Development of a Fast Alignment Method of Micro-Optic Parts Using Multi Dimension Vision and Optical Feedback

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Abstract: A general process of electronic assembly is composed of a series of geometric alignments and bonding/screwing processes. After assembly, the function is tested in a following process of inspection. However, assembly of micro-optic devices requires both processes to be performed in equipment. Coarse geometric alignment is made by using vision and optical function is improved by the following fine motion based on feedback of tunable laser interferometer. The general system is composed of a precision robot system for 3D assembly, a 3D vision guided system for geometric alignment and an optical feedback system with a tunable laser. In this study, we propose a new fast alignment algorithm of micro-optic devices for both of visual and optical alignments. The main goal is to find a fastest alignment process and algorithms with state-of-the-art technology. We propose a new approach with an optimal sequence of processes, a visual alignment algorithm and a search algorithm for an optimal optical alignment. A system is designed to show the effectiveness and efficiency of the proposed method.

Keywords: Visual and Optical alignment, Micro optical devices, Search algorithm, Optic communication

1. INTRODUCTION

Nowadays, optic communication is highly interested in increasing of communication demand in information society. And it has the advantage of possible broadband transmission and excellent performance about stability and convenient maintenance and repair [1-3]. As parts used in this optic communication are of very small size with tolerance of 0.001 mm order and require very precise assembly, the manual operation may not be enough to satisfy the desired throughput and quality. Therefore, only automatic manufacturing process can satisfy the desired performance. Many researches are in progress to this end [4-9].

Typical assembly process of micro-optic devices is composed of two consecutive processes of coarse visual alignment and the following fine optical alignment. The optical alignment using a tunable laser corresponds to functional alignment of optic communication. The automation of these processes is a key competitiveness of the micro-optic industry.

A comprehensive effort has made to automate these processes, but the result is not satisfactory in throughput and quality because of the small size/tolerance and nonlinear characteristic of optic transmission. The bonding technology is also another problem of low speed, but it is beyond scope of this research. In this research, we are mainly concerned with fast visual and optical alignments.

We analyzed existing automatic processes and found that the speed can be enhanced with software development and without hardware change. The main ideas are the following;

(1) The assembly sequence can be optimized based on sensitivity analysis of all directions.
(2) For each axis, the appropriate search algorithm can be derived.
(3) Optimal sequence of assembly and adaptive selection of search algorithms based on current status.
(4) Fine calibration of stages (precision robot) can enhance the alignment performance

These four ideas are investigated and implemented into our effective and efficient search algorithm to enhance the assembly speed. The result of this new approach is less than 40 seconds for an assembly. Compared to 123 seconds of existing approaches, this enhancement is proved to be a great progress.

This paper is consisted as follows; In Chapter 2, we explain a micro optic device and the assembly system. In chapter 3, we analyzed the sensitivity of each axis for alignment. In Chapter 4, appropriate search algorithm for each axis is derived. In Chapter 5, we tested assembly and alignment. The results are used to derive a best search with adaptive selection of search algorithms. In Chapter 6, conclusion is made.

2. TASK AND SYSTEM

In this chapter, we explain about micro optic device parts and the assembly system.

2.1 Optic communication passive device

We studied the alignment process of Core Holder and Collimator to produce TFF (Thin Film Filter) that is passive device of the optical component. TFF is the technology separates (DeMux) or combines (Mux) specific lights among the source of lights in DWDM (Dense Wavelength Division Multiplexing) system, in the case of DeMux, it functions separating whole wavelength in many channels by only allowing passing the lights that wish to separate and reflecting the other remaining lights. Therefore, alignment of band-pass filter reflection is very crucial because by reducing the loss of band-pass filter combining DeMux, we can minimize the accumulation damages those are the biggest shortcomings of TFF way DeMux. The required position of optic element is less than 1 ㎛ and the required degree is 0.001° combining band-pass filter. Since the resolution required for the alignment optic elements is higher than tolerance, it requires active alignment [5].

2.2 Previous align process

As shown in Fig. 1, the existing align process and required time are arranged. Importantly, this research targets the improvements on 4, 5, 6, 7, and 8 items. The target items are essential parts for the alignment of Core Holder and Collimator, and they require both geometrical alignment and optical alignment. The existing controversial points are the application of slow vision feedback, motion control which does not regard the kinematics and the inefficiency of Hill Climbing Algorithm. We improve the existing task by implementing the ideas which we previously introduce.

Table 1 Previous align process

Task	Required Time (sec)
01. Transfer to task loading position	5
02. Character input	-
03. Transfer to task position	5
04. Vision centering	31
05. Rotation for checking the epoxy apply position	16
06. Holder rotation	26
07. Vision centering	30
08. Tilting operation	20
09. Z axis rising & final tilting operation	7
10. Transfer to epoxy apply position	7
11. Transfer to detailed tilting operation position	7
12. Detailed tilting	7

2.3 System configuration

Fig. 1 displays alignment stage. The stage comprises 7 axes that run using all stepping motor and we display the specification of details in table 2. The wave of 1550nm is used for optical source to get optical feedback, the SONY XC-55 is used for vision recognition, and the HexSight from Adept is used for vision analyze program.

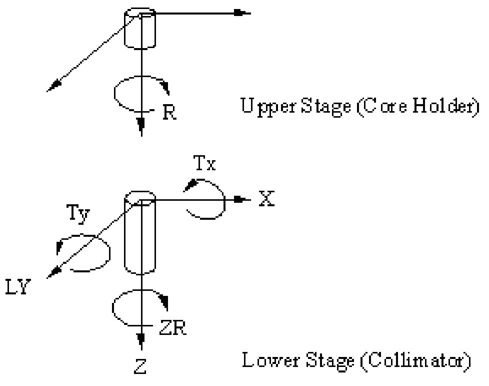


Fig. 1 Alignment stage.

Table 2 Specification of axes.

Align Axes	Range	Resolution (w/ H.S.)	Max. Speed	Repeatability
LY	200mm	2 ㎛	20mm/sec	≤±1 ㎛
Z	12mm	0.36 ㎛	3.7mm/sec	≤±0.5 ㎛
X	20mm	1 ㎛	20mm/sec	≤±0.3 ㎛
Tx	±5°	0.001°	10° /sec	≤±0.005°
Ty	±5°	0.00125°	12.5° /sec	
R, ZR	360°	0.002°	20° /sec	≤±0.01°

We examined the target system of alignment. In next Chapter, we will analyze alignment sensitivity that is precession of the active alignment design on the system that we have explained.

3. ANALYSIS OF SENSITIVITY

Optical alignment has more space to examine and each axis couples than geometrical alignment by vision. We can reduce the total processing time and the searching space compass by searching the most sensitive effects of axis through the sensitivity analyzing because the task to find the loss of optic lights is crucial. There was already progress on study of DWDM band-pass filter and its reflection sensitivity analysis, we were able to observe that alignment sensitivity of Z axis came out in very small scale [5]. In this study, we analyze experimentally the alignment sensitivity of X, Y, Tx, Ty axes except Z axis by using the alignment target Core Holder and Collimator. Optical loss is measured by changing the position of each element in the condition of the parts alignment is completed. We confirm the alignment sequence of existing process by this result as a basis and propose the alignment method and search algorithm with character sensitivity of each axes. The measure value of the each graph displays the return loss express near source when the measure value is close to 0 dB.

3.1 Measurement of optical loss at X, Y axes

The distribution transfer is caused by return loss when the transfer of X axis is happened and we display that in Fig. 2. Fig. 3 displays the measured optical signal. The result, when the X axis is transferred, there is the maximum intensity of light with little loss in certain division. While in the rest division, there is the intensity of light with rapid loss. We can get the same result at the Y axis. This result shows that we can place the X, Y axes at the minimum loss position only with the geometric alignment of Core Holder and Collimator.

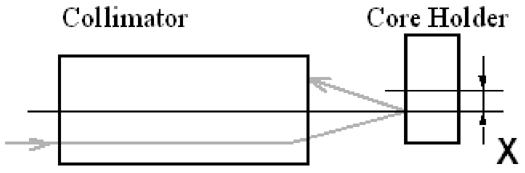


Fig. 2 Loss expectation in X axis.

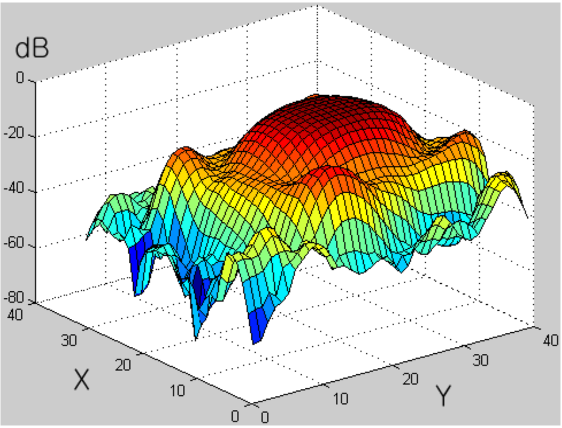


Fig. 3 Actual optical signal in X and Y axis.

3.2 Loss expectation in R axis

Also the loss occurred by changing the spin axis R as in Fig. 4, and the results are shown in Fig. 5. In the measured result, we can recognize the rapid reduction of the loss at the spin angle in the certain division.

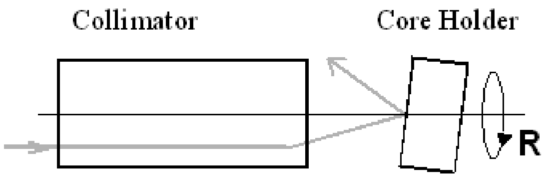


Fig. 4 Loss expectation in R axis.

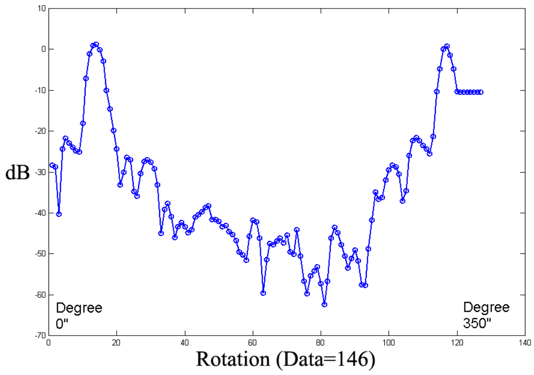


Fig. 5 Actual optical signal in R axis.

3.3 Loss expectation in Tx, Ty axes.

Except the change of X, Y and R axes, the light loss happens when θdegree inclination happens in alignment process as in Fig. 6. From Fig. 7, which measures the optical signal of the actual Tx, Ty axes, we can see that the dB of the optical signal decreases rapidly as the angle increases. Since the sensitivity of Tx and Ty axes are much higher than other axes, we could reach the conclusion that alignment of Tx and Ty axes requires accurate search algorithm.

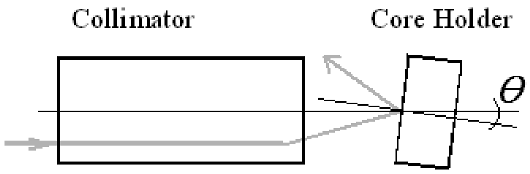


Fig. 6 Loss expectation in Tx axis.

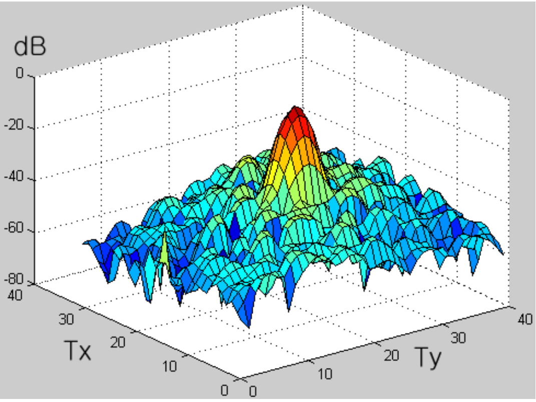


Fig. 7 Actual optical signal in Tx and Ty axis.

In next chapter, we display improved align process and propose the proper search algorithm with the alignment of sensitivity which is analyzed so far.

4. PROPOSED FAST ALIGNMENT METHOD

In this chapter, we reorganize the existing align process by applying the idea introduced above and introduce search algorithm for Peak Search.

4.1 Task sequence

We reorganize the 4, 5, 6, 7 and 8 items which are targets of this research among the existing align process in table 1 and display them in table 3.

Table 3 Task sequence

Task	Feedback		Actuator						
	Vision	Optic	R	X	Y	Z	Tx	Ty	ZR
1. X, Y axes alignment	■			■	■		■	■	
2. R axis alignment & Epoxy apply position checking		■	■						
4. Tx, Ty axes alignment		■					■	■	

First, we perform the geometrical alignment for assembly. We already proved through the sensitivity analysis that the geometrical alignment is sufficient to perform X and Y axes optical alignment. The reason why Tx, Ty axes are used together with the alignment of the X, Y axes are to prepare for the situation where the Core Holder's position goes steep. After the optical alignment of X, Y axes, we go away from the noise level through rotation of R axis and finished the preparation for Peak search. At this moment, by checking the position of Core Holder for Epoxy apply at the same time, we can carry out the task as a first step which was the second step of existing process. Since the R axis transfer is required to check position of Core Holder and R axis alignment. In Fig.*, we display the relation of castle space and Core Holder recognized in vision. At last the perform Peak Search through tilting of the Tx, Ty axes. We can remove the additional vision centering task in existing process by movement of each axes considering kinematics. By performing five axes of alignments for the optical alignment, two optical parts are exposed to optimal optical path.

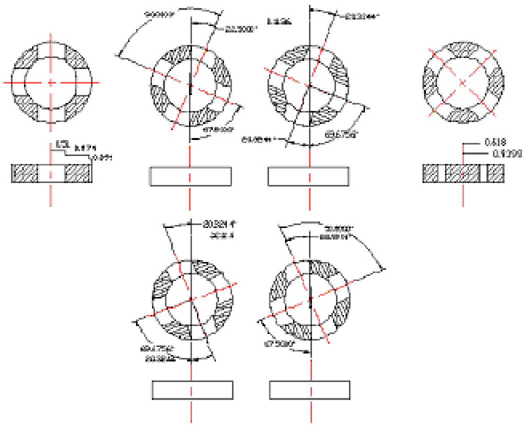


Fig. 8 The castle shape following the Core Holder rotation

4.2 Search algorithm

With the geometric information, the optical parts using the vision X and Y axes are arranged the each axes to search the optimal position where the reflection loss is minimum. We proposed the three Tx, Ty axes search algorithm.

4.2.1 Hill Climbing algorithm

The search structure of Hill Climbing algorithm is logically simple, without crucial error, it carries out the optical search easily. However, compare to other algorithm, it doesn't happen to change for delicate transfer, it might fail to find the maximum value at near the maximum spot. In order to overcome these problems, we applied the Progressive Peak Search and compared.

4.2.2 Progressive Peak Search algorithm

Progressive Peak Search algorithm decides the step by the intensity of light to prepare Hill Climbing's inefficient search which is cause by the interval control simple ness. The entire logic is very similar to Hill Climbing, but the transfer distance depends on the light answer response like the Eq. (1).

$$X = X_{\min} + (X_{\max} - X_{\min}) \times \left(\frac{PPV - V_{\det}}{PPV - PPV \times \%PR}\right). \quad (1)$$

Where

PPV : Peak Power Voltage

$V_{\det}$: Voltage reading at detector

$\%PR$: %Power Range Scale

4.2.3 Steepest Search algorithm

Steepest Search algorithm is different from Hill Climbing in that the Tx and Ty axes both move instead of just one of them. Though the Eq. (2) for calculating the steepness of Tx, Ty axes, we can find the direction of minimum loss position, and thus, can find the minimum distance. However, it has the side effect of being very sensitive to the initial position, and thus, has to be taken care of when setting the initial position or condition.

$$\tan\theta = \frac{Ty2 - Ty1}{Tx2 - Tx1} \qquad (2)$$

Where

$Tx2, Tx1$: 2 points measured along Tx axis for unit length

$Ty2, Ty1$: 2 points measured along Tx axis for unit length

We have designed the task for active alignment and have suggested the algorithm used in each task. In the following Chapter, we will confirm the optimal algorithm through experiment.

5. EXPERIMENT AND RESULT

We have performed the alignment experiment using the previously suggested priority of alignment and algorithm. As a whole, it could be divided to geometric alignment using vision and application of optic search algorithm for peak search. We have used the method where the arrangement ends when the optical response is below certain loss in order to arrange R axis.

5.1 Geometrical alignment

In this study, we apply the channel R and G to the two camera to get the input from each camera, thus it can be obtained 3-Dimension coordinate system by outline abstraction of obtained vision. We chose Diffuse Back Lighting method to get accurate recognition because the target object may include transparent parts. We have extracted the edge with 1/10 sub-pixel exactness and formed model to get the location data [5].

We embody the 3-Dimension by recognizing the X-Z, Y-Z, the 2-Dimension plain. We have performed the geometrical alignment of X, Y, Tx and Ty axes by switching Core Holder and Collimator's location data to actual location value using vision. The response was relatively quick, since it took form 180ms to 300ms to analyze one frame. It took an average of 2.9 seconds to process and arrange the image, each obtained from two cameras, and completed the alignment within the allowed error limit of 5㎛, 0.10° . The number of axes used is four, and since the X, Tx, Y and Ty axes are coupled, we have controlled actuator using kinematics analysis. In Fig. 9, we have displayed the Core Holder and Collimator where the geometrical alignment is completed. And in order to check the position of Core Holder, we display the castle space recognized at vision in figure.

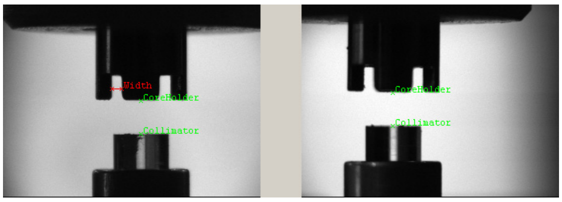
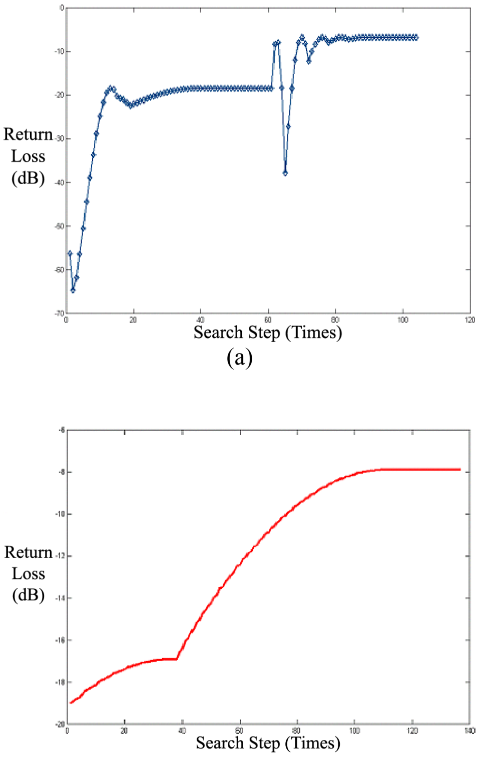


Fig. 9 Geometric alignment of Core Holder and Collimator

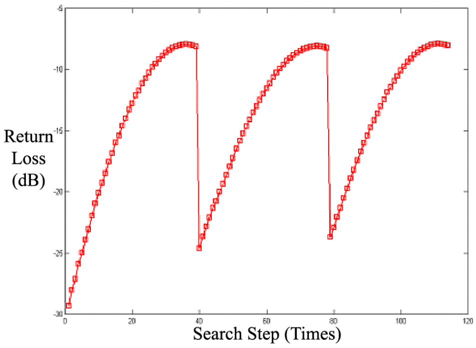
5.2 Experiment of optic search algorithm

After the X, Y and R axes are arranged, we have searched using the previously suggested three algorithm. We have displayed each result in Fig. 10. The horizontal axis displays the number of movement of each axis, while the vertical axis displays return loss.



(a)

(b)



(c)

Fig. 10 Search Result; (a) Hill Climbing;
(b) Progressive Peak Search; (c) Steepest Search

The result of Hill Climbing algorithm achievement has fast convergence in early stage, but it converges after big error is occurred in case of changing movement direction or changing alignment axis. Meanwhile, the Progressive Peak Search algorithm achieves with an allowable error, but it converges at almost same movement time as Hill Climbing. In case of Steepest Search algorithm, it converges with low movement time relative other algorithm because of it aligns with using two axes at the same time toward to minimum loss point. According to this, when you search certain project required searching multi-degree of freedom, it has advantage to use multi-axis at the same time than simply searching each axis with one-axis expansion.

Also, the search step is one of the main factors for time required. The wide-step search is strong for noise, and able to achieve the task rapidly, yet difficult to get accurate measurement. On the other hand, short-step takes longer time to search. The table 4 shows the appropriate algorithm depends on initial optic response, and initial step through out the experiment.

Table 4 Algorithm selection and Search step by Optic response

Algorithm	**Initial optic response**	**Initial step**
Hill Climbing	-30dB above	minimum step $\times 2^8$
Progressive Peak Search	-30dB above -20dB under	Depends on the light answer response
Steepest Search	-20dB above	minimum step $\times 2^3$

5.3 The experimental result

The table 5 shows achievement time of the task. The geometrical alignment can be achieved relatively fast by using vision recognition. The reasons for this are vision's fast response time, and there is relatively less time to move actuator for parts alignment. The average searching time of each search algorithm is alike at the same condition. This is the experimental result of each search algorithm without considering the optical response status of performed search algorithm previously. It is expected to show high performance if the search is performed by choosing appropriate algorithm depends on its optical distribution status with covering up merits and demerits of each algorithm. In table 6, we display separately the required additional time to check position of Core Holder. 0 degree is aligned position and it repeats periodically at 90 degree. We can get certain required time of checking position of Core Holder which depends on the initial position and it needs 2.7 seconds on average.

Table 5 Result

Task		**Required Time (sec)**				**Avg.**
		1	2	3	4	
1. X, Y axes alignment		2.93	2.94	2.94	2.92	2.94
2. R axis alignment		11.97	12.17	12.70	12.40	12.31
3. Tx, Ty axes alignment	Hill Climbing	21.23	26.17	20.83	26.91	23.79
	Progressive Peak Search	21.16	20.85	13.88	21.87	19.44
	Steepest Search	16.73	26.88	17.75	25.07	21.61

Table 6 Required time for checking position of Core Holder

Initial Position			0°	5°	10°	15°	20°
Required Time (sec)			1.4	1.7	2.6	3.9	4.1
25°	30°	35°	40°	45°	50°	55°	60°
3.7	3.7	3.0	3.7	2.8	2.8	2.8	2.3
65°	70°	75°	80°	85°	**Avg.**		
2.4	2.5	2.8	1.8	1.4	**2.7**		

6. CONCLUSION

In this study, we show how to shorten the task period of search system that has more than double feedback and multi-degree of freedom. We also show the way to decide of 3-D position and we achieved geometrical alignment based on this. By analyzing and experimenting the sensitivity of each axis, we show how to decide the alignment method. We also understand that efficient and active alignment is possible with deciding follow search algorithm by the previous result. The result of this research present how to search multi-degree of freedom alignment system, and also how to increase the efficiency of task which requires fast and accurate search. Also, we expect more efficient alignment with improvement of search algorithm for Peak Search and the way to search multi-degree of freedom system.

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