"LUCIAN BLAGA" UNIVERSITY OF SIBIU

Syed Usama Khalid Bukhari

DOCTORAL THESIS

(Summary)

COMPUTER VISION APPLICATIONS IN INDUSTRIAL ENGINEERING

PhD. Advisor:
Rector Prof. Dr. Ing. Ioan BONDREA

1 Abstract

Europe is considered as the birthplace of the industrial revolution; the wars in Europe (World War I and II) became the primary reason to have a proper check on quality. Nowadays, quality is the foremost criterion to judge any product. A QA system, which ensures 100% accuracy, is what every company aims to attain. This is pushing companies to spend hefty amounts of resources to achieve better quality. With the advancement in technology, its use has increased in the field of industry, as companies found automation of the processes give fast, reliable and cost-effective results.

*A similar scenario refers to a multinational company "**Continental AG**" whose goal was to increase the productivity of DQ 200 TCU control unit's manufacturing plant by automating its human-based inspection system. As the company wants to retain the current hardware and does not desire to invest in a complete machine vision system, a new research question is raised, which motivated the research presented in this thesis.*

This thesis starts off with a systematic survey to get an overview of computer vision-based technologies, which are used to make inspection and training easier in an industrial environment. A detailed overview of the existing system, requirements of the company, practical limitations, and challenges of using existing technologies led to an explicit research question "Can a fast and reliable, vision-based quality inspection system be developed, without making any changes to the current infrastructure"?

The identified research question is then addressed by presenting a potential framework that proposes two parallel inspection systems 1) Augmented Reality base inspection system 2) fully automated inspection systems. Working and functionality of both systems are discussed in details.

*In the end, the proposed framework is established by developing the functionality of both the systems. Results are gathered by case studies and detailed experiments using a dataset of **30,000 images**, and presented, discussed and critiqued upon.*

The thesis ends with a commentary on the presented work, its limitations, and possible future directions.

2 Introduction

The awareness of how much quality assurance is essential and profitable came in its due time. Europe is considered as the birthplace of the industrial revolution; the wars in Europe (World Wars I and II) became the main reason to have a proper check on quality. After the World War II, when Japan uplifted its industry, they placed special emphasis on the quality of the product putting European and American companies under new crises. New unknown companies dominated some well-known European and American companies. Those who managed to survive lost huge shares in the market and went into a financial crisis. Eventually, companies around the world learned the importance of quality of a product and that of building customer confidence.

Nowadays, quality is the main criterion to judge any product. This is pushing companies to spend hefty amounts of resources to achieve better quality. As the field of computer vision and machine learning got mature and cost of computer-based processing went low, the majority of companies started to look for a shift from human inspection to vision based inspection systems.

Research presented in this thesis is related to a scenario; where a human based inspection system recuperates, to increase the productivity.

Continental AG, commonly known as **Continental** is a leading German automotive manufacturing company The QA system that is required to be reformed belongs to DQ 200 TCU control unit's manufacturing plant i.e. improvement in terms of time for quality assurance is required after the board is passed through the soldering process. As the company wanted to retain the current hardware and does not desire to invest in a complete machine vision system, a new research question is raised.

Q: Can a fast and reliable, vision-based quality inspection system be developed, without making any changes in the current infrastructure?

3 Thesis Structure

The thesis is structured as follows

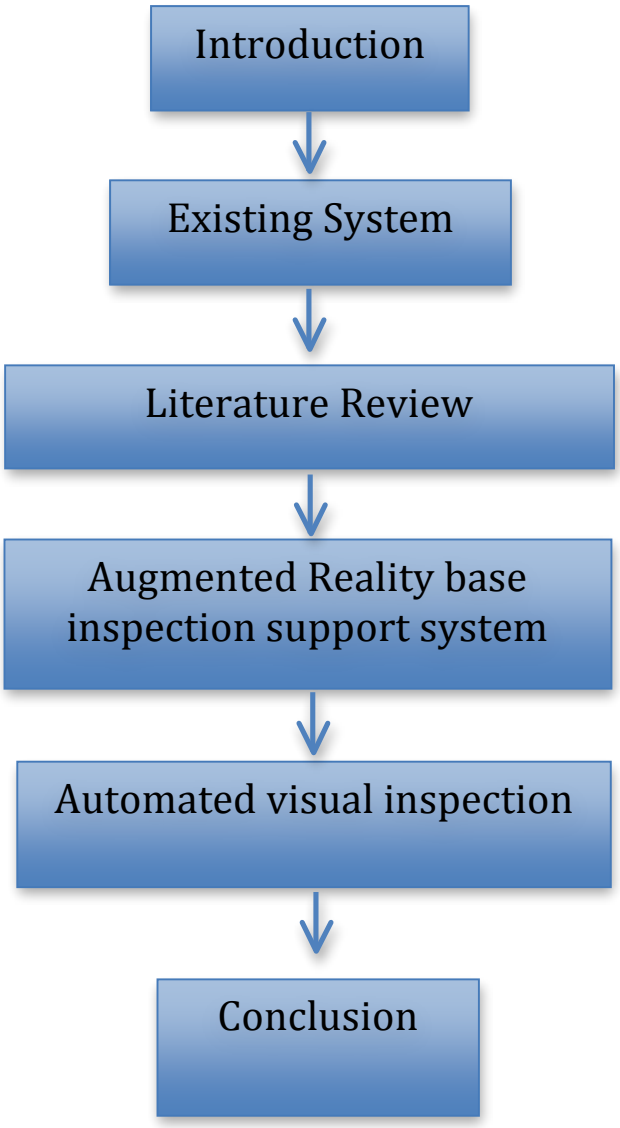

Figure 1 Flow diagram of Thesis Structure

Chapter 1 contains a brief history of usage of computer vision in industrial environment since 1930 till to date. The chapter highlighted the key and important events and inventions made in industry using computer vision technology. After presenting the industrial perspectives over vision systems in industrial environments, the key points for further research direction are identified.

- *Vision base systems are essential for the quality inspection in the industry due to a number of tangible and intangible benefits.*
- *Development of a customized vision system required fewer resources and has more chances of success.*
- *The design of a vision system needs total control over software and hardware.*

These findings led to objective of the research, which is followed by the main research question. "**Can a fast and reliable, vision-base quality inspection system be developed, without making any changes in current infrastructure."**
The chapter future explains the research methodologies and structure of the thesis.

In ***Chapter 2*** working of the existing system is explained with the reasons and needs to change the system. Detail analysis of functional and non-functional limitations were identified and discussed. A mathematical model of productivity calculation is developed to estimate the production output of current system. In the end of chapter a well though two-step approach system is proposed.

Chapter 3 is divided into two main sections *1) Understanding the use of the Automated Visual Inspection (AVI) system for quality control in Printed Circuit Board (PCB) manufacturing plants. 2) Understanding the Augmented Reality (AR) and how it is being used to help in an industrial environment.*
Detail scientific surveys are done for both AVI and AR systems in industrial environment followed by critical analysis. In the end key findings are extracted from both surveys and discussed.

In ***Chapter 4*** working of the AR module of the proposed system is discussed in details. For analytical results, case studies are conducted and presented in the chapter. A comparison between existing system and AR system is then presented showing the positives and negatives of using AR system, in given scenario.

In ***chapter 5*** an explanation of the automated visual inspection system module, along with the requirements of every single image, their checking criteria, and the solutions for them is discussed in details. Results are gathered using 30,000 images and then those results are compared with existing system and AR system using the production calculation mathematic model.

Chapter 6 concluded the thesis, by summarizing the thesis, emphasizing the key findings, contributions and future work.

4 Research Extracts

The following key insights have been drawn from the research presented in this dissertation:

- The increasing need to automate quality assurance systems in the industry is growing.
- Literature review shows an increase in the use of augmented reality in an industrial environment.
- Due to varying scenarios and environments, customized AVI systems are required to get the desired results.
- In chapter 4, results of the case studies show that with a very limited training and use of augmented reality, good results can be achieved even from a totally new user.
- Computer vision and machine learning have evolved to such a degree that even in a scenario, where control to change or to modify image acquiring system is not possible, however a customized AVI system can be built on a standard laptop, which has the ability to learn and evolve with time.
- An AVI or AR system can dramatically increase the productivity in the field of QA.

5 Limitations of the Research

The followings are the main limitation of the process used to conduct the research:

Reflection on the case studies and limitations of this research

- Case studies were conducted to get the result of AR system. As the sample set of the case studies was limited, results generated by those are just a rough estimate of human behavior; a real life deployment of the system is needed to get accurate results.
- In AR system, how, where and what information is displayed on the monitor is decided by a single person. Hence, no optimization in information display was performed. Such a task requires proper research.

Reflection on the experimental studies and their limitations

- AVI system was developed with a limitation of no control over the general environment, lighting, ability to add any new hardware and image acquiring system. Some control over few variables can give significantly good results.
- AVI system was tested using a non-dedicated machine, with non-optimized code and a limited data set. A dedicated machine with optimized code and access to an increased amount of data can give much better results.
- The data, on which the proposed system was trained, did not contain information about the mistakes made by the skilled workers. For example, if a skilled worker rejected a board, which did not have any errors in it or accepted a board, which had defects in it. Therefore, the system after learning from that data set is also prone to making those errors.

6 Research contributions

The main contributions of this research can be divided into three broad categories: Theoretical contribution, practical contribution, and scientific contribution. Figure 6.1 illustrates the flow of events and their connections to meet the overall objective of the research. These are discussed in more detail in the following sub-sections.

6.1 Theoretical contribution

The theory was developed to show the need, usage and limitation of the quality control systems in the industry.

- ***Industrial perspective***: Chapter 1 presented the industrial perspective, which shows current vision systems their usage, limitations and future requirements in the industry, especially in the field of quality inspection. Key points are identified to gather the guidelines for future progress in the field.

- ***Knowledge of the domain of application***: Chapter 2 presented a focused real-time industrial problem, with detail knowledge of the existing system and pinpointing the exact task. This gives an insight of actual industrial needs.

- ***Focused and Systematic literature review:*** Three detailed systematic literature reviews were conducted for chapter 3. First survey gives an over view of usage of computer vision in the field of automobile industry. The survey contained over 70 scientific research papers and books references. It is then published in a conference at the university *[1st International Conference for Doctoral Students IPC 2013, Page 294]*. Second survey gives a detail overview of usage of AVI system in industrial environment. A scientific paper is generated using this survey and currently it is in review process. Third survey gives an oversight of AR technology and its usage in industrial environment. Both second and third surveys have over 40 research paper and book references. Third survey is also transformed into a research publication and currently it is in review process of a renowned journal. These reviews are one of the main contributions, as they not only reaffirm the industrial perspective but also gives a detailed overview of academic and industrial research.

This theoretical contribution led to the thinking process on how to solve the problem at hand, which resulted in the design of a two-way automation module solution. Figure 6.1 shows the block diagram of the main contributions.

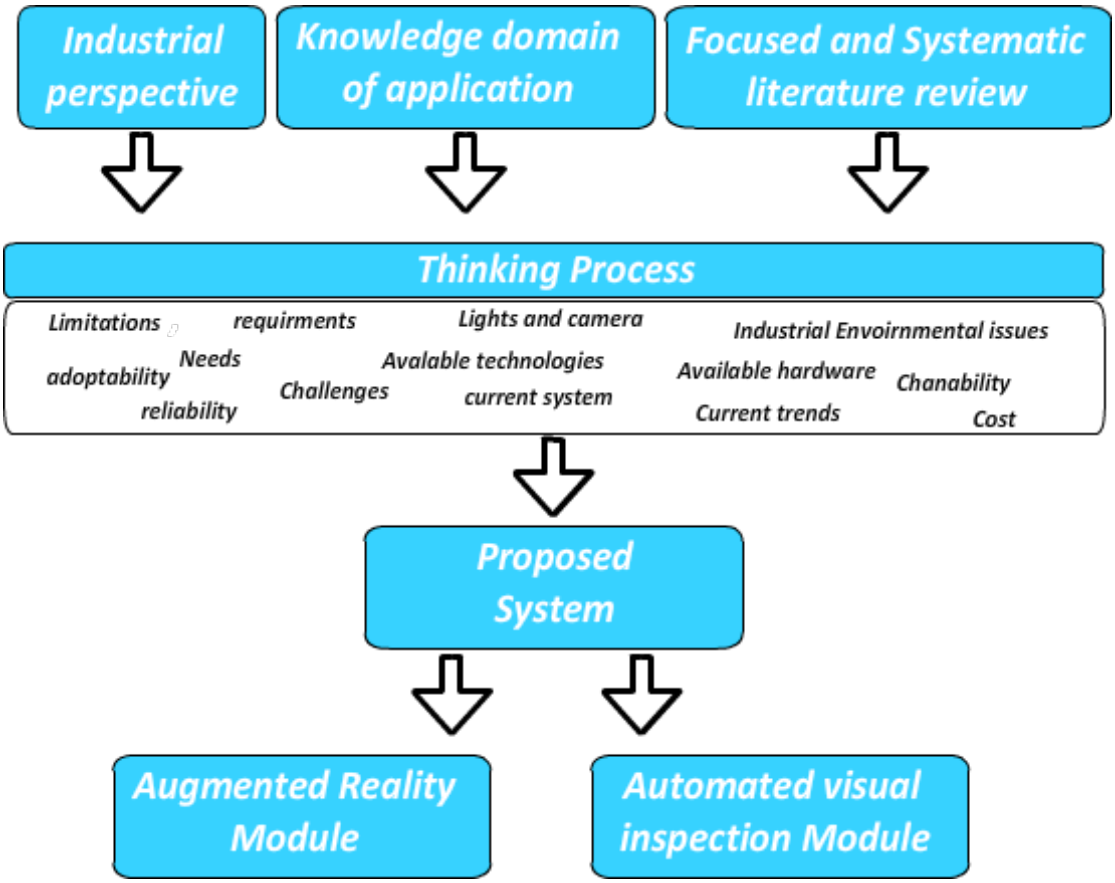

Figure 2: shows the block diagram of thinking process and main contribution

6.2 Practical Contribution

Development of two parallel yet coherent modules of automating the existing system is an important practical contribution to this research.

Augmented reality based Inspection system: An AR system was developed, which can be very helpful in industrial environments since it does not require many changes in the existing system. The main objective of the system is to display useful augmented information and conversion of the fuzziness of the system to somewhat canniness. Converting fuzzy information to discrete information helps in making fast and more accurate decisions. The system uses very simple and fast computer vision techniques, which not only help the AR system to identify images and finding markers for information alignment but also give an added advantage to calculate runtime information of the board,

making things easier for the human user. The results show that processing time to inspect one board and training time of a new user reduced significantly.

Automated vision inspection system: A system was developed to convert a skilled user based quality assurance system into a fully automated quality assurance system. It is a tailor-made system developed for a highly focused industrial task. The main objective of the system was to minimize the time of inspection of the board after soldering has been done. The automated system takes on an average 13.7 seconds to complete all the tasks in parallel mode whereas 143.7 seconds in serial mode. This time was calculated using MacBook Pro running an un-optimized Matlab code. The time can be decreased significantly if the same system is made to run on a dedicated server, in parallel, with optimized code.

Experimental data: For experimental purposes, ***30,000 images*** are used, which were gathered from the company. As the company's system was unable to save any true negatives images, long hours are spent observing the system and waiting for true negative images to appear. Information of every single true negative image is gathered carefully. With the help of operators and instructors of the company number of different kinds of true negative images are developed which, are subsequently presented and get approval from plant engineers and operators. Learning of the systems is done only on true positives images and developed true negative images are used to check the robustness of the system. Results of the experiments are provided in chapter 4 and chapter 5.

Nevertheless, experimental data is still a small sample set, compared to the real time scenario. According to a standard calculation of machine learning, the system cannot perform 100% in the real time scenario. All systems need to keep evolving in real life to reach to 100% results.

The system is designed in a way that, it can evolve in real time scenarios; the results show how its performance gets better with time.

6.3 Scientific Contribution

The research done in the thesis is rearranged and published in different renowned and respectable journals and conferences. In total, **seven** scientific papers are generated, among which four are already published where three of the papers are under review or construction process.

List and summary of scientific publication is

- The first paper was a survey paper title *"Use of computer vision in automotive: a brief survey*", the paper is published in "*1st International Conference for Doctoral Students IPC 2013. Page 294".* The paper contains a detail overview of use of computer vision technology in the automobile industry. With over 70 references of scientific papers and books and a critical analysis this paper gives a broad overview of the field of computer vision in automobile industry.
- The need to develop a good edge detection algorithm which is fast and adjustable to the requirements at hand, lead to publish the second paper in "*Studies in Informatics and Control, ISSN 1220-1766, vol. 23 (2), pp. 163-170, 2014*" with the title "*Fast Edge Detection Algorithm for Embedded Systems*". The paper contains working of the algorithm and its results, which clearly shows that the propose algorithm requires less resources and is much faster than other known algorithms.
- The mechanism and results of augmented reality system for inspection of PCB, are put in an other scientific paper which is published in an other journal *"Industrial Engineering Letters 5.7 (2015): 1-4."* with the title "*Augmented Reality System to Help Train New Skilled Workers for PCB Inspection*". The paper contained the whole working of AR system and its results.
- To generate the ground truth form different images, a new GA technique is proposed, which is then published in "*CISSE Online E-Conference, Page-4 2014.*" with the title "*Dynamic Population for Genetic Algorithms*". The new technique is useful in number of ways and can be use in other fields beyond computer vision.

- The paper on the working of whole AVI system with results and the process how to transform a human operated system into automated system is currently in a review process of "PLOS One" with the title "*Migration from Manual to Automated PCB Inspection System: A Case Study*".
- A survey paper on AVI systems in industrial environment is currently under progress. The paper contains over 40 references of scientific papers and books. The paper talks about AVI systems since 1980 till today, making this paper a complete overview survey about state of the art in the field of AVI.
- Another survey paper on augmented reality and its use in Industrial environment is under process too. This paper talks about augmented reality in general, its use and then explains the use of AR in industrial environment and its future.

7 Summary

Development of an automated inspection system as per the need of industry is a challenging task. This challenge becomes more difficult, if some limitations bound the task at hand. The research presented in this dissertation offers a possible solution to a well-defined focused industrial task. Though this came with its price, as a very limited flexibility was available to design the whole system.

Two module-based system is proposed for the task at hand; one module is based on the augmented reality whereas other is a complete automation system, which uses computer vision and machine learning to fulfill the requirements. Results show that both the systems meet the required specifications, and they both can complement each other if implemented one by one.

8 Published Papers

- *Syed Usama KHALID BUKHARI, Remus BRAD, Constantin BĂLĂ ZAMFIRESCU, Fast Edge Detection Algorithm for Embedded Systems, Studies in Informatics and Control, ISSN 1220-1766, vol. 23 (2), pp. 163-170, 2014.*
- *BUKHARI, Syed Usama, Ioan BONDREA, and BRAD Remus. "Augmented Reality System to Help Train New Skilled Workers for PCB Inspection. "Industrial Engineering Letters 5.7 (2015): 1-4.*
- *Use of computer vision in automotive: a brief survey. PETRUSE, Radu, et al. "1st International Conference for Doctoral Students IPC 2013. Page 294-300" (2013).*
- *Dynamic Population for Genetic Algorithms, CISSE Online E-Conference, Page 4-6, 2014.*
- *BUKHARI, Syed Usama, Ioan BONDREA, and BRAD Remus. "Migration from Manual to Automated PCB Inspection System: A Case Study" , PLOS ONE (under review)*
- *BUKHARI, Syed Usama, Ioan BONDREA, and BRAD Remus," Use of Augmented Reality in Industrial Environment, A survey", Virtual Reality* (2016) (under review process)
- *BUKHARI, Syed Usama, Ioan BONDREA, and BRAD Remus, "Use of Computer Vision in industrial Environment, A survey", journal of Electronic Testing* (under review process)