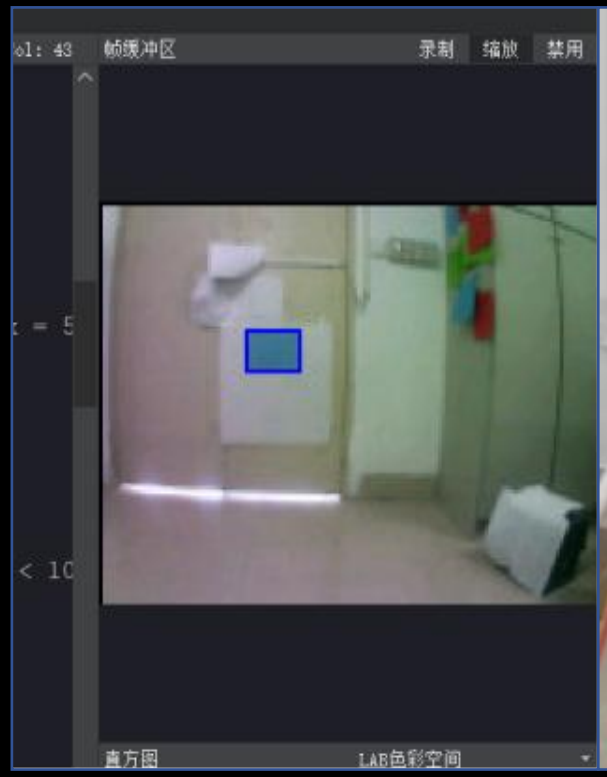
Product Flow Diagram



Finished Product



Test Procedure



Results & Color and Shape

Test Objects	Color Recognition	Shape Recognition
Red/Blue/Green Rectangles	√	√
Red/Blue/Green Circle	√	√
Red Triangle	√	√

Note: Rectangular and circular objects are relatively easy to recognize. However, in color-blob-based image recognition, triangular objects are more susceptible to environmental interference, making them more difficult to identify. As a result, only red triangles can be reliably detected.

Results & Distance Measurement

Mesure Distance	2.01m	2.87m	2.54m
Actual Distance(m)	2.0m	2.9m	2.5m
Error(m)	0.01m	0.03m	0.04m

Note:here is a small discrepancy between the tested distance and the actual distance; however, its impact on subsequent measurements is minimal.

Results & Centralized Positioning

Tests Number	Test Image	The dotting situation at the center of the image
1	Rectangle	Basically close to the center
2	Rectangle	Basically close to the center
3	Rectangle	Basically close to the center
1	Round	Basically close to the center
2	Round	Basically close to the center
3	Round	Basically close to the center
1	Triangle	Basically close to the center
2	Triangle	Significantly offset
3	Triangle	Significantly offset
1	Squar	Basically close to the center
2	Squar	Basically close to the center
3	Squar	Basically close to the center

Note:In the actual test environment, some fluctuation in measurement errors was observed. The PID control function may not be fully optimized, resulting in minor oscillations during servo rotation.

Results & Ball-shaped objects

Test Object	The dotting Situation At The Center Of The Image	Surface Distance (m)	Actual Distance (m)
Basketball	Basically close to the center	2.10	2.05

Attachment

Result & Rectangular Measurement

测试所用的矩形 对角线长度为36.37cm，长为29.7cm，宽为21cm												
蓝色矩形				红色矩形					绿色矩形			
长度	长	宽		距离	长度				距离	长度		
36.25	20.97	29.57	2.39	2.086	35.94	20.75	29.34	33.46	2.66	35.85	20.70	29.27
36.04	20.75	29.27		2.25	36.4	21.02	29.72	34.49	2.5614	36.88	21.29	30.11
36.27	20.98	29.58		2.537	36.75	21.22	30.00	34.06	2.347	36.45	21.05	29.76
36.57	21.16	29.83		2.755	37.01	21.37	30.22	33.61	2.202	36	20.79	29.39
35.04	20.76	28.57		2.966	36.71	21.20	29.97	34.05	2	36.44	21.04	29.75
36.034	20.924	29.364		平均值：	36.562	21.111	29.851		平均值：	36.324	20.97	29.66
		平均对角线长度：		36.30666667	平常宽长度：		21.00299616	平均长长度：		29.62405791		

Result & Square Measurement

测试所用的正方形 对角线长度为53.740cm，长宽为38cm													
蓝色正方形					红色正方形					绿色正方形			
距离	长度	长	宽		距离	长度	长	宽		距离	长度	长	宽
2.8002	53.79	38.04	38.04		2.34	54.3	38.39	38.39		2.564	53.81	38.05	38.05
2.665	54.01	38.17	38.17		2.5	53.15	37.59	37.59		2.459	53.85	38.05	38.05
2.473	53.79	38.01	38.01		2.6044	54.17	38.3	38.3		2.354	54.31	38.41	38.41
2.33	54.27	38.72	38.72		2.6912	53.98	38.17	38.17		2.178	53.76	38.11	38.11
2.097	54.66	38.65	38.65		2.837	54.20	38.32	38.32		2.791	54.43	38.48	38.48
平均值：	54.104	38.318	38.318		平均值：	53.96	38.154	38.154		平均值：	54.032	38.22	38.22
			平均对角线长度：		54.032		平均长宽：		38.23066667				

Result & Circular Measurement

测试所用的圆形 直径为21cm											
蓝色圆形				红色圆形				绿色圆形			
	距离	长度			距离	长度			距离	长度	
	2.8	21.07			2.13	21.3			2.5	21.33	
	2.6	21.35			2.33	21.36			2.603	21.05	
	2.5	21			2.5	21.02			2.34	21.45	
	2.3	21.18			2.808	21.05			2.087	20.86	
	2	21.2			2.937	21.25			2.9	20.98	
	平均值：	21.16			平均值：	21.196			平均值：	21.134	
					平均值：	21.16333333					

Result & Triangular Measurement

测试所用的三角形 边长为21cm		
	红色三角形	
	距离	长度
	2.124	20.67
	2.324	21.63
	2.486	20.34
	2.684	21.33
	2.846	20.96
	平均值:	20.986