

Table S1 Specifications of our designed omni-directional optical system.

Parameters	Design result
EFL	0.3633 mm
FOV	80°–135°
F/#	1.8
Sensor	1/3 inch CMOS Digital Image Sensor
Active pixels	2304 (H) × 1535 (V): Entire array 5.07 mm (H) × 3.38 mm (V)
Pixel size	2.2 μm

Table S2 Number of pixels for each zone and real ray heights on the sensor.

Pattern	Zone (1)		Zone (2)		Zone (3)		Zone (4)	
	Pixels	Y_T (mm)	Pixels	Y_T (mm)	Pixels	Y_T (mm)	Pixels	Y_T (mm)
11th	166	0.3652	169	0.3718	168	0.3696	164	0.3608
10th	182	0.4004	184	0.4048	185	0.4070	179	0.3938
9th	201	0.4422	204	0.4488	204	0.4488	197	0.4334
8th	226	0.4972	227	0.4994	227	0.4994	221	0.4862
7th	253	0.5566	255	0.5610	255	0.5610	249	0.5478
6th	287	0.6314	290	0.6380	289	0.6358	283	0.6226
5th	329	0.7238	334	0.7348	330	0.7260	325	0.7150
4th	385	0.8470	383	0.8426	386	0.8492	378	0.8316
3rd	449	0.9878	453	0.9966	453	0.9966	447	0.9834
2nd	525	1.1550	530	1.1660	532	1.1704	526	1.1572
1st	615	1.3530	618	1.3596	621	1.3662	615	1.3530

Table S3 Measured and theoretical values.

Pattern	Distance	Pattern height	Base height		θ	y_T	<i>DIY</i>	tan(θ)
	X	Y_T	Y_B	$Y_p = Y_T - Y_B$				
11th		1.150		0.857	49.318	0.3573	-15.3640	1.163
10th		1.050		0.757	52.791	0.3912	-18.1542	1.317
9th		0.950		0.657	56.616	0.4313	-21.6817	1.518
8th		0.850		0.557	60.809	0.4794	-26.2007	1.790
7th	0.997	0.750	0.293	0.457	65.374	0.5378	-32.0758	2.182
6th		0.650		0.357	70.299	0.6098	-39.8435	2.793
5th		0.550		0.257	75.545	0.6998	-50.3153	3.879
4th		0.450		0.157	81.051	0.8132	-64.7367	6.350

3rd	0.350	0.057	86.728	0.9549	-84.9620	17.491
2nd	0.250	-0.043	92.470	1.1269	-113.3910	-23.186
1st	0.150	-0.143	98.162	1.3339	-152.4706	-6.972
unit	(m)		(degree)	(mm)		

Table S4 The calculated focal lengths.

	Result (zone 1)	Result (zone 2)	Result (zone 3)	Result (zone 4)
$\sum_{i=1}^{11} \left(\frac{y_{T_i}^2}{\tan^2 \theta_i} \right)$	0.5652	0.5775	0.5768	0.5481
$\sum_{i=1}^{11} \left(\frac{y_{T_i}}{\tan \theta_i} + \frac{y_{T_i} \cdot DIY_i}{\tan \theta_i} \right)$	1.5137	1.5302	1.5292	1.4907
EFL (mm)	0.3734	0.3774	0.3772	0.3677

Table S5 Focal length sensitivity for tolerance.

Surface	Radius	EFL (mm)	Thickness	EFL (mm)	Surface	Index	EFL (mm)
	Delta (Newton rings)		Delta (mm)			Delta	
2	5	0	0.05	-0.0004	2	0.001	0
3	5	0	0.05	-0.0013	4	0.001	0.0002
5	5	0.0001	0.05	-0.0022	6	0.001	0.0003
6	5	-0.00015	0.05	-0.0013	8	0.001	0.0000
7	5	0.0002	0.05	-0.0029	11	0.001	0.0007
8	5	-0.0001	0.05	-0.0017	12	0.001	-0.0004
9	5	-0.00015	0.05	0.0006	14	0.001	0.0004
stop	5	0	0.05	0.0006	16	0.001	0
11	5	0.0006	0.05	0.0007			
13	5	-0.00085	0.05	0.001			
14	5	0.00065	0.05	0.0005			
15	5	-0.00055	0.05	0			
16	5	-0.00025	0.05	0			
		0.001434		0.0046			
		0.00085		0.0029			

Table S6 Permissible errors for focal length (in mm).

Measured value	0.3739	
Theoretical value	0.3633	
Standard deviation	Normal	0.004844
	Triangular	0.006851

Uniform		0.008390	
		(-)	(+)
Permissible level (σ)		1	
Maximum	Normal	0.3609	0.3657
variable	Triangular	0.3599	0.3667
range	Uniform	0.3591	0.3675
Permissible level (σ)		2	
Maximum	Normal	0.3585	0.3681
variable	Triangular	0.3564	0.3702
range	Uniform	0.3549	0.3717
Permissible level (σ)		3	
Maximum	Normal	0.3560	0.3706
variable	Triangular	0.3530	0.3736
range	Uniform	0.3507	0.3759
Permissible level (σ)		4.5	
Maximum	Normal	0.3524	0.3742
variable	Triangular	0.3479	0.3787
range	Uniform	0.3444	0.3822