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► **To cite this version:**

Tomislav Stipancic, Bojan Jerbic. Self-adaptive Vision System. First IFIP WG 5.5/SOCOLNET Doctoral Conference on Computing, Electrical and Industrial Systems (DoCEIS), Feb 2010, Costa de Caparica, Portugal. pp.193-200, 10.1007/978-3-642-11628-5_21 . hal-01060803

HAL Id: hal-01060803

<https://inria.hal.science/hal-01060803>

Submitted on 17 Nov 2017

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Self – adaptive Vision System

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Abstract. Light conditions represent an important part of every vision application. This paper describes one active behavioral scheme of one particular active vision system. This behavioral scheme enables an active system to adapt to current environmental conditions by constantly validating the amount of the reflected light using luminance meter and dynamically changed significant vision parameters. The purpose of the experiment was to determine the connections between light conditions and inner vision parameters. As a part of the experiment, Response Surface Methodology (RSM) was used to predict values of vision parameters with respect to luminance input values. RSM was used to approximate an unknown function for which only few values were computed. The main output validation system parameter is called Match Score. Match Score indicates how well the found object matches the learned model. All obtained data are stored in the local database. By timely applying new parameters predicted by the RSM, the vision application works in a stable and robust manner.

Keywords: active vision system, self adaptation, active behavioral scheme, experiment planning, response surface methodology.

1 Introduction

The development of robotics is dictated by increasing demands of humanity. Today's robots are involved in almost all areas of human activity, namely: medicine, technology, research and accessibility of hazardous or unclean areas, etc. Service Robotic is a term that appears to indicate just one step in robot evolution. This evolution moves from the simplest industrial robots and goes to the highly sophisticated personal robots, which aim to be universal. Such robots would be able to exist alone in the surroundings just like human beings, regardless of their original purposes. The prerequisite for intelligent behavior of any artificial system is thus the ability to perceive its environment [1]. To do that, it is necessary to establish some kind of active sensing structure which is able to deliver timely fresh information to the system. Such a structure has to have the capability to determine what to do with the acquired information and to make proper decisions with respect to timely appropriate actions. Information detection and determining what to do with the collected information in a controlled manner is an approach in robotics called Active Sensing [2]. Such systems can often contain different subsystems responsible for

different behavioral schemes. There are trends in today's robotics which are suggesting that robotic systems have to include the active sensing unit with one or more active behavioral schemes. Active Sensing Unit has to decide what behavioral scheme to choose according to an actual environmental savior or actual system needs and to seek optimal solutions to make desired actions. For example, Active Placement Scheme can be related to the vision sensor positioning, Active Vision Parameter Scheme can be related to the proper vision parameter determination, Active Calibration Scheme can be related to the timely calibration of vision sensors, Active Model Construction Scheme can be related to the 3D object interpretation, Active Illumination Scheme can be used for choosing proper light sources at the right moment, etc. [2]. In the proposed approach it is very easy to find similarities with human beings because they cannot imagine their life without the system of active perception. Humans collect new information with their vision sensors – eyes. The brain is constantly analyzing and triangulating its 3D environment combining collected information with previously collected experience and knowledge, defining distances and relationships between objects in the observed scene. Active eyes usage goes to such lengths that people sometimes automatically change the viewing angle and object distances in order to complement missing information.

This article describes one behavioral scheme as a part of the research related to the Active Sensing. The main task of this particular behavioral scheme is to take care of the active vision parameter adaptation and it will be the part of the robotic system which conducts two more schemes: Active Calibration Scheme and Active Positioning Scheme. Active Vision Parameter Adaptation Scheme provides the needed vision acquisition accuracy and decreases the level of noise which can occur in constantly changing environmental conditions. High accuracy and low level of noise are very important for robotic vision, especially in assembly or disassembly operations where robots have to precisely manipulate with small parts, often in poor light conditions. The proposed scheme decreases the need for special light sources and techniques which are the most common vision application ingredients. The main accent was set on an experiment planning by using Response Surface Methodology (RSM) to develop Active Vision Parameter Adaptation Scheme. RSM [3] was used to determine the connection between input and output parameters at the beginning. Luminance in the room was used as an input parameter value. Intrinsic vision sensor parameters, such as Brightness and Gain, were used as an output value. Great potential lies in experiment planning [4]. In order to have optimal application output results it is very important to see a picture large enough at the beginning. Such an approach enables us to have better understanding of parameters dependences and gives the opportunity to guide the experiment to produce better results at the end. The presented scheme can be also used as a framework for other applications, because almost all vision sensors have similar or the same input vision sensor parameters. Along with such a conclusion, the analyzed idea was presented like a framework in order to facilitate easier future reproduction of the concept for everyone.

2 Contribution to Technological Innovation

Traditional methods for machine vision to better interpret scenes are usually focused on post- image processing. Usually, these approaches deal with current states to extract more information about the object surfaces AFTER vision sensor taking the pictures. Approach proposed in this paper is focused on adaptation of the vision system to the current light conditions BEFORE vision sensor taking the pictures. Such an approach facilitates further vision analysis and saves time-consuming enhancement processing, which is very important in a machine vision system, especially for real-time applications [2].

3 Equipment and Software

A Basler scA1400-17fc camera was used to acquire images from the object in the scene. The main characteristics of this camera are relatively high resolution (1392×1040 px) and color image representation. It is rather small and suitable for mounting directly to the robot hand. In this application, the camera was connected with the NI Compact Vision System (NI CVS - 1456) which was used for image acquisition and later image processing. The CVS is an all-in-one vision system which comes from National Instruments Company and contains a processor, a memory, an operating system and an I/O interface. The vision application set-up was carried out by means of the NI Vision Builder for Automated Inspection (VBAI) software, based on NI LabView and containing a number of tools for image acquisition, image preprocessing and processing, system communication with other external devices, etc. This software has to be installed on a PC. After the application configuration, the next step was to upload all data from the PC into the CVS, responsible for all later actions regarding the vision application. Fig. 1 shows the equipment and the hardware system configuration used in the experiment.

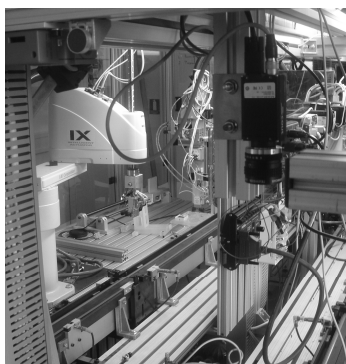


Fig. 1 Equipment and hardware system configuration.

The device for measuring the luminance is called a luminance meter. In this application the XYL-III All Digital Luminance-meter was used. To provide

measurements and later data analysis this device can be connected to a PC via RS-232 interface. Luminance describes the amount of light leaving a surface in a particular direction and can be thought of as the measured brightness of the surface as seen by the eye or a vision sensor and it is very important for this particular application [5]. It is expressed in Candelas per square foot, or more commonly, Candelas per square meter (Cd/m^2).

4 Experiment Description

Reliability of scene inspection by a vision system is strongly connected to the set of parameters chosen for a specific vision application [1]. If environmental conditions change over time, these parameters should either be optimized at the beginning of the process or changed on-line constantly. By changing vision parameters on-line constantly, vision system attains fresh information during the time which results with relatively high robustness and precision. The first step of the Active Vision Parameter Adaptation Scheme development was to make an experiment which was crucial for dependence determination of inner parameters. Beside that, the experiment brings hidden information on the system response regarding different input values. Such information can help in determining weak points of the experiment enabling better process understanding and optimization. The relationship between input and output factors was provided by means of Response Surface Methodology (RSM). The RSM [6] can be found as a part of the Design Expert software [7] which was used in this particular case and it represents a collection of mathematical and statistical techniques used for process optimization and analysis. It consists of a group of techniques that can be used in the empirical study of relationships between one or more measured responses with an arbitrary number of input factors. It comprises: designing a set of experiments, determining a mathematical model and the optimal value of the response, thus providing a better understanding of the overall system behavior. The empirical relationship is frequently obtained by fitting polynomial models. The main purpose of the first and the second order experiment designs was data collection for fitting such models. The first order polynomial model can be expressed by the general Equation 1,

$$y = \beta_0 + \sum_{j=1}^k \beta_j x_j + \varepsilon \quad (1)$$

where y is response, $\beta_0, \beta_1, \dots, \beta_k$ are the unknown regression parameters, x_1, x_2, \dots, x_k are the input factors, k is the number of input factors and ε is random error. The CCD (Central Composite Design) was used to describe responses and to estimate parameters in the model. This design consists of a factorial portion, an axial portion and a centre point. It's well suited for fitting a quadratic surface, which usually works well for the process optimization. If the distance from the center of the design space to a factorial point is ± 1 unit for each factor (Table 1.), the distance from the center of the design space to a star point is $\pm \alpha$ with $|\alpha| > 1$. The precise value of α depends on certain properties chosen for the design and on the number of factors involved.

Applied load and sliding distance were considered as model variables. So, with respect to the system input parameters (Luminance and Match Score), the system will use output factors (Gain and Brightness) previously predicted by means of the RSM.

Table 1 Factors for response surface study.

| Factor | Unit | Low Level (-1) | High Level (+1) |
|-------------|---------------------|----------------|-----------------|
| Luminance | Cd / m ² | 0 | 300 |
| Match Score | - | 800 | 1000 |

A particular vision tool called Match Color Pattern Vision Tool (Fig. 2.) was used to detect an object in the field of view. This tool can be found as a part of the vision software (VBAI). In the beginning of the configuration, the tool has to learn a template which contains an object(s) or a feature(s) of interest in the first line. Later, with respect to the learned template, the vision tool searches for similarities in the field of view. The match score is a value that indicates how similar a potential match is to the template image and it ranges from 0 to 1000. A score of 1000 indicates the perfect match. It was determined that a value lower than 800 of the match score results with positioning error which was too large for the developed vision application. Such values were not taken into consideration. The presented method can be used in combination with different vision tools for different purposes.



Fig. 2 Match Pattern Color Vision Tool setup.

During the experiment, a luminance value ranged between 0 and 300 cd/m². The experiment was made far from windows. This resulted with relatively stable light conditions without high values of sunlight illumination. To provide even more stable conditions, windows were covered with curtains. It was very important to repeat the experiment in different light conditions to analyze as many possibilities as possible which resulted in a more robust application. A luminance measurement was taken with and without curtains on windows and neon lights switched on and off. A gain value represents the number of times a vision device amplifies a light input. It can be very useful in poor light conditions where it is necessary to make a more visible scene. Gain values ranged between 192 and 1023. An image brightness definition was connected with a pixel definition and it ranged between 0 and 255.

The Design-Expert software was used for the experiment design and analysis. The Design-Expert contains a set of statistical and numerical tools that can be used for processes optimizations, predictions, etc. The first step of the experiment design was to enter information about the Central Composite Design - CCD (Alpha Level, Center Points, etc.) and information about the analyzed vision application (Table 1). The software led us to define a missing portion of the CCD. By entering the data, the Design-Expert calculates the coded distance “alpha” for placement on the star points. The next step was to make a real experiment by combining data provided by the Design-Expert and to acquire responses. For the purposes of this experiment, 13 input factor variations (Figure 4) were collected and analyzed.

| Std | Run | Block | Factor 1 A:Luminance cd/m2 | Factor 2 B:Match Score | Response 1 Gain | Response 2 Brightness |
|-----|-----|---------|----------------------------------|---------------------------|--------------------|--------------------------|
| 1 | 5 | Block 1 | 0.00 | 800.00 | 856 | 223 |
| 2 | 11 | Block 1 | 300.00 | 800.00 | 203 | 14 |
| 3 | 6 | Block 1 | 0.00 | 1000.00 | 1004 | 232 |
| 4 | 1 | Block 1 | 300.00 | 1000.00 | 260 | 83 |
| 5 | 13 | Block 1 | 0.00 | 900.00 | 897 | 211 |
| 6 | 4 | Block 1 | 362.13 | 900.00 | 241 | 11 |
| 7 | 9 | Block 1 | 150.00 | 758.58 | 440 | 147 |
| 8 | 2 | Block 1 | 150.00 | 1000.00 | 501 | 161 |
| 9 | 3 | Block 1 | 150.00 | 900.00 | 444 | 152 |
| 10 | 12 | Block 1 | 150.00 | 900.00 | 444 | 152 |
| 11 | 7 | Block 1 | 150.00 | 900.00 | 444 | 152 |
| 12 | 10 | Block 1 | 150.00 | 900.00 | 444 | 152 |
| 13 | 8 | Block 1 | 150.00 | 900.00 | 444 | 152 |

Fig. 3 Design – Expert Layout Table.

By filling values into the table, process of designing the experiment was completed. As it was mentioned before, the Design-Expert has a broad set of numerical and statistical tools for extracting extended information about the analyzed process. In this paper the main emphasis was set on the process prediction. Figure 5 shows the Point Prediction Table which holds information about input factor combinations and their related responses.

| Factor | Name | Level | Low Level | High Level | Std. Dev. | Coding |
|--------|-------------|--------|-----------|------------|-----------|--------|
| A | Luminance | 158.11 | 0.000 | 300.00 | 0.000 | Actual |
| B | Match Score | 862.16 | 800.00 | 1000.00 | 0.000 | Actual |

| Response | Prediction | SE Mean | 95% CI low | 95% CI high | SE Pred | 95% PI low | 95% PI high |
|------------|------------|---------|------------|-------------|---------|------------|-------------|
| Gain | 411.431 | 7.52 | 393.64 | 429.22 | 18.75 | 367.09 | 455.77 |
| Brightness | 140.54 | 3.85 | 131.43 | 149.65 | 9.61 | 117.62 | 163.26 |

The Factors Tool window displays two sliders. The top slider is for Factor A (Luminance) with a value of 158.108. The bottom slider is for Factor B (Match Score) with a value of 158.108. The window also includes a 'Gauges:: Sheet' button and a 'Default' button.

Fig. 4 Design – Expert Layout Table along with Factors Tool Window.

Input factor values can be changed by means of the Factor Tool Window. It is sufficient to move the slider placed at the Factors Tool Window to see new responses with respect to the input values. The Design – Expert Layout Table provides information used for future point prediction optimizations of this application. The next configuration step was related to the data storage into the database.

5 Vision Application Description

The Active Vision Parameter Adaptation Scheme described in this article contains: a vision application (NI Compact Vision System – software and hardware), a PC, a luminance meter and a database. The PC was used as a host of the Active Behavioral Unit and the vision software (VBAI). The main task of the Active Behavioral Unit was to provide communication and data management between all system components. It is a fact that the vision sensor takes pictures of the object from different angles and positions in the space. That results in timely different light conditions between picture shots. To ensure relatively similar conditions for taking pictures from different positions, the vision system gets new vision parameters from the database before taking new pictures. Information acquired from the luminance meter was the main criteria for determining which parameters to pick from the database. Figure 6 shows the active sensing flowchart which describes one common “pick-and-place” robot application.

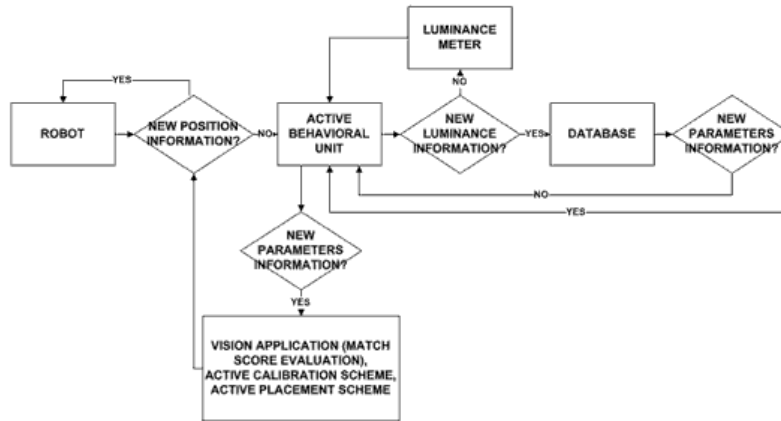


Fig. 5 Active Sensing flowchart.

6 Conclusion

This paper provides a description of a particular Active Behavioral Scheme which is included in one bigger robotic system that relies on the Active Sensing paradigm. Described scheme enables the system to become much more robust and to become relatively resistant to timely new light conditions in the observed scene. The vision parameters determination is provided by means of Response Surface Methodology which can also be used for an experiment weak point determination. Instead of using the RSM, future work will be related to usage of neural networks in connections between input and output parameters determination. It would be interesting to analyze influence of other factors to vision application too (such as measuring of the room ambient light). The research described in this article will be a part of a PhD Thesis

where the main emphasis will be set on Active Placement Scheme which is taking care of spatial positioning of the Vision Sensor [8].

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