TECHNOLOGICAL ADVANCES IN VISION SENSING AND MEASUREMENT

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Abstract

From smart industries, there is an impulsion for smaller and faster technologies. This trend is driving advances in the development and application of vision measuring systems that can be automated and integrated with advanced technologies for speed, to deliver precise and repeatable levels of accuracy. Vision based measurement technologies trend as fast growing and evolving in industrial and non-industrial sectors due to its low cost, accessibility of PC based hardware, software and due to its user-friendliness. Though there is substantial potential for the increased deployment of vision systems, several significant problems have to be addressed to sustain growth in the area of industrial machine vision. This paper presents the technological advances in machine vision and computer vision systems that resolves some of the limitations and directs to the future research required to solving these problems.

Keywords

Vision based measurement, Machine vision, Computer vision, Image sensors, Artificial Intelligence

Introduction

Measurement and sensors are confined to Industrial applications until image measurement came into light. Vision base measurement is a generic tool that can be used in monitoring and control of many applications that found its way outside factories. It has the flexibility of automating manual tasks that are much quicker and precise, simplifying the modest tasks that usually need complex algorithms and computations of higher costs. Integration of Machine and Computer Vision provides reliability, reduces overall uncertainty and increase the accuracy of measurements that were done manually. They provide complimentary information to increase reliability to deal with errors and uncertainty inherent with the sensors and provide data on time per operations requirement. The key drivers for the development of machine vision markets are as a result of factories requiring automations of manual tasks and quality checks, the growing demand for Artificial Intelligence(AI) and Internet of Things(IoT) integrated systems dependent on machine vision, the growing acceptance of Industrial 4.0 technology that uses vision to improve the productivity of robotic automation, and increase in smart factories across the globe. Machine vision software is also the fastest growing segment lately due to the increase in integration of AI into industrial machine vision software to enable deep learning in robotics technology.

Machine vision regardless of its several benefits continue to have some hurdles to be utilized to its best potential. The performance of machine vision based methods are still affected by slight changes in environmental factors. The complete automation of integrity assessment of detecting defects and damages has not yet been accomplished. The major output of the machine vision is data and the data to be useful needs programming which can be difficult with unknown challenges. The image processing algorithms have still a lot to advance. An important challenge is to develop vision based measurement systems that are both accurate and precise even though the applications vary from one to another, which have to be often customized to their specific requirements. This paper recommends the newer technologies available which can be integrated with the present vision systems to fill the gaps and are beneficial for taking the machine vision systems to the next level.

What is Vision measurement?

Vision measurement usually consists of a visual sensor that captures an image and a processing image unit such as a programmable logic controller PLC or operations unit. There are two types of vision, one is the machine vision and the computer vision. Machine vision is used in industrial and robotic applications while computer vision can be used in industrial systems and daily life applications, depending on the availability of the computers and processor-based systems. Both of them use common algorithms even though they differ in engineering design, applications and implementation. Machine vision depends on digital sensors inside industrial cameras which acquires images with the help of expert optics, so the hardware and software provide supervision to devices based on the images measured, processed and analyzed.

A visual sensor is a sensor that can capture an image of the physical scene containing the measurable. There are many visual sensors, cameras with infrared or visible-light or scanners with infrared, x-ray and laser are used as visual sensors. The image attained by the cameras is the image as seen by human eyes, but the x-ray and laser sensors need controllers or operation units to measure and obtain the result. For visual sensors that use cameras, the orientation, focal length, aspect ratio, distortion and position are the key factors of measurement.

The components used by vision systems connect and communicate with machines by discrete IO signals or through serial connections like ethernet, ethernet/IP or RS232 connected to a programmable logic controller (PLC) which controls the machines based on the information received and the logic programmed. The serial connections provide interface to operators by connecting to an engineering workstation or Human Machine Interface(HMI) for monitoring and controlling industrial applications.

There are multiple phases of vision measurement process. In the first phase, the abnormalities of the image captured by the visual sensor are identified and fixed. In this stage the images are modified to black and white binary image. The second phase is to examine the image to find the information required to find the measurable subsequently. In this stage the image is divided into multiple segments to find the edges of the article, color analysis and contour detection to identify individual components of an object. The analysis may result in the measurable or provide further information of the measurable. The next phase is to use computational machine learning intelligence techniques such as pattern, shape, recognition and matching to identify the measurable.

Machine vision system are classified as 1D, 2D and 3D. The 1D machine vision examines one line of signal at a time for all digital signals instead of the full area scan. 2D machine vision is the most commonly used in industrial applications to perform area scans and capture snap shots of various resolutions. 3D vision system is primarily used in Robotic applications which requires multiple cameras with added laser sensors. 3D vision systems provide detailed information such as volume, height, planarity and surface. The camera or the product moves to be scanned completely, the laser sensors measures the height and the planarity while the camera measures the volume and the surface.

Applications of Vision Measurement

Machine vision systems are populous both in industrial and non-industrial applications. They are widely used to automate applications, production facilities with non-contact, non-invasive and non-destruction inspection of products. Vision based measurement is extensively used in automated manual repetitive tasks, tasks that require fast feedback in critical systems, simple tasks that are otherwise time taking such as counting, measurement, location and decoding are most common applications.

Several platforms utilize machine vision systems as PC based systems, vision controllers, standalone vision systems, simple vision sensors, and image-based barcode readers. PC based vision systems are easy to interface with cameras, processors and the application software. [1] Vision controllers offer the flexibility with the configuration of 3D and multi-camera 2D applications and they are also very cost effective and robust in harsh industrial environments. Standalone vision systems are built-in systems with camera sensor, lighting, auto focus optics, processor, and communications. These cost-effective systems are compact that can be installed at primary process and manufacturing areas where defects and equipment issues can be known instantly. Vision sensors and image-based barcode readers are user-friendly single point inspection vision systems with dedicated communication system and processors. They can be easily interfaced with any machine with no programming requirement. Line scan applications need single line scan camera to scan the entire part surface, they have high resolution, are compact and fits in very small spaces. This system is very well suitable for manufacturing facilities with products in continuous motion.

Vision based measurement and instrumentation applications:

- Security: Surveillance, headcount and detecting fire
- Automotive measurement: camera-based surveillance analyzes the driver alertness and detect potential driving errors
- [2] Food industry: quality control, analyzing nutrition and counting calories
- [3] Agriculture: Identification, detection of weeds and quality assessment
- Biometric vision measurement: Detect the human face, iris, fingerprint, hand gesture and palmprint
- Medical Instrument Measurements: Allergic reactions, skin problems, diet monitoring of chronic ill patients
- Education: Assistive technology for visually impaired
- [4] Temperature detection: Infrared camera measures temperature of objects with vision in industrial applications that are difficult to measure
- [5] Robotics: robot sensing and navigation to detect objects, obstacles, and paths; manufacturing and industrial robotic applications; assistive robots for elderly and disabled; inspection of complex shapes in industrial applications
- Textiles: Measurement of fabric quality
- Three-dimensional coordinate of measurement of large mechanical equipment that are hard to measure
- Rail transport applications: Automation of

Figure 1 Robotic Machine vision sensor camera system

inspection of Trains braking system, measurement of brake shoe thickness, detection of discrete surface defects in rail heads

- Industrial and manufacturing: Defect detection of manufactured products, moving products on conveyers, inspection of complex shapes, inspection of high-quality welding, 2D and 3D monitoring and characterization of combustion flames, Vision-based measurement systems for static and dynamic characteristics of overhead lines, fill-level inspection system at a brewery, and heat detection in steel production
- [6] Autonomous vehicles: Machine vision cameras with optimum Field of View (FOV), Frame rate and Megapixels (MP) play an important role in the safety of autonomous vehicles.

Applications of Vision based measurement (VBM) are indeed vast in many research sectors and industries, and are becoming even more widely used due to increased affordability and capability of VBM hardware and software such as surveillance, safety and security, human-computer interfaces, vehicular technologies, transportation systems, industrial quality inspections, assistive systems, and robotics among others.

Key Benefits and Limitations

Machine vision exceeds at quantitative measurement of a structured scene with its speed, accuracy, and repeatability compared to human vision.

- The vision measurement system reduces the operations and manufacturing costs by identifying defects and abnormalities in earlier phases that can be missed by human error and manual labor process
- Machine vision increases safety and benefits the operations in manufacturing industry by reducing human involvement in hazardous areas and conditions, it reduces human contamination in clean rooms, prevents physical contact with the products eliminating damage by human error
- Reduces the overall footprint of production equipment when unified with vision system to perform all required functions such as assembly, testing and inspection
- Machine vision is more effective where conventional machine vision inspection methods such as pattern matching need to find the differences amongst the master image and captured product images.
- Machine vision systems support manufacturing to perform complex tasks with better precision and speed.

Machine vision increases quality, productivity, production flexibility, reduces down time, lower production and equipment costs, reduces material scrap, provides complete process control by detection, inspection, measurement, automating manual tasks by optical recognition and identification.

Industrial vision systems mandate superior reliability and robustness due to its use in medical devices manufacturing, military and government applications. However, PC based machine vision development tends to be long and complicated, so it is usually limited to large installations and appeal mostly to advanced machine vision users and programmers. Some reliability issues in vision measurement occurs with the camera and lighting. Lighting conditions affect the measurement of the system. The fluctuations of lighting and the shadows directly affects the pixels of the resulting image thus impacting the accuracy of the measurement. The camera components used and the camera angle can have a major impact on the quality of the image taken. The lenses, hardware and software should be suitable for that application and the effect they have on image taken for measurements and analysis. The camera angle can be affected by the vibration and bearing system of the machine it was installed on, the fluctuations of the position affects the shape, position of the measurable which will impact the output. The efficiency of computational algorithms of the vision measurement with noise present can also impact the final measurement of the application. Identify and evaluate all individual contributions to the impact of the uncertainty to get the best possible measurements. The primary challenge is there will not be a standard vision-based measurement system for all applications, a customized system needs to be developed to integrate the imaging and sensing devices with PC-based tools or processors to develop measurement systems unique for each application that are accurate, precise and user-friendly.

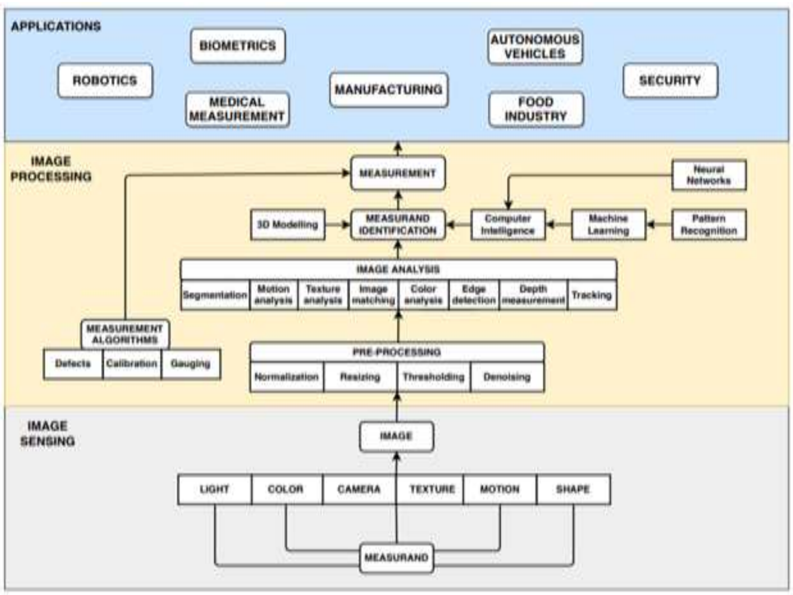

Figure 2. Machine and Computer Vision Hierarchical Diagram

[7] The traditional machine vision defect inspection requires manual setting of a threshold requiring the measurement of every possible defect of an object in an image. The deep learning algorithms software contrast to rules-based algorithms can be trained to automatically learn and analyze defect criteria and acceptable defects. The limitation would be for the users to develop a new deep learning model which needs more time and resources needed each time a new type of defect occurs, or a product variation is introduced. See Vision systems hierarchical diagram in Figure 1.

Performance of machine vision based systems are affected by environmental factors such as lighting conditions, illumination changes, large viewport distance and outdoor arbitrary camera movements. Machine vision and computer integration is a rapidly evolving research area and requires interdisciplinary familiarity in control theory, signal processing, artificial intelligence, probability and statistics. Implementing a machine vision system requires technology skills in camera design and building automation solutions, embedded design, algorithm development and mechanical engineering. Considering the exponential growth potential and at the same time, understanding the above challenges it is important to have more research into these issues to venture into this space further.

Advances and Trends

To address the current technical issues and challenges there have been many recent advances in the machine vision and computer vision technologies. To overcome the common challenges of high-speed imaging, to transfer and capture large amounts of image data requires the machine vision with high frame rates to capture images at high speeds in a short period of time for better images, high sensitive sensors to capture enough light for high-speed imaging, and fast data transfer applications to process the enormous amount of image data.

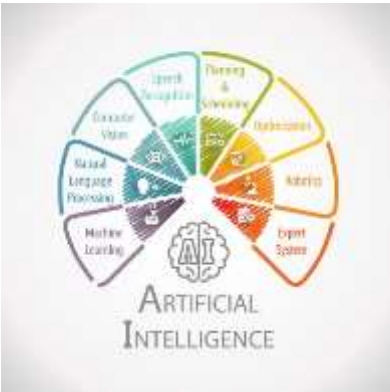

Figure 3 Artificial Intelligence Automation

Deep Learning and AI

AI, machine learning and deep learning are the latest advanced trends of the machine vision. AI, Artificial Intelligence is the machine vision search algorithms. Machine learning that uses neural networks to allow computers to learn by example is called deep learning. With this technique, the deep learning excels in language processing along with the image and sound recognition. Cloud based deep learning is the latest computer vision trend for the autonomous vehicles where cloud-based Machine vision is performed. During the learning process, the deep learning requires graphical processors for deep learning and requires human training. Deep learning algorithms use neural network classifiers permitting image classification, object detection, segmentation at high speed. The latest surveillance cameras are using neural network machine learning algorithms to go beyond traditional functions like monitoring and recording and offer additional video analysis features such as crowd density monitoring, stereoscopic vision, facial recognition, people counting and behavior analysis. This local processing can then be delivered into the IoT and thereby integrated into broader analysis software within the cloud. See Figure 3 for the automation applications that AI can offer. The limitations of the technology are that deep learning is not for all applications and cannot overcome bad lighting. The good thing about it is it can be trained like humans and the results are only reliable if it is previously trained on the application to be used.

3D Measurement and Imaging

3D imaging is a powerful and cost-effective technology for machine vision applications. A huge benefit of 3D imaging is that it provides x and y coordinate locations, depth and space information of a view which eliminates the issues of shadows and color changes in vision measurement. The software application with system integration are the primary reasons for the success of 3D imaging solutions. 3D imaging is widely used in metrology and robotics guidance and safety. It is used in applications where the products or the imaging system are in motion or running at high speed. Three-dimensional imaging is compatible for applications where the products or objects are homogenous and randomly oriented. 3D measurement and imaging are strong trends in the machine vision market that has many challenges in speed, accuracy and resolution and needs advancement in case of measurement errors that occur due to error in position of objects, when picking heterogeneous and unknown objects.

Confocal Technologies

For the thickness measurement of translucent, mirrored and diffused surfaces, Confocal is a perfect technique. Confocal systems can produce higher-quality images because of the ability to remove out-of-focus results. This technology uses the point illumination and a spatial pinhole to eliminate the out-of-focus signal returning from the measurand and by using an objective lens through which different colors of light focus at different points, the peak of the wavelengths can be detected by a spectrometer and converted to a height calculation. The prime benefit of this technology is having a high lateral resolution image. Limitation of Confocal systems is its ability to scan moderately smaller areas which require cycle times to extract an entire surface.

Semantic Instance Segmentation

Semantic segmentation and Instance segmentation vary. Semantic segmentation groups pixels of a specific object group while Instance segmentation recognizes pixel level object outlines. This technology is unique in determining where in the picture the objects are located and identifying all pixels belonging to the objects in the picture. This tool is widely being used in geographical mapping, traffic improvements for city planning and development.

Non-visible, Thermal imaging - infrared wavelengths

Figure 4 Thermal image inspection of heating equipment

The latest advancement is the imaging or thermal imaging from non-visible light in IR wavelengths by propagation of LED illumination capable of creating light in various IR wavelengths. These IR wavelengths from 7000 to 1400nm are well suited for automated inspection applications while thermal imaging is always used for automated heat profiles testing. Thermal imaging with non-contact precision temperature measurement with non-destructive testing of an area in machine vision and automation controls. Near Infrared (NIR) and Short-wave infrared (SWIR) wavelengths from 700-1000nm and 1000-2800nm has been used in machine vision since ages. SWIR wavelengths are absorbed by transparent materials. NIR wavelengths eliminates power glare of machine vision lights that distracts the vision and it also helps highlight the features of specific colors, parts and materials. The limitations to be considered and tested prior are the unpredictability of the wave lengths illumination with the materials. Moreover, the SWIR technology can be expensive. Figure 4 shows the thermal image inspection for non-contact temperature measurement.

White Light Interferometry

White Light Interferometry provides very high vertical resolution, as well as increased throughput by its ability to perform area scanning against single-point scanning. It can also measure the overall surface profile at surface roughness resolutions. White Light Interferometry is a noncontact optical method for surface height measurement on 3-D structures of various profiles, providing resolutions down to the single-digit nanometer range. One of the limitations of this technology is that it is highly dependent on the object's refractive and optical properties.

Liquid lenses and high-resolution optics

Devices that changes focus depending on an external signal from a change in current or voltage without requiring to change the lens are Liquid lenses. This technology is used in machine vision devices, smart cameras and sensors. The integration of the machine vision optics and cameras with the liquid lenses devices is the recent trend and is making this technology useful for multiple applications. This technology adds value in applications where the dynamic and auto focus changes are required to change the imaging distance of different areas or parts that need more focus. The limitations include the selection of optical gears specific to the applications and the calibration issues due to the focus changes. Embedded processing that automatically control liquid lenses can somewhat ease the implementation of the Liquid lenses technology.

CMOS

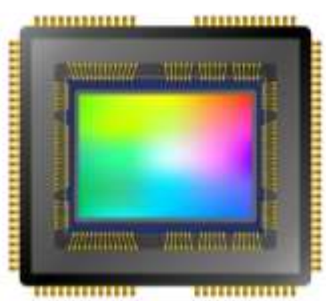

Figure 5 Vector CMOS image sensor

Historically, Charged Couple Device (CCD) have emerged into the markets replacing the tube-based imagers. In CCD image sensors, each pixel collects light and then is moved across circuit through horizontal and vertical shift registers which takes time and power. Complementary metal oxide semiconductor (CMOS) image sensors are now in demand driving the growth of image processing and machine vision inhabiting the smart phone industry, tablets, computers, smart cameras and automobile LED lighting. CMOS sensors use smaller ADCs for each pixel column allowing for higher frame rates than CCD, see in Figure 5 the vector image of the CMOS sensor. They offer megapixel photo sites, programmable options, multiple readout windows, and high dynamic range. CMOS sensors have undergone major improvements over the years making most modern CMOS sensors equal or superior to CCDs for image quality, image speed, and overall value. For specialized machine vision and low volume applications, CMOS attached with processors will be the most cost-effective selection of choice. The limitations with this technology include the low light level performance which could be fulfilled by the backside illumination techniques.

Advanced lighting techniques and processing

Modern image sensors complicate the selection of optical components due to increased resolution and sensitivity requirements. The advanced lighting techniques trends are auto controlled, multi-spectral devices that has more advanced capabilities in illumination components. High definition range HDR images and 3D representations of an object can be created using high quality advanced lighting angles of multiple image views.

Robotics and IoT

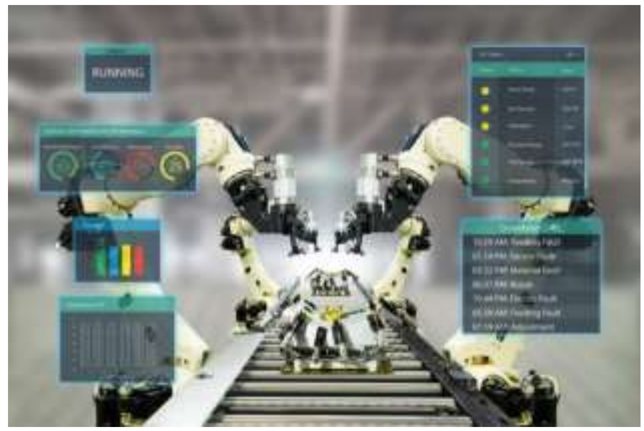

Figure 6 Smart factory using automation robotic arms

Robotics are increasingly being used in industrial automation in repetitive and monotonous tasks that does not need critical thinking which helps increase productivity and improve quality, eliminating human errors. Machine vision and computer vision algorithms in robotics is uniting the industrial systems to the Internet of Things (IoT) and are optimizing the industrial systems operations. Robotic systems are bringing new ways of inspecting and monitoring systems or equipment with autonomous robot systems being connected to Internet of Things (IoT), see Figure 6. High performance of the cameras, affordability of the image sensors, the ease of processing and decision making has enhanced the robotics market for automation in the industries. Robotics also decrease the load on the networks and servers due to the fact that the sensors can directly communicate with the equipment not requiring network communications. Robotic vision inspection solutions will be dominant for many years while they are already being used in industries such as medical devices, pharmaceuticals, food & drink, automotive industries that provide vision systems for quality control.

Edge Computing

Edge computing technology permits for the data to be analyzed and processed at the physical location optimizing the system performance instead of gathering data at the network datacenter which can be unreliable. Technology at the edge tend to learn and fine-tune by itself based on the experience, does not need network accessibility and therefore can be faster in real time. This is another technology that is highly considered for autonomous vehicles.

Embedded imaging

Merging the image capture and processing by a device is embedded imaging. This is a developing trend used in smartphones and self-driving automobiles. In this technology, the cameras contain the vision processing to perform tasks in the camera internally instead of using external computer. To configure and create applications for image processing, a programmed processor is required in a chip or a camera. This imaging can be used in very specific applications like AI or deep learning in case of cameras with programmed embedded image process applications.

Conclusion

Due to the high-quality cameras, deep machine learning technologies and the visual and augmented reality, vision sensing is becoming more exciting and emerging as a strongly connected technology. Vision based measurement increases cost reductions and profitability by increasing yield and reducing defects by providing consistent and reliable results. High-speed machine vision cameras with the advanced technical features are also transforming applications across the automotive, defense, engineering, industrial medical, and scientific research industries further encouraging them to develop new measurement tools. Machine vision cameras capable of high-speed image capture are no longer intended for just complex, high-value applications, they are being used in a variety of settings all over the world. This paper summarizes the current achievements and open challenges in vision-based technologies. There are many latest technologies that have been integrated with machine vision to overcome the limitations and challenges of obtaining high resolution and quality images, automation of focus changes, thickness measurement of translucent surfaces, image processing for detailed information, moving objects measurement, precision image measurements in higher temperatures, cost effective solutions for customized machine vision and low volume applications, independent and local processing vision technologies. Further research and progress are required in automation of damage detection of large object or surfaces, illumination issues that effects the accuracy, measurement errors of untrained and unknown objects, higher cost of the optical gears and trending technologies, unpredictability of IR Wavelengths with different materials, and refractive and optical performance dependability. Despite of significant improvement over the last 10 years in Vision sensing technologies, there are still challenges to get its reputation and future progress from the hurdles it faces. However, the future awaits, and these innovations will further lead to the evolution of newer technologies.

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