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Design and Implementation of High-Precision Control System of Focus Alignment of Near-Infrared Laser for Fire Detection

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Abstract

Recently, context-awareness technology is commonly used in various fields such as detection of objects, persons, and smoke using visible infrared laser. During laser light acquisition process between source and receiver, blockage and attenuation events should be considered. The focus alignment upon receiver plays an important role in the acquisition process so that, In this paper, focus alignment algorithm of infrared laser in distant (min. 100m) is developed and implemented by visible infrared laser based image processing technique and a high-precision control method for auto-focus alignment system using extracted features between transmitters and receiver local oscillators. The present method allows various laser embedded devices using proposed alignment system for deviation in response to the external environment and initial setting for the smoke detection.

Keywords: *Near-Infrared Laser, visible infrared laser, focus alignment algorithm, high-precision control, smoke detection*

1. Introduction

If a fire occurs, early detection is required to avoid a serious possibility of massive injuries. The smoke detection method at the beginning of ignition of fire is popularly used to spend less time to notice rather than thermal detector. Especially, a chemical fire detector is sensitive enough to measure a small amount of chemical parameters caused by a fire and detect it more promptly[3-4].

However, its response time and range of detection are varying from minutes to hours depending on the distance between sensors in a traffic tunnel, subway station, or underground shopping center. Upon installing sensors and detectors closer to reduce the response time, a relatively high cost of installation and labors are remained[5-7].

In order to solve this issue, a fire infrared smoke detector that covers over 100m has been developed. Although laser line targeting onto detector with high accuracy and automatic alignment system independent of environmental bias are required in the fire infrared smoke

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detector, a resolution of 100m physical distance depending on the structure of the receiver and transmitter causes angular disturbance [8].

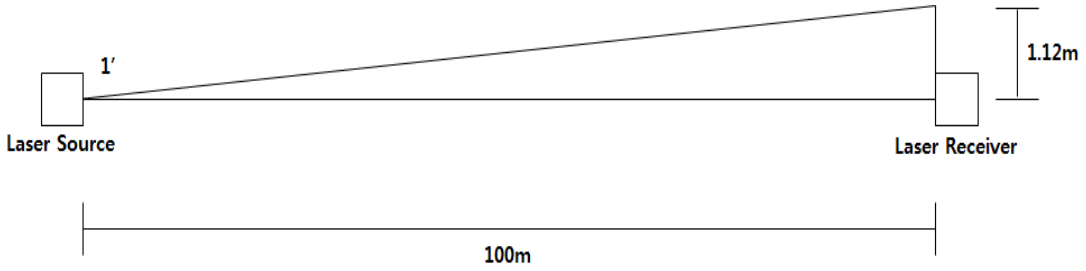

Figure 1. A Distance Onto Target in Response to Angular Failure

As in Figure 1, the position of received laser is shifted more than 1m from the detector in response to inaccurate irradiation with 1 degree error. For example, it is necessary to have a high-precision control system control system with 0.1 degree increment when the spatial resolution of the fire detector module is 10cm across. Therefore, in this paper, we designed the auto-focus matching algorithm that determines whether the alignment of the laser points on target is appropriate and implemented the high precision controller system.

2. Materials and Methods

An optical fire detector sensor is generally used in large open areas and effective at detecting fires with low cost. It works by the increment of light scattering upto 15% from smoke particles. It allows an early fire detection and has become widely used in sensitive applications. However, they are usually more expensive to install compared to thermal sensors and are more resistant to accidental alarms. Moreover, it is necessary to install less than 15 units at a time in order to prevent an electrical malfunction due to the amount of unstable power consumed for lasers. Therefore, there is limitations for multi-purpose usage in various fields. As shown in Figure 2, the optical smoke detector consists of ① Optical chamber, ② Cover, ③ Case moulding, ④ Photodiode (detector) ⑤ Infrared LED.

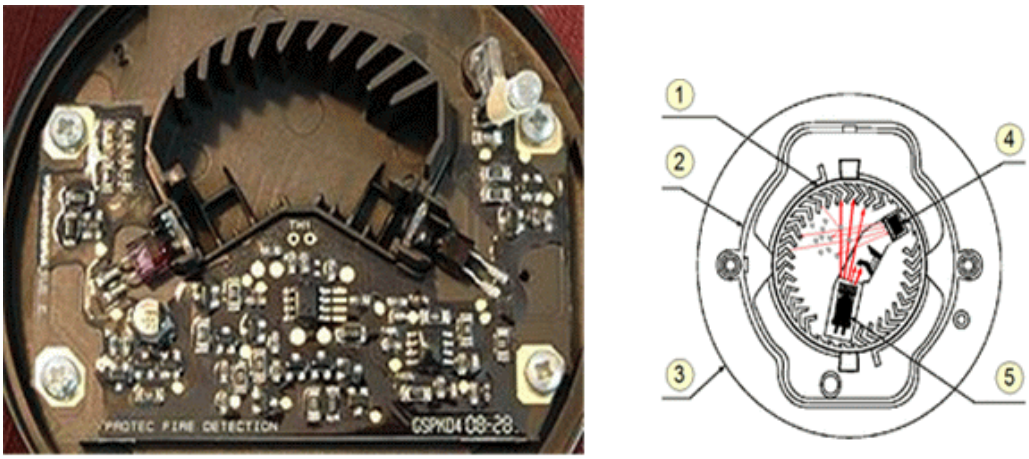

Figure 2. Optical Smoke Detector with the Cover Removed

Class-2 infrared laser based smoke detector systems are installed which perpendicularly cross through each other and keep a 100m distance between source and receiver. It determines the presence of fire by realtime monitoring and measurement of sharp decrement of average light intensity from receiver. Since long distance optical transmission from source to receiver, additional auto focus alignment algorithm may be required to achieve higher transmission quality. Therefore, high precision auto-focus alignment algorithm using infrared laser and image processing technique is developed and angular control unit for laser transmission using worm gear with stepping motor is designed and implemented.

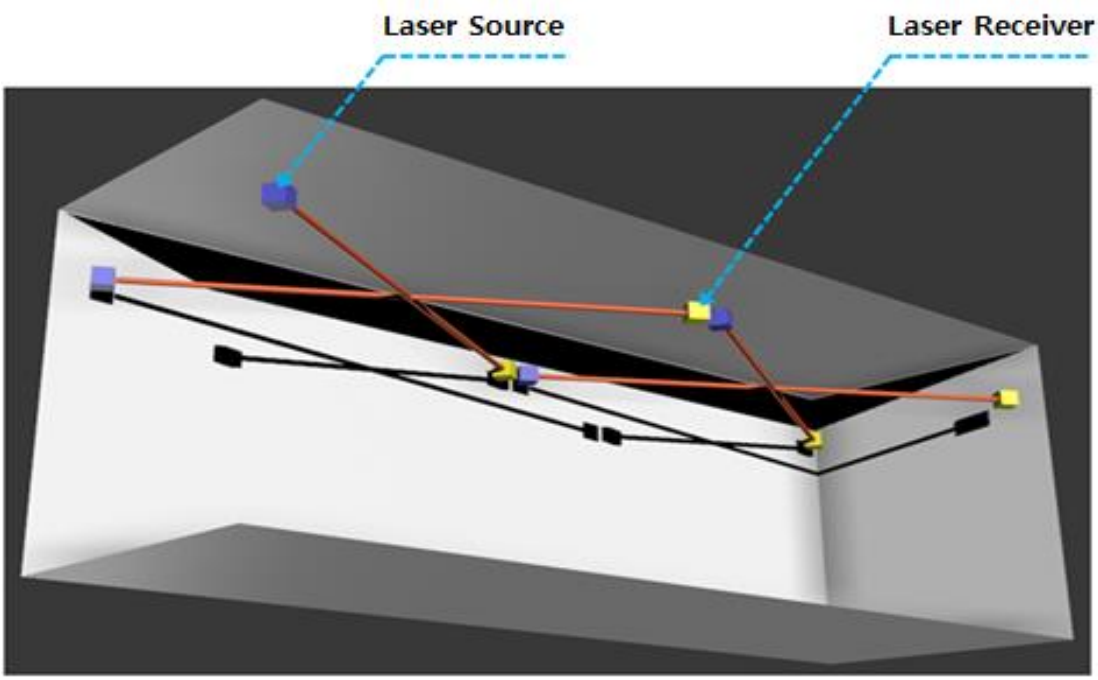

Figure 3. Installation of Infrared Laser based Smoke Detector Systems

A. Configuration

High precision controller is comprised of two axial worm motor units in the laser oscillator as shown in Fig. 4 and laser transmitter consists of

1) infrared(IR) laser transmission module: Class 2 laser transmitter

2) visible light irradiation module: visible light laser

3) controller module: worm gear or stepping motor

4) wired/wireless communication module: ethernet cable or Zigbee standards

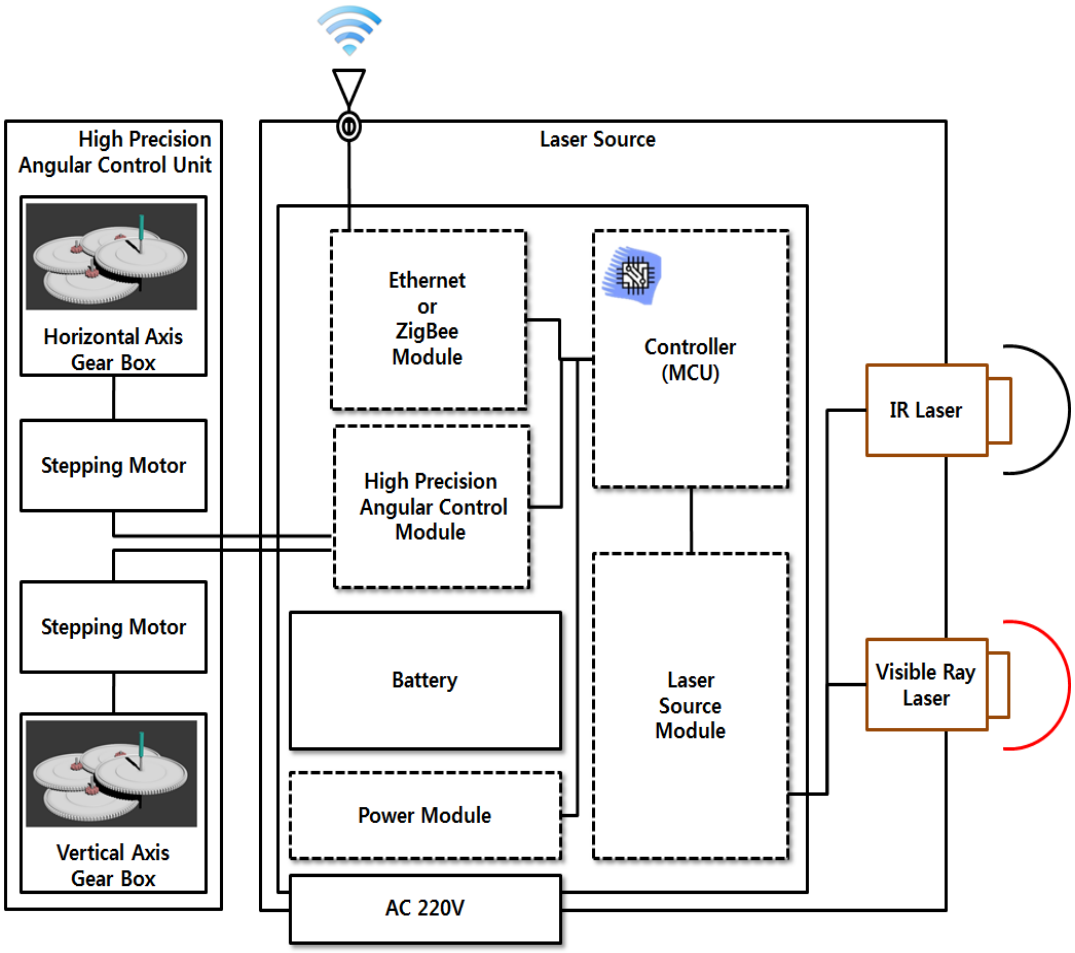

Figure 4. Schematic Diagram for Laser Transmitter

The detector module including a digital camera for image processing as shown in Figure 5 consists of

1) laser detector module : Class 2 laser transmitter

2) digital camera module : angular analysis using telephoto or zoom lens attached camera

3) wired/wireless communication module : ethernet cable or Zigbee standards

- Laser light-receiving section: Class2 IR laser receiver module

- Camera module: video processing of the angle of the rays of visible light laser (telephoto / zoom lens attached)

- Wired / wireless communication module: Zigbee wireless communication or Ethernet cable

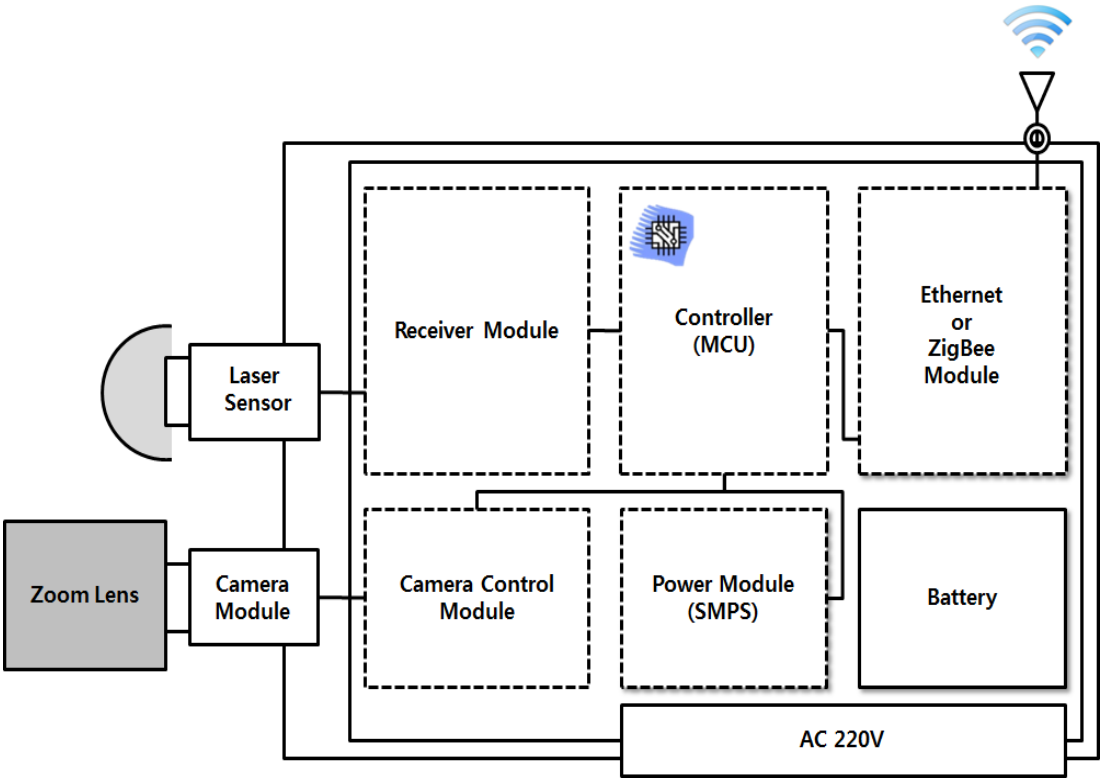

Figure 5. Schematic Diagram for Laser Receiver

B. High Precision Angular Control

4th-level worm gear having 1/10 ratio threads can precisely control the desired angular positioning of the source and receiver in 3-dimensional space. The worm screw gear continuously rotates the base plate and control plate via stepping motor.

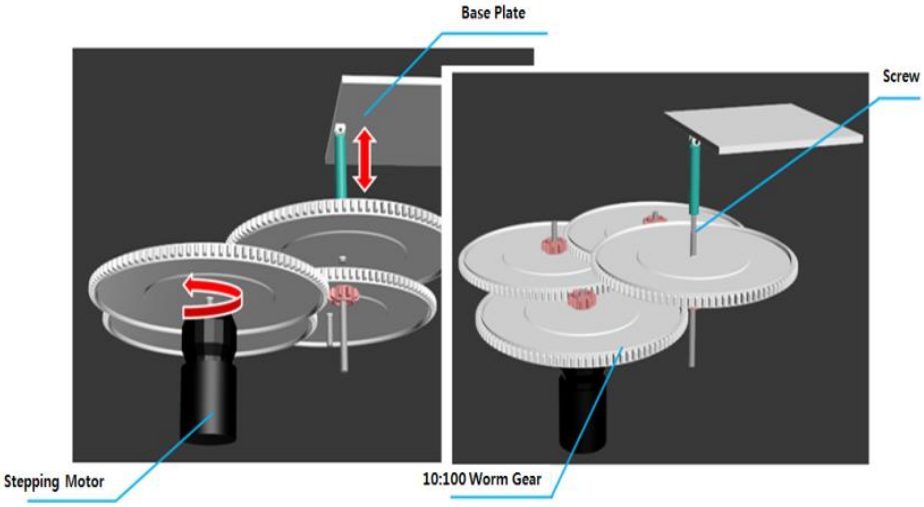

Figure 6. Schematic Figure for High Precision Control Unit

A schematic outline for the high precision auto focus alignment system can be explained as follows :

1) Laser source is installed on the control unit

2) Angular difference in orientation and distance between transmitter and receiver is calibrated by high mag. digital camera

3) Acquired XY position data from the auto focus alignment system is transferred to transmitter

4) Angular correction for laser transmittance from the source is performed by high precision control unit. Auto-focus alignment control unit consists of two stepping motors and worm gear box to control forward/reverse rotation for the laser projection angle and match the visible laser point and camera lens with high accuracy

5) Once the matching procedure for the projection module with visible laser and camera has been complete, infrared laser instead of visible laser is projected onto the light receiving unit. The automatic matching procedure executes with respect to the separation distance between the receiving camera module and receiver unit, angular distance from visible laser to infrared laser projection module etc.

6) Auto-focus high precision control unit automatically adjusts biased compartments of the initial setup stage and external environment according to incoming laser intensity. Focus matching camera module plays a role as an auxiliary function of internal CCTV monitoring for normal condition.

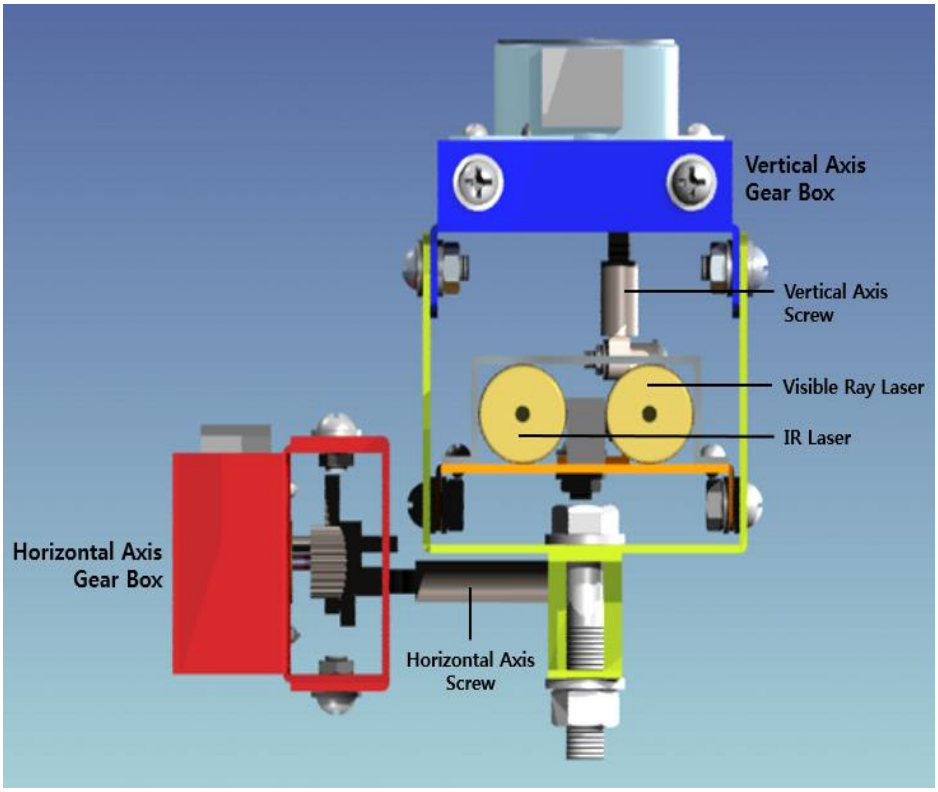

Figure 7. Configuration of High Precision Control Unit Consists of Two Stepping Motor and Worm Gear Box

C. Auto-Focus Alignment

A straight propagation pathway of the laser prior to focal matching from the integrity module in camera shows in Figure 8. The angular difference is calculated by image processing technique and it is forwarded to the high precision control unit for laser transmitting module to perform matching procedure.

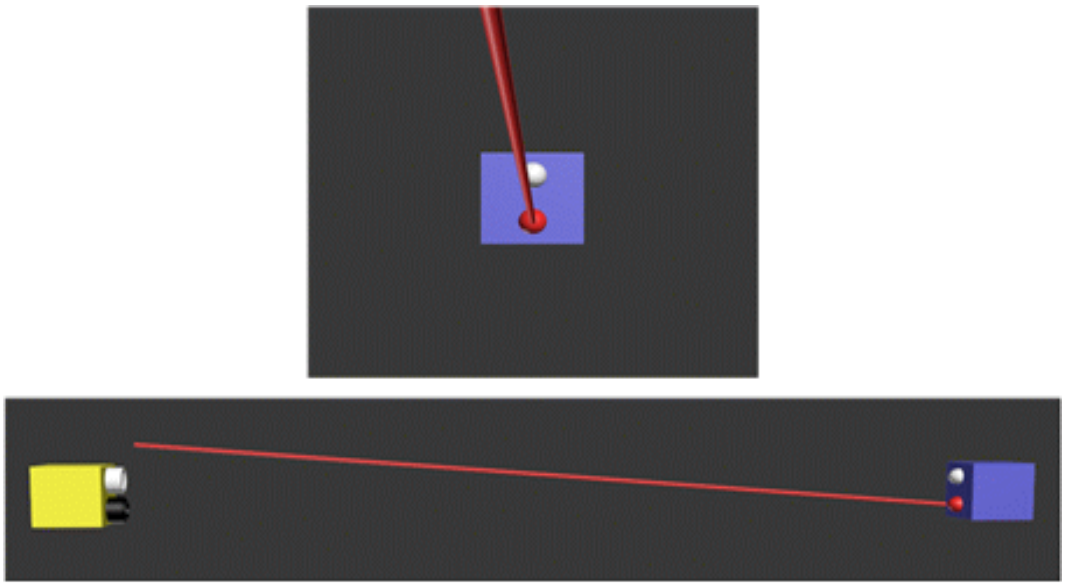

Figure 8. A Close View of the Propagation Pathway

The auto-alignment procedure can be explained as follows:

1) extract features for pathway analysis of transmitted laser using digital camera

2) configure the angular deviation according to the reference features

3) generate numerical data including the angular deviation and send to the transmitter via wired/wireless communication module

4) control the stepping motor by received angular deviation data

5) transmit real-time measurements of the pathway from digital camera until it disappears

6) repeat previous step until it is aligned and turn on/off visible light laser and infrared laser to detect fire

After the alignment complete, this receiver can acquire infrared laser signal and it disappears as in Figure 9. As a result of that, separated infrared laser is simultaneously matched when visible laser is matched.

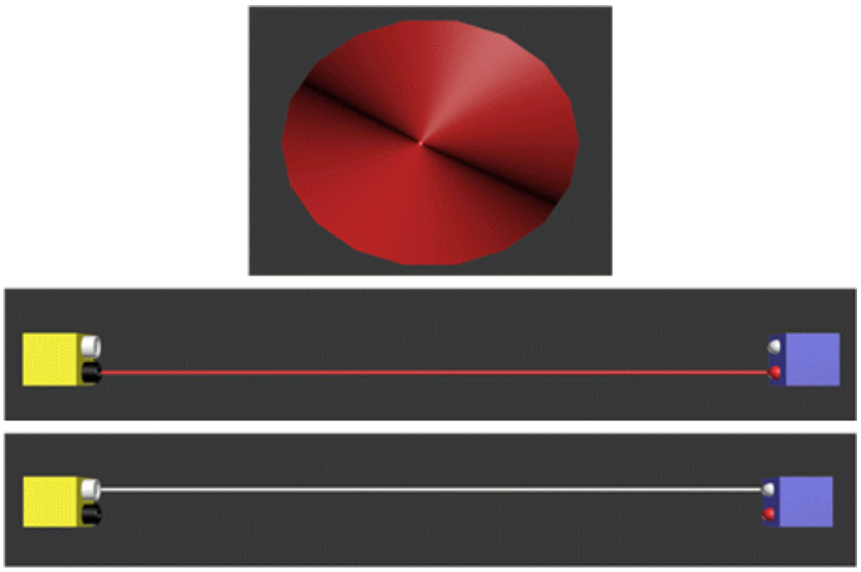

Figure 9. A Close View of Matched Laser Pathway

The basic calculation of the moving distance of the laser spot at 100m distance (d) is as follows;

$$d = (\frac{7.5}{360} \times P) \times (\frac{1}{10^{\omega}}) \times 10000$$

1) The stepping motor that controls rotation has a step angle of 7.5°
2) Screw pitch (P) = 0.4mm
3) Number of 1/10 ratio worm gear (w) = 4

Measured distance per a step is 0.008mm.

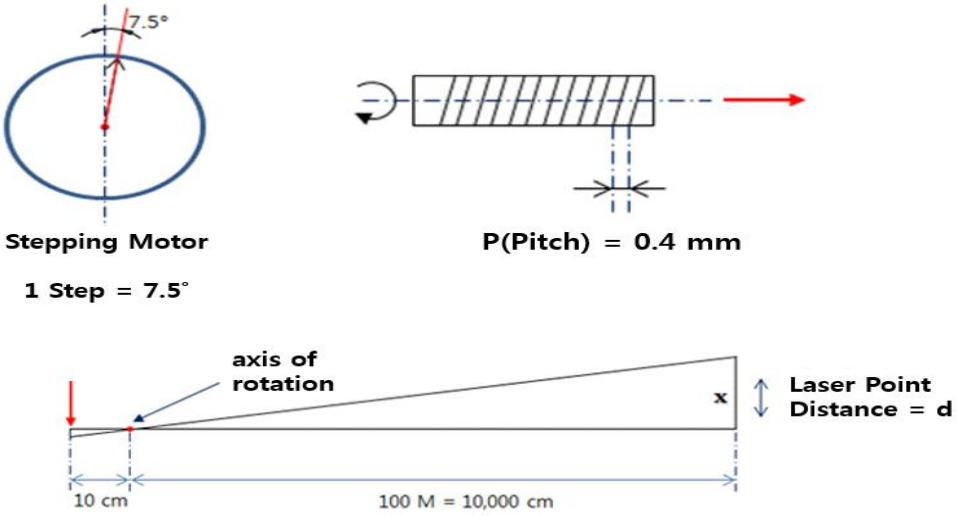

Figure 10. Control Technique of Stepping Motor

D. Design High Precision Controller for Automatic Alignment Method

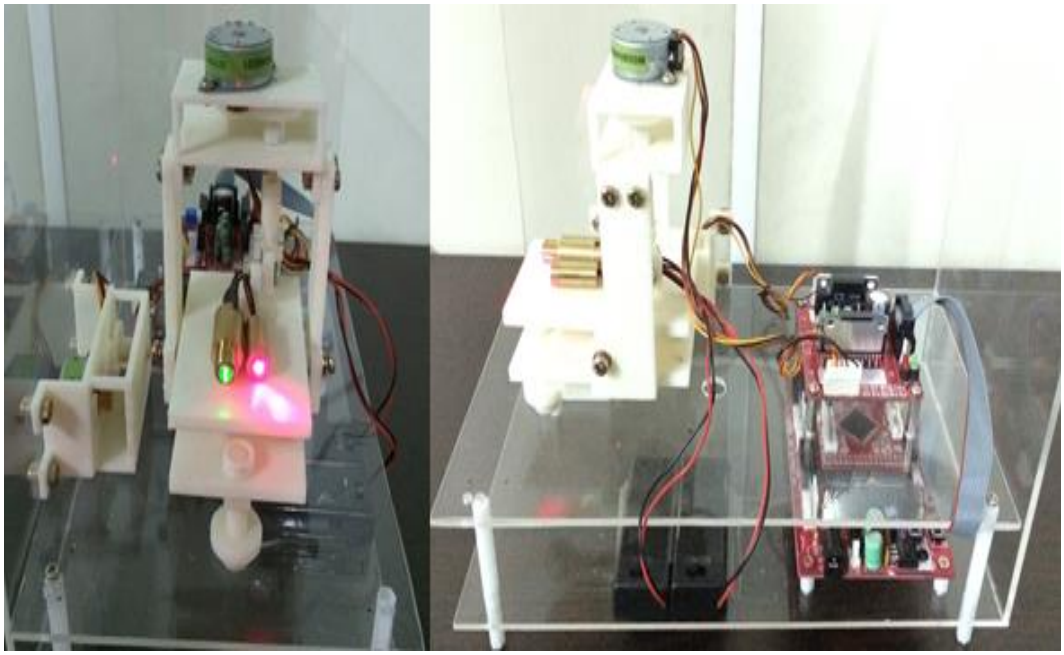

Figure 11. A Prototype of Auto Focus Matching Device

Figure 11 shows the laser transmitter with an auto focus alignment applied device designed and implemented in this paper. All compartments of this equipment is designed by RP and implemented twice the size of mounting apparatus in practice. Screw pitch processed in a 5mm due to processing limitations of 3D printers and composed of 2th-level worm gear. This equipment used the AVR ATmega 128, and Green infrared laser and red infrared laser are assumed visible laser and infrared laser, respectively.

4. Conclusions

A representative application of the smoke detector is an aspirated type detector using photoelectronic detector with an internal ambient condition sensing region and it works by the increment of light scattering upto 15% from smoke particles. It allows an early fire detection and has become widely used in sensitive applications. However, they are usually more expensive to install compared to thermal sensors and are more resistant to accidental alarms. Moreover, it is necessary to install less than 15 at a time in order to prevent an electrical malfunction due to the amount of unstable power consumed for lasers. Therefore, there is limitations for multi-purpose usage in various fields.

In this paper, laser transmitter and receiver unit are separately installed from the smoke detector and high precision control unit is designed and implemented for auto-focus matching procedure. As a result of that, it allows an early fire detection at a distance (over 100m) and its ubiquitous monitoring system coupled to a ZigBee or ethernet and wired/wireless network provides the technical current status (*i.e.*, operational status, battery status, *etc.*). In addition, auto-focus aligned camera module can provide information as an emergency event so that plays an important role as an auxiliary function of internal CCTV monitoring in metro tunnels, subway, urban utility tunnels and underground shopping malls to contribute to minimize deaths and injuries due to fire. Further implementation of high precision auto focus

algorithm using feature extraction from the acquired images and automatic alignment controller will be necessary in the near future.

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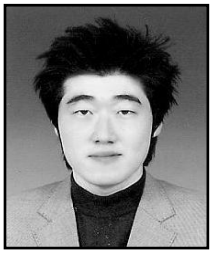

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