Measurement and Calibration System of Arrow's Impact Point using High Speed Object Detecting Sensor

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Abstract— **Currently, the method used to analyze the manufactured arrow's performance is to use the accumulated impact points of arrow. The impact point of arrow is appeared by shooting the arrow repeatedly with same force to a target paper using a shooting device. The method has some weak points, such as low accuracy, it needs long time to do the experiments because the arrow is shoot in several times, and difficult to digitize between impact points. Therefore, the measuring system for comparing manufactured arrows performance objectively and confirming quality and performance of arrow methodically and a sensor that can measure high-speed-moving object is needed. In this paper, line lasers are placed upper side and left side of a square-shaped frame, and photodiode sensors are installed at the opposite side of line lasers. When fired arrow goes through the square shaped frame, the voltage acquisition device measures the voltage level difference of photodiodes. Impact points of arrow are shown using the data derived by voltage acquisition device. A neural network calibration method is implemented using impact points which are printed out precisely by manufactured grid plate. The calibration method replaces the impact points included errors with precision and high reliability impact points.**

Keywords-measuring systemt; calibration; neural network; impact point; photodiode; arrow

I. INTRODUCTION

Currently, the bow and arrow are used as a tool for hunting, recreation, sports to hobbies. Since 1972, at the Munich Olympics to date, archery rules have been revised and changed drastically. The quality and performance of bow and arrow is needed for not only getting a good score at Olympics but also increasing of customers demand for leisure. Especially, there are plenty of ongoing researches about arrow which has complex manufacturing process and should analyze scientifically, but there are no systems and intuitive numerical data for evaluating [1][2]. The intuitive numerical data means information which can be expressed as coordinate points, such as distance between impact points, two impact point coordinate that has maximum distance, and so on. Generally, the method or reference used to evaluate arrow's quality and performance is to use data based on testimonials by hunters who have used bow and arrow for a long time, by technicians who produce leisure sporting goods, and by customers. In addition, previous research results through patents have biased technology that optimizes producing process using manufacturing variables. There is testing process for getting performance of arrow. First, attach shooting sheet on target. Second, shoot an arrow repeatedly with changing angles of nock every time. Third, check impact points of arrow and measure how dense they are. The denser of impact point, the better of performance and quality of the arrow. Analyzing impact point of arrow using shooting sheets has some disadvantages, such as low accuracy, should be replaced frequently and periodically, and the difficulty of digitize between impact points. The other way to gather data of arrow's performance is using high-speed camera, but it has also disadvantages that can see only limited angle images, and highly expensive price. For overcoming disadvantages of traditional analyze process, this paper suggest that by using of line laser and photodiode sensors which have high resolution and fast response rate, the measurement of high-speed moving arrows produced good results. By installing photodiode sensors in array formation, it can obtain the voltage level changes in the position to be passed by the arrows in the frame. All data from the photodiode sensors are acquired by Data Acquisition Device (DAQ), produced by National Instruments (NI). Then, they are transferred to Host PC connected by port or slot. This transferred data is shown by LabVIEW program in PC. However, initially appearing impact point of arrow includes errors that occurred by light of line laser and structure of photodiode array. To compensate the errors, this paper suggests calibration method using neural network (NN) [3][4].

The remaining part of the paper is organized as follows: In section 2, we describe about measuring impact point of arrow system. Additionally it describes that previous measuring system which has some drawbacks and theoretical explains about suggested method. Section 3 gives a calibration algorithm using NN. Also it includes experiments and results to proof calibration. Finally, a conclusion is drawn in section 4 with an outlook to future work.

II. MEASURING SYSTEM DESIGN OF ARROW'S IMPACT POINT

In this section, the problems of current used measuring system of arrow's impact point in real manufacturing

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company are discussed. And also the solving problem by the proposed novel hardware structure and method of impact point using measuring data are showed.

A. Problems of impact point measuring system

Fig. 1 indicates structure of arrow. It consists of point, insert, shaft, crest line, fletching, and nock. It also can be divided into three parts, each part named arrowhead, shaft of arrow, and feathering. Arrowhead is usually made from stone or metal which is attached to the end, and its role is to penetrate targets substantially. Shaft of arrow is made from composite materials, generally produced in the form of aluminum core wrapping by carbon fiber. Traditionally, feathering is made from feathers. But in modern, it is made from plastic materials. It can prevent shaking of arrow, and also ensure stability of flight.

Due to advance manufacturing process and materials, it is possible to produce arrows which have not only good quality

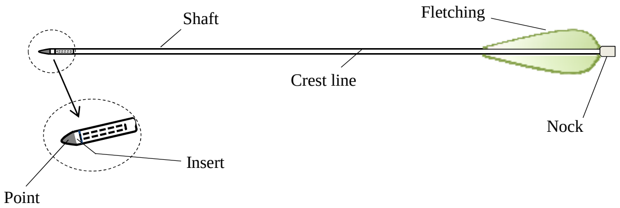
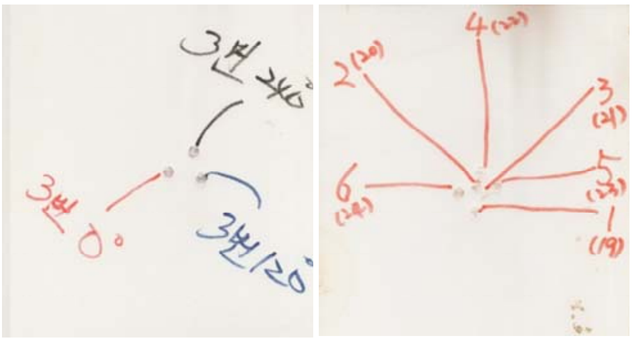


Figure 1. Structure of arrow

(a)



(b)

Figure 2. Arrow shooting environment and test sheet of impact point: (a) Arrow launch pad and shooting environment, (b) Analyzing density of arrow's impact points by handwriting.

but also good performance, and increased flight distance and accuracy. Both flight distance and precise accuracy are largely affected by characteristic variables of arrow, such as weight, external diameter, spine, straightness, angle and shape of feathering. According to these characteristic variables, the impact point and flight distance of arrow shows different. Hence, there are plenty of researches and experiments about impact point's density by attaching shooting sheets on target that find out relations between characteristic variable, impact point and flight distance. But in case of measuring arrow's impact points, commercialization of technologies and systems are lacking. And arrow manufacturing company focuses on patents and technologies that optimizing the characteristic variables that occurring in production process. That disproportionate development caused by difficulties of determining objective performance of produced arrow because there is no measuring and classifying system of arrow's impact points, also there are no data numerically represented. Analyzing technology of arrow's impact point density is still in the early stage, and there are only a few available measuring platforms using handwriting and high-speed camera. Handwriting process is shown in Fig. 2b. First, attach shooting sheet on rational distance from target. Second, shoot an arrow repeatedly changing angles of nock every time. Third, check impact points of arrow and measure how dense they are. If impact point of an arrow has high density, then the arrow is determined that it has good quality and performance. But analyzing impact point of arrow using handwriting, there are some disadvantages, such as; low accuracy, it should be replaced frequently and periodically, and it is hard to digitize between impact points. In case of high-speed camera, on the other hands, it can compare arrow's shape while flying to other arrows using obtained video or images, but it can only watch restricted view angles. And it is hard to digitize between impact points, like handwriting. Fig. 2a shows the

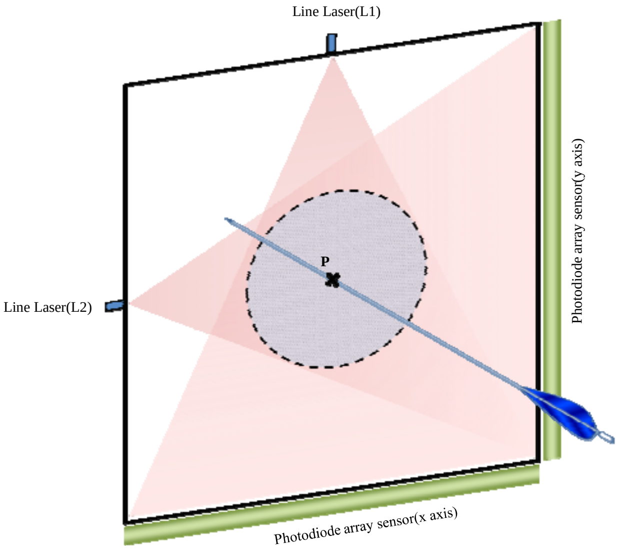


Figure 3. Single frame for measuring arrow's impact point.

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pictures of launch pad and shooting experiment environment which are actually used in manufacturing industry. It is about 39 meters far from launch pad to target. And the launch pad can shoot arrow with the same force. Fig. 2b shows the pictures that currently used handwriting impact points of arrow result in manufacturing company.

B. Hardware design for detecing high speed moving object

In order to solve current system problem that using handwriting and high-speed camera, this paper suggests hardware design for measuring impact point using novel structure and sensors. Photodiode sensor is suitable for measuring position of arrow moving in high speed, and considering response sensitivity of photodiode, it is appropriate pair that red light line laser [5][6][7]. The photodiode has 5.6mm diameter, spectral sensitivity is 450~1050nm range. Power consumption of a line laser is 100mW, and the laser straightly emits red light laser with spread 60 degrees because of inner structure consists of small size mirror in the module. Since photodiode is converting device that converts light energy to electrical energy, so photodiode voltage level changes relying on light intensity of line laser. When arrow passes the experimental structure consists of photodiode and line laser, namely the frame, voltage level changes of photodiode can be measured. Based on the measured data, impact point of the arrow can be represented. As shown in Fig. 3, two line lasers installed in L1, L2 position at the single frame, 80 photodiodes on the substrate installed opposite position of line laser. Position of the line laser should be placed in the center of photodiode substrate. And position should be in the form of coordinates, so square-shaped frame is used. The length of one side is 65cm, and each side is exquisitely crafted in right angle.

An arrow has high flight speed, average 250km/h and maximum 300km/h. For obtaining one point of the high-speed arrow, sampling time should be about 5ms to 15ms. For measuring and dealing with large amount of data, analog input module that have high sampling rate and cover lots of channels relying on number of photodiodes is needed. Therefore, this paper chooses DAQ device, produced by National Instruments, which has high sampling rate and can handling lots of input channels. In order to measure the data that is output from a number of photodiodes, 8:1 Multiplexers(74HC/HCT4051) are used, and the MUX is controlled 3 bit digital signal generated by NI 9401 module. Signals from MUX are connected 20 channels as input using NI 9205 analog input module. The NI 9205 analog input module has maximum 250kS/s on sampling rate, also has 32 analog input channels. 20 channels used in this paper, and 20kS/s for each channel. One channel of NI 9205 connected to output of MUX, and each MUX cover 8 photodiodes. NI cDAQ 9718 8-slot USB chassis performs not only synchronizing NI 9401 and NI 9205 module, but also sending analog signal that input analog signal from NI 9205 to Host PC. Trigger signal occurs when arrow is shot on launch pad then NI-9178 chassis take the signal as input, and acquiring data during 1 second. Due to obtain data for 1 second, the number of acquiring data from one photodiode is 2500. The acquired data is sent by computer bus connected slot or port from DAQ to Host PC. The computer bus performs communication interface between DAQ device and computer for transmitting and receiving commands and acquired data. Fig. 4 shows hardware design of suggested system that starts emitting red light line laser, causes changing voltage level of photodiode, DAQ measures the changes and finally sends the measured signal to Host PC.

C. Impact point expresion using voltage level scale

In previous section, the explanation of devised structure for expressing impact point and measuring data generated by photodiode sensor using NI DAQ were described. As shown in Fig. 5, the flowchart present the entire processes from

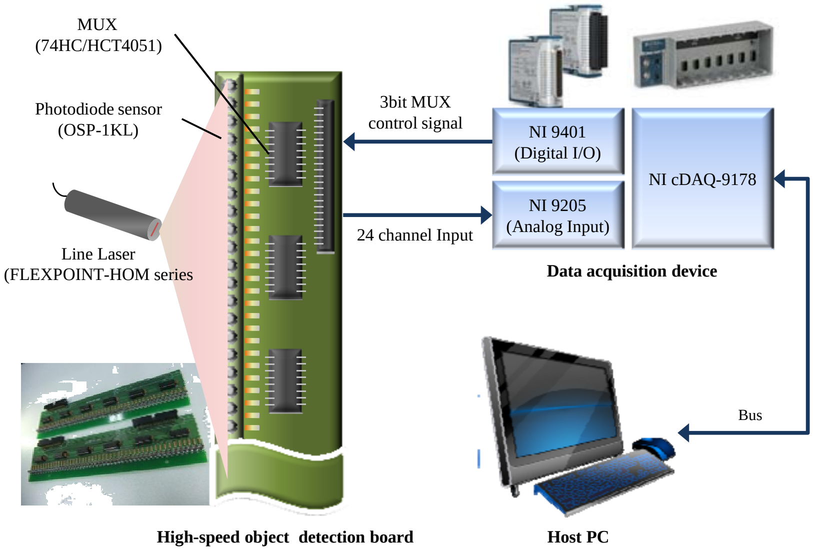

Figure 4. System design of measuring impact point.

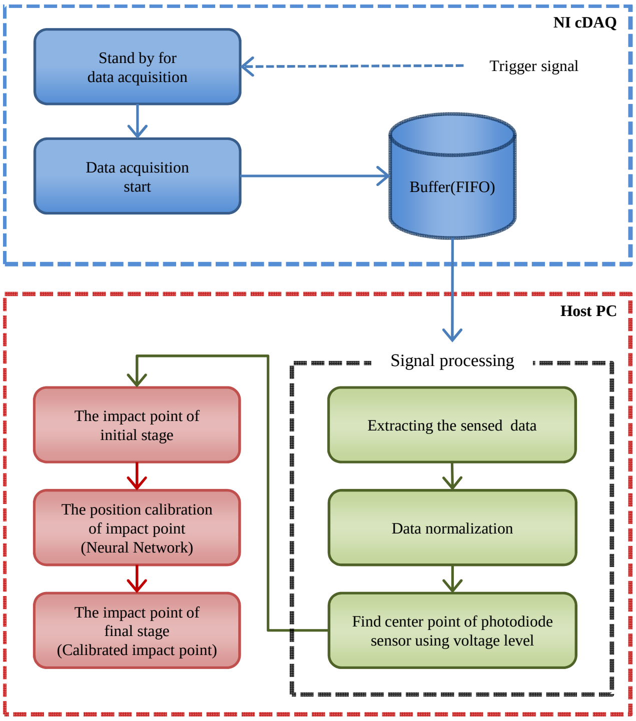

Figure 5. Overview system.

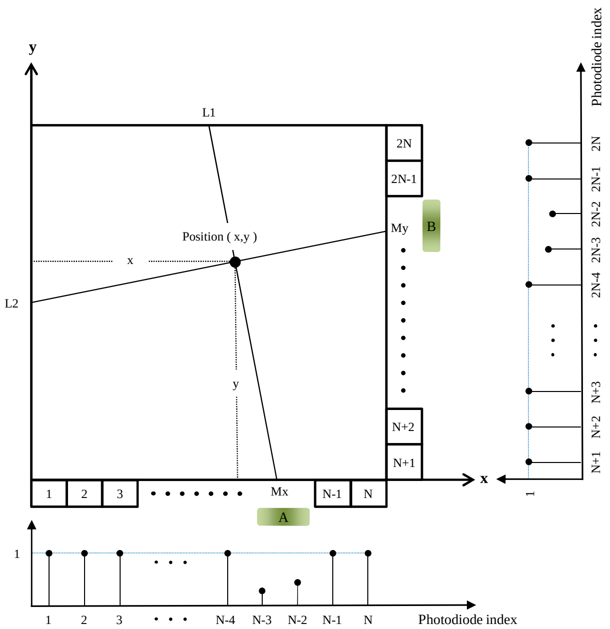

Figure 6. Impact point expression using voltage level scale.

sending measured data to Host PC using NI DAQ to expressing impact point through processing of the transferred signal. When line laser emits light to single photodiode sensor, output voltage of the photodiode is about 0.5V. On the other hands, if some object makes shadow by passing above the single photodiode, then output voltage is dropped at about 0.3V.At the moment of shooting arrow the trigger signal appeared. After the trigger signal, acquiring time begins during 1 second. Due to obtain data for 1 second, the number of acquiring data from one photodiode is 2500. The voltage dropping levels are slightly different each other because of photodiodes sensitivity. And because of line laser spreading angle, 60 degree as mentioned earlier, there are voltage level difference between photodiodes which located center position and photodiodes which located edge of the substrate. The center position of photodiodes has higher voltage level than the edge position ones. In order to make voltage level equivalent, min-max normalization method [8] is used. The extracted data is normalized in Host PC, the normalized data is used for obtaining center point of photodiodes that changing the voltage level because of shade of arrow, finally initial impact point is expressed including errors. Errors that occurring square-shape steel structure for measuring arrow's impact point are calibrated using NN.

If an arrow passes through single frame, shade occurs by the arrow in A, B region that part of photodiode array as shown in Fig. 6. Due to the shade by the arrow, voltage level of photodiode sensor drops. Using the voltage level of the photodiode and its index, center of photodiodes is derived. For finding center point of photodiode shaded by the arrow, equation of finding center of mass [9] is used, and it is represented in,

$$P = \frac{\sum_{i=\alpha}^{\beta} V_i K_i}{V_{total}}, \tag{1}$$

where, K indicates index of the photodiodes. V means dropped voltage level by the shade of arrow, and V_{total} is total dropping voltage level by the shade. The center point of photodiode which shaded by the arrow is shown in Fig. 6. Where M_x is center point of A region, and M_y is center point of B region. In other words, the intersection point of $\overline{L1M_x}$ and $\overline{L2M_y}$ is the impact point of the arrow, represented as Position(x,y).

III. CALIBRATION AND RESULT OF ARROW'S IMPACT POINT USING NEURAL NETWORK

The calibration algorithm for improving precision of measuring arrow's impact point using grid calibration plate is applied. The grid calibration plate has grid points that have 1cm interval each other and the plate attached on single frame. The measuring data before applying calibration algorithm using grid plate at the frame and each grid point that the position of arrow is shown in Fig. 7. In the figure, the measuring data before applying calibration algorithm shows gradually increasing tendency of error through center to edge of frame. Neural network method with back propagation learning is used as calibration algorithm. NNs are systems that are deliberately constructed to make use of some organizational principles resembling those of the human brain. A number of recent reviews have identified a

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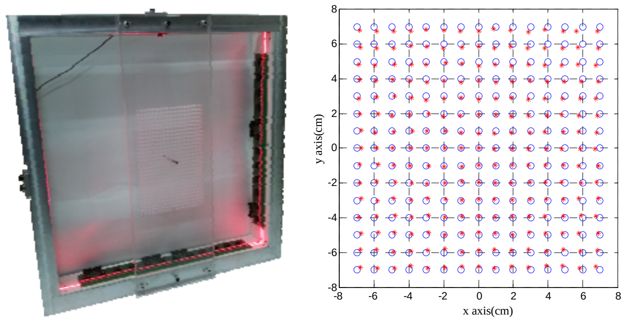
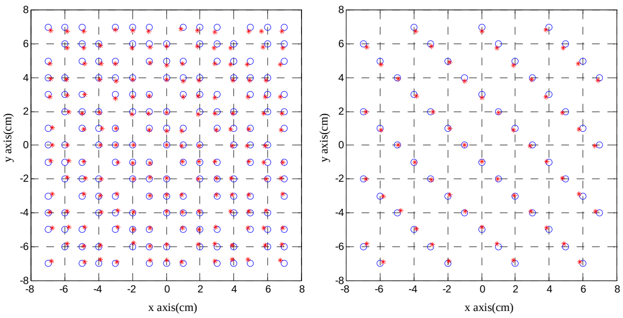


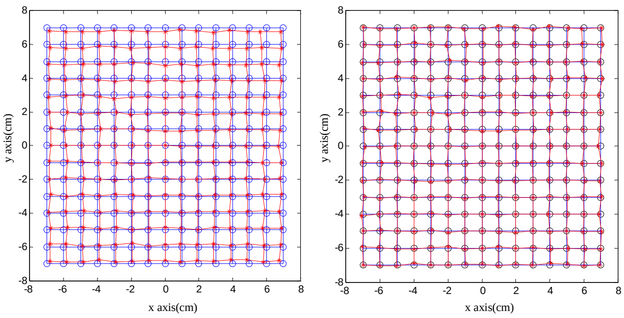
(a) (b)

Figure 7. (a) Grid plate installed on the frame, (b) Measuring data of grid point before applying calibration algorithm.



(a) (b)

Figure 8. Split of learning: (a) Training data, (b) Test data.



(a) (b)

Figure 9. Result of calibrated data using NN: (a) Before calibration, (b) After calibration.

TABLE I. RESULT OF CALIBRATION ALGORITHM

	Training error	Test error
Before calibration	3.172mm	
After calibration	0.544mm	0.617mm

diverse range of adaptive system [10], process optimization [11], pattern matching and classification, function approximation, optimization, vector quantization, and data clustering [12]. Investigations have also been completed in various aspects of calibration and analysis of measurement errors [13][14][15]. The structure of NN is 2-6-2 feed-forward form, and uses Levenberg-marquardt algorithm, and its learning rate is 0.01. The activation function of hidden layer is tangent sigmoid function, and output layer's activation function is linear function. For learning NN, 225 data that measuring at grid plate are classified into 169 training data and 56 test data as shown in Fig. 8.

The result of grid point calibration using NN is shown in Fig. 9 and Table Ⅰ. It can be found that error is fairly calibrated not only center of frame but edge of frame. And average error is also improved that comparing 3.17mm before calibration to 0.62mm after calibration result. For deriving error, MAE (Mean Absolute Error) method is defined by,

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left\|(\widehat{x_i},\widehat{y_i})-(x_i,y_i)\right\| = \frac{1}{n}\sum_{i=1}^{n} Error, \qquad (2)$$

IV. CONCLUSION

This paper suggests that the novel structure can measure impact point of arrow, the sensor can detect high-speed moving object, and the system can represent impact point of the arrow using the voltage level change of photodiode sensor. In order to make measuring system, square-shaped steel frame is produced which length of one side is 65cm, and the photodiode sensor and line laser is attached at the frame. When an arrow passes the frame, NI 9205 device is acquiring voltage level changes of photodiode sensor at any points, and sending the data to Host PC through NI cDAQ-9178. Changing interval is extracted using the voltage level of photodiode sensor, and the impact point of arrow is represented by index and voltage drop size of the photodiode. But the represented impact point includes error due to structure of substrate that designed for detecting high-speed moving object and angle of light emitted by line laser. Therefore, the represented impact point is distorted at this moment. For solving this problem of impact point, calibration method is applied using NN. After calibration, average error is decreasing from 3.17mm to 0.62mm. Now, it can digitize among the impact points, also the result can be used as manufacturing variables that use for performance analyzing with other arrows and also making arrow. Our proposed measurements method is a reflection in the manufacturing process that classifying manufactured arrow characteristics, choosing appropriate arrow for user, and determining quality and performance objectively.

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