WHITE PAPER

New technologies drive superior scan performance

There has been plenty of publicity recently about the use of MEMS in a laser scanner. The manufacturer of a MEMS-based scan engine is promoting the idea that simply replacing a single component of an otherwise conventional laser scanner, somehow results in significant performance improvements. This claim ignores the fact that a laser scanner is a very complex system in which the device that scans the laser (the MEMS device) is only one of several things that influence scanning performance. As will be described below, the improvements in the new SE950 and SE955 go far beyond simply replacing the scanning mechanism.

Introduction

Since its introduction in 1998, the SE900 has been the world's largest selling small scan engine. The success of the SE900 has been based on an unsurpassed combination of small size, high scanning performance and superior reliability. In fact, the SE900 has performed its function so well that there has been little reason to replace it.

Over the last two or three years, however, a number of new developments have become available which have the potential to significantly increase the performance of a scan engine. Two new scan engines have therefore been created to take advantage of these developments. The SE950 is a new undecoded scan engine, and the SE955 is a new scan engine with an on-board decoder. These two engines will replace the SE900 and the SE923. The SE955 is the first decoded laser scan engine that includes on-board decode circuitry without extending the circuit board out of the engine envelope. This makes it the smallest decoded laser scan engine ever built.

The liquid polymer scan element

Around three years ago, Motorola introduced the LS2208 handheld scanner. This scanner was the first to use our newly developed Liquid Polymer (LP) scanning technology. The LS2208 has now become one of the fastest selling handheld laser scanners of all time, providing extensive real world experience with LP technology. LP technology has proven to be so reliable that we offer it with a lifetime warranty. In the SE950 and SE955, LP scanning technology has been configured for use in small scan engines. The same lifetime warranty offered with other scanners that use LP technology is offered with these engines.

Aside from proven reliability, LP scanning technology has several distinct advantages over MEMS for use in a laser scanner. For example, much has been made of the high speed at which MEMS devices can scan. In fact, higher speed is not always better for a laser scanner. As scan speed increases, the signals that the scanner must process increase in frequency, making it more difficult to distinguish them from noise. As a result, the working range of the scanner will be decreased. It is very difficult to design reliable MEMS devices that run at less than a few hundred scans per second, which is too fast for optimum signal quality in a small scan engine. An LP scan element, on the other hand, can be designed to operate at whatever speed is best for the scanner in which it is to be used. In the SE950 and SE955 we have designed the scan element to run at 100 scans per second. We have determined that this is fast enough to make the scanner extremely responsive, but not so fast as to ruin the signal quality. This is one factor that contributes to the superior working range of LP-based scan engines.

It is a common belief that the only function of the scanning device, such as LP or MEMS, is to scan the laser beam. In fact, most high performance scanners also use the scan element to scan the optics that collect and concentrate the laser light that is reflected off the bar code. Scanning the collection optics allows the scanner to reject unwanted light, such as sunlight, which can mask the weak laser signal. Scanned collection optics require the use of a large scan mirror, because the larger the mirror, the more light can be collected and the greater the working range of the scanner. LP scan elements can carry large mirrors, but MEMS devices cannot. As a result, MEMS scanners must use stationary collection optics, so their working range is reduced and their performance can be more severely degraded in some lighting conditions.

It has been claimed that MEMS devices are reliable because they are frictionless. The promoters of MEMS imply that this feature is a unique property of MEMS technology. They fail to mention that Motorola has been producing frictionless laser scanners for around 15 years.

In fact, with literally millions of frictionless scanners already deployed, Motorola has far more experience with frictionless scanning technology than any other company. LP scan elements are our latest frictionless technology, and are the beneficiary of this extensive experience. LP devices on accelerated life tests have operated an equivalent of over 200 years of normal scanning use, without any failures. The life tests continue, and we don't anticipate any failures.

Multi-focus laser optics

Lasers are famous for their ability to project a beam of light over a long distance without the beam diverging (spreading out), as light from other light sources does. Although laser light can be focused to diverge much less than other light sources, divergence cannot be totally eliminated. It is this unavoidable divergence that is one of the things that limits the working range of laser scanners, especially when scanning bar codes with narrow bars or spaces. When the laser beam diverges too much at a distance from the scanner, the scanner can no longer resolve small bars and spaces, so a bar code with small bars and spaces can not be decoded beyond that distance.

Motorola invented special laser focusing optics that have the ability to counteract divergence of the laser beyond that which can be accomplished with conventional optics. This new optical system was first used in our SE1500, which provides extraordinary range. The new SE950 and SE955 use a similar focusing concept, but in this case the technology is optimized to extend range on bar codes with very narrow bars and spaces, giving the new engines superior working range on high and medium density bar codes.

The shape of the laser beam is also controlled so as to project an elliptical laser spot on the bar code, as opposed to a conventional circular spot. The elliptical spot helps the scanner ignore defects in the printed bar code, improving performance on damaged and poorly printed bar codes.

Parallel signal processing with variable resolution

One potential advantage of high scan speed is that it can give a scanner more attempts to read a damaged bar code, increasing the chances that it will read quickly. Unfortunately, increasing the scan speed also degrades signal quality, which can actually make it more difficult to read some bar codes of marginal quality. This loss of signal quality partially cancels any advantage that might be expected from the higher scan speed. The SE950 and SE955 therefore use a different approach, which also increases the chances of a rapid decode, but doesn't degrade signal quality.

Both new scan engines use two individual signal processing circuits, each optimized to read different kinds of bar codes. One is designed to read damaged or poorly printed bar codes while the other excels at reading high density bar codes. Both circuits can also easily process good quality bar codes. The outputs from both of these processing circuits are available to the decoder on every scan, so even though the scanner is running at 100 scans per second, the decoder gets 200 chances to decode the bar code every second.

The two signal processors are designed to compliment each other, so one, the other or both will succeed in decoding the vast majority of bar codes. In the event that a bar code is extremely disfigured, however, the scanner can automatically adjust both circuits to further improve the chances of obtaining a rapid decode. For example, if the bar code is badly scratched, the resolution of the signal processing circuits can be reduced enabling the scanner to ignore the defects. When scanning bar codes with very narrow bars or spaces down to around .004 in. (0.1 mm), maximum resolution is employed to assure accurate detection of every bar and space in the bar code.

Notice that this ability to process the bar code two ways every scan, and to vary resolution as necessary, is a far smarter way to assure quick response on bad bar codes than simply running at higher speed, such as MEMS scanners do. If a higher speed scanner doesn't vary its resolution as might be necessary to read a damaged bar code, it won't matter how fast it goes because each scan will fail. On the other hand, a scanner with variable resolution and parallel signal processors will be better able to read the damaged bar code in a small number of scans, so it doesn't need as high a scan speed to be responsive on bad quality bar codes.

Adaptive electronics

When a bar code is positioned close to the scanner, there is a lot of reflected laser light for the scanner to detect, producing a strong signal for the signal processing circuitry to work with. As distance between the scanner and bar code increases, however, the signal becomes smaller and weaker. As it becomes weaker, it is more susceptible to being masked by various kinds of electrical noise. Sources of electrical noise that may degrade a scanner's performance come from other electronic devices that may be positioned close to the scanner or powered by the same power supply as the scanner. The circuitry within the scanner itself also produces some unavoidable noise, which can ultimately limit the working range of a scanner.

The SE950 and SE955 include circuitry that automatically adjusts to compensate for signal variations that result from scanning from different distances, and from scanning bar codes with different print contrasts, so as to maintain the signal applied to the signal processing circuits at an optimum level. The scan engines also include automatically varying noise filters to remove noise that might otherwise degrade scanning performance.

Productivity

As mentioned above, the claimed advantage of a MEMS-based scanner is that it produces a large number of scans per second. This, however, should not be confused with higher scanning productivity. In other words, a higher number of scans per second won't necessarily translate to an ability to scan more bar codes per hour.

For example, in many environments bar codes are not located in a position that is convenient to scan. Some bar codes may be positioned low down near the floor or up on a high shelf. In this situation, a scanner with more working range will be much easier to use, minimizing the need for the operator to bend, reach or climb. The various optical and electronic advantages of the SE950 and SE955, which have been described above, yield a working range that is around double what a MEMS engine is expected to achieve on most bar codes, making the SE950 and SE955 significantly easier to use in many common scanning applications. In addition, the SE950 and SE955 have excellent angular tolerance, allowing the user to shoot bar codes from extreme angles better than most other scanners. This makes it possible to quickly read bar codes without wasting time repositioning bar coded packages so as to allow the bar code to be scanned head on.

As mentioned above, the SE950 and SE955 also include various optical and electronic improvements that are designed to minimize how many scans are needed to read even the most badly damaged bar code. As a result, the scanner decodes rapidly, even on damaged bar codes that other scanners can't decode at all. Scanners without these improvements, even if they have very high scan speed, can provide significantly lower scanning productivity whenever bad quality bar codes are encountered.

In the section about the Liquid Polymer scan element, it was explained that MEMS scanners must use static collection optics, which results in performance degradation under some lighting conditions. This, of course, throws away any potential advantage of the increased number of scans per second, for users who work in those lighting conditions. The first scan engines built by Motorola, over 10 years ago, used static collection optics. While these engines seemed to work well in most indoor lighting conditions (but not very well outdoors), we found that users who scan bar codes on high shelves sometimes had problems, because when the scanner was aimed upwards at a bar code positioned over the operator's head, a light fixture on the ceiling was sometimes within the field of view of the static optics, drowning out the signal and preventing responsive decoding. This experience showed that static collection optics are not suitable for scan engines that must work well in every environment.

Even in environments where none of the issues just described are present, a MEMS scanner may still fail to live up to the promise of improved speed suggested by the high number of scans per second. Each individual decode attempt may be slowed down by the inability of the MEMS device to accelerate up to full scan angle quickly. This is visible to the user as a scan line that starts out short and grows longer at a visible rate. Decode cannot occur until the scan line becomes long enough to entirely cover the bar code, which might not happen for several scans after the scanner is activated. This slow start-up behavior can be particularly detrimental when scanning long bar codes which can't be entirely covered by the scan line until full line length is achieved.

The MEMS device will coast for a second or two after decoding a bar code, so a second activation immediately following a first one might feel faster, because the device is already moving. In real world applications, however, there are usually at least several seconds between attempts to scan one bar code and the next, giving the MEMS device time to coast down and nearly stop between scan attempts. In this common situation, the user will have to wait for the scan line to grow enough to cover the bar code every time a new scan is attempted, unless the scan element is permanently activated, which can waste power in battery powered applications.

The slow start-up is the result of the electrostatic drive used with MEMS devices. An alternating electrostatic field is used to attract the moving mirror first in one direction and then in the other, causing it to rotate back and forth. The electrostatic field can be quite weak, requiring several scans before it can accelerate the moving mirror up to the full scan angle. The LP scan element used in the SE950 and SE955, on the other hand, is driven magnetically. This magnetic drive can apply much more torque to the mirror, bringing it up to full angle in a minimum number of scans, even when a large mirror is used. As a result, startup time for the scan element doesn't negatively impact scanning productivity.

Other features

Some unique features have been designed into the new scan engines. For example, two different scan angles are available. The wider angle can be used when it is important to read wide bar codes close-up to the scanner. The narrower angle is useful when it is necessary to read one bar code that is positioned close to other bar codes. These engines can also produce a static laser spot that facilitates accurate aiming even in bright sunlight.

Conclusion

The new SE950 and SE955 scan engines utilize numerous advances in laser scanner design. This results in a far more competent engine than could have been achieved if only a single part of the system, such as the scanning device, had been changed. This combination of improvements result in a small engine that provides performance that is superior to some scan engines that are many times larger. This high performance is accompanied by reliability backed by extensive field experience and excellent warranty.

Scan engines provide a convenient way to design bar code reading capability into a broad variety of products. In most cases, once the scanning product leaves the factory, the product manufacturer has no control of the environment in which it may be used, or of the quality of the bar codes that must be scanned. It is therefore critical to select a scan engine that will provide the best possible performance in the broadest range of environments. A MEMS or Linear Imaging engine may prove to provide adequate performance in undemanding applications, but in environments that include poor quality bar codes, operation in sunlight, or where additional working range can increase productivity, the SE950 or SE955 is designed to offer the superior performance and productivity that users will appreciate.

Scanned vs. static collection optics

All laser scanners include two optical systems. One system, which is known as the scanning optics, includes the laser, lenses to focus the laser beam, and a scan mirror that moves the laser beam rapidly across the bar code. The other system is known as the collection optics. This system has two functions. One is to collect laser light that reflects off the bar code, and to concentrate that light on to a photo-detector. The other function of the collection optics is to prevent light from other sources, such as sunlight, from reaching the photo-detector. The ability of the collection system to perform both of these functions well has a huge impact on the performance of the scanner.

There are two different kinds of collection optics used in laser scanners today. One is a static system, which is used in MEMS-based scanners. The SE950 and SE955, on the other hand, use scanned collection optics. Both kinds of systems can do a good job of collecting and concentrating laser light, but scanned collection optics are better for rejecting bright external light sources, which can interfere with scanner performance. Scanned optics, however, require the use of a relatively large scan mirror, which means that MEMS-based scanners, with their inherently small scan mirrors, are unable to use scanned collection optics. Instead, MEMS scanners are forced to make do with static optics.

Figure 1A illustrates how a scanner with static collection optics sees the bar code. The static collection system must be designed to be able to collect reflected light along the entire length of the scanned laser line so that a bar code anywhere along the line can be "seen" and decoded. The area from which light can be collected is called the "field of view", and is outlined by the dotted oval.

When scanning in a dark room, the only light striking the bar code within the oval is laser light, so the scanner doesn't see any other light which could interfere with scanning performance. When operating under bright lighting conditions, however, external light sources will also illuminate the bar code and surrounding label within the field of view. Some of this light will be reflected towards the scanner and will be collected by the

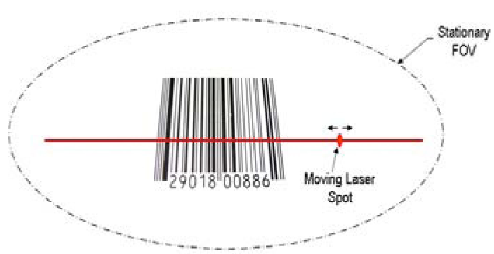


Figure 1A - Scanned collection optics

collection optics, and concentrated on to the photo-detector. This external light tends to mask the laser light, making it more difficult to decode the bar code. If the external light is bright enough, it can completely hide the laser light and the scanner will not function.

Figure 1B shows what a scanner with scanned collection optics sees. Notice that the large oval field of view of the static system has been replaced with a small circular field of view centered around the moving laser spot. When scanned collection optics are used, the field of view can be much smaller than with static optics, because the scanner doesn't have to be able to see the entire scan line at once. Instead, the field of view is scanned along with the laser beam, so the scanner is constantly looking only at the part of the bar code where the laser is striking at any moment.

Figure 1B - Scanned collection optics

The amount of undesired ambient light collected by a scanner is proportional to the area of the field of view, and as you can see, the use of scanned optics allows the area of the field of view to be dramatically reduced. Scanned collection optics can generally be designed with a field of view that is as small as around 5% of the field of view of a static system, giving the scanner a 20 to 1 advantage when operating in bright lighting conditions.

In a scanner with static optics, various electronic techniques can be employed that help the scanner distinguish the laser from bright external light sources. These techniques can sometimes prevent total failure of the scanner in bright sunlight. This isn't a perfect solution to the problem, however, because the added circuitry inherently introduces some electrical noise into the system. This noise will be present even when the scanner is operating in dimly lit environments, degrading performance even when bright light is not present. In other words, these techniques can be used to avoid total failure in bright sunlight, but at the expense of reduced performance when sunlight isn't present. No such additional circuitry is needed in a scanner with scanned collection optics, so no additional noise is added, and the scanner can achieve maximum performance in any kind of lighting conditions.

The use of scanned collection optics in the SE950 and SE955 is one of the primary drivers of the superior working range that these scan engines provide. Scanned collection optics can only be implemented when a large scanning mirror is used. This is why MEMS scanning technology, which severely limits mirror size, was rejected for use in these scan engines.

Different scanning mechanisms drive different optical systems

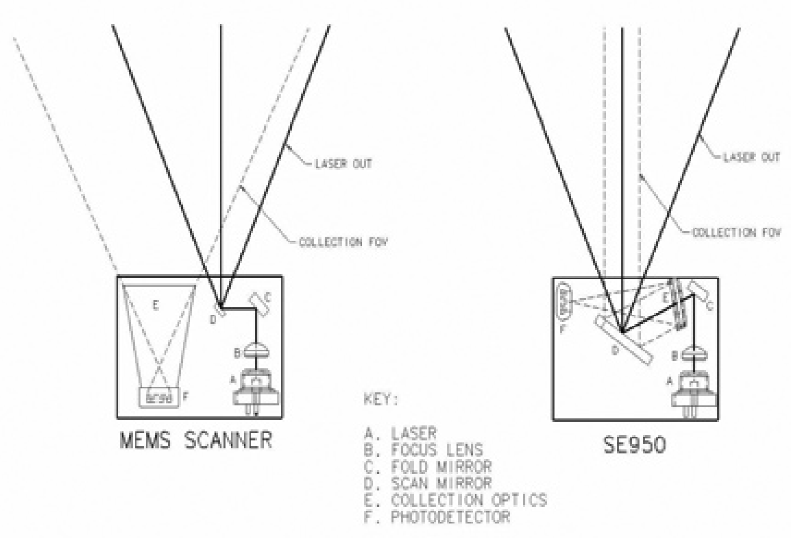
It has been claimed that a scanner using MEMS is an entirely new kind of scanner. In fact, in every meaningful way a MEMS scanner is just like any other laser scanner. All laser scanners have always used a moving mirror to scan the laser, and MEMS is simply another way to do so. Numerous mechanisms have been used to move the mirrors in laser scanners including stepper motors, galvanometers and brushless DC motors, to name a few. Yet manufacturers of scanners using these different kinds of scanning devices never claimed that their scanners were anything other than laser scanners. There is no reason a scanner using MEMS should be considered to be anything but a laser scanner either.

The diagram below shows that a MEMS-based scan engine and the new SE950 each include all of the same components, although the positioning and size of the components differ. These differences are driven by the different capabilities of the scan mechanisms and by the different performance goals of the two designs.

The designers of the SE950 set out to develop a scan engine with the highest possible performance in the limited available space. This goal dictated the use of a scanned collection system. An LP scan element was then developed specifically for the SE950. This device was designed to scan the largest mirror that could fit in the available space. The LP element was also designed to scan at 100 scans per second because Motorola has determined this to be an optimal speed for a small scan engine. Notice that this design goal could not have been achieved with a MEMS scanning device because MEMS mirrors must be small, and they cannot be made durable enough for use in a scan engine unless designed to operate at extremely high scan speeds, which may be inappropriate and undesirable.

The SE950 design started with a decision to provide maximum performance, and then technology appropriate to achieve that goal was selected. In situations where the initial decision is to use a MEMS scanner, the engineers must work within the limitations of MEMS technology. As you can see in the diagram, this requires the use of static collection optics positioned next to the laser/scanning system. The disadvantages of a static collection system are described elsewhere in this paper.

As the diagram below shows, the scanning system and collection optics in the MEMS scanner are two isolated subsystems, each of which is designed to function independently. In the SE950, on the other hand, the two subsystems coexist in the same volume and share the large scan mirror. This is a more difficult design job, but the superior results justify the extra effort.



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