Areas of Innovation and Proprietary Developments

- By applying advanced laser technology, the information of both ball and club can be captured in great detail, which enables the product to achieve the most complete data set with the highest accuracy possible. Such accuracies of ball flight and swing information are not obtainable by any other known technology today.
- By applying the proprietary and innovative means to construct a two-dimensional laser optical net, the product is capable of catching all swing related information in a restricted area. The laser sensor net arrangement is unique and patented.
- By applying proprietary computer algorithms, instant ball tracking and swing analysis can be achieved, based on a three-dimensional space coordinate calculation with techniques of laser image recognition, mirror image rejection and image re-construction.

Physical Parameters and Resolutions

Physical Parameters	Measurement Resolution	Interpolated Resolution	Principle of Measurement	Field Tested
Swing Path	1.5 degrees	**< 1 degree**	Laser image interpolation	Yes
Ball Speed	0.25%	**< 0.25%**	Laser image cross section	Yes
Ball Take-off Angle	1.0 degrees	**< 0.1 degree**	Laser positioning	Yes
Ball Azimuth Angle	1.0 degrees	**< 0.1 degree**	Laser positioning	Yes
Ball Back Spin (100% capture rate)	Approx. 10%	**Approx. 10%**	Laser positioning & angular momentum conservation	Yes
Ball Side Spin (over 85% capture rate)	Approx. 20%	**Approx.15%**	Laser positioning & angular momentum conservation	Yes
Clubface Impact Angle	1.0 degrees	**< 0.5 degree**	Laser image interpolation	Yes
Club Head Speed	2%	**< 1%**	Laser image interpolation	Yes
Club Head Impact Position	0.5 inch	**0.25 inch**	Laser image recognition	Yes
Carry Distance (down range) Total Distance (inc. offline)	4.9% 9.2%		Aerodynamic calculation (Based on robot field test)	Yes

Note: measured numbers indicate resolution or accuracy which are physically obtained with laser grids prior to additional image processing, **bold** numbers indicate interpolated resolution or accuracy achieved by advanced laser image processing, and verified by over 500 robot shots data from actual field test.

All physically measured resolutions and interpolated resolutions are field tested with robot, high-speed camera, and human golfers, and fitted for actual data accuracy. The values listed in the resolution table are depicted within realistic dynamic ranges (i.e., ball speed from 50 mph to 150 mph, take-off angle from 0 degree to 55 degrees, etc.). Measurement resolutions under test conditions outside the dynamic ranges do not necessarily meet the specifications quoted in the table.

Why Use Lasers?

One apparent fact is that the laser beam is exceedingly directional and highly collimated. Because the laser beam consists of only plane waves and narrow frequency bandwidth, it is both spatially and temporally coherent. Unlike other light source such as an incandescent light bulb, which incoherently pours out the radiant energy over a large solid angle, it delivers high flux and radiant power in a single diffraction-limited beam. The laser beam will thus generate ball and club swing images in a crisp and clearly defined pattern with great details, which provide the needed resolution to calculate ball and club swing information to within 1% of ball speed and less than 0.1 degree of ball launch and azimuth angles. In the case of incoherent light source with typical TO packaged detector arrangements, used by most of our competitors in the floor mat based club head detection or IR LED ball detection systems, the images are blurry, of low contrast, and highly indecisive. It is worthwhile to point out that a 0.2 inch uncertainty with a 6-inch measurement distance represents about a 2-degree error in ball take-off angle and azimuth angle, which translates into about 40 yards error in driver distance calculation for a 200-yard drive.

To illustrate the difference between coherent and incoherent, non-collimated images, Figure 1 and Figure 2 show the contrast of image edge definition between white light or IR LED images and collimated laser images, respectively.

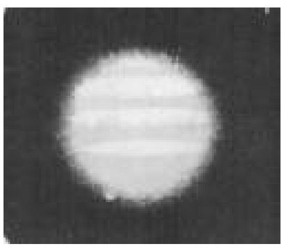


Figure 1(a)

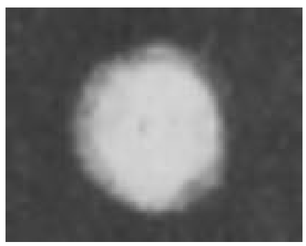


Figure 1(b)

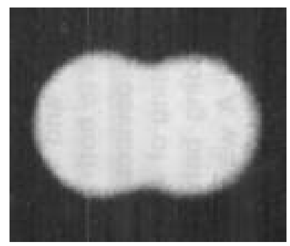
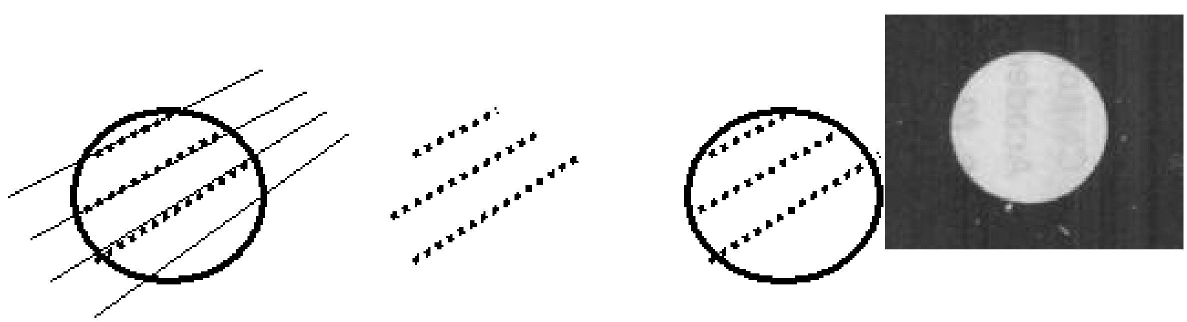


Figure 1(c)

Figure 1(a) and 1(b) show the blurring image as result of incoherent, non-collimated light sources such as incandescent light bulb or IR LED, at shorter and longer distance from the detector plane, respectively. Figure 1(c) indicates a double blurry image when multiple light sources (in this case two sources) are used as in the case of IR LED technology. Thus special and expensive electronic signal process schemes of either signal modulation or emitter signal scanning must be applied to distinguish the actual position of the ball with respect to the spatial coordinates.



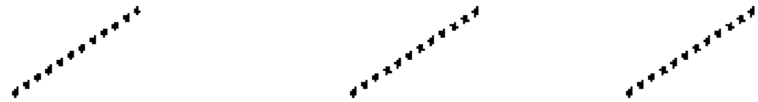


Figure 2(a) Figure 2(b) Figure 2(c) Figure 2(d)

Figure 2(a) shows a well-defined, sharp image created by a coherent, collimated laser light source. Because the edge of the image is well defined with excellent contrast, it is then possible to use limited number of laser beam cross sections to re-construct the ball image in three-dimensional space. Figure 2(b) shows multiple laser beams (four beams in this case) generated from a coherent single laser source. The cross sectional information is then presented in Figure 2(c) and Figure 2(d) with superior spatial resolution (for a 120 mph golf ball, the resolution is better than 0.25%).

The spatial resolution inherent to floor mat detection systems is limited by detector spacing and electronic complexity to roughly 2 degrees of ball trajectory and swing path angle. For a 200-yard drive, this translates into about 7 yards in lateral distance error, but most importantly it gives over 40 yards in driver distance error, with an uncertainty of 2 degrees in ball take-off angle. Mainly, the physical dimensions and arrangement of the detectors with other than laser light sources are responsible for this large deviation. Arrangements to achieve better spatial resolution with IR LED technology are possible only if the measurement distance between the ball detection and hitting tee position is increased from a preferred position of about 1 foot to over 10 feet. However, even at that large distance, the IR LED or white light shadowing techniques can detect only “Yes” and “No” of a passing ball. They cannot produce high enough contrast or data to re-construct the golf ball image to calculate accurately the ball take-off angles (both inclination and azimuth angles) and ball speed, as in the case of laser imaging technique. This is the reason that some expensive golf simulators need to have a space setup of up to 12 x16 feet, which increases the cost of electronics and optical components drastically, not to mention floor space! With our low cost laser technology and our proprietary image recognition and processing algorithms, the angle resolution is improved more than 10 times to approximately 0.1 degree. This angle resolution gives uncertainty errors of less than 0.5 yard in lateral distance and less than 2 yards in driving distance for a 200-yard drive.

Additional Advantages of Using Laser

Another advantage of using a laser source is the narrow frequency band (or wavelength) which allows detectors to distinguish real signal image from strong ambient and/or sun light to allow outdoor usage without expensive signal modulation/demodulation scheme. Additionally, because of its light weight, high output power and added efficiency, compact size, and the reliability of today’s solid state semiconductor lasers, it is possible to design a portable and battery operable Golf-Station. With other light sources such as incandescent light bulb or multiple LEDs (in fact, over 250 LEDs are needed to cover a detection area of 8x8 sq. feet), the idea of having a portable and battery operable unit becomes an impossible task.

Competing Technologies

Floor Mat Detection

If one uses a typical detector spacing of 0.2 inch and a 6-inch swing path distance, this arrangement gives a swing path angle detection limit of 1.9 degrees, excluding the club shadow image quality which is extremely poor with incoherent white light source. If measuring the club face angle, then both the top-down shadow shapes of the club (which is not always a straight line) and the individual detector’s triggering point restrict the detection limit. If two detectors with aperture diameter of 0.05 inch are placed with 1-inch spacing to detect the club face angle, then an error range of 2.8 degree is expected. Again this is an estimate without adding the error from the poor quality of the club shadow image created by white light source. So in reality the detection error will be even worse than the calculation given here. It is basically impossible to have reasonable accuracy to predict any ball information from this kind of system.

If additional errors in angle detection are introduced in swing path measurement, then the ball side spin will change accordingly. So if a ball is traveling initially with 1.5 degree face angle, and -3 degrees in swing path angle, then a slicing spin of 380 rpm is introduced. But if an uncertainty error of 2 more degrees is introduced due to non-coherent light detector arrangement, then the side spin will increase to 530 rpm, giving an distance error of 12 yards for a 200-yard drive.

Ball Tracking IR Technology

The large dimension (over 10 feet in distance) triple-LED net arrangement with scanning emitter scheme could achieve reasonable accuracy in principle. If an average detector spacing of 0.75 inch is used, then the detection limit of golf ball azimuth and take-off angles of 0.36 degree is calculated, which is better than the floor mat detector system but is still about 4 to 10 times worse than the laser technology. To cover the whole range of angle detection, a total of over 300 emitter and detector pairs are needed to form one single frame. With a total of 3 frames to form the complete system, the number of LED emitters and detectors is close to 1,000 each. Also, because the individual detector cannot distinguish light signals sent by multiple adjacent LED emitters, special coding (i.e., modulation) or signal scanning techniques must be applied to acquire accurate data. This will increase the system cost dramatically.

By applying the third LED net to measure the ball bouncing angle from hitting the projector screen and to use the data to predict side spin cannot be accurate. Since the ball bouncing angle and speed from the projector screen depend on the stiffness of the projector screen that bounces the ball back, which cannot be qualitatively measured correctly to give meaningful prediction. The IR technology cannot be field-tested and cannot be outdoors used, and it is 100% not portable.

Radar Technology

The radar technology uses high frequency impulses to track the return signals from the golf ball and determines the ball speed. However, the resolution of signal detection is limited by many factors: including but not limited to signal to noise ratio, multi-path signal return, ball flight angles, and the most significant limitation being that it is only one dimensional characterization of ball movement. If one needs to obtain three-dimensional flight information on golf ball movement, two to three radar systems have to be installed on three axes to provide the information. However, how to synchronize the signals from three independent systems presents a major problem. That is one of the reasons that so far this technology has not been proven practically useful and accurate. The use of taping metal foil to the ball in order to detect ball spin is even more unrealistic for the angles of ball's rotating vector (the combined angular vector of ball back and side spins) significantly affects the data received by the radar antenna. Under some conditions, this technology may provide useful data on the ball speed and club speed, but it is unable to provide any meaningful data on ball spins, especially on side spin. Furthermore it cannot provide any data on ball and club swing angles. With all these deficiencies, it is not likely that the radar system will be a viable technology to impact the golf industry.

High-speed Camera Technology

High-speed sequential exposure camera technology is by far the only technology that could provide usable data on ball take-off and azimuth angles, backspin (RPMs), and ball speed. However, not only is the price of a professional system extremely expensive, the uncertainty of determining key parameters due to ball compression and oscillation from club impact remains. In order to determine measured data accurately, reference planes need to be established or calibrated with the image setting, which introduces additional sources of error. Further, the significant limitation of a one-dimensional characterization of ball movement seriously restricts the accuracy of ball flight prediction, although, image extraction may give some indications on the second axis motion, but will be limited by achievable image resolution. Two to three camera systems may be required on different axis to provide additional information for three-dimensional analysis. Even so, how to synchronize the data from multiple independent camera systems presents a serious integration challenge. Hence, the most valid applications for high-speed camera systems are used in equipment R&D works such as club or ball designs. The attempt of performing automatic image recognition that integrates both ball and club movements simultaneously in a three-dimensional space will be challenging with high error rates expected due to image resolution limitations, environmental constraints such as variable lighting and deflection conditions, and complex image recognition criteria.