# Development of intelligent manufacturing system and inspection technology for optical small elements

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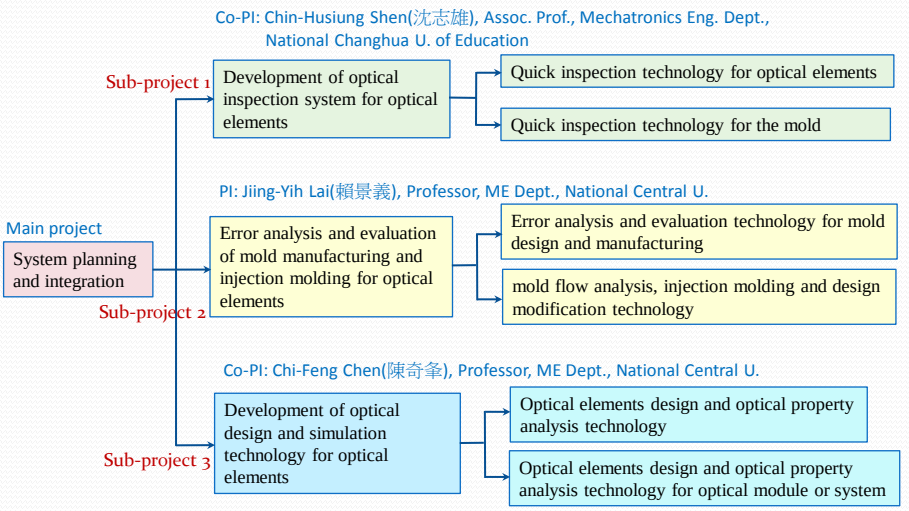
## Outline

- Structure of the project
- Background, project objective and proposed structure
- Specific technologies involved in this project
- Current simulation and experimental results
- Conclusion

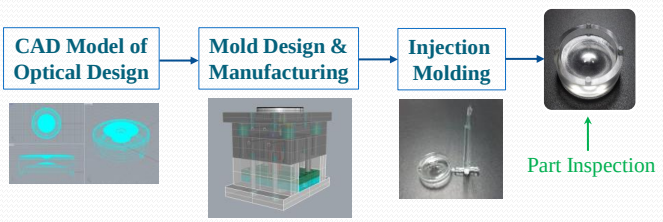
## Development of intelligent manufacturing system and inspection technology for optical small elements




# Background, Project Objective and Proposed Structure

# Problems on the Development of Optical Elements

- In injection molding of optical elements, possible reasons for a part failed to reach the required accuracy are as follows:
  - Improper design
  - Manufacturing inaccuracy
  - Inspection uncertainty
- Typical manufacturing process of plastic optical elements




- Questions frequently occurred
  - Difficult to analyze the reasons causing the problem
    - Mold design? Mold manufacturing? Injection process?
  - Difficult to evaluate the surface geometry and material behavior
    - Specific dimensional measurement only.
  - If mold flow analysis and optical simulation are included, how accurate they are?

## Project Objectives

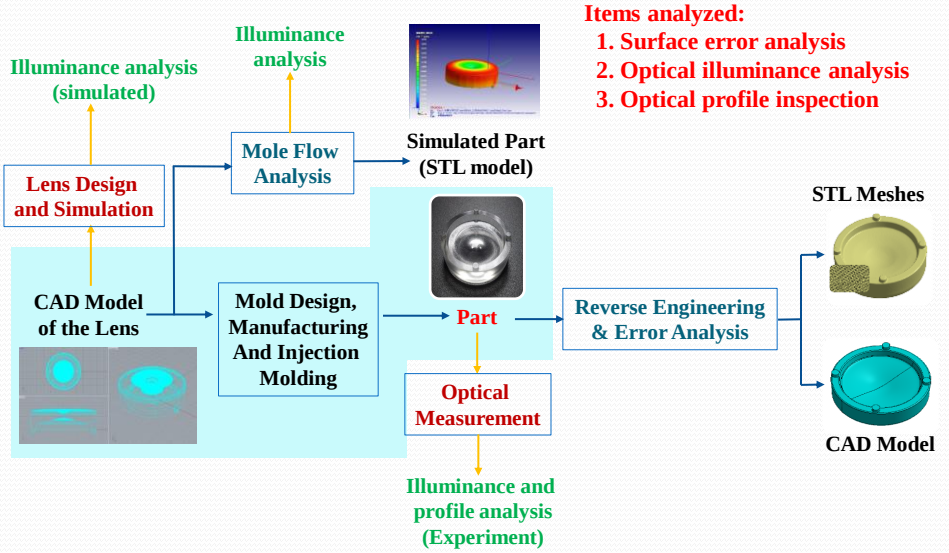
- To establish a systematic approach for the development and inspection of small optical elements, which can
  - increase the capability of handling the product quality
  - realize the manufacturing prediction
  - reduce manufacturing cost
  - reduce time for product development and testing

- To integrate
  - surface measurement technique
  - mold flow analysis
  - reverse engineering technology
  - error analysis
  - optical design technology

  for optical elements manufacturing and inspection

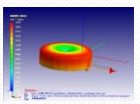
- To develop an optical inspection system
  - for fast and efficient measurement of small optical element profile

# The Proposed Structure




- Lens design and simulation is implemented to aide the CAD model design of optical lens
- Mold flow analysis is implemented to aide the mold design and injection manufacturing process
- Some more processes are added for the inspection purpose
  - Optical measurement: to analyze the performance of the injection part, including illuminance and surface profile inspection
  - Reverse engineering: to reconstruct the CAD model from the scan data of the part
  - Error analysis: to analyze surface errors among different kinds of data and CAD models

## Specific Questions Addressed



- How accurate is the injection part?
- How accurate is the mold manufacturing?
- How accurate is the mold flow analysis?
- Optical performance
  - Combine optical simulation and mold flow analysis for better design of the injection part
  - Employ optical measurement for quality verification of the injection part

## Specific Technologies Involved in this Project

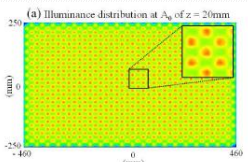
1. Lens Design and Simulation
2. Reverse Engineering
3. Error Analysis
4. Mold Flow Analysis
5. Development of Optical Inspection System

# 1. Lens Design and Simulation

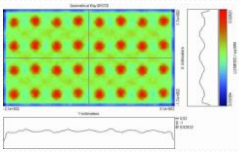
Use side emitting lens as an example

- **Motivation**:
  - In LED display, the thickness of backlight module is limited in order to reduce the thickness of the overall product.
  - The reduction in the thickness may cause a bright spot, and hence result in uneven light emit.
- **Objectives:**
  - To resolve the hot spot problem for direct type backlight module.
  - With appropriate lens design, the thickness of backlight module <3 cm.
  - With a 2 mm diffusion plate, allows evenness of the light>80%

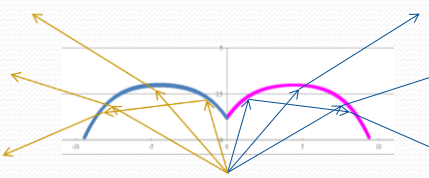
LED package and arrangement



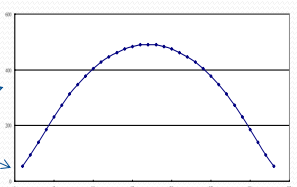

Hot spot



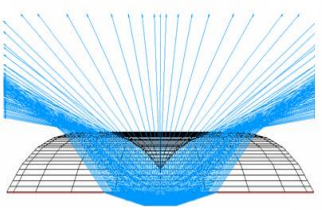
## Lens Design Concept



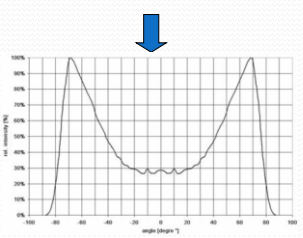
Use slope structure to reflect the light from the center to both sides



Original distribution of light intensity



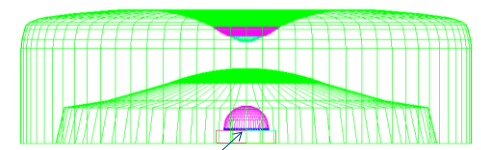
OSRAM Side-emitting Lens



Design objective: reduce light intensity to 50% of the peak value for the region within 20° from the center point

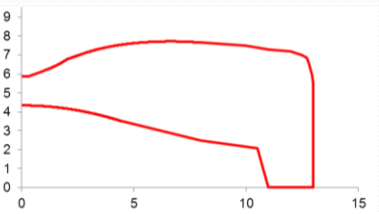
## Section Profile and CAD Model Design

Wireframe model of the lens

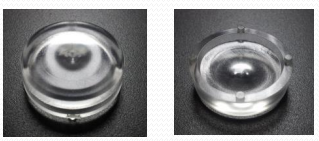


Light source

Three important faces contribute the entire function the lends, including the top face, side face and bottom face



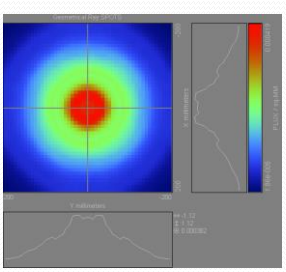

Cross sectional view of the lens



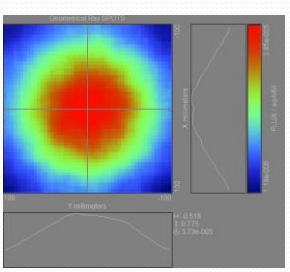
Injection part

## Results of Lens Design

- Illuminance analysis
  - Before adding the diffusion plate, illuminance values are still high from the center (right), which causes the appearance of the hot spot.
  - When a 2 mm diffusion plate is implemented, the light diffusion plate can sideways diffusion (left). It solves the hot spot problem of the direct backlight module.

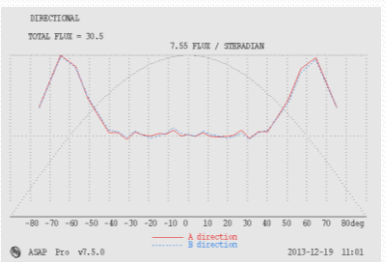


without diffuser

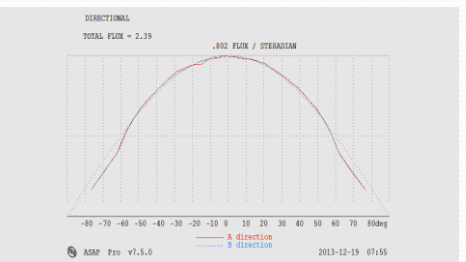


with 2mm diffuser

- Luminous intensity analysis
  - Reduce luminous intensity of the light of the center within ± 20° to the peak of 50%.
  - a small central angle of ± 40° of the light energy is much lower than the exit angle of 50° ~ 70°. Approximately ± 65 ° angle of the light intensity is the strongest.
  - add diffuser plate is able to meet Lambertion.



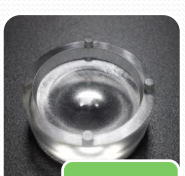

Light intensity distribution(without diffuser plate)




Light intensity distribution(with 2mm diffuser plate)

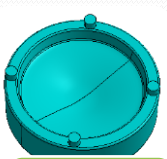
## 2. Reverse Engineering

- Apply optical scanning device to acquire the surface points of the part, physical model, or prototype
- Employ the best fit technology to obtain the best surface model from the surface points.
- The surface quality should be seriously considered

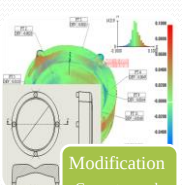


Part

Optical Scanning



CAD construction
- Dimensional evaluation
- Surface construction



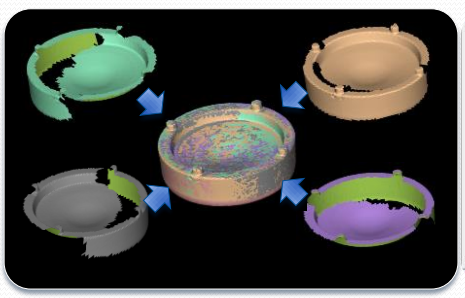
Modification
- Geometry and surface
- 2D drawing

# Optical Scanning

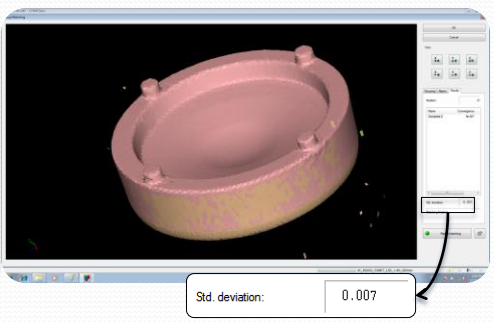
The surface points of the part are obtained through multiple-views scan with a camera-type scanning device. The standard deviation of the points is about 0.007 mm, while the final accuracy is about 0.02 mm after the data is processed.

- Camera-type scanning

**Multi-views scan**

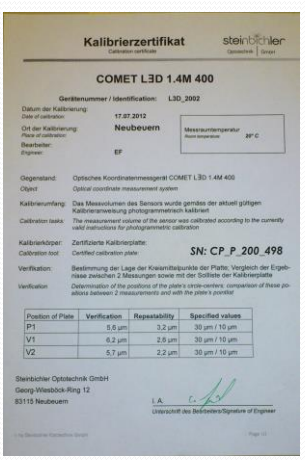


**Fine positioning**




# Specification COMET 400

- Left plot: Calibration certificate of the scanning device (Repeatability and precision)
- Right plot: Camera resolution and specification of the scanning device (FOV400mm employed)



Kalibrierzertifikat

steinbichler

COMET L3D 1.4M 400

Gerätenummer / Identification: L3D_2002

Datum der Kalibrierung / Date of calibration: 17.07.2012

Ort der Kalibrierung / Place of calibration: Neubeuern

Bearbeiter / Engineer: EF

Gegenstand / Object: Optisches Koordinatenmessgerät COMET L3D 1.4M 400 / Optical coordinate measurement system

Kalibrierumfang / Calibration tasks: Das Messvolumen des Sensors wurde gemäss der aktuell gültigen Kalibrieranweisung photogrammetrisch kalibriert / The measurement volume of the sensor was calibrated according to the currently valid instructions for photogrammetric calibration

Kalibrierkörper / Calibration tool: Zertifizierte Kalibrierplatte / Certified calibration plate: SN: CP_P_200_498

Verifikation / Verification: Bestimmung der Lage der Kreismittelpunkte der Platte; Vergleich der Ergebnisse zwischen 2 Messungen sowie mit der Sollliste der Kalibrierplatte / Determination of the positions of the plate's circle-centers; comparison of these positions between 2 measurements and with the plate's pointlist

| Position of Plate | Verification | Repeatability | Specified values |
|---|---|---|---|
| P1 | 5,6 µm | 3,2 µm | 30 µm / 10 µm |
| V1 | 6,2 µm | 2,6 µm | 30 µm / 10 µm |
| V2 | 5,7 µm | 2,2 µm | 30 µm / 10 µm |

Steinbichler Optotechnik GmbH
Georg-Wiesböck-Ring 12
83115 Neubeuern

i.A.

Unterschrift des Bearbeiters/Signature of Engineer

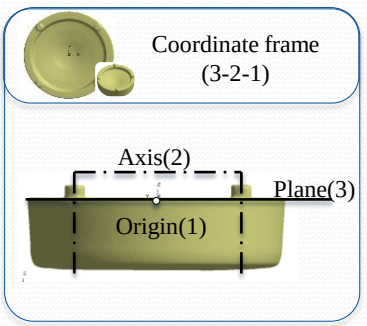
COMET L3D - 1M

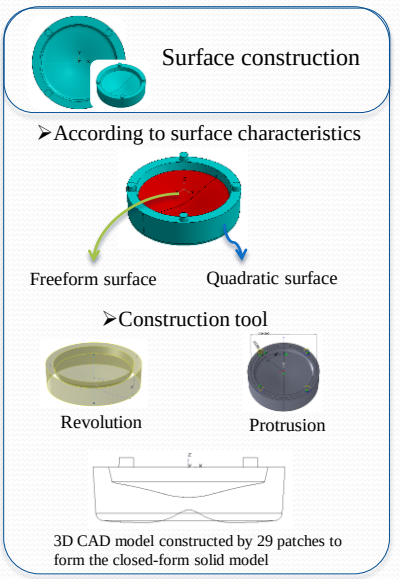
| | | |
|---|---|---|
| Camera Resolution | 1 MPixel | |
| Measuring field | Measuring volume in mm³ | Point to point distance in µm |
| 100mm | 92x69x60 | 79 |
| 200mm | 200x150x140 | 170 |
| 400mm | 370x277x250 | 316 |
| Fastest Measuring Time in Seconds | 2,5 | |
| PC | With Desktop-PC or Notebook available | |
| Sensor Positioning | tripod or sensor stand with manual turn and tilt axis, robot | |
| Automatic Object Positioning | rotation table, robot | |

http://www.steinbichler.com/products/optical-scanning/comet-l3d.html#systems

## CAD Model Construction

- Firstly, define the coordinate frame.
- Next, generate surfaces in terms of the following two surface characteristics: freeform surface and quadratic surface.
- Finally, Generate all surface models. The final model is composed of 29 surface patches.



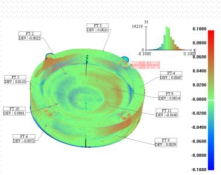




## Dimensional Modification

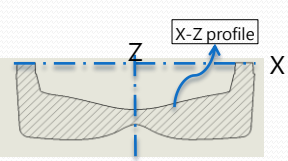
- Dimensions may be modified in terms of the applications:
  - Fully copy, no modification is needed.
  - Data is modified in terms of actual design, e.g. the sectional curve can be modified in accordance with the requirement in optical design.

➢Surface continuity check

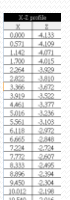
➢Dimensions modified to fit the tolerance



➢Error analysis (RE process)

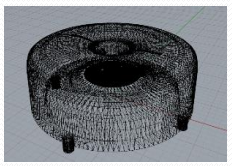



➢Evaluate sectional profile for optical analysis

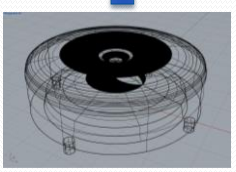


# 3. Error Analysis

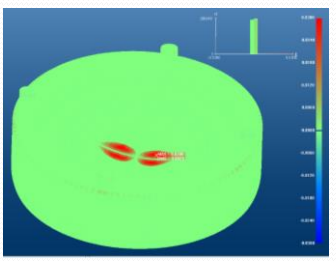
- To analyze the difference between two object surfaces.
- Several kinds of error analysis situations: point-to-points, points-to-CAD model, points-to-STL meshes, etc.
- Example: Mold flow analysis (STL meshes) vs. Original CAD model (*.igs file)



STL meshes
(Mold flow analysis)



Original CAD model



Error distribution

# Points-to-CAD Error Analysis

- Closest point searching concept
  - Convert the CAD model into triangular meshes
  - Meshes subdivision
  - Closest point searching
  - Iteration to find real closest point

**Convert CAD to meshes**

•Convert all surface models into triangular meshes, including un-trimmed and trimmed surfaces. The number of meshes is adjusted in terms of the size of each surface

**Meshes subdivision**

•Based on the bounding box of the entire set of meshes, divide the volume into cells. Record the cells on the boundary of the object surface.

**Closest point computation**

•Evaluate the corresponding cell of a data point. Find a set of meshes which lie within the cells. Find the mesh which is closest to the data point.

**Iteration for real closest point**

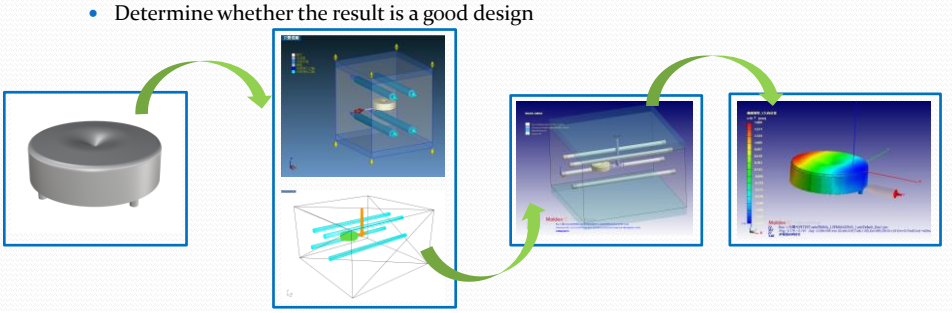
•Use Jacobian Inversion method to evaluate the point which is closest to the data point. An iteration algorithm must be implemented to find the closest point.

# 4. Mold Flow Analysis

- Modex3D mold flow analysis process
- Parameters to be determined by users
- Output of mold flow analysis
- Initial simulation: Original side emitter
- New mold design & simulation results
- Cave design: one cave vs. four caves

## Modex3D Mold Flow Analysis Process

- Step1:Design Model
  - Meet the needs of the model
- Step2:Input Model
  - Build solid mesh of the optical lens design. Different ways of building solid mesh can affect the simulation results.
- Step3:Simulating
  - Get some simulation results in different stages: Filling, Packing, Cooling, and Warpage.
- Step4:Results
  - Determine whether the result is a good design

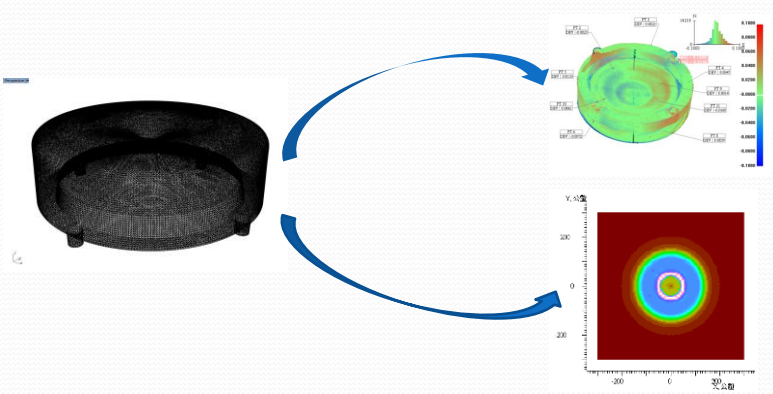


## Parameters to be Determined by Users

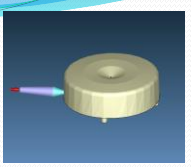
- The injection molding parameters can be adjusted freely by the user
- Set the parameters for the situation of actual plastic injection.


## Outputs of Mold Flow Analysis

- The output of the .stl file of the warpage analysis can be used for another analysis .
  - Surface deformation analysis
  - Optic simulation analysis



## Initial Simulation: Original Side Emitter



- The simplest design: one mold with one cave. Use this example for testing the entire process of Modex3D. Some of the phenomena found are:
  - The setting of plastic melt temperature can increase the warping displacement, volume shrinkage and thermal displacement of the final part
  - Increase the holding pressure can reduce the volume shrinkage effectively
  - Increase the cooling time can reduce the volume shrinkage and residual stress

## 5. Development of Optical Inspection System

**Phase Development**

Phase 1. Line projection
Phase 2. Phase-Shifting projection

**Preliminary Design of Phase 1**

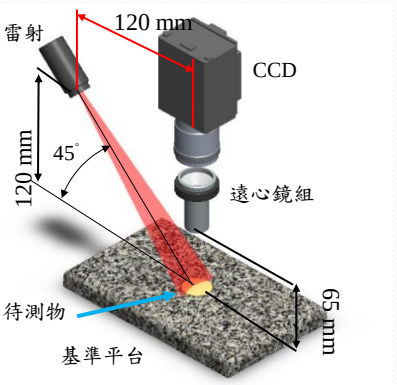
CDS Background ellimination
Base line of projection line
Median and Savitzky-Golay Filter
Deviation of projection line
Deviation of projection line to Height
Calibration with Gauge
User interface and Data acquisition
User defined measuring area
Measurement of Small optical element

**Assembly of System and Testing**

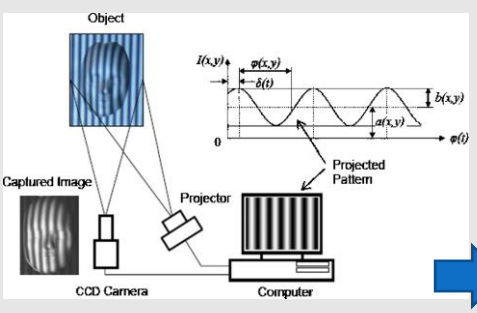
Assembly and integration of system
Measurement of Small optical element
Resolution measurement of system
Tolerance test of Laser marking line
Tolerance test of Platform
Tolerance test of

## Phase 1: Design of Line Projection System

- Using a laser projection marker with 0.38 mm width, it is projected with $45^0$ inclination angle. The laser module is installed at 120 mm height and the telecentric lens module with is positioned at 65 mm from the measurement platform。
- High resolution 744×480 RGB32bit CMOS image module with USB interface




## Phase 2: Phase-Shifting projection

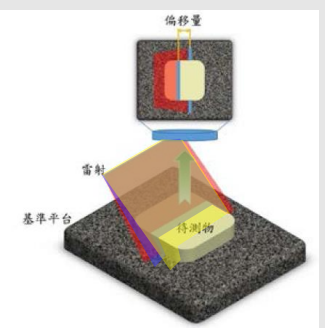



$$I_0(c,r) = a(c,r) + b(c,r)\cos\left[\frac{2\pi c}{d} + \phi(c,r)\right]$$

$$I_1(c,r) = a(c,r) + b(c,r)\cos\left[\frac{2\pi c}{d} + \phi(c,r) + \frac{\pi}{2}\right]$$

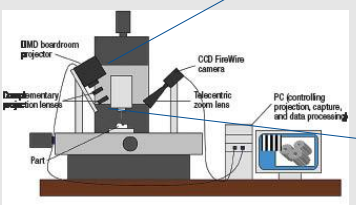
$$I_2(c,r) = a(c,r) + b(c,r)\cos\left[\frac{2\pi c}{d} + \phi(c,r) + \pi\right]$$

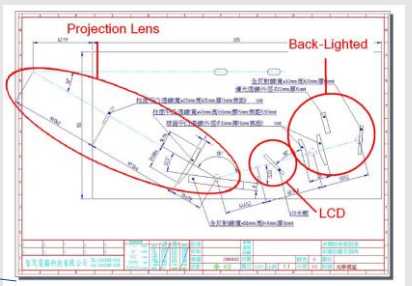
$$I_3(c,r) = a(c,r) + b(c,r)\cos\left[\frac{2\pi c}{d} + \phi(c,r) + \frac{3\pi}{2}\right]$$



## Preliminary Design of Phase-Shifting Projection

Optical Design of Phase-Shifting projection



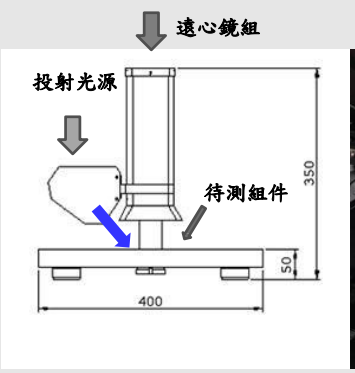



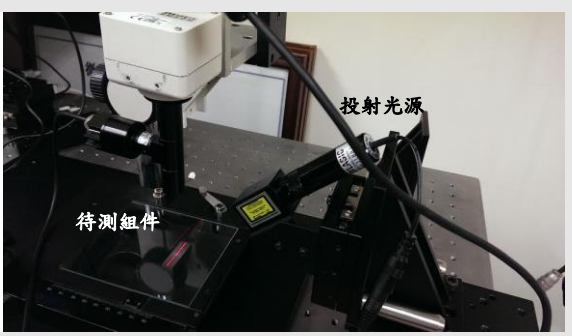

**System Design and Algorithm**

- **DMD Phase Modulation**
- **Algorithm of Four Phase-Shifting with CDS**

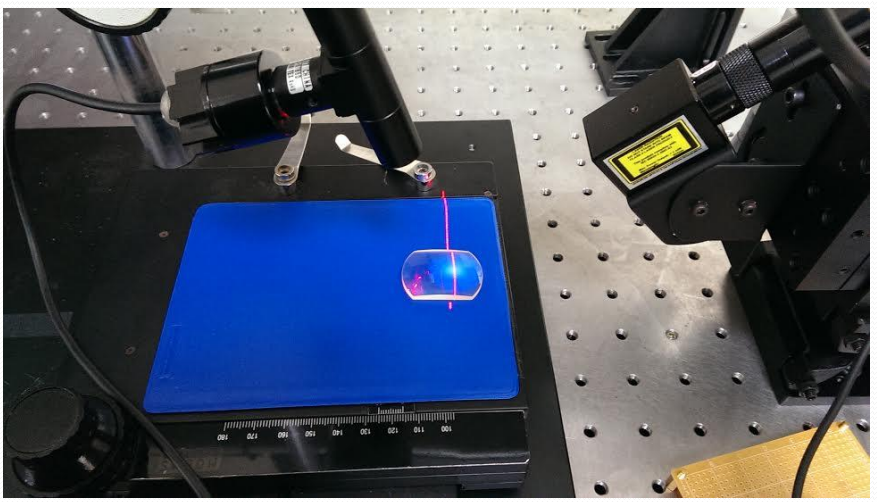


## Design and Prototype of Line projection



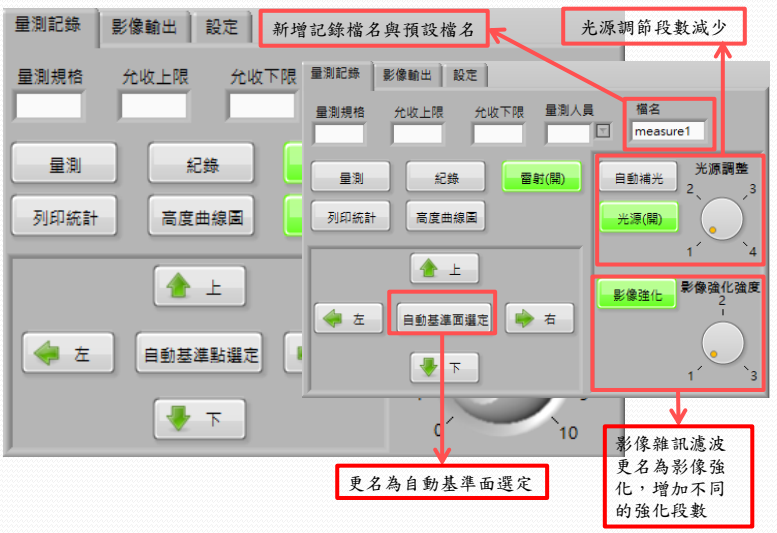



## Lens Measurement with Prototype of Line Projection

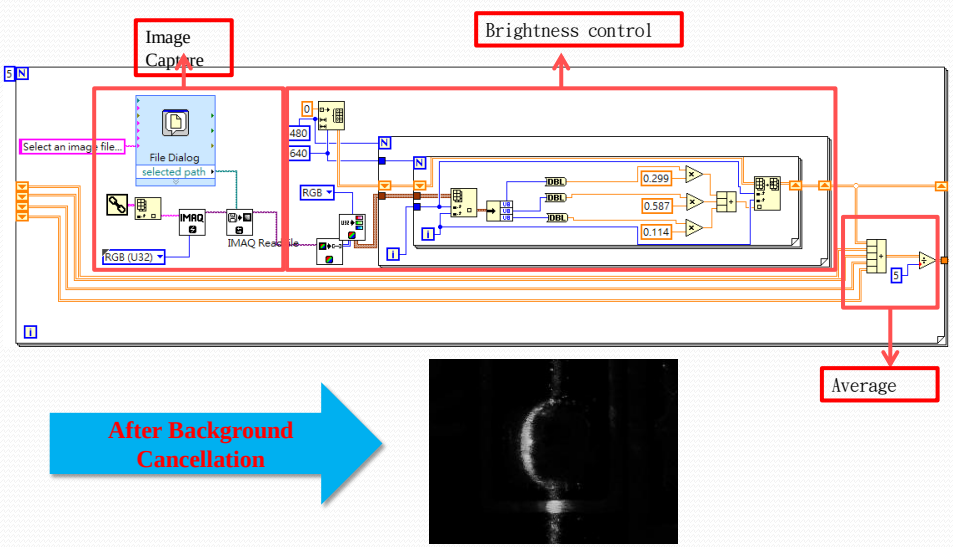


## Design of User Interface

## Control Panel and System Parameters Setup




## Background Elimination :
## Double sampling images with Laser projection



## Current simulation and experimental results

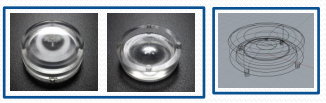
1. Cases study
2. Various kinds of error analysis
3. Illuminance analysis
4. Preliminary test of the optical inspection system

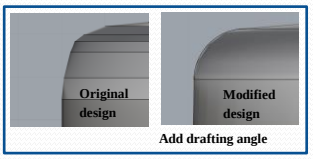
## 1. Cases Study

- Original side emitting lens
  - The original CAD model (original optical design)
  - The prototype part (injection part)

- 1st mold design, manufacturing, and injection molding
  - Modified CAD model (3D CAD model of the mold)
  - The injection part (new part produced by the injection molding)
  - The scanning data of the mold
  - The STL data from the mold flow analysis
- 2nd and 3th mold design, manufacturing, and injection molding
  - To be implemented

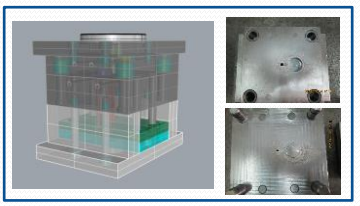
# 1st Mold Manufacturing and Injection Molding





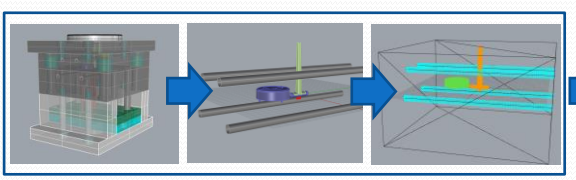
Add drafting angle

- A drafting angle is added in the mold design. In addition, the mold manufacturer modifies the CAD model slightly for the reason of machining.
- An injection molding testing has been implemented to obtain the sample parts from this mold and injection process.
- The parameters used in injection molding are recorded for the use in mold floe analysis.



Launch（隆泉）LCH-80B（肘節式）

# Mold Flow Analysis



Parameters
溫度:230℃
射壓:80kg/cm²
射速:15cm³/sec.
保壓壓力:70kg/cm²
保壓時間:8sec.
冷卻時間:20sec.

- Separate all components from 3D mold model and generate solid meshes for each of them individually.
- Acquire the parameters of the injection machine and use them in the mold flow analysis.
- Modify the solid meshes in terms of the condition of real mold.

Question: Model3D does not provide the data base for the injection machine used in this experiment.

Solution: Add new data base manually to generate the parameters for the machine used. However, the parameters input may not be accurate totally.

# 2. Various Kinds of Surface Error Analysis

- Error analysis is implemented between different types of data to investigate the source of errors.

side emitting lens

- Types of error analysis:
  - Total surface comparison: The scanned points are compared with the entire CAD model
  - Partial surface comparison: The scanned points are compared with the CAD model region by region
  - Sectional curve comparison: Sectional points are compared with the sectional curve of the CAD model

➢ Part STL data vs. Original CAD model
- To investigate the deviation between the injection part and the original CAD design.

➢ STL data from MFA vs. Part STL data
- To investigate the deviation between the result of MFA and the injection part.
- Can be used for the parameter setting in MFA

➢ STL data from MFA vs. Original CAD model
- To investigate the prediction of MFA.

➢ Part STL data vs. Part RE CAD
- To conform the accuracy of the CAD model generated by reverse engineering technology.

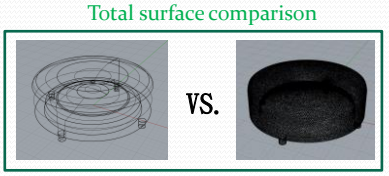


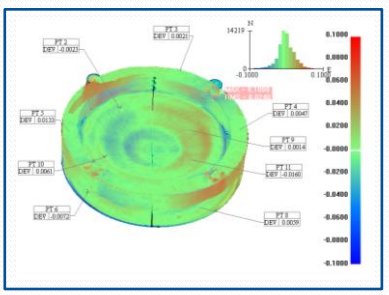


MFA: mold flow analysis
RE: reverse engineering

# Total Surface, Partial Surface and Sectional Curve Comparison

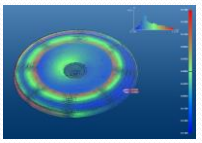
Total surface comparison



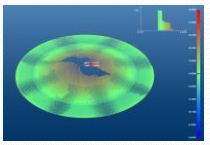



Partial surface comparison

Part STL data vs. Original CAD model



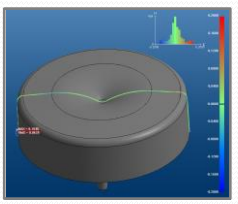
Max 0.2031

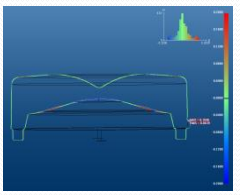


Max 0.4423

Sectional curve comparison

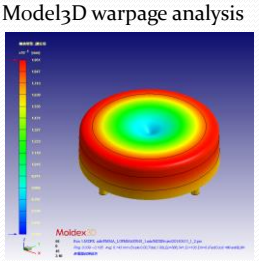
Part STL data vs. Modified CAD model





# Results of Total Surface Analysis- Warpage Analysis

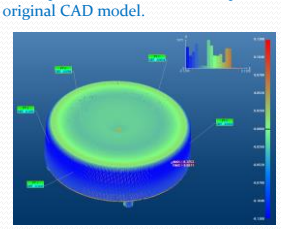
Model3D warpage analysis



- Through points to CAD error analysis, we can obtain the trend of the error distribution.
- However, a detailed understanding of the errors locally is still inconvenient as the entire set of data is quite huge.

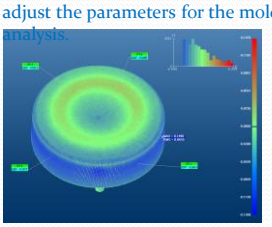
◆ Part STL data vs. Original CAD model

- A comparison between the MFA prediction and the original CAD model.



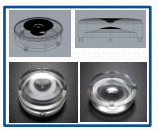
◆ MFA STL data vs. Part STL data

- Investigate the difference between the MFA prediction and real injection part.
- Could be necessary to conduct a study to adjust the parameters for the mold flow analysis.

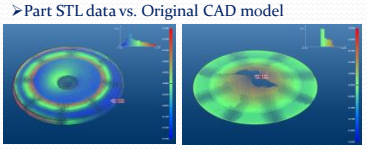


## Results of Partial Surface Comparison

- Two findings are described below:
  - If the original CAD model or the part STL data are served as the reference, the points near the center are not distributed regularly. => May need to re-build the CAD model or re-generate the meshes.
  - There is deviation between the part STL data and the original CAD model. => A draft angle is designed on the mold. It results in the deviation between the injection part and the original CAD model.

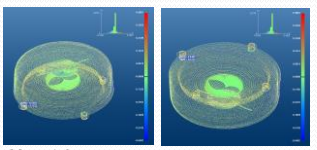


➢Part STL data vs. Original CAD model



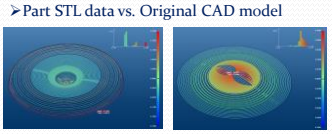
Max 0.2031 Max 0.4423

➢MFA STL data vs. Part STL data



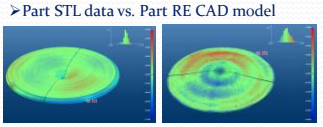
Max 0.6482

➢Part STL data vs. Original CAD model



Max 0.2258 Max 0.0918

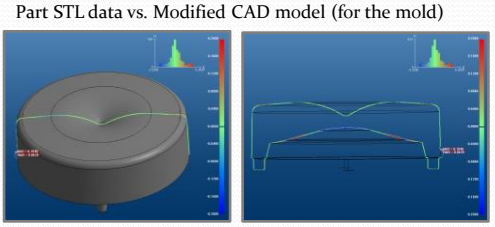
➢Part STL data vs. Part RE CAD model



Max 0.1278 Max 0.0584

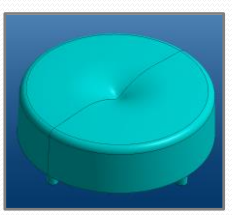
## Results of Sectional Curve Analysis

Part STL data vs. Modified CAD model (for the mold)



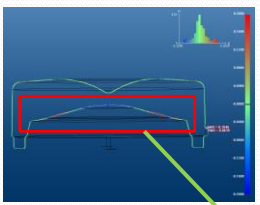
Significant deviation was found on the bottom curves between two sets of data. It indicates that something may be wrong either on the mold manufacturing or the injection process.

Scan points of the injection part

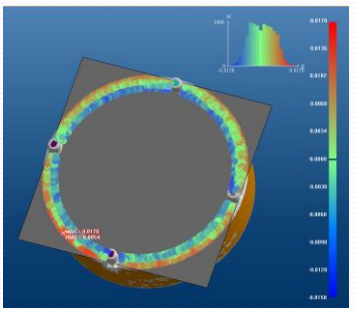


The CAD model by RE technology

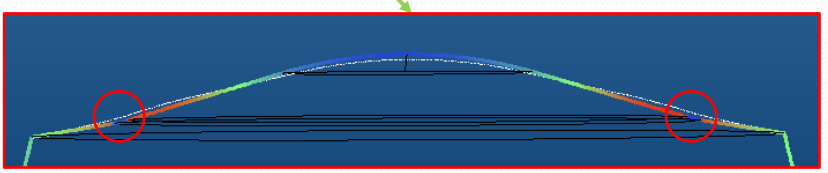
Part STL data vs. Modified CAD model



Registration verification



Plane fitting error, Max: 0.0170, RMS: 0.0054



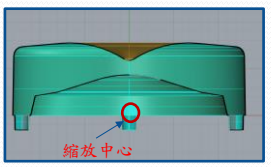
## Preliminary Conclusion

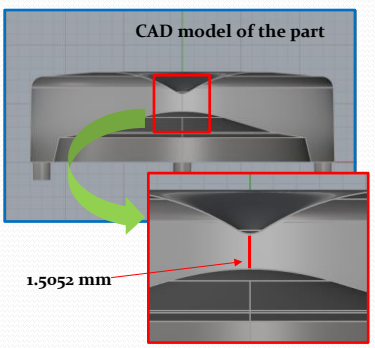
| Item | Mold flow analysis vs. modified CAD model | Part STL data vs. Modified CAD model |
|---|---|---|
| Max error | 0.1247 mm (Location: side face) | 0.1604 mm (Location): lower face) |
| Rms error | 0.0501 mm | 0.0470 mm |
| Upper face | Error range: approximately 0.01-0.03 mm | Error range: approximately 0.01-0.05 mm |
| Lower face | Error range: approximately 0.01-0.05 mm | Error range: approximately 0.01-0.16 mm |
| Side face | Error range: approximately 0.08-0.12 mm | Error range: approximately 0.01-0.02 mm |

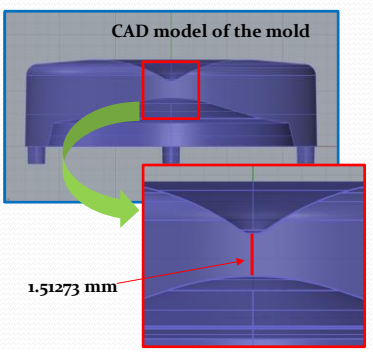
- Based on the left result, the side face has more error as an amount of shrinkage is added on the CAD model of the mold.
- Based on the right result, the lower face has more error than the other two area, which might be due to the manufacturing error on the mold in this area.
- Conclusion: Upper faces on both results are quite similar. There might exist some errors between the CAD model of the mold and real mold. A scanning of the mold surface is necessary to verify such an observation.

## Shrinkage Design for the Mold

- The original CAD model is expanded uniformly along three axes.
- The expansion ratio is 0.5%, namely the CAD model is expanded 1.004 along each axis.
- The accuracy of the CNC machine: +/- 0.1 mm
- Need to inspect the mold in order to verify its accuracy.

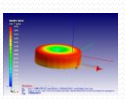


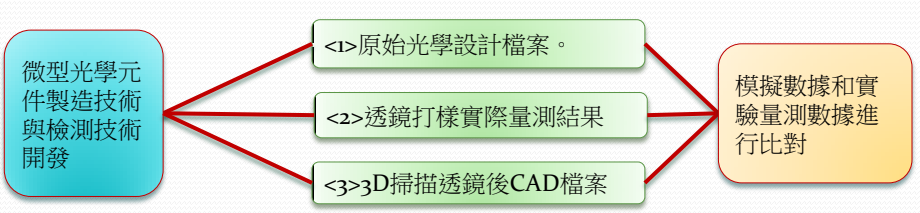




## 3. Illuminance Analysis

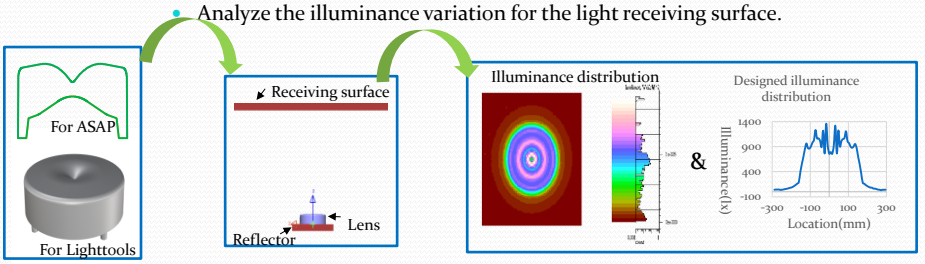
- Illuminance simulation
  - Theoretical illuminance due to optical design
- Illuminance measurement
  - Measurement of real parts
- Illuminance analysis due to MFA
  - Simulated illuminance from mold flow analysis
- Comparison of three kinds of analysis





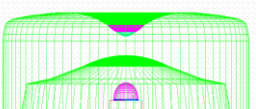
## Illuminance Simulation Steps

- Step1: Import the data of lens
  - ASAP: Import the profile data from Sub-project 2 and rotate 180° to form a three-dimensional model.
    (ASAP can only read point coordinates and formula.)
  - Lighttools: Import the CAD construction from Sub-project 2.
    (Lighttools can only read CAD model.)
- Step2: Geometric model verification and Parameters setting
  - Set the position of the light source, reflector, lens and the light receiving surface.
  - Set the shape and pixel of the light receiving surface.
- Step3: Analysis
  - Analyze the illuminance variation for the light receiving surface.

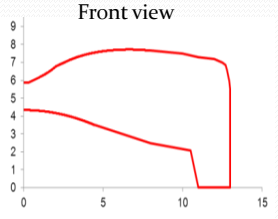



## Theoretical Illuminance Due to Optical Design

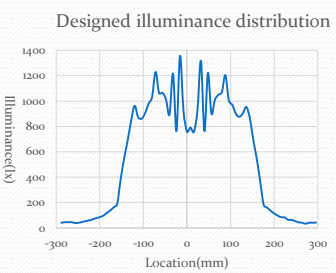
1. Solve the problem of the top of light source will be a bright spot (hot spot) is generated.
2. Let the thickness of direct backlight module will less then 3cm by lens design.
3. Let the evenness of direct backlight module will greater than 80% with the 2mm diffusion plate.



Front view

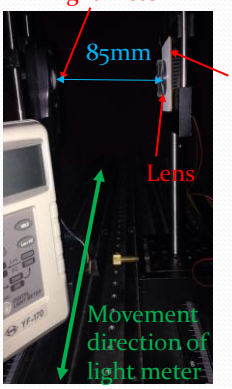



Cross sectional view

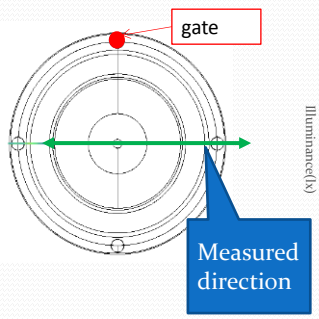


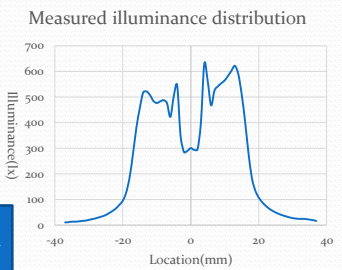
## Measurement of Real Parts

- Measured illuminance by using the light meter.
- Measured illuminance distribution：
  The result is shown that the illuminance distribution is not symmetrical.



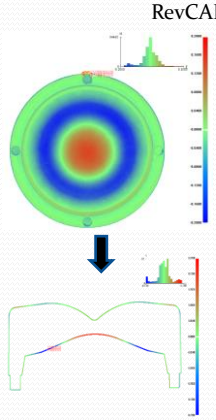

Measurement of the environment

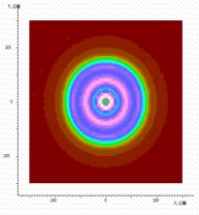


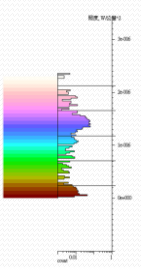



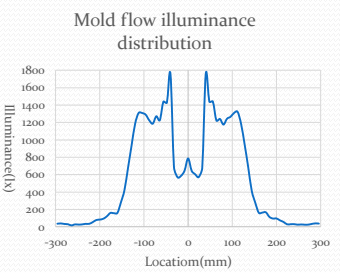

## Simulated Illuminance from Mold Flow Analysis (Mold Flow Illuminance )

- We can't accurately know the illumance distribution from each surface, so we figure out the method that analysis illuminance for diffirent dimension.
- We can get the lens profile for diffirent dimension by using RevCAD.(Lens profile is provided by sub-project 2.)





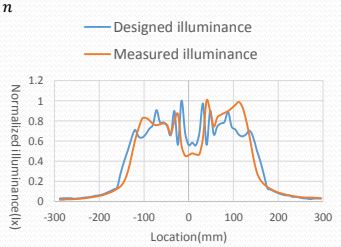




## Comparison of Three Kinds of Analysis

- Designed illuminance distribution vs. Measured illuminance distribution：
  The measured illuminance is lower than the designed illuminance at the center of lens.
  The illuminance is not symmetrical in the range of location -100 ~ 100(mm).
- Root-mean-square error(RMSE)=0.139
  where $\hat{y}_t$：Normalized designed illuminance, $y_t$：Normalized measured illuminance measurements

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{t=1}^{n}(\hat{y}_t - y_t)^2}{n}}$$



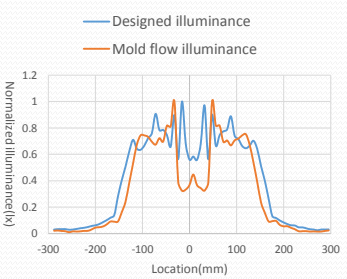

## Comparison of Three Kinds of Analysis

- Designed illuminance distribution vs. Mold flow illuminance distribution：

  The illuminance distribution of the central of the lens is rising on both sides in mold flow illuminance distribution and it may cause the hot spot.

  The mold flow illuminance is lower about 24.8% than designed result at ±16(mm).

- RMSE=0.165

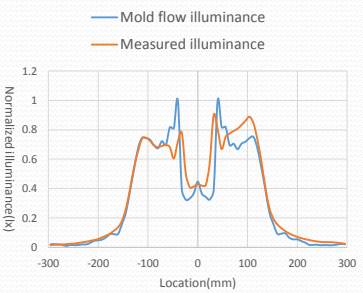


## Comparison of Three Kinds of Analysis

- Measured illuminance distribution vs. Mold flow illuminance distribution：

  The measured illuminances are 22%, 10% and 20% lower than the mold flow illuminance at location -40mm, 40mm and 104mm, respectively.

- RMSE=0.133

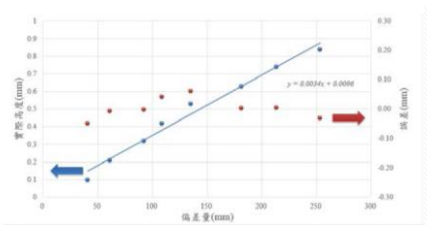



# 4. Preliminary Test of the Optical Inspection System

## Preliminary Test of Slab

| 校正片數量 | 實際高度 (mm) | 偏差量 (pixel) | 估計高度 (mm) | 誤差 (mm) |
|---|---|---|---|---|
| 1 | 0.1 | 40.63 | 0.15 | -0.05 |
| 2 | 0.21 | 60.96 | 0.22 | -0.01 |
| 3 | 0.32 | 91.94 | 0.32 | 0.00 |
| 4 | 0.42 | 108.43 | 0.38 | 0.04 |
| 5 | 0.53 | 134.83 | 0.47 | 0.06 |
| 6 | 0.63 | 181.42 | 0.63 | 0.00 |
| 7 | 0.74 | 213.46 | 0.74 | 0.00 |
| 8 | 0.84 | 253.21 | 0.87 | -0.03 |

表 1.校正片高度偏差、估算高度之誤差

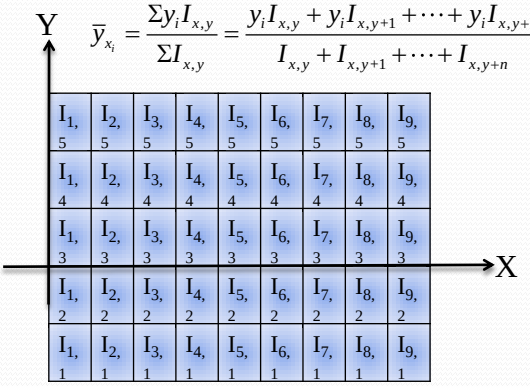


Maximum Error =0.06 mm
After Calibration error under 0.02 mm

## Line Calculation with Brightness Weighting

- $\bar{y}_{x_i}$ : Laser marker position
- $y_i$ : Y coordinate of each pixel for fixed x
- $I_{x,v}$ : Brightness of pixel (x, y)

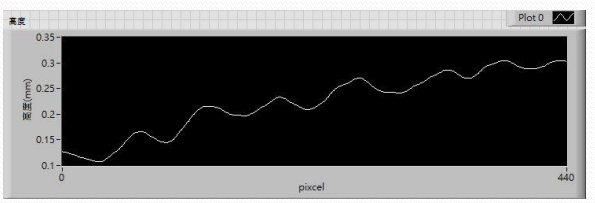
$$\bar{y}_{x_i} = \frac{\Sigma y_i I_{x,y}}{\Sigma I_{x,y}} = \frac{y_i I_{x,y} + y_i I_{x,y+1} + \cdots + y_i I_{x,y+n}}{I_{x,y} + I_{x,y+1} + \cdots + I_{x,y+n}}$$




## Measurement of Fresnel Lens

- Procedures of Measurement：

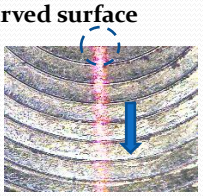

- Morphology and Analysis



## Preliminary Measurement of Fresnel Lens

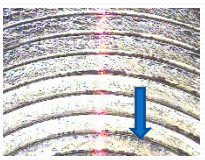
**After Cancellation of curved surface**

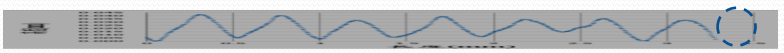
- No.1



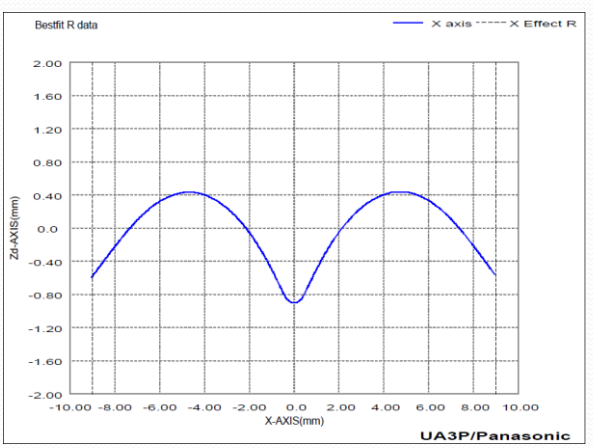
Optical Axes Margin

- No.2





## Measurement of Profile with FZ Interferometer: Panasonic UA3P



## Conclusions

- A systematic approach has been developed and tested for the accuracy analysis of small optical elements in terms of mold manufacturing and injection molding.
- Combine mold flow analysis and optical simulation during the development of optical elements in order to improve the quality of the injection parts.
- An optical inspection system has been developed for the purpose of online inspection. An initial system, including hardware and software, has been setup and tested. Preliminary test results are available.