

Advanced ultrasonic technology proved to be the most reliable and error-free system for use in an automatic pin scoring application.

An Automatic Ultrasonic Bowling Scoring System

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Over the past several years, the bowling industry has undergone major modernization. With the introduction of computer-controlled automatic scoring, systems now automatically detect both the number and locations of the pins left standing after each bowling ball is rolled. The following article describes one such system—an automatic ultrasonic scoring system that was developed and is being mass produced by Massa Products Corporation for use by the AMF Bowling Companies, Inc. to locate the positions of all standing pins, no matter where they slide over the pindeck.

DEFINING THE PROBLEM

Photo 1 shows a typical pinspotting machine located at the end of a bowling alley. At the start of a game, ten pins are positioned on the alley under the pinspotter in a triangular pattern. When a bowler rolls a ball down the alley, some of the pins are usually knocked down and others slide to different positions over the pindeck. An effective automatic scoring system must quickly and accurately determine the exact number and position of the pins left standing, no matter where the pins may have slid over the pindeck.

WHY ULTRASONICS?

Ultrasonics is sound of a frequency above the range of human hearing, usually considered to be greater than 20 kHz. The microphones and loudspeakers used to receive and transmit ultrasonic sound are called transducers. Ultrasonic trans-

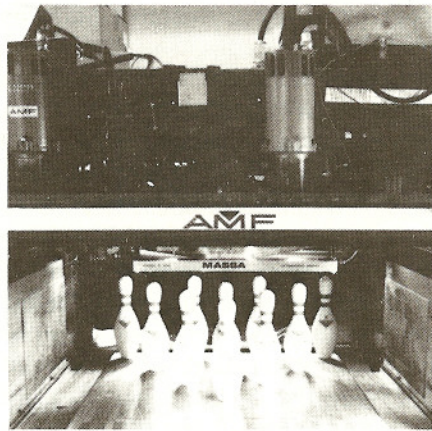


Photo 1. An AMF Pinspotter is shown with the Massa Ultrasonic Array mounted above and in front of the ten standing pins.

ducers can be combined with special electronic circuits to provide systems that are ideally suited for noncontact sensing and high-precision mechanical position determination in many industrial applications. Because of the relatively low velocity of sound in air (343 ms at 20°C), ultrasonic systems can easily be designed to very accurately measure the exact distance to a reflecting object by simply transmitting a sound pulse from the ultrasonic transducer and measuring the elapsed time for the reflected echo to return.

► **Range and Bearing.** The ability to obtain accurate range and bearing of targets makes ultrasonics an ideal sensing technology for inexpensive automatic bowling pin detection over optical systems, which have several drawbacks. Exact pin positions can-

not be determined with an inexpensive optical system because the range information cannot be easily obtained. These systems only scan the pindeck and attempt to count the number of light reflecting targets that appear in the field of view. In the bowling industry, however, it's important to know the positions of the standing pins, in addition to the number, so that the bowler can better determine where the second ball should be rolled to have the best chance of obtaining a spare. An ultrasonic system measures the time for the sound to travel from the transducer to the target and back again, thus the position of the pins can easily be determined. However, with an optical method that uses light, which travels at approximately one million times the speed of sound, the measurement of position of the bowling pin would require the measurement of echo time intervals with an accuracy better than one millionth of a millisecond, which is impractical.

Optical systems have two other drawbacks when compared to ultrasonic pin sensors. First, if the standing pins slide so that one pin is directly behind another, the optical sensor will only "see" and count one pin. Ultrasonic sensors, however, are positioned to look down over the tops of the pins, so they will all be accurately counted.

Secondly, an optical system will fail if the pins are dirty or if any background walls or surfaces are good light reflectors. Consequently, the entire background area must be painted flat black and the bowl-

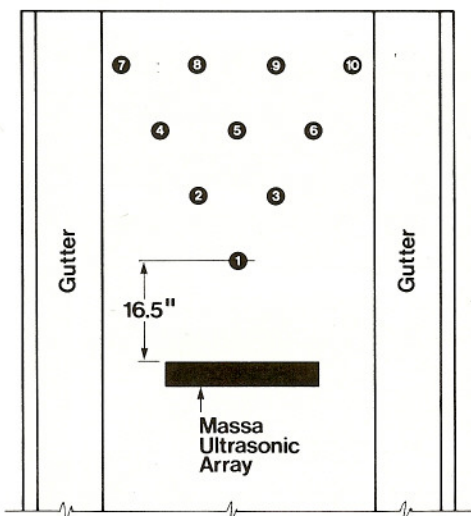


Figure 1. This plan view of the back of a bowling alley shows the spots for the ten pins and the location of the Massa Ultrasonic Array in front of the pin triangle.

ing pins must be washed on a regular basis to ensure high reflection of light from their surfaces. With the ultrasonic system, the pins will reflect the sound no matter how dirty or "banged up" they are.

SYSTEM DESCRIPTION

Each ultrasonic system is designed to independently control two bowling lanes and consists of two ultrasonic arrays connected to a common Z80-based electronic control board. An ultrasonic array is mounted under each pinspotter machine above and in front of the pins. Each array is located 16.5 in. in front of the number one pin, as shown in Figure 1, and 22 in. above the pindeck, as shown in Figure 2.

Each array contains 14 ultrasonic transducers precisely positioned so that the entire pindeck is insonified by 14 accurate ultrasonic beams. The array bar is a rigid aluminum extrusion with 14 precision cavities machined into the front edge to hold the transducers. The axis of each cavity is machined at a different angle in both the horizontal and vertical planes so that the entire pindeck will be insonified by the 14 separate sound pulses (see Photo 2).

A circuit board containing both the amplifier and detection circuits is also located in the array bar. This allows the signals to be processed inside a completely shielded enclosure. All of the signals going in and out of the grounded array housing are digital, eliminating any possibility of picking up the transient electromagnetic noise that can occur on low-level analog signal leads.

► **Ultrasonic Transducers.** The heart of the pin sensing system is the ultrasonic transducers that operate at 150 kHz. The optimum frequency of operation was chosen after considering several design criteria. As the frequency of sound increases, the sound absorption increases as the sound wave travels along the air path from the transducer to the pin and back again. The attenuation at 150 kHz is 2 dB/ft. Since the maximum round-trip distance between a transducer and the farthest pin is 8 ft, the maximum total attenuation at 150 kHz is 16 dB, which is acceptable for detecting the echo. However, any spurious ultrasonic sounds generated more than 8 ft away would be very greatly attenuated before reaching the array, and therefore would not be detected as false echoes.

The wavelength of sound is also a function of frequency. The higher the frequency, the shorter the wavelength. In order for a target to produce a good echo in an ultrasonic ranging system, the reflecting surface must be several wavelengths in dimension. At 150 kHz, the wavelength of sound is approximately $\frac{3}{32}$ in., which is sufficiently small compared to the size of a bowling pin to ensure a good echo reflection.

The choice of frequency of operation is also critical in ensuring a reasonable size for the transducer. The system design requires that the transducers produce narrow beams of sound that contain the transmitted sound within a 12-degree conical angle. To produce such narrow radiation beam patterns, the radiating surface of the transducer must be large compared to the wavelength of sound being transmitted. The larger the ratio of diameter of the radiating surface of the transducer to the wavelength, the narrower the beam angle. To produce a 12-degree beam angle, the radiating surface of the transducer must

be six wavelengths in diameter. The 150 kHz transducers designed for the system are slightly over $\frac{1}{2}$ in. in diameter. If the frequency was much lower, the transducers would become too large to fit into the space allotted.

A more critical aspect of the beam pattern concerned the side lobes that are generated in the transducers. A conventional narrow-beam transducer produces additional radiation lobes outside the main beam as shown in Figure 3. Although the side lobes are reduced in amplitude, a pin located along an axis of the secondary lobe of a conventional transducer could still produce a large enough echo to be detected. This would be interpreted by the sensing system as a pin standing along the axis of the primary beam, which would, therefore, incorrectly register an extra pin, causing a scoring error.

To eliminate the side lobe problem, Massa developed the Model TR-2404 ultrasonic transducer, which produces a narrow 12-degree beam of sound. Its construction, however, eliminates all side lobes, so that only the primary beam of sound is produced (see Figure 4).

The resonant frequency of the transducers must be very accurately controlled during the manufacturing process to ensure optimum system operation. Within each array, the resonant frequencies of all 14 transducers are held within a tolerance of ± 0.3 percent. The ruggedly constructed transducer is also shockproof, so it can survive high-impact hits by flying pins without damage, and will not pick up bowling machine vibrations. The transducer is completely sealed so that it is unaffected by the dusty environment.

METHOD OF OPERATION

The ultrasonic scoring system is completely automatic, and even self-calibrates

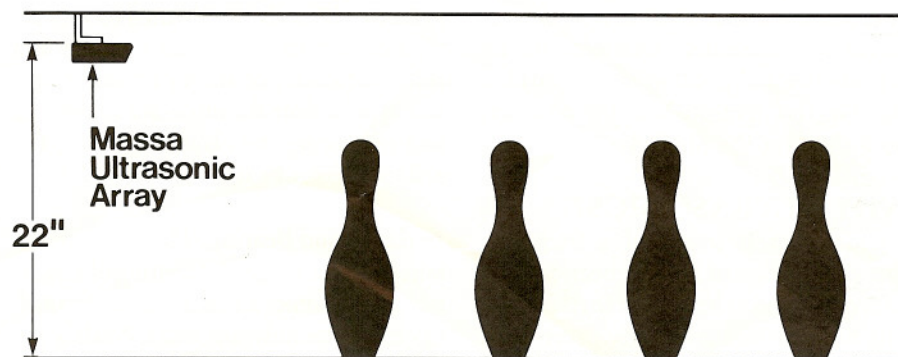


Figure 2. The side view of the back of a bowling alley shows the four rows of pins and the location of the array.

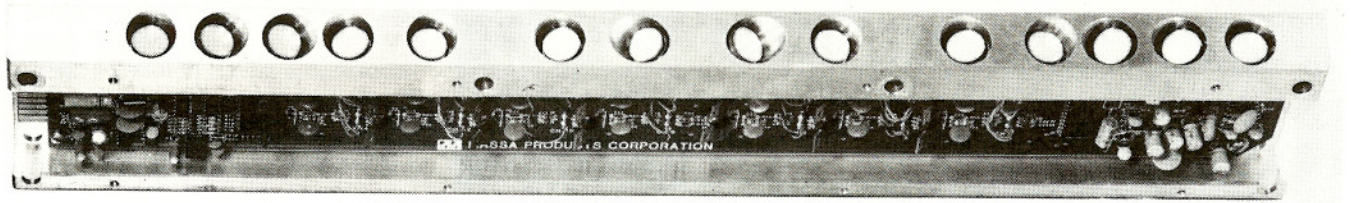


Photo 2. The Ultrasonic Array consists of 14 precision 150 kHz narrow-beam transducers mounted in an aluminum channel. The circuit board is shown mounted in the channel.

to compensate for any variations caused by changes in the velocity of sound at different temperatures. At the start of a game, the pinspotter sets up ten pins in a triangular pattern. To calibrate the velocity of sound, the control electronics next cause one of the transducers that insonifies the pindeck area in the vicinity of the number five and nine pins to initiate an ultrasonic pulse. A 130 V, peak-to-peak 150 kHz tone burst is applied to the transducer, which in turn sends out a sound pulse that travels through space. A portion of this sound reflects from the number five pin; another portion reflects from the number nine pin. These two acoustic echoes return to the transducer and are converted into an electrical signal that is amplified by the electronics in the array. If the echo signal exceeds the system detection threshold, a 5 V digital signal is generated. This digital signal is then transmitted by the interconnection cable to the control electronics.

Figure 5 is an oscillogram of the signals

produced by the reflected echoes from pins five and nine when they arrive at the appropriate receiving channels. The top trace shows the amplified received analog acoustic signal. The large pulse at the left of the trace is caused by the 130 V, peak-to-peak transmit tone burst. The first echo signal, which arrives at approximately 5½ ms, is caused by the reflection from the number five pin, and the second echo, which arrives at approximately 7¼ ms, is caused by the reflection from the number nine pin, which is farther away. The bottom trace on Figure 5 is the output of the detection circuit. A 5 V signal appears during the time that the two large echoes from pins five and nine remain above the threshold.

The control electronics measure the time period from the start of the acoustic pulse to the return of the reflected echo. Since the speed of sound is a function of temperature, the system must be calibrated for the temperature of the bowling lane. Because the computer knows that

the number five pin is on its spot at this time, it also knows the exact distance from the transducer to the pin. The computer then automatically adjusts the processing algorithms to compensate for any variation in the speed of sound as required to maintain the correct pin measurement over the pindeck during bowling.

► **Operation.** The system automatically calibrates for speed of sound variations each time ten pins are placed by the pinspotter. When the bowler rolls the first ball, it knocks down several pins and then hits a switch at the back of the lane. This switch sends a signal to the control electronics board indicating a ball has just been bowled. The computer waits 1.7 s to allow for late falling pins, and then sequentially pulses each of the 14 transducer channels in the array. Each channel sends a digital signal to the control electronics whenever any echoes are received. Since the computer knows in which direction each of the narrow-beam transducers is pointing, it is

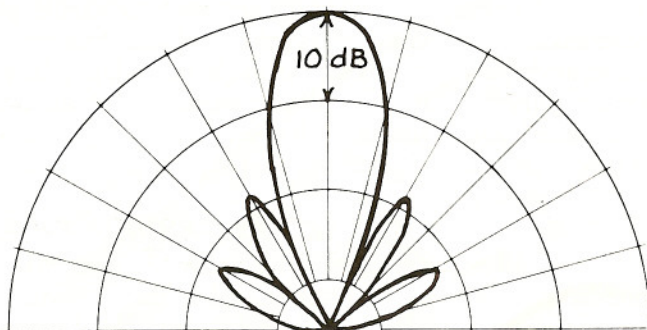


Figure 3. Secondary lobes are shown on either side of the primary beam in this radiation pattern from a standard narrow-beam transducer.

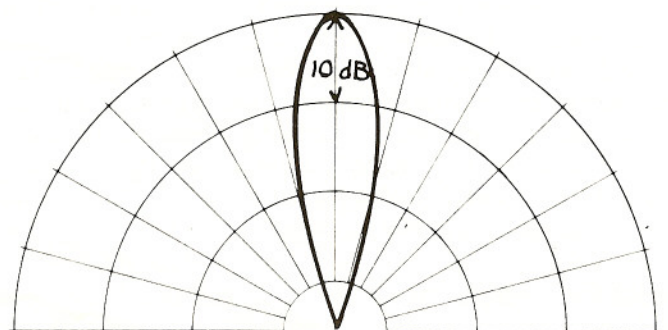


Figure 4. The special design of the Model TR-2404 ultrasonic transducer eliminates all secondary lobes.

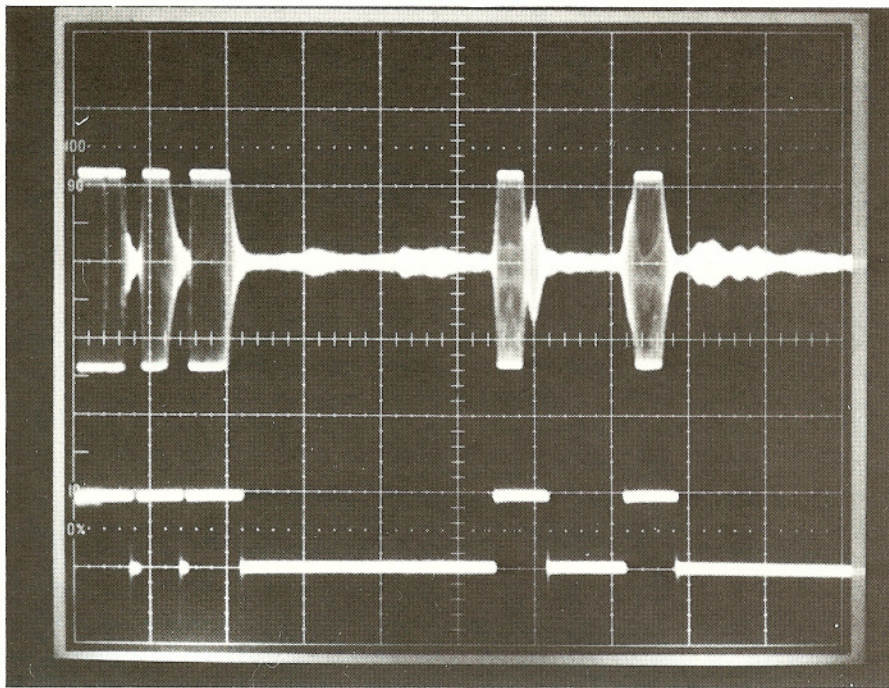


Figure 5. This output signal of one of the 14 ultrasonic channels shows the return echoes from pins five and nine. The top signal is the analog output and the bottom signal is the digital output. The horizontal scale is 1 ms per division.

able to calculate the exact range and bearing of the reflected echoes and, therefore, the exact location of each standing pin.

It takes 0.3 s to accumulate the data from the 14 channels and determine which pins are standing. For increased reliability, all areas of the pindeck areinsonified by at least two transducers in the array. In addition, all the transducers are sequentially pulsed a second time. A pin

must be detected during both detection sequences in order to be called standing.

The control electronics then send the standing pin information to the graphics computer, which displays on a screen in proper scoring format the number of pins knocked down. In addition, the positions of the standing pins are displayed, together with an indication of where the second ball should be rolled in order to obtain a spare.

Meanwhile, the pinspottter is sweeping the deadwood from the pindeck and replacing the standing pins. The bowler then rolls the next ball, and the exact sequence is repeated, except that all pins are swept and ten new pins are placed on the pindeck. In this manner, the score is automatically updated and continuously displayed to the bowler.

An additional benefit occurs when a strike is bowled. The control electronics recognize the strike and instantly signal the pinspottter to sweep the pindeck and drop ten new pins, rather than waste time by first going through its normal cycle of trying to pick up any pins that might be left standing.

CONCLUSIONS

Massa has been manufacturing large quantities of ultrasonic scoring systems for several years and successful installations have been made in over 24,000 bowling lanes. The system speeds up bowling games by as much as 25 percent. The AccuSonic Automatic Scoring System pays for itself in a relatively short period of time because of the additional number of games that can be played during a given period of time.

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