Trends and Developments in Industrial Machine Vision - 2013

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ABSTRACT

When following current advancements and implementations in the field of machine vision there seems to be no borders for future developments: Calculating power constantly increases, and new ideas are spreading and previously challenging approaches are introduced in to mass market. Within the past decades these advances have had dramatic impacts on our lives. Consumer electronics, e.g. computers or telephones, which once occupied large volumes, now fit in the palm of a hand. To note just a few examples e.g. face recognition was adopted by the consumer market, 3D capturing became cheap, due to the huge community SW-coding got easier using sophisticated development platforms. However, still there is a remaining gap between consumer and industrial applications. While the first ones have to be entertaining, the second have to be reliable. Recent studies (e.g. VDMA [1], Germany) show a moderately increasing market for machine vision in industry. Asking industry regarding their needs the main challenges for industrial machine vision are simple usage and reliability for the process, quick support, full automation, self/easy adjustment at changing process parameters, "forget it in the line". Furthermore a big challenge is to support quality control: Nowadays the operator has to accurately define the tested features for checking the probes. There is an upcoming development also to let automated machine vision applications find out essential parameters in a more abstract level (top down).

In this work we focus on three current and future topics for industrial machine vision: Metrology supporting automation, quality control (inline/atline/offline) as well as visualization and analysis of datasets with steadily growing sizes. Finally the general trend of the pixel orientated towards object orientated evaluation is addressed. We do not directly address the field of robotics taking advances from machine vision. This is actually a fast changing area which is worth an own contribution.

Keywords: machine vision, state of the art, technologies involved, trends

1. INTRODUCTION

Compared to physics, electrical engineering, mathematics, etc. machine (or computer) vision is still a rather young field of research. Despite of this fact machine vision very soon became an essential tool e.g., for the automation process in the production industry. In order to derive current trends within this area, we first state the core items of the technology, give essential historical data, briefly outline the state of the art and focus on three methods.

1.1 Interrelations of machine vision

Several sciences and technologies intersect with and have a major influence on the field of machine vision. First of all the foundation of all machine vision is found in physics, e.g., in the radiation of electromagnetic waves (mainly light) or particles (corpuscular radiation), reflected by surfaces of objects, refracted or absorbed by different materials. The amount of radiation is transformed to readable electrical charges. Electrical engineering provides the readout of these charges, signal handling, and the overall electrical procedures including storing the generated images or signals into the memory of a computer device. Using informatics and mathematics all of the information present within the generated data is segmented and broken down to that single piece someone is interested in, as well as to calculate relationships between the real and virtual world. Finally bionics helps to understand and use human thinking in fast and global recognition of the content of any input.

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1.2 Machine vision vs. human perception

While machine vision steadily moves on from pixel to object detection and object oriented evaluation, human perception first focusses on objects and if necessary step by step features are explored down to the pixel level. Fig. 1 shows the same content within two views: On the left there is the gray level display as is seen by the naked eye while on the right there is the same information (zoomed in) in numbers as stored in the computer memory.

172	161	148	142	140	133	130	139	124	94	85	92
165	156	142	141	136	107	113	100	76	64	62	60
154	142	119	104	100	72	74	61	55	55	60	58
135	122	92	63	66	57	54	58	56	55	57	56
96	82	64	61	64	53	59	61	60	54	61	67
66	61	57	63	56	54	55	64	57	58	76	90
62	56	52	55	59	57	55	63	68	56	91	130
56	50	50	47	52	64	62	85	118	97	80	159
48	48	54	50	49	60	60	94	150	133	74	163
64	57	52	48	48	64	63	79	145	142	80	153
72	67	58	49	43	64	64	72	102	110	74	147
88	84	68	48	50	75	88	75	87	82	73	152
98	104	93	79	73	91	108	90	80	63	92	165
89	101	104	97	90	91	93	91	75	69	127	176
69	89	107	105	99	102	86	74	76	116	164	181
95	81	79	93	92	89	80	82	119	161	182	184
118	109	93	84	84	90	106	127	159	185	184	180
139	132	126	118	122	141	146	161	181	188	183	176
146	147	141	142	146	154	162	170	177	182	176	166
144	156	152	152	156	155	161	164	161	161	155	143

Figure 1. Human perception (left) vs. machine vision (right, zoomed in) of the same visible environment

Human/creatures perception is physically a mostly parallel information flow: Every single receptor in the retina has a connection for transferring its stimulus to the neuronal network of the brain [2]. This network consists of a huge amount of neurons which are connected by synapsis to some neighbor neurons. Every neuron and the connected synapsis is a decision making unit: They control the amount of transferred stimulus by a chemical modification of the line. This chemical data set is the so far trained knowledge of the human/creature. Because of this rather parallel structure the whole scenery is recognized at a glance.

The process of capturing images by a sensor up to evaluating the scenery is commonly done by a serial information flow. Starting with the read out of a CCD-device, than with the serial signal connection, and ending up by a very few number of decision making units. The reason for this fact is found in the main idea of computers, the von Neumann or Princeton architecture (1945) [3] (single instruction, single data). Therefore the serial information workflow is inherent for any type of a synthetic evaluation device. This automatically leads to first read/interpret details (single values/pixel) and secondly put the information together by additionally interpreting all found values.

2. HISTORY

The history of machine vision has been driven by sciences, industry and consumers. All of them do have different goals and approaches. Science is interested in exploring the fundamental behavior of things as well as novel applications. Engineers (users and developers) aim to provide reliable quality with reasonable budget (revenue). Industry is mainly interested in earning money while for consumers the main priority is entertainment at low budget. Not all of these goals are prone to converge as some of them are highly contradictory. In the following we will show that all of these groups did and still have a common impact to the further growing up of machine vision. For understanding the trends of machine vision in future we will first state various milestones of its development in the past: Invention of the CCD sensor, implementation of the PCI-bus, and introducing Kinect as a cheap, open, and powerful machine vision device for capturing 3D sceneries as high lightning some state of the art.

2.1 Invention of the imaging semiconductor circuit – the CCD sensor

In 1969 Willard S. Boyle and George E. Smith (both employees by Bell Laboratories) invented the CCD-Sensor by accident: Trying to improve digital buffering capabilities by any replacement of the former magnetic bubble memories they used capacitors to store charges as digital information. They built a semiconductor device containing capacitor elements in rows and columns. They realized that these elements are also sensitive to light. The more light enters the capacitor over a defined period of time the higher the voltage of their charge. In 2009 they have been awarded the Nobel Prize for this invention [4].

2.2 Introduction of the PCI-Bus

Machine Vision in general started with the increasing usage of computers. However a milestone boosting the usage and application of machine vision was the implementation of the PCI-bus in 1992. This event symbolized a breakthrough in terms of data transfer speed to the main memory for the machine driven evaluation. Prior the PCI-bus due to the huge amount of image data and the bottle neck of the bus it took up to several minutes to do simple evaluations – unusable for most of the industrial processes. Using the PCI-bus it took just a quarter of the transfer time.

2.3 Kinect put into the market

While machine vision continued to mature various approaches have been presented for capturing 2D information and more recently also going for 3D. In 2001 the first reliable 3D devices got to the market, whose lateral, depth and time resolution as well as the robustness was weak, but the price tag was relatively high (some k$) [5]. In 2010 Microsoft introduced Kinect ($ 145) in combination with Xbox to the consumer market [6] and in 2012 the technology was made available to science by the introduction of the Kinect for Windows SDK [7]. This had have a huge impact to many scientific/engineering groups e.g. dealing with robotics guidance or more general gesture control and man machine interfaces.

3. STATE OF THE ART

In the following section we state three main current and future topics for industrial machine vision: (1) Metrology supporting automation, (2) quality control (inline/offline) and (3) visualization of huge datasets. These separated fields have their own development process and feature characteristics. Another growing field taking advantages of machine vision – robotics with all of its topics – is not part of this work. We reverence to other surveys.

3.1 Metrology

Dimensional measurement for metrology in the field of machine vision is continuously pushing its start of the art towards optical/physical limitations. There are many systems and solutions available which have built in standard functionalities, e.g., to measure outer/inner diameter of circles, edge angles, relative object positioning etc. Furthermore there are smart cameras available with integrated micro controllers supporting the evaluation in one box. In the field of metrology supporting the productivity automation processes have to be accurate and robust. Even under harsh environmental conditions (e.g., steel plant, outdoor equipment, etc.) the equipment has to operate near the physical limits: The accuracy is close to or even beyond the wavelength of light or other used radiation.

3.2 Quality control

Quality control in machine vision has been an issue for years and continues its relevance in both science and industry. Continuously growing amounts of data are input into vision systems. In order to cope with this growing nature of the generated data, techniques for data reduction, clustering, registration, segmentation or feature extraction are necessary in order to support the capturing unit. The quality of all these processes has to be assured in a fast, objective and robust way, providing equal or superior results as experienced operators. Systems have to learn to distinguish between the different types of error such as false negative or false positive errors. Quality control needs to check the preselected features of objects in time as the processing time is limited. Furthermore due to given quality standards a 100 % check of mass products has to be achieved e.g. within the aeronautics industry.

Finally, there is an uncertainty of the kind of quality machine vision systems can handle in respect to the need of the human operator. For example dealing with textures humans quickly distinguishes quality between proper and bad probes. But if you ask for the concerning parameters which can be entered to the machine vision driven system you are not sure to end up with the same results.

3.3 Visualization

At first glance visualization might seem to be off topic for machine vision. However only visualization allows for transport the relevant information to the operator at the time it is needed. So due to increasing automation levels a strong need for simple but meaningful visualizations of huge datasets is observable. Domain specialists and operators aim to get an overview of the current state of a process in real time, before they may dig deeper in to data on demand using focus and context techniques. Currently passive visualization as well as interactive visualization techniques is state of the art. Passive visualization comprises the generation of resulting images, video sequences of a certain process state, whereas interactive visualization allows the interaction with the data in order to focus on the features or regions of interest. A further challenge for the future might thus be interactive steering, which allows to directly influence the data generation process from visualization.

Visualization as a task is at the end of the data processing pipeline. But already now many algorithms in visualization converge to machine vision. Furthermore machine vision increasingly uses the computation power of graphical processing units (GPU coding) which were formally used mainly in computer graphics, the foundation of all visualization techniques. To note just a few of the application areas GPUs are currently used the area of highly sophisticated and FPGA implemented algorithms regarding projective geometry (gaming industry) as well as the area of 3D reconstruction is mentioned here. Finally visualization deals with huge data generated either by 3D capturing devices like computed tomography [8] or by any simulation process of electrical/mechanical/topological or many other investigations. In these areas visualization may provide guidance in parameter space explorations in terms of the data generation process as well as for simulations. Summing up, in any case the main task of visualization is to provide a quick understanding in a simple but efficient way.

4. TRENDS

Driving factors for trends in case of industrial machine vision originate in complete different (orthogonal, independent) fields:

- Engineers (users): production factories, automation departments
- Scientific and engineering (developers) groups serving the needs of the users
- Consumer market for general entertainment needs
- Supplier market for HW devices and SW tools.

The user engineers needs to get his production line running. He wants to get a certain output in quantity and quality. Therefore he needs according sensor equipment. He is not really interested in machine vision – just takes it if necessary.

Scientific (in the case they work heading industrial machine vision) and developing engineers are the one who support the users with the suitable equipment. They have to know the technological needs at the plants, have to select the proper devices, combine them and set them efficiency to work. If the systems don’t get paid by revenues of the plant they face commercial problem.

The huge consumer market consists of all users of any computer system for any purpose. Because of this big mass of used computer devices the costs are low. The main item is entertainment (in case of machine vision). The applications have to be funny, extraordinary. Reliability is not really a topic. But they have to be cheap.

The suppliers want to earn their money by selling cameras, lenses, lightning, even hole systems. Their primary job is not implementing machine vision systems to the users.

4.1 Trends in hardware for machine vision

There are close trends visible dealing with the hardware which are inherent within the technological progress: Pixel size will remain as is with slight or no changes, resolution will go up slightly, noise tends to go down, chip size grows again after being reduced the last decades [9]. The huge market of consumers in collaboration with the vision industry pushes USB as a standard interface for most of the industrial cameras. Additionally CoaXPress for high speed applications beside GigE Vision will keep its portion while FireWire will lose importance [10]. VDMA (German union of machine and plant engineering) predicts a constantly growing market for the field of machine vision [1]. In detail they observe a trend for more machine vision systems (camera plus extra evaluation systems), less smart cameras (camera including an evaluation unit) but more smart sensors (ready to use, no extra coding available sensors using matrix cameras for specialized tasks like matrix code reader etc.).

Another trend will be the type of the captured radiation: The main focus now is the visible and NIR spectrum (350 nm up 1.1 µm for silicon-type and up to 1.4 µm for germanium-type detectors). Beside these most significant capturing devices other ranges are and will increasingly become available (means affordable) for machine vision tasks: Long range infrared sensors, terahertz sensors, neutron cameras, ultra violet, X-ray, and gamma-ray.

4.2 Trends in supported features for quality control

Quality control is a typical implementation where different approaches of human perception vs. machine vision are obvious: The human operator sees at first the object which probably consists of an amount of single objects. Secondly he goes for all the objects and checks their quality (size, position, defects, and deviations against proper conditions). At the end the operator tries to confirm/dismiss the overall quality by identifying any missing feature – if there is no missing feature the quality is signed. Nowadays machine vision systems have to be told which single features of the object have to be checked for evaluating the overall quality. In future they will more and more be able to recognize the scenery by themselves by focusing on the objects within the measuring area. After knowing the scenery the concerning details will be checked if necessary.

Figure 2. Quality control – which features define the cleanness of the coffee cup?

Fig. 2 shows the aspect of defining quality related features vs. others which are at the probe but not essential for estimating the cleanness.

The general trend goes from the pixel orientated view to the object orientated evaluation. Nowadays the operator has to accurately define the tested features for checking the probes. There is an upcoming development also to let automated machine vision applications find out essential parameters in a more abstract level (top down). Either there is a training phase after erecting the systems at the production line: The operators get series of pop-ups of uncertain quality issues and by the way the operators make their decision the system learns how to act. Or even the operators don't know exactly how to define a proper quality. This is a bit more challenging situation. Machines have to think as the object users (not the production operators) for directly checking the features of the probe against the needs of the user.

4.3 Trends in supporting the visualization tasks

The interactive visualization will be still in the focus of research to render increasingly complex spaces e.g., of modelling, simulation, or of parameter-set analyses. The challenge is to provide images in real time while interactively changing focus and context. For example for scanning composite materials using X-ray computed tomography the generated dataset includes all fibers, pores or particles within the data structure. A single 3D rendering of the complete dataset would generate a cluttered an overloaded view, which is difficult and tedious to analyze. Using more sophisticated data exploration or clustering techniques however, classes of the structures of interest may be determined and encoded using opacity and colors transfer functions (fig. 3).

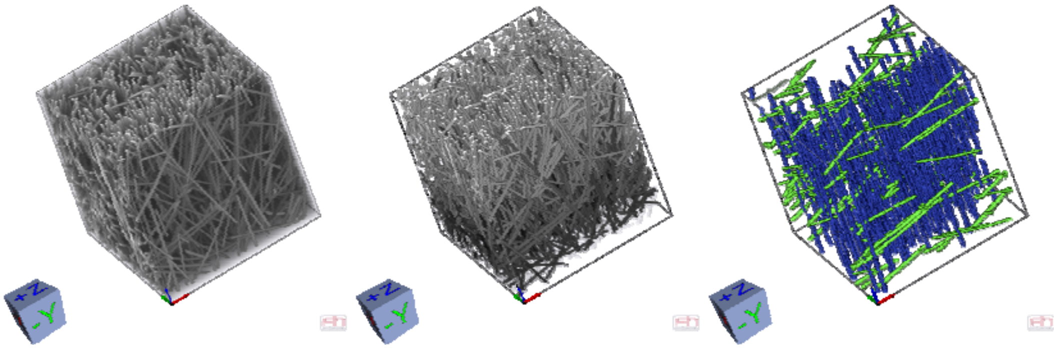

Figure 3. Composite material by X-ray computed tomography
3D rendering (left), labeled image (center), clustered (right)

All these clustering and data exploration methods shall be interactive and adjustable in accordance to the operator's need. Interactive steering will be further explored to directly influence the data generation process from visualization. Especially in the field of simulations first approaches have been presented, e.g., for exploring flooding simulations in case of dam breaks by the usage of known topography. Instead of calculating all theoretical flow scenarios the user explores the underlying parameter space and focusses on interesting scenarios.

5. CONCLUSION

We showed our main idea to come up with the trends in industrial machine vision. Starting with the fundamental ideas of machine vision, the driving factors, and the state of the art we developed our view of trends within three methods: The metrology, quality control, visualization. Within metrology the physical limits are reached, sensors will become smarter, some increasing resolution, lower pixel noise. Additional capturing technologies will enter the line of industrial available sensors. For quality control machines will gain in decision level for proper/improper checks by increasingly orientate rather on the object than on the details. In the field of visualization the

REFERENCES

[1] Munkelt, O., "Industrielle Bildverarbeitung weiter auf hohem Niveau", VDMA, (2012).
[2] Marques de Sá, J. P., "Pattern Recognition", Springer, 1-20 (2001).
[3] Godfrey, M. D. "First Draft of a Report on the EDVAC", IEEE Annals of the History of Computing, Vol. 15, No. 4 (1993).
[4] dpreview, "Nobel Prize for inventors of the CCD image sensor", http://www.dpreview.com/news/2009/10/6/nobelprize (6 January 2014).
[5] MESA imaging, "MESA Imaging History", http://www.mesa-imaging.ch/history.php (December 2013).
[6] Avancini, M., "Using Kinect to emulate an Interectivce Whiteboard", Facoltà di Scienze Mathematiche, Fisiche e Naturali, Università Degli Studi Di Trento, Italy, (2011).
[7] Microsoft, "Steve Ballmer: 2012 International Consumer Electronics Show", http://www.microsoft.com/en-us/news/exec/steve/2012/01-09ces.aspx (December 2013).
[8] Heinzl, C., "Analysis and visualization of industrial CT data", PhD Thesis, Institute for Computer Graphics and Algorithms, Vienna University of Technology, Austria, (2009).
[9] Warren, C., "Vision yearbook 2013/2014," Europa Science, 4-10 (2013).
[10] Wilson, A., "Camera Interfaces: USB 3.0 Challenges Mainstream Camera Interface Standards", http://www.vision-systems.com/articles/print/volume-18/issue-10/departments/technology-trends/camera-interfaces-usb-3-0-challenges-mainstream-camera-interface-standards.html, VisionSystem Design, (December 2013).