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Profile based image analysis for identification of chopped biomass stem nodes and internodes

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ABSTRACT

Because of their significant variation in chemical composition, segregation of chopped biomass into nodes and internodes helps in efficient utilization of these feedstocks. Stem internodes having low ash content are a better feedstock for biofuel and bioenergy applications than nodes. However, separation of these components is challenging because their physical characteristics are similar. We applied an image processing technique to identify nodes and internodes of chopped biomass from scanned digital images. In this study, we utilized the object profile identified differences in the node and internode components and tested on chopped corn stalks and switchgrass stems. We considered four methods of image processing including rectangularity, solidity, width-, and slope-variation and developed an ImageJ plugin for the node–internode identification. Digital chopping of the ends of the objects was necessary for identification, especially dealing with projecting fibers and chipped rough ends, and an algorithm was developed for this. Among the methods tested, width-variation gave the best identification accuracy (97–98%), followed by rectangularity (93–96%), solidity (86–91%), and slope-variation (69–82%). Rectangularity – a relatively simpler method, and solidity – a standard ImageJ output, can be directly used to perform identification. The developed approach of node–internode identification can be easily applied to other chopped biomass and similar materials, and its application may lead to efficient biomass end use in biofuel and bioproduct industries.

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1. Introduction

Biomass is one of the potential and sustainable renewable energy resources for industrial fuel production to supplement fossil fuels and generate cleaner energy. Milling or comminution of biomass is the required pretreatment for biomass before actual utilization through various energy conversion pathways, such as combustion, gasification, and biofuel production, as well as densification (Miao et al., 2011; Gil and Arauzo, 2014). For example, with corn stover, milled particles of 6.4 mm are suitable for gasification (Raman et al., 1981), 0.5–3 mm for ethanol production (Paulrud, 2004), and 5.6 mm for briquetting (Öhgren et al., 2006). Milled biomass produce a more stable flame, low ash emissions and CO_2, and high burnout when compared to pellets and bales, in combustion (Tumuluru et al., 2014). Further, freshly harvested long stems/straw of biomass cannot be fed directly to a hammer mill or any size reduction machinery; therefore, it must be chopped prior to milling for bulk flow and uniform feed rate (Bitra et al., 2009a,b).

The chopped biomass plays an important role in feedstock supply logistics as well. The delivery cost of chopped biomass (\$40 Mg^{-1}) is less than the delivery cost of bales (\$44–\$47 Mg^{-1}) or ensilaged chops (\$48 Mg^{-1}), but slightly higher than the delivery cost in the form of loafs (\$37 Mg^{-1}) (Kumar and Sokhansanj, 2007). Pipeline hydro-transportation, which has a significant potential to replace the traditional truck transportation (Vaezi et al., 2013), uses the chopped biomass as raw material.

Chopped biomass contains various morphological components of feedstock, which varies in their chemical composition. Among the various morphological components, stalks of biomass dominate the overall volume or mass. Within biomass stalks, for example switchgrass and corn, nodes are rich in cellulose and lignin content, and internodes are rich in glucan content (Philip Ye et al., 2008; Liu et al., 2010; Hu et al., 2010). Biomass with high lignin and cellulose content are more suitable for thermal combustion, whereas those rich in sugars and starch are for biochemical conversion (Labbé et al., 2008). Therefore, if segregated, these nodes and internodes, can be advantageously used for biomass conversion for combustion or ethanol production. An alternative and recent potential use of biomass is bioproducts, which are high end chemical products. Biomass may be valued for other products, such as

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paper production from grass instead of trees or for more novel uses, such as supercapacitors from pyrolysis of cellulose under ammonia (Luo et al., 2014), or low-cost carbon fiber production from lignin derived from biomass (Baker and Rials, 2013). The uniform feedstock produced by segregating the chopped biomass prior to processing would increase the efficiency of the utilization process and enable consistent outputs (bioenergy, biofuels, and bioproducts). However, research efforts on segregation or separation of the biomass components are scarce.

Separation of nodes and internodes of chopped biomass was best achieved by pneumatic principle, when sufficient density and terminal velocity differences among the separating particles exist, over other physical separation principles (Klasek et al., 2006). However, with pneumatic separation, the terminal velocity range was narrow and highly influenced by the moisture content and size of the node and internode segments. Apart from the physical means of separating the biomass nodes and internodes, the visual differences in the nodes and internodes can be advantageously used for identification using computer vision analysis (Pothula et al., 2014).

Applications of computer vision are reported by several researchers for successful classification, defect detection, quality assessment, and grading of various fruits and grains in agricultural and food engineering (Brosnan and Sun, 2002, 2004; Du and Sun, 2004, 2006). Computer vision systems, however, are less utilized in biomass processing applications and only a very few research efforts were reported. Particle size distribution (PSD) analysis of milled biomass and airborne wood pellet dust were reported by Igathinathane et al. (2008, 2009a,c) using computer vision with ImageJ plugins.

A full fledged computer vision system consists of both algorithms (software) and mechanical components (hardware) that actually performs the desired action. Verifying the functionality of the algorithm in computer programming environment is always done prior to any hardware design, as considerable costs are involved in the development of custom hardware, which performs actual separation or grading or application (Du and Sun, 2006).

Presence of dark spots along the major axis may lead to misclassification of internodes as nodes in color based identification reported (Pothula et al., 2014). From the binary images, it can be readily observed that the outline of the object (profile) can be used as a distinguishing feature that does not involve any color information. Object profile represents the presence and absence of bumps for nodes and internodes along the length, respectively, would be an alternative approach for identification, which also addresses the issues with color based identification, is the principle of this research work.

The present study thus focuses on development and testing of an algorithm for identification of nodes and internodes of chopped biomass using image analysis through user-coded ImageJ plugin. Therefore, the specific objectives are (1) to develop algorithms and ImageJ plugins based on four methods, namely rectangularity, solidity, width-variation, and slope-variation from the object profiles, and (2) to test the plugin using chopped biomass stems of corn and switchgrass images and compare the identification accuracy of the methods developed. Feedstock component streams of uniform quality, generated from such separation techniques, are expected to impact positively the efficiency of operation and quality of the products in biofuel, bioenergy, and bioproduct industries.

2. Materials and methods

2.1. Test material

Two biomass material, namely corn stalks ('TS8002GT' variety; planted May 2012) and switchgrass ('Sunburst' variety; seeded May 2008) were collected from the experimental field plots of North Great Plains Research Laboratory (NGPRL), USDA-ARS, Mandan, ND, USA. Both corn stalks and switchgrass stems were manually cut just above the ground using a sickle; leaves and other plant material were separated and the stems were stored at ambient temperature before sample preparation. The stems, which were about 1.2–1.5 m long, were cut into 25–40 mm size pieces for image acquisition. Switchgrass stems were about 2–6 mm thick, and a sharp pair of scissors was sufficient for cutting, whereas for corn stalks, which were about 10–30 mm thick, a light duty shop band saw was used.

2.2. Image acquisition

Digital images of manually separated nodes, internodes, and node–internode mixtures of corn and switchgrass were acquired using a flatbed document scanner (Model: Canoscan 8800F, Canon USA Inc., NY, USA). Scanner lid was kept open for obtaining clear black background. A transparent overhead projector sheet was laid on the glass bed of the scanner and the samples were spread on the sheet. Touching and overlapping sample objects were separated manually for easy delineation as individual objects. Although, the singulated arrangement is challenging, but not impossible, in a practical setting of automatic separation system. Several algorithms, such as watershed (Igathinathane et al., 2012), ellipse fitting (Zhang et al., 2005), and Fourier analysis based (Mebatsion and Paliwal, 2011) were applied to resolve the touching objects segmentation. All input digital images were acquired with 600 dots per inch (DPI) or 0.0423 mm/pixel resolution in color using the Joint Photographic Experts Group (JPEG) format. The overall dimensions of the image corresponds to the transparent sheet size (216 mm × 279 mm), on which the samples were spread for imaging. Scanner software allows to specify the color, DPI, and size of the output image before scanning the sample. For each biomass, images of exclusive nodes, exclusive internodes, and node–internode mixture of samples were obtained.

2.3. Image analysis

The proposed image analysis algorithm uses the difference in surface roughness of object profile for the identification of nodes and internodes. Nodes, where leaves and cobs emerge, were wider (increased diameter) compared to the internode (reduced but uniform diameter) portions of the stem. Therefore, if followed along the stem profile, nodes show their presence by clear bumps, while internodes will be smoother. To identify these profile features, four methods, namely rectangularity, solidity, width-variation, and slope-variation were developed in this work, and their details are presented subsequently. All the codes for the image analysis was written in Java, using Fiji (Java 1.6_024, 64-bit; ImageJ, Ver. 1.49i, Rasband, 1997) as the platform for the ImageJ plugin development. The algorithm for profile based identification of the chopped biomass nodes and internodes involves several operations (Fig. 1), some of which are common in general image processing applications.

2.3.1. Preprocessing

All color digital JPEG images acquired from the flatbed scanner were first preprocessed using standard Fiji (ImageJ) menu commands. The preprocessing includes RGB to grayscale conversion (Image ▷ Type ▷ 8-bit), median filtering (Process ▷ Filters ▷ Median...) and thresholding (Image ▷ Adjust ▷ Threshold...[Yen]). The sequence shown in the parenthesis are the actual Fiji commands that operated on the opened image.

Median filter was essential to smoothen the minute pixel color variations that leads to better thresholded image. The biomass samples, especially corn node samples have a lot of color variation (e.g.,