Computers and Electronics in Agriculture 119 (2015) 201–208

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Original papers

# Fault-tolerant optical-penetration-based silkworm gender identification

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ARTICLE INFO

*Article history:*
Received 17 March 2015
Received in revised form 10 September 2015
Accepted 11 October 2015

*Keywords:*
Optical sensors
Spectral imaging
Image processing
Silkworm pupae
Sericulture
Agri-photonics

ABSTRACT

This paper proposes and experimentally demonstrates a fault-tolerant optical-penetration-based silkworm gender identification. The key idea lies in the exploitation of the inherent dual wavelength of white and red light illumination. In particular, the image of the posterior area of the silkworm pupa created under white light is not only transformed into an optical region-of-interest but also is used for pinpointing the female silkworm pupa, thus speeding up the identification time twice. For the male and unidentified female silkworm pupae, their images are later on analyzed under red light illumination, implying fault-tolerant operation of the system. Other important features include low cost, ease of implementation, and simplicity in terms of process control. Experimental demonstration shows a highly accurate 92.5% in identifying female silkworm pupae with a faster average system speed of 26.38 ms under white light illumination. Under red light illumination, the remaining male and unidentified female silkworm pupae are clarified with an improved accuracy of 98.9% and the total average analytical time of 53.50 ms.



## 1. Introduction

Sericulture industry is one of the important agricultural sectors that play a significant role in the economic growth and people life styles for several countries (FAO, 2012). There are several quality-monitoring processes needed for this industry in order to obtain long and high quality raw silk as well as to sustain high quality breeders. Apart from the breeder selection criteria and the artificial hatching process, a highly-accurate silkworm gender identification process is greatly desired. Typically, it is accomplished through visual inspection at the abdomen segment of the silkworm pupae. Although this approach is cost effective and non-destructive, it requires well trained officers, is very time consuming, and affects the eye sight of the officer (Jordan et al., 1899; Lim et al., 1990; Aruga, 1994). Other physical parameters of the silkworm such as its mass (Seo et al., 1985; Babaei et al., 2009) and its shape (Khan et al., 2009) can also be analyzed for the gender identification of the silkworm pupa. Unfortunately, these two parameters always require the initial mass or shape reference prior to gender identification process and they show an undesired very low 50% accuracy (Keawhorm, 2011). Magnetic resonance imaging (MRI) (Liu et al., 2008) and near infrared (NIR) spectroscopy (Jin et al., 1995) are by far two promising approaches in which the gender of the silkworm can be pinpointed without removing it from the cocoon. Nonetheless, the practical deployment is very far-fetched as the cost of the equipment and maintenance in these two approaches are not easily affordable. In addition, their operating procedures are very time-consuming.

Another method is the optical fluorescent imaging as it is applied to separate Thai jasmine rice grains from other foreign rice varieties (Suwansukho et al., 2011, 2014) and to analyze the ripeness level of the green fruit (Intaravanne et al., 2012). Previously, the fluorescent imaging under ultraviolet-A (UVA) light sources was exploited for the silkworm pupa sex identification (YuQing et al., 2010; Xiaolong et al., 2011). Unfortunately, as silkworm pupa races are regularly improved through cross breeding, genetic-engineering, and dye-modified diet (Tansil et al., 2011), the optical fluorescent imaging technique is limited to identify the gender of certain silkworm species. In order to solve the aforementioned problems, we proposed and showed for the first time a highly-accurate optical-penetration-based silkworm pupa gender sensor structure (Sumriddetchkajorn and Kamtongdee, 2012; Kamtongdee et al., 2013a,b). The silkworm sex determination via our optical method is suitable for mature silkworm pupae whose ages are more than five days (Kamtongdee, 2014). Taking into account that the unwanted optical noises scattering from the

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http://dx.doi.org/10.1016/j.compag.2015.10.004
0168-1699/

surrounding area near the silkworm pupa and the transparent support cause the incorrect silkworm gender identification, the confined regions of interest (ROIs) were applied (Kamtongdee et al., 2013a,b), leading to the improvement of identification accuracy compared to our previous approach in (Sumriddetchkajorn and Kamtongdee, 2012). However, the black image area corresponding to the important organ of the female silkworm pupa contains fewer amount of image pixels which sometimes cannot be effectively located. In addition, in the practical point of view, the worker has to carefully place the silkworm pupa in such a way that its bottom part is inside the two ROIs. Larger ROIs can ease the alignment problem, but the undesired optical noise is increased. Furthermore, there are still unwanted optical noises near the body of the silkworm pupa which is difficult to confine in rectangular ROIs. To overcome these concerns, we have recently proposed a scalable optical ROI and once combined with image magnification, polarization filtering, and image processing operations improve the accuracy in the identification of the silkworm gender (Kamtongdee et al., 2015). Rather than only converting the original image of the silkworm pupa created under white light illumination into the scalable optical ROI as appeared in our recent work, this paper shows that the female silkworm gender can be firstly and simultaneously pinpointed at this stage. This implies that the silkworm gender identification can be completed quickly. In the case that the silkworm gender cannot be categorized under white light illumination, it will be rechecked under red light illumination in which the scalable optical ROI created under white light illumination is applied, thus leading to a more system fault tolerance. Additional key features include ease of implementation and control.

## 2. Fault-tolerant optical-penetration-based silkworm pupa gender identification architecture

### 2.1. Proposed system arrangement

The schematic diagram of our fault-tolerant optical-penetration-based silkworm gender identification structure is illustrated in Fig. 1. The silkworm pupa under investigation is placed on a transparent support which can be made from an acrylic or a glass slide sheet. Underneath the transparent support, a two-dimensional (2-D) digital camera is installed with a fitting length $Z_1$ and is aligned such that the posterior area of the silkworm pupa is in the field of view of the camera. Additionally, a short focal-length lens is mounted in front of the 2-D digital camera in order to enhance the region of interest. In addition, the transparent support and the silkworm pupa are in between two polarizers #1 and #2. These two polarizers are aligned in such a way that light passing consecutively through the polarizer #1, transparent support, and polarizer #2 has the lowest optical intensity, thus functioning as an optical noise suppressor. For the area of the transparent support that has the silkworm pupa on top, light can pass through with higher optical intensity creating a high-contrast image of the silkworm pupa. Above the silkworm pupa, white and red light-emitting diodes (LEDs) are located with an appropriate length of $Z_2$ from the transparent support. Under white light illumination, the image of the posterior area of the silkworm pupa looks yellowish (Sumriddetchkajorn et al., 2013) and it is currently used to create a scalable optical ROI (Kamtongdee et al., 2015). As the optical ROI is automatically fitted to the size and shape of silkworm pupa, image noises around the body of the silkworm pupa are eliminated. Rather than using the image of the silkworm pupa under white light illumination only for the creation of the optical ROI, this work extends its functionality for simultaneously identifying the female silkworm pupa. If the gender of silkworm pupa is unknown at this stage, it will be rechecked under red light illumination. Our redundancy in pinpointing the silkworm gender implies a more system fault tolerance.

Apart from the optical part, an electronic controlling and processing unit (ECP) handles in controlling the two LEDs and the 2-D digital camera. The ECP commands the white LED light source to operate at its maximum intensity in order for the system to generate the scalable optical ROI and at the same time identify the female silkworm pupa. For the red light source, the ECP will increase the LED intensity until a small black region of the female silkworm pupa is clearly detected. If the small black region cannot be located and the LED intensity reaches the maximum level, that silkworm pupa is identified as male.

### 2.2. Operational flowchart

After the silkworm pupa is placed on the transparency support, the ECP turns the white LED to the ON state and the 2-D digital camera captures the color image of the posterior area of the silkworm pupa as shown in Fig. 2. To keep only the yellowish area of the image, the color image thresholding is applied which in turn converts the color image to the binary image. In this case, the yellowish area of the image is highlighted as white while it is totally black for the remaining image areas. As the main image of the silkworm pupa is roughly obtained, the centroid analysis of the image is applied in order to obtain the central coordinate of the image. The obtained binary image is also inherently fitted to the size and shape of the

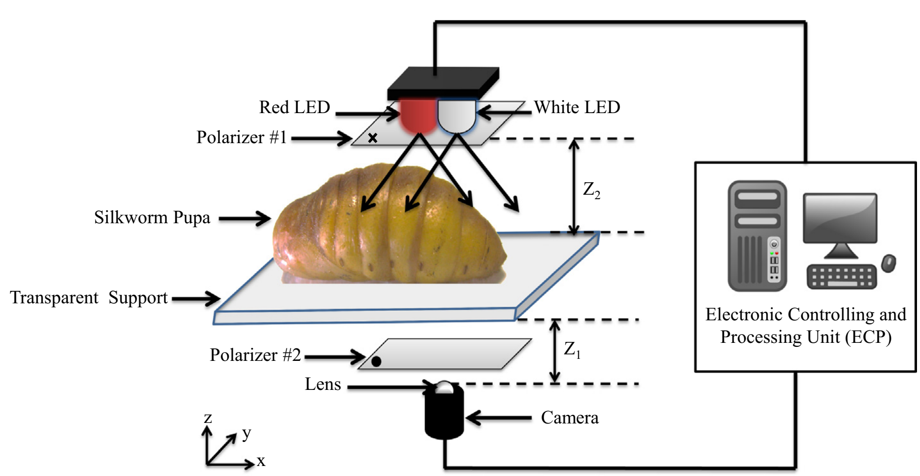


**Fig. 1.** Proposed structure of the fault-tolerant optical penetration-based silkworm pupa gender identification. LED: Light Emitting Diode.