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Research paper

Extended Design Science Research Methodology For Parallel Vision System

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Abstract

Vision system implements image processing in its design and development. The process involves a series of static and dynamic images that are received from a real-time environment. The vision system produces an important outcome in term of object features that are meant for observation, for example, object location, identity, orientation, and others. The previous research in image processing has incorporated a test-driven agile simulation as a research methodology. However, the research methodology for the vision system remains lack of attention. This paper investigates the possibility of the Design Science Research Methodology (DSRM) for vision system application. First, the vision system framework that involves image processing is presented. Second, qualitative content analysis to find a match between vision and DSRM components is demonstrated. Third, investigation on the parallelization of the vision system is reviewed and finally, the extension of DRSM to accommodate parallelization is exposed. The selected case study in this paper involves a vision system for an autonomous robot whereby a parallelization is employed to accelerate computation. The analysis shows that the customized DSRM match with the parallel vision system development stages. The customized DRSM will assist the vision engineers to design the vision system efficiently.

Keywords: *Design science research, image processing, research methodology, the parallel vision system*

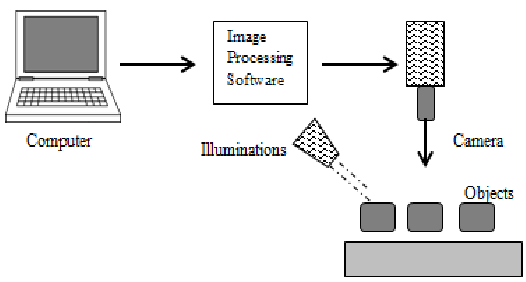
1. Introduction

The vision system is a very important component in many industrial applications such as visual inspection and quality control [1]–[3]. Usually, the inspection and quality control is performed by the human (experts) with the specific skill set. However, they are difficult to find and maintain. Besides, it may take the time to develop the skills especially for those systems that demand precision. Moreover, human works slower than machine and this limitation makes the vision system in highly demanding to replace human to perform particular tasks. Some of the applications like object tracking and automation (robot guidance, intelligent system, etc.) are the examples of those systems that need precision and speed [4], [5]. In other situations like nuclear inspection or chemical processes, the inspection may be too difficult or dangerous to be done by the human hence the vision system can effectively substitute them. The same situations may also apply to the underwater and aerial view inspection [6]–[8]. The latest vision system has implemented advanced technology that has improved productivity and provides significant advantages to the industries. Therefore, many industry applications have benefited and shown the huge interest of the vision system.

The characteristic of the vision system is applying image-processing software to analyze a series of images received from one or multiple cameras in a real-time manner. The camera usually has fix height to inspect the intended object features or moving the camera with eye level height. The scene is then sufficiently illuminated for a better reception to image analysis module. In most industrial applications, the vision system is designed for objects with the exact location. However, there are some applications includes moving objects like robotics and surveillance system that are more complex. When the process involves a complex computation, parallelization is employed. Parallelization is defined as a method to perform normal sequential steps of computer program concurrently by dividing the tasks into sub-tasks and assign them to many processors. In a vision system, parallelization most likely applied to image processing. The component of a vision system with and without parallelization is shown in the Fig.1.

The objectives of this paper are:

1. Overview of the framework of the vision system.
2. Demonstrate the content analysis to find a match between DSRM and vision system framework.
3. Discuss the Test-Driven Agile Simulation (TAS) and expose the customized DSRM for the vision system.
4. Discuss the Parallel Design Pattern (PDP) and expose the customized DSRM for the parallel vision system.



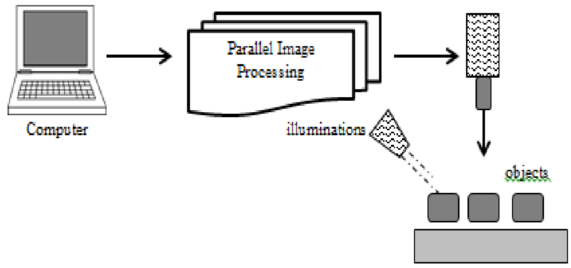


Fig. 1: Sequential and parallel vision system

This paper is organized as follows: section 2 describes the framework of the vision system. Section 3 provides a detailed explanation about DSRM matches with the vision system framework. Section 4 presents three things: the extended DSRM with Test-Driven Agile Simulation (TAS) for the sequential vision system, discuss the Parallel Design Pattern (PDP) for the vision system and enhanced DSRM to handle the parallelization. Section 5 describes the evaluation of the customized DSRM over Parallel Vision System for an autonomous robot. Section 6 shows conclusion with some research highlighted and section 7 is the acknowledgment to University Kebangsaan Malaysia (UKM) for supporting research in this paper.

2. Vision System's Framework

The framework of the vision system starts with requirements[2]. The design and development should follow the application domain and tasks to accomplish. For example, some applications need to differentiate defects in the products while other applications need to provide guidance, tasks alignment, measurement, verification, detection, tracking, etc. After requirements are specified, the decision on design and development can be taken. In order to achieve a reliable system, the quality of the acquired images is deemed important and necessary[9]. Whereby image-processing system comes in this part. The image processing system follows the sequence of steps from image acquisition, image pre-processing and feature extraction through image segmentation and classification. Image pre-processing includes image enhancement to improve the quality of the acquired images. With good quality of acquired images, the analysis will be performed more accurately. The outcome of the vision system is the qualitative and/or the quantitative information such as images, color, size, shapes, orientation, etc. Fig.2 depicts the framework of vision system from the application domain, requirement specification, image processing system and the outcomes.

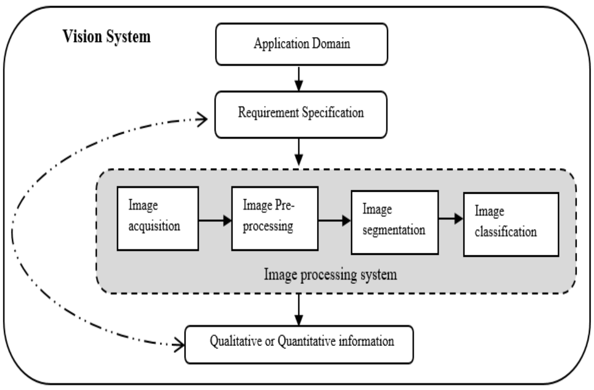


Fig. 2: The framework of the vision system

The framework of the vision system does not work in one way but involves iteration between the requirement specification and the outcomes. The two-way arrow in Fig. 2 shows the possible iteration that may happen when the outcome does not meet the initial specification. The iteration helps the vision system to achieve its goal. It also reflects the complexity of the image processing system to produce meaningful information to the vision system. Hence, the complexity of the vision system requires strong algorithm of image processing system to solve problems. The previous researchers share some works in the development methodology for image processing system. One of them employs Test-Driven Agile Simulation (TAS) [10]with the specified environment like VERITAS [11]. However, the development methodology for vision system has never been discussed clearly for both with and without parallelization. Recently, DRSM has become popular in information system [12], software engineering [13] and information technology field[14]. With the increasing interest of DRSM, there are many opportunities to explore the feasibility of employing DSRM for other fields including vision system. The intention is to help the design and development of any systems more efficiently.

3. Design Science Research Methodology (DSRM)

Generally, DSRM is a problem-solving process[15]. The DSRM can be defined is a paradigm that consists of seven guidelines in order to solve complex real-world problems[12]. Interestingly, the seventh guideline states the research results should be communicated effectively to the specified audience. This makes DSRM popular as the only methodology that encourages researchers to publish the research findings. Besides, the concept of artifact in DSRM makes this methodology is more flexible to be accepted by a variety of research fields.

The key principle in DSRM is the knowledge and understanding that a design should start from a clear problem statement and the solution is coming from the building application of an artifact. The seven guidelines are illustrated in Table 1 below. Those seven guidelines show the steps of DSRM with the expected results of each step. Interestingly, the first guideline itself has directed the researcher to the think about the possible outcomes like construct, model, method or instantiation. In a vision system, the method is recognized as the algorithm that is derived from the application domain where the method will be applied. This shows the consistency of the first guideline in DSRM with the initial step in the vision system framework.

Table. 1: The seven guidelines of DSRM

Guideline 1	Design as Artefact Design-science research must produce a workable artefact in the form of a construct, a model, a method, or an instantiation	Result: Purposeful artifact
Guideline 2	Problem Relevance The objective of design-science research is to develop technology-based solutions to important and relevant business problems	Result: Specified problem domain
Guideline 3	Design Evaluation The utility, quality, and efficacy of a design artefact must be rigorously demonstrated via well-executed evaluation methods.	Result: the integration of the artefact within the technical infrastructure of the business environment
Guideline 4	Research Contributions Effective design-science research must offer clear and verifiable contributions in the areas of the design artefact, design foundations, and/or design methodologies	Result: Novelty: solving problem in more effective and efficient
Guideline 5	Research Rigor Design-science research relies upon the application of rigorous methods in the construction and evaluation of the design artefact	Result: adherence to appropriate data collection and analysis techniques
Guideline 6	Design as Search Process The search for an effective artefact involves utilizing available means to reach desired ends while satisfying laws in the problem environment.	Result: discover an effective solution to a problem
Guideline 7	Communication of Research Design-science research must be presented effectively both to technology-oriented and management-oriented audiences.	Result: Research must be presented both to technology-oriented as well as management-oriented audiences.

The second and third guideline in DSRM emphasizes the problem domain and design evaluation. This is consistent with the vision framework in defining the requirement specifications. Commonly, the requirement specification defines the infrastructure and platform of the vision system. The infrastructure states the hardware, software and operating system that will be used in the vision system.

The fourth, fifth and sixth guidelines are consistent with the iterative steps of a vision system that comprises of requirement specification, image processing system and outcomes. Research contribution in DRSM is similarly with the vision system framework in looking for a solution through an image processing algorithm. In a vision system, series of experiments with numerous "what-if" questions are involved in the development. The purpose is finding the best solution.

The research rigor and design as a search process in DRSM similarly with image processing concept that begins with image acquisition as data collection in the vision system. Subsequently, the images will be analyzed by the image pre-processing system to ensure the data (images) are appropriately captured. While iteration continues, the evaluation step involves naturally, checking the consistency between the outcomes and the required specifications. While this process progressing, it actually looking for the best solution by utilizing the possible argument and parameters in the vision system algorithm.

The only guideline in DSRM that never mention in the vision system framework is the seventh guideline i.e. communication of research. However, this gap is not that technical so the vision framework is not able to get the benefit of the seventh guideline. By employing the seventh guideline of DSRM, the vision engineers will be motivated in publishing their research works, exchange ideas with others and improve the current technology for better use in the future. Innovations may come from communication. Hence, this discussion finds that DSRM is well matched with the vision system framework.

4. The Extended Design Science Research Methodology

As discussed in section 3, that DSRM is well matched with the vision system framework. This section looks into the detail steps of the vision system and how the DSRM can be customized to accommodate the steps. Firstly, the image processing methodology i.e. Test-Driven Agile Simulation (TAS) will be reviewed and the customized DSRM for vision system is exposed. Secondly, the Parallel Design Pattern (PDP) is reviewed and the customized DSRM for parallel vision system is exposed.

4.1. Test-Driven Agile Simulation (TAS)

Fig.3 portray TAS in detail and Fig. 4 shows challenges in image processing handling high-level system design with the transformation and validation steps in it. By employing TAS, the high-level design can satisfactorily direct to the refined-level design with attention to the hardware architecture. Based on this development model, the DSRM can be mapped with the vision system framework.

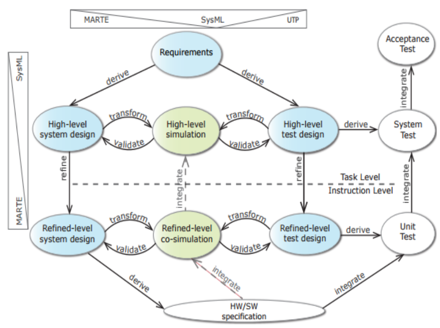


Fig. 3: TAS overview

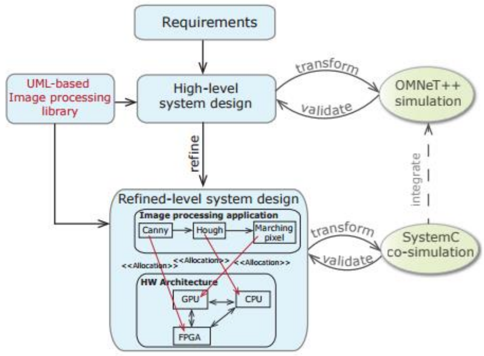


Fig. 4: TAS integration with image processing

The following Fig.5 shows an additional step i.e. Publication that has been added to the vision framework to match the seven guideline in DSRM. Figure 6 shows the extended DRSM meant for the vision system. The figures explain clearly how the guideline in DSRM is able to use in vision system steps of development.

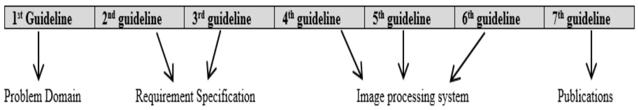


Fig.5: Mapping DSRM and Vision system framework

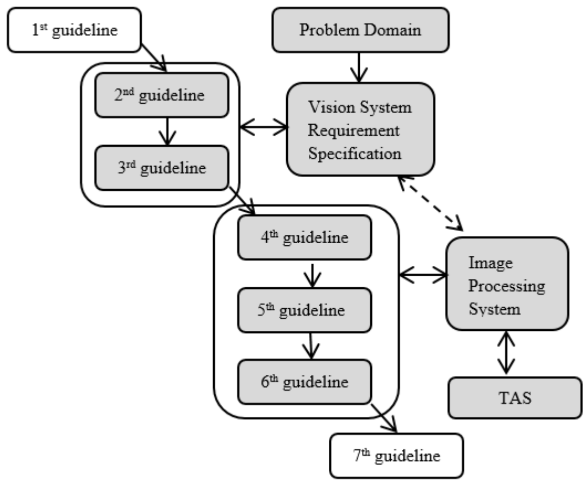


Fig. 6: Extended DSRM for the vision system

4.2. Parallel Design Pattern (PDP) and the Customized DSRM

Vision system encounters large data volume and utilizes complex image processing algorithm to solve the problem. This makes computer vision is a good nominee for parallel processing [16]. Design pattern refers to the good practice or good solution to a recurring problem in a particular context including parallel processing. Since the challenge of writing a parallel version of image processing algorithm, a parallel design pattern is introduced to assist designers in performing parallelization. The purpose of having design pattern is to record the best practices in a way that can be used by others who face the similar problems. In a vision system, PDP applied to the image processing part. Hence, the customized DSRM to handle parallelization occurs in 4^{th}, 5^{th} and 6^{th} guideline as depicted in Fig. 7.

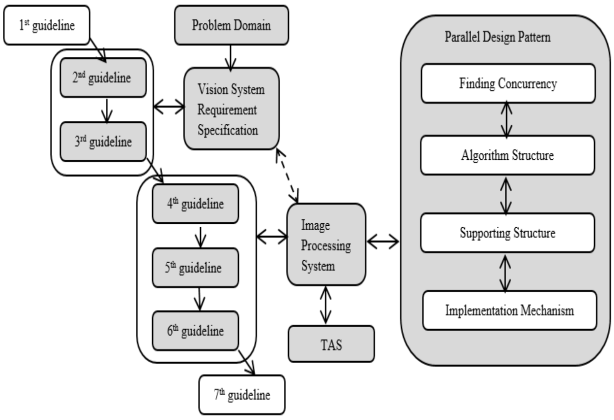


Fig. 7: Extended DSRM for the parallel vision system

Fig.7 provides the explanation as follows. Generally, there are three levels of difficulties in parallelization. First, not every algorithm efficiently works in parallel if the designer does not know how to balance a number of parallel execution units with the increasing computation complexity. Second, the algorithm that has successfully parallelized does not the same level of stability as known in the sequential algorithm. Third, the parallel algorithm has imbalance load due to non-uniform data distribution. The PDP hence is important and provide a guideline in handling parallelization [17].

The PDP is organized with four design levels as per Fig.7: 1) finding concurrency, 2) algorithm structure, 3) supporting structure and 4) implementation mechanism. In finding concurrency, the designer focuses on the potential concurrency in handling problem. In the algorithm structure, the designer finds a strategy to change the structure of the current algorithm into parallel. In supporting structure, designers do the blueprint design that is ready for implementation and it may involve share data structure. Lastly in implementation mechanism, designer map the design into a particular programming environment [18].

DSRM includes evaluation as the key activity because it offers feedback for further development with a better quality design. In this paper, the development of a colorless algorithm for object detection and tracking is selected as a case study to investigate whether the customized DSRM can help the development stage of this algorithm. A previous work by[19] offered an evaluation scheme for framework assessment and the scheme is found applicable to evaluate the customized DSRM.

5. Evaluation

DSRM includes evaluation as the key activity because it offers feedback for further development with a better quality design. In this paper, the development of a colorless algorithm for object detection and tracking is selected as a case study to investigate whether the customized DSRM can help the development stage of this algorithm. A previous work by[19] offered an evaluation scheme for framework assessment and the scheme is found applicable to evaluate the customized DSRM.

The following fig.8 illustrates the evaluation process and results. There five scales used to evaluate the process following the customized DSRM i.e. (- -) for most negative, (-) for negative, (0) neutral, (+) positive and (++) for most positive. The scale is assessed based on the development process of the colorless algorithm with its parallelization.

The Assessment Profile	(- -)	(-)	(0)	(+)	(++)
1st guideline of DSRM					
• Problem Domain			Δ		
2nd and 3rd guideline					
• Requirement and Specification				Δ	
4th, 5th and 6th guidelines					
Image Processing system					
• Finding the best method for colorless algorithm				Δ	
• Evaluate the colorless algorithm in detecting location, orientation and identity				Δ	
• Find the best tracking method for location and orientation					Δ
• Find the best tracking method for identity				Δ	
• Iteration process in finding the best method		Δ			
Parallelization					
• Finding Concurrency		Δ			
• Algorithm structure		Δ			
• Supporting structure			Δ		
• Implementation Mechanism				Δ	
• Iteration process in parallelization		Δ			
7th guideline					
• Publication (conferences, journal, discussions)				Δ	

Fig. 8: Evaluation of extended DSRM

The results in figure 8 demonstrate smooth process from problem domain until image processing system to detect object location, orientation, and identity. However, the challenges occur during parallelization in finding concurrency points in the algorithm and developing the right structure to solve the problem. Once this stage is accomplished then the implementation mechanism has fewer challenges.

The results suggested that the iteration process is happening many times for both image processing and parallelization. This stage considers the most critical ones in the development because iteration makes time and cost spent higher. However, the development of this algorithm has been completed and ready for publications.

6. Conclusion and Future Work

This paper explores the research methodology for the parallel vision system. Since DSRM has become popular in an information system, information technology, and software engineering fields, then the exploration selected the DSRM to be investigated over a parallel vision system. The analysis and evaluation have confirmed that DSRM can be customized to meet the requirements and process in the parallel vision system. With this work, the proposed customized DSRM can be one of the alternatives methodologies for the parallel vision system.

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