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Digital image processing based identification of nodes and internodes of chopped biomass stems

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A B S T R A C T

Chemical composition of biomass feedstock is an important parameter for optimizing the yield and economics of various bioconversion pathways. Although chemical composition of biomass varies among species, varieties, and plant components, there is distinct variation even among stem components, such as nodes and internodes. Separation of morphological components possessing different quality attributes and utilizing them in 'segregated processing' leads to better handling, more efficient processing, and high-valued products generation. Using equipment to separate morphological components such as node and internodes of biomass stem that have closely related physical properties (e.g., size, shape, density) is difficult. However, as the nodes and internodes are clearly distinct in appearance by visual observation, the potential of digital image analysis for node and internode identification and quantification was investigated. We used chopped stems of big bluestem, corn, and switchgrass as test materials. Pixel color variation along the length was used as the principle of identifying the nodes and internodes. An algorithm in MATLAB was developed to evaluate the gray value intensity within a narrow computational band along the major axis of nodes and internodes. Several extracted image features, such as minimum, maximum, average, standard deviation, and variation of the computational band gray values; ribbon length of the computational band normalized gray value curve (NGVC), unit ribbon length of NGVC; area under NGVC, and unit area under NGVC were tested for the identification. Unit area under NGVC was the best feature/parameter for the identification of the nodes and internodes with an accuracy of about 96.6% (9 incorrect out of 263 objects). This image processing methodology of nodes and internodes identification can form the supporting software for the hardware systems that perform the separation.

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1. Introduction

In recent years biomass feedstock has become a potential source of various renewable energy, fuel, and product applications due to its environmental benefits and local availability. Biomass feedstock can be either converted into gaseous or liquid biofuels in biochemical conversion or can be used directly in thermo chemical conversion (e.g., combustion; McKendry (2002)). Optimum energy conversion depends on the relative proportions of chemical composition (cellulose, hemicellulose and lignin) of biomass (McKendry, 2002). Other researchers (Sluiter et al., 2010; Ye et al., 2008) also reported the conversion yield from a biochemical process and process economics standpoint were determined by the accurate analysis of chemical composition of biomass feedstock.

Chemical composition of biomass feedstock varies with plant variety, location, harvest and storage time (Hames et al., 2003). Liu et al. (2010) reported that morphological components, such as nodes, internodes, leaves, and pith contribute to chemical composition of biomass feedstocks. They also reported that the switchgrass internode contains high glucan content than nodes, thus internodes are more suited for ethanol production. Jung and Vogel (1992) analyzed leaf and stem fractions of switchgrass and big bluestem and found the best predictors for fiber digestibility differed among species, plant parts, and maturity and leaves contained less lignin than stems. Hu et al. (2010) found that the chemical and structural analytical results (heat combustion value, extractive contents, and chemical compositions) among the morphological components of switchgrass (nodes, internodes, and leaves) were significantly different. They reported that lignin and glucose content of switchgrass differed by 3.4% and 8.7%, respectively, among the node, internode and leaves. Ye et al. (2008) studied the chemical composition of corn using Fourier

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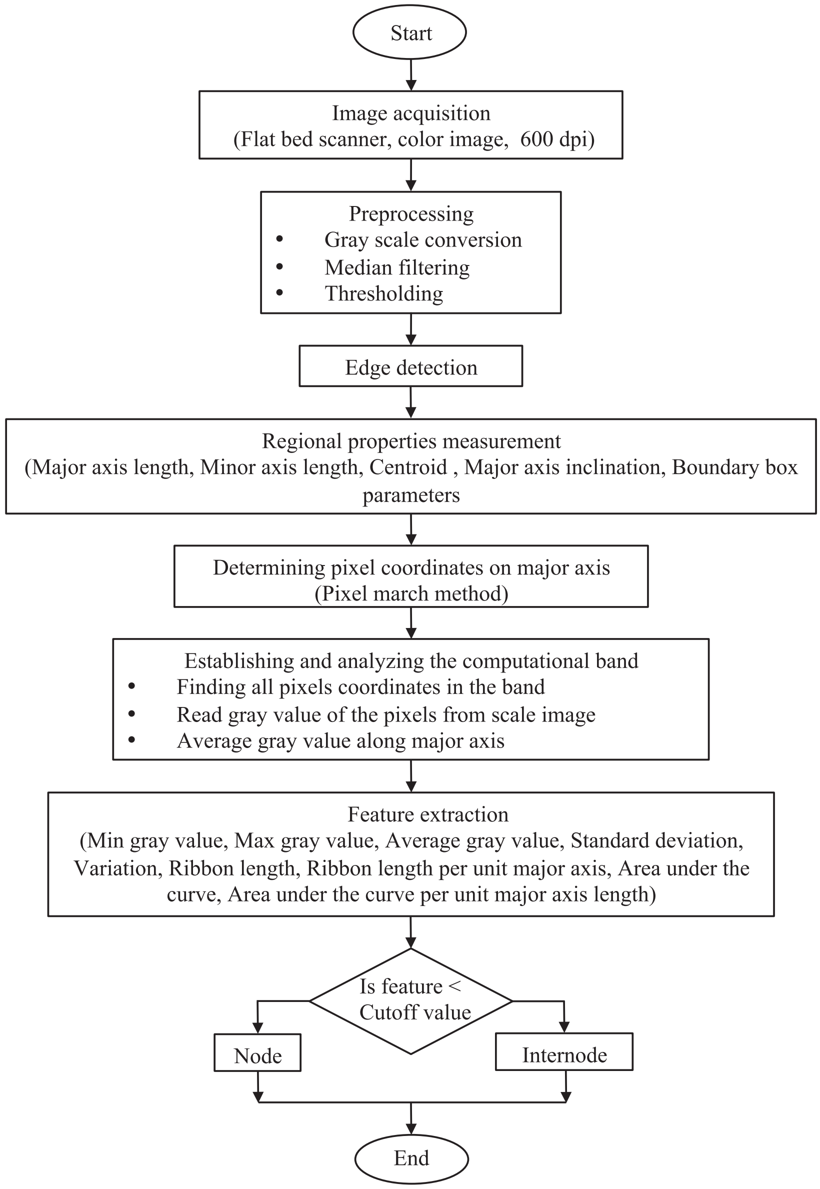

Fig. 1. Image analysis flowchart for identification of nodes and internodes of biomass stems.

transform near infrared (FT-NIR) technique and observed large variations among the separated corn morphological components. They found that the node has the lowest sugar content followed by leaf, internodal rind, internodal pith, sheath, and husk. Their results also indicate that the chemical composition not only differed between the nodes and internodes, but also among the whole plant composition. For example, with switchgrass the glucan composition of internodes (41%) or nodes (35%) were clearly different from the whole plant (36%), which also had leaf portion included (Ye et al., 2008). The whole plant may represent the biomass processing in the usual manner without components separation, and clearly illustrates the lost opportunity of processing a glucan-rich material, if made available by some separation techniques.

From the above literature it is clear that the internodes are richer in sugars than nodes. Labbé et al. (2008) reported that feedstocks with high lignin and cellulose content are more suitable for co-firing, whereas those with sugars and starch content are best suitable for ethanol production. Thus, the chopped biomass having nodes and internodes with distinct chemical compositions, when segregated in a preprocessing operation, can be efficiently utilized in co-firing or ethanol production streams, respectively. Furthermore, while considering the mechanical strength of these components, Yore et al. (2002) observed in rice stem cutting study that the shear energy reduced by two times and shear force by three times at internodes compared to nodes. This result indicates that nodes might require more mechanical energy in the preprocessing size reduction than the internodes. Therefore, based on preprocessing and downstream applications, from mechanical and chemical standpoints, segregation of nodes and internodes from chopped biomass is supported and will lead to efficient processing and products.

There is limited information in the literature regarding development of equipment to physically separate the morphological components of biomass; however, a separation technology for nodes and internodes of biomass is in demand by the biomass processors (Klasek et al., 2006). The research by Klasek et al. (2006) evaluated the separation of node and internode segments of dry samples of wheat and dry and wet samples of corn pith, corn rind and switchgrass. They reported that pneumatic separation has advantages over other common separation principles (threshing, vibratory,