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Novel Solution for Automated Processing of Harvested Rods in SRC Nurseries

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The proposed paper describes the design of an industrial machine prototype (the ROD Picker) which will be used for rod processing in Short Rotation Coppice (SRC) farms. This device has been developed under the collaboration of six partners from four different countries: Egedal Maskinfabrik A/S - Denmark, Salix Energi Europa AB - Sweden, Lempe Gbr - Germany, TTZ Bremerhaven – Germany, TU Dresden – Germany and U.P. from Timisoara – Romania (information regarding the project is available at http://rod-picker.eu/).
SRC farms are considered as having an increasingly important role in the agricultural development of efficient biomass production. Using fast growing trees species (willow, poplar or eucalyptus) bio-energy can be produced, thus contributing in two major directions of the EU strategy: tripling the use of renewable energy resources by 2020 and decreasing the impact of wood industry requirements on domestic forest resources. Consequently, increased attention has been focused on exploiting fast growing trees species.
Processing of energy plants is currently a process in which the majority of the tasks are performed manually. This reflects on the overall performance of production. After harvesting of the wood material during winter months, cutting of plants at specific dimensions is done manually. With obvious limitations, this manual labor will be replaced by an automated process which integrates state of the art technology. The purpose is that of increasing wood biomass production efficiency.
The ROD Picker prototype is innovative machinery designed for harvesting, cutting and packaging the wood material coming from SRC farms. Experimental results and extended functionality test confirm that the concept of this prototype has been properly constructed.

1. Introduction

Biomass is recognized as an important player among renewable energy resources. It accounts for approximately one third of total renewable energy sources. Proliferation of biomass exploitation technologies is sustained by an EU recommendation for tripling the use of such energy in the process of exploiting renewable resources. If in 2005 renewable resources accounted for 8.5 % of the total energy sources, by 2020 the common share of these resources will increase to 20 % (European Commission, 2009). Innovative solutions to biomass conversion into different materials, chemicals or bio-fuels are a current concern for researchers and engineers from all over the world. Gallezot (2011) discusses different strategies to achieve sustainable conversion from biomass to bio-products. The analysis is sustained by a literature study and experimental laboratory results. Simone et al. (2011) present an interesting research regarding the gasification of woodchips and show the amount of wooden biomass converted to electrical energy out of the harvested quantity.
Wooden biomass represents about 85 % of the total biomass production. Beringer et al. (2011) have conducted a simulation study on global bio-energy potential from dedicated biomass plantations in the 21st century. Biomass sources will represent 15 % - 25 % of future energy resources while energy plantations

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account for up to 60% of the total potential. This situation constantly impacts domestic forest resources and natural ecosystems. The perspective has caused a change in political vision. Increased attention has been focused on exploiting fast growing trees species like willow, poplar or eucalyptus. However, depending on the potential of each particular geographical area, large-scale cultivation of energy crops remains controversial in geographical areas which provide biodiversity and habitat for many endangered species.

Fast growing tree species is contribute to the protection of soil, are less dependent on climate conditions and demand less chemicals for the cultivation process. Short Rotation Coppice (or SRC) farms are defined as efficient wooden biomass production sources with a rotation period of under 30 y. Johnson et al. (2013) discuss the many different applications, including heat and electricity generation, of wooden biomass. The authors specify that wooden biomass resources are becoming more expanded as they generate economic and environmental benefits. Schweier and Becker (2013) provide an useful economical study of the efficiency of SRC in Germany. Issues regarding harvesting costs, transportation and processing costs or market prices are discussed. Among other conclusions, the paper underlines that if political focus is on SRC expansion, farmers could be helped by increased subsidy payments. In the EU, it is expected that SRC farms will constantly expand in the next 10 y. More than 176,000 ha are necessary for this process. Consequently, existing plantations will increase by 30 % in size, yearly, for the following decade. Willow and poplar are the predominant species which are being harvested (European Environment Agency, 2008).

The basis of any SRC farms resides in the planting material (or cuttings). After harvesting the wooden material during winter months, cutting of plants at specific dimensions is done manually. With obvious limitations, this manual labor is to be replaced by an automated process which integrates the latest industrial technologies with the purpose of increasing biomass production efficiency. The EU (2011) encourages technological developments of new concepts in the direction of increasing wooden biomass throughput. Bentini and Martelli (2013) provide an evaluation study regarding a multi-purpose prototype machinery (the the biotriturator) used for harvesting herbaceous energy crops. This device proves to be extremely effective solutions for smaller farms.

A prototype system, the “Rod Picker”, destined for harvesting and automatic processing of SRC rods has been developed under the cooperation of three private companies, one technology transfer institute and two technical universities. The present paper discusses only the automatic processing module since this is the task in which the authors were involved.

This module includes operations of cutting, sorting, bundling and packaging of freshly harvested rods. It will be distributed to the SRC farming industry with a target efficiency improvement of 60 % regarding wood processing costs. Two key aspects will be addressed by this prototype machinery. First of all, process automation and increased rod processing speed will help farmers obtain better production results. Secondly, the SRC machinery market will benefit from an innovative tool which could help increase the overall wooden biomass production by 30 %.

The remaining part of this paper is organized as follows. Section II presents the system for the rod processing operations. Proposed technical approaches, measurement technologies and implementation details are discussed. Section III discusses conclusions concerning both the functionality performance and the future developments.

2. Overview of the Cutting, Sorting and Packaging Module

2.1 Performance guidelines

Figure 1 presents the schematics of the Rod Picker system. There are two main units/modules which perform different actions. As an ensemble, the modules provide a solution for the entire rod processing production process, from field harvesting to selection and cutting. Unit I is mobile and it was designed and implemented at the partner T.U. Dresden – Germany. It performs field harvesting operations and transportation to the processing depot. Unit II is fixed and it was designed and implemented at the partner from U.P. Timisoara – Romania. It is located in the processing depot and performs activities of cutting, sorting, bundling and packaging of harvested rods. Module II includes two separate sets of components: the *Measuring and Cutting Component* and the *Sorting and Packaging Component*. The second component is still under development and will be discussed in future works. The *Measuring and Cutting Component* has been developed and will be the focus of the following sections.

Unit II (or Module II) has been designed in accordance with the input provided by experienced SRC farmers. The processed energy trees species are Salix spp. and Populus spp. The cutting procedure must function after some imposed limitations. Processed rod diameter will be between 7 mm (minimum) and 25 mm (maximum). The length of the rod will be between 1.2 m (minimum) and 2.4 m (maximum).

Consequently, the processing module will start to cut at 25 mm diameter and at 2.4 m length using all rods. There will be two groups of rods destined for the packaging process: 50 rods when processing Salix spp. and 25 rods when processing Populus spp.

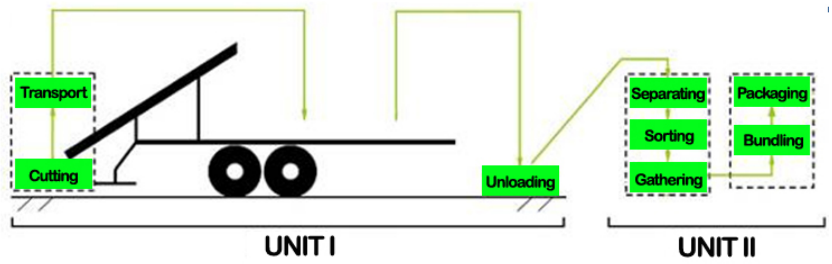

Figure 1. Rod Picker prototype concept

The autonomously detects and sorts out damaged or multiple branched rods. In this case, it is possible that some rods will be more curved and with additional smaller branches, the selection (as previously mentioned) cannot be possible in all situations and loses may increase. Rejected cuttings will be stored in a separate container for ulterior energy recovery.

Some efficiency/performance considerations for the sorting, bundling and packaging of harvested rods are presented in the following lines:

- Currently, at the Lempe partner, 6 people process 2 boxes/day (one box contains 5,000-6,000 m, about 3,000 rods).
- For the proposed project the team targets more than 2 boxes/day with less than 6 people operating the machine.
- Automatic printing of labels with information customized according to farmer needs will be available.

2.2 UNIT II functionality features

Freshly harvested rods (output from Unit I) will be prepared for the separating, sorting, gathering, bundling and packaging stages. Currently these actions are performed manually. Figures 2 and 3 present the design and actual implementation of the measuring and cutting components. This concept is absolutely new, designed for the first time, based on the production values analysis and end users operation conditions.

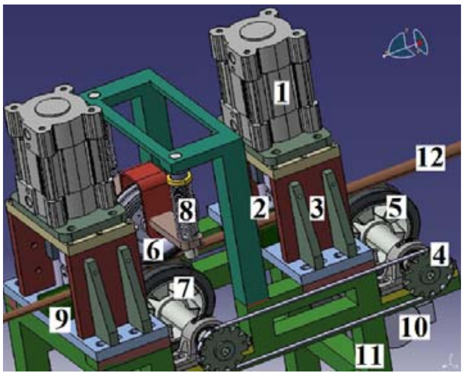

Figure 2. Measuring and Cutting Component Schematics: 1 - air cylinder for blade powering; 2 - blade and it's support and guiding; 3 - cutting skeleton; 4 – rotary wheels for belt movement; 5,6,7 – rod guiding wheels (fixed and mobile); 8 – fixing spring; 9 - opposite blade ensemble; 10,11 – frame components; 12 – processed rod

Figure 3. Actual implementation of the Measuring and Cutting Component

A loader (the system is designed in a modular concept and could be extended for more processing parallel lines) will ensure that the machine is supplied with harvested rods, inserted with the thicker side forward. Initially, an optical analysis system (video inspection using the LeanXCam) verifies the rods with additional smaller branches or significant curves. These parts of the rods will be cut off. The rod continues the movement along the processing line where a secondary cutting system (see component 9 in Figure 2) is responsible for cutting at the specified dimensions. After passing through the measuring and cutting procedure, the rods travel on the sorting and packaging component. This design of this component will be presented in future works.

After bundling, the rod packets will be put in boxes, in alternative positions, for efficient usage of the space. An operator controls and insures that the process runs as expected. The end user benefits from a Control Panel which displays basic parameters like: tree species, processing speed, rod length, rod diameter, number of processed rods and meters of processed rods.

The cutting cycle is approximately 1 s and allows cutting forces of up to 8 kN. The powering part is used for the rod movement in conditions of adjustable speed. A Control Unit ensures that the functionality of Unit II is in accordance with required specifications. For user interaction an Operator KP300 Monochrome Panel was connected to a PLC (S7 - 1200), currently only for minimal functionality and testing purposes. The Main Motor (1FL-5060, 4A, 4 Nm, N max = 2,200 rev/min, N nom = 2,000 rev/min) is controlled by a Sinamics V60 Motor Driver. This Driver is supplied by 3x230VAC and a 24VDC industrial power supply.

2.3 UNIT II Measuring and Cutting Component automation

The structure of the measuring and cutting component is presented in Figure 4 as a block diagram. Its purpose is to grab the rod, push it through the cutting devices, while measuring it and cutting it to the accepted size. Unwanted smaller branches removal is also included in this process.

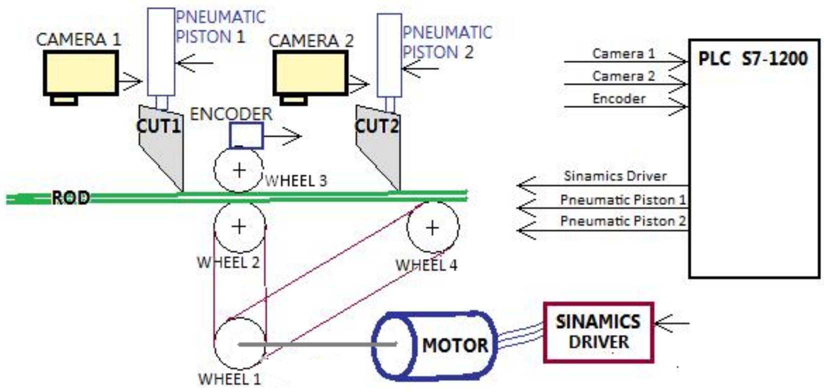

Figure 4. Block diagram of the measuring and cutting component

The rod is grabbed and pushed forward by Wheels 2 and 3 actuated by the corresponding Motor through Wheel 1. Unwanted smaller branches are detected using Camera1 (the LeanXCam). A specially designed knife (Cut1) is actuated by Piston1 only if smaller branches are detected. Camera2 measures the diameter of the rod using an on board image processing method. An Encoder (Omron E6B2) measures the length of rod. The knife at Cut2 is activated according to the restrictions presented in Section 2.1.

One of the most important components of the system is the LeanXCam device with on board signal processing which can take up to 60 images/s. These images have to be processed and the detection of the target diameter has to be signaled. It will also detect any damaged rods and generate a signal which triggers the cutting (removal) of the unwanted part. Image processing needs to be synchronized with the speed of rod movement along the processing line. A problem which could affect the measurement accuracy of this approach is the environmental conditions in which the cameras operate. For example, dust particles resulting from rod cutting operations might cover the lens and thus cause unwanted image blurring. For solving this issue an automated air cleaning system is to be integrated. The video inspection developed algorithm will be presented in future works because of complexity constrains.

All the signals (sensing or actuating) are read or provided by a SIEMENS S7-1200 PLC, according to an automation algorithm.

The sensing signals are:

- Camera1 – logical signal – “1” when a branch is detected on the rod, “0” if no branch is detected.
- Camera2 – logical signal – “1’ when 7 mm ≤ measured diameter ≤ 25 mm, “0” outside imposed limits.
- Encoder – logical signal – pulse for every 1/1000 rotation of shaft.

The Actuating signals are:

- Sinamics driver – logical signal – pulse as a reference for 1/4000 rotation of motor shaft.
- Pneumatic Piston1 and Pneumatic Piston2 – logical signal – positive edge “0” to “1” determines the advancement of Cut1 towards the rod during the cutting process. The negative edge “1” to “0” determines the withdrawal of Cut1 from the rod (in the last version, for speed reasons, the withdrawal of piston is made with another command line).

In exploitation of the Rod Picker measuring and cutting component the following working regimes have been implemented.

They are:

- *Initialization* – Start Up procedure performed everytime the machine is powered.
- *Nominal regime* – includes the following situations.
    - actions when branches are detected (diagram presented in Figure 6.a).
    - actions when length is reached (diagram presented in Figure 6.b).
    - actions when diameter is inside the limits (diagram presented in Figure 6.c).

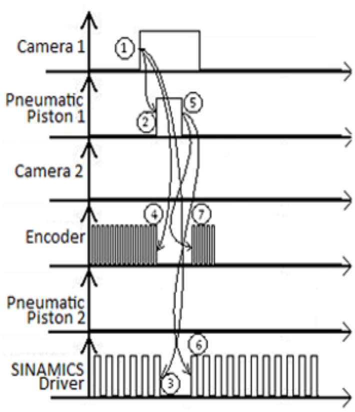

Figure 5.a. Actions performed when branches are detected

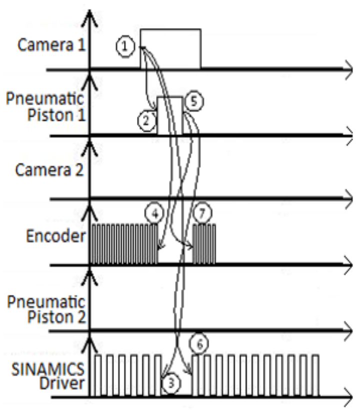

Figure 5.b. Actions performed when length is reached

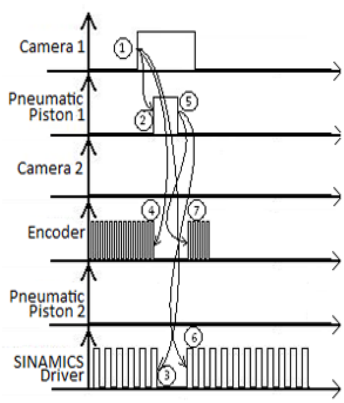

Figure 5.c. Actions performed when diameter is inside the limits

Figures 5.a, 5.b, and 5.c contain all the signals monitored during the functioning of the measuring and cutting component.

When unwanted branches are detected (see Figure6.a), the Camera1 signal becomes “1” (1). This will determine the motor to stop after a certain delay (3), in order to allow cutting. The piston is actuated (2) and the rod is cut. After the piston has withdrawn (5), the motor starts to move again (6). Meanwhile, the encoder is counting the length of rod until the moment of cutting (4). The count by encoder can be restarted, if necessary (7).

In the case of Figure 6.b, when the diameter of rod becomes less or equal to 25 mm (1), motor stops (3) and the piston is pushed to cut the rod (2). After Cut2 has withdrawn (4), the motor resumes the movement (6) and the encoder starts to count length. When count reaches 2400 mm (7), motor stops again (9), piston for Cut2 is actuated and the rod is cut.

For Figure 6.c, the first actions are identical to the ones presented in Figure 6.b. The diameter of 25 mm is detected and the rod is cut (1), (2), (3), (4), (5) and (6). The length is less than 2.4 m, but camera detects a diameter less or equal to 7 mm (7). After a certain delay (due to geometrical disposal of camera relative to the knife for Cut2), the motor is stopped (10), the rod is cut (9), and the count is stopped (8) providing the exact length of rod.

3. Conclusions and future development of the Rod Picker

As reported in different specialty literature sources, there is an increasing demand of specifically designed agricultural machines capable of providing increased processing speed of wooden biomass resources. Such dedicated energy crops are produced in SRC farms. This paper presents the design of a prototype called the Rod Picker which will be used in energy plants farms for efficient harvest processing. The

prototype was developed under the collaboration of three private companies, one technology transfer institute and two technical universities, representing four different countries.
The device includes two functional Units/Modules representing a complex piece of machinery developed by researchers, engineers and experienced people working in energy plants production. The implementation requires knowledge in mechanical engineering, computer programming, sensors, measurement systems or image processing. The focus of the present paper was on the automation and functionality of the measuring and cutting component, generally describing other device parts.
As demonstrated, the presented automation approach in viable and has been successfully tested during the development stages.
Future development of the prototype includes specific components integration (photoelectric sensors, inductive sensors, limiters, switches, trouble signalling) with the purpose of self diagnosis and work safety. This represents an extra function of the Control Unit which will periodically perform an auto diagnose of the whole system. This task implies more sensors, increased complexity of the control algorithm and issuing of alarms (lights, sounds, messages on the Operator Panel, accompanied or not by the stop of all operations). Testing of the sorting and packaging component is a priority in the coming weeks.

Acknowledgement

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