Visual Simulation of Machine Concepts for Forest Biomass Harvesting

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ABSTRACT We present work-in-progress of applying simulator technology for developing, demonstrating and evaluating new machine concepts and work methods in off-road environments. In particular we consider a new concept machine for making efficient biomass harvesting in the process of thinning in dense forest stands and we describe how this machine concept is realized in a virtual environment and plan for simulator experiments.

KEYWORDS: simulator based design, machine concept, work method, virtual experiment, harvesting, forestry, robotics

INTRODUCTION

Virtual Reality have found applications in a number of areas in science and technology. In particular simulator technology is used widely. Common simulators are training simulators, e.g. for aircraft pilots, heavy machine operators, surgery and military training. The same technology can also be used for simulator based design [1], where virtual or real prototypes are tested in a partially or entirely virtual environment. The work presented here describes a joint effort in collaboration between academia and industry to apply simulator technology in the development process of the next generation of forest machines and similar types off-road vehicles.

Forest machines are manufactured at low volume, compared to, e.g., the automobile industry. There was a period of strong technological development between 1960s-1980s that in northern Europe replaced manual tree felling with the two-machine cut-to-length system. This harvesting system is well established and the machines are well optimized and current development is dominated by optimization of the machine production system and only incremental improvements of the machines. Significant increase in forestry efficiency with environmentally and economically sustainable technology will require significant change in technology platform and work methods, including semi-autonomous or fully autonomous machines [2]. This transition has been setup as long term goal for the Swedish forestry industry and realizing this involves deciding on and refining a number of technologies.

We focus here on visual interactive simulation of technology for biomass harvesting of whole trees. In a few decades when oil supplies decline, there will be a change in society's energy sources, and considerable increases in the supply of biomass are likely to be required (cf. Ref. [3]). To meet future demands for raw material, it is important to increase biomass growth in the forest and make the harvesting technology even more efficient. Deciding on specific technologies for this is difficult. The forestry process is very complex and new concepts and work methods should be optimized with respect to productivity, forest biology, operator work environment, logistics of the raw material from felling to processing unit and should rely on available and emerging solutions in robotics, automation, sensor and human-machine interaction (HMI) technology. Simulator technology, that was originally developed for operator training, have been used for several years for studying the operator behaviour and work load in forest machines and evaluating methods for improving the HMI, including semi-autonomous crane control and display systems [4]. Our plan is to further increase the use of simulator technology to facilitate the R&D process of new machine concepts and work methods in off-road environment. An important tool in forestry for evaluating techniques is by time studies [5]. These give the time consumption per produced volume, which in turn can be translated directly into economic value. A thorough time analysis also gives the time consumption for each of the sub-processes, thus revealing the bottlenecks in the production flow.

THE SCENARIO AND MACHINE CONCEPT

For a particular scenario we consider harvesting of whole trees in dense forest stands that have not been subjected to pre-commercial thinning (PCT). High stem density in young forests can be a sign of high biomass growth potential. In Fennoscandia, large areas that have not been subjected to PCT, and thus support dense stands, are becoming suitable for harvesting biomass. In Sweden, young forests, 11-30 years old, account for 22% (4.9 million ha) of the total forestland [6]. The particular stand we consider [7] has average tree height and mass of about 6 m and 50 kg, respectively, at an areal density of 9000 trees×ha^{-1}. Already, large areas of young forests are suitable for harvest, and these stands are costly to treat by current forest management systems (conventional PCT) even if they contain high volumes of biomass [8].

Efficient systems for harvesting biomass from this type of stand is yet to be developed. These should meet the requirements of environmentally sustainable, economically profitable and provide an attractive work environment for the operator as well as optimal long-term growth effect on the forest stand – the majority of the trees in these stands are left for further growth. We develop technique for virtual experimentation and demonstration of alternative approaches in machine design and harvesting method.

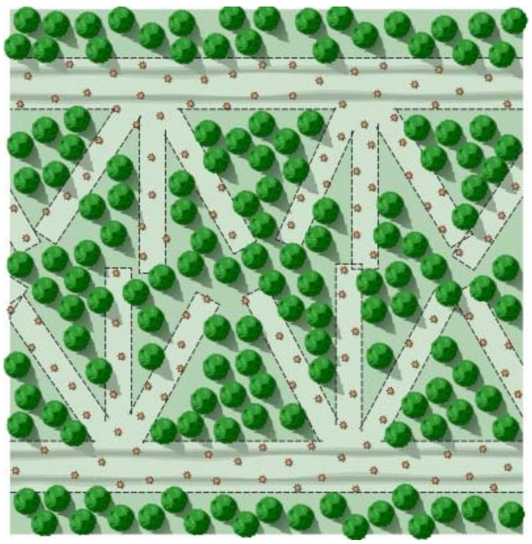

Figure 1. Illustration of geometric area based felling. The machine works along strip-roads and fells corridors sideways in fan shaped patterns. Image by P. Torneus, SKOGEN 11-06.

We consider two harvesting techniques for dense young stands, *conventional multi-tree harvesting* and *geometric area based felling*. Single-tree harvesting is very time consuming as it for each individual tree involves both re-positioning of the harvester head and motion to pile or transportation tray. With conventional accumulating felling technique, the harvester head is re-positioned to fell every single tree but accumulates a number of trees, up to the capacity of the head, before moving them to pile or tray. Geometric area based felling is developed for cutting and accumulating many small-dimension stems at high capacity. In this system the handling unit is not a single tree but a corridor area where all trees are harvested in the same crane movement cycle. The machine advances through the stand by harvesting along strip-roads, 15-20 m apart (depending on crane length) and 3 m wide, and by felling corridors of trees in a fan shaped pattern sideways to the strip road, see Figure 1 for an illustration. Each corridor corresponds to a single crane movement cycle and has size up to 1×10 m which implies about 9 trees per corridor for the particular stand [7] under consideration. The strip-road is harvested with the same type of crane motion. The trees are collected in piles at the corridor start points and made to bundles to facilitate the further logistics. A pile may include up to 50 trees. As showed in Ref. [9] using discrete-event simulation, the benefits of applying area-harvesting systems in young, dense stands may be considerable, predicting reduced time consumption and increased the productivity by up to 30%, and when these measures were combined with area-harvesting productivity could be more than doubled. Similar tests will be made with the technology we are developing here.

Virtual experiments can be made with models of existing as well as hypothetical machines. We focus on a machine concept developed for thinning in dense forest stands in year 2017 [10], see Figure 2.

Figure 2. Illustration of the machine concept for harvesting in young dense forest stands. The machine is unmanned, semi-autonomous and operated remotely. The harvester may be equipped with a single tree harvesting head, a conventional accumulating multi-tree harvester head or a harvester head with long chainsaw sword for corridor harvesting.

The machine is unmanned, semi-autonomous and operated remotely. Having removed the operator cabin the crane may be placed in centre which improves stability and gives the same reach distance in all directions. The size of the machine is about 4 m long and 2 m wide (distance between wheel pairs), weight of 2.5 tons and total crane length[1] of 8 m. For optimal mobility in terrain, the wheels are suspended on pendulum arms with active damping [11] and the steering is done with individual 4 wheel steering with electrical motors. The harvester may be equipped with either a single tree harvesting head, a conventional accumulating multi-tree harvester head or a harvester head with a 1 m long chainsaw sword for corridor area harvesting [9]. The main role of the operator is to select which trees or areas to be harvested and what should remain. Operation may be remote but local with direct visual contact with the machine and forest or remote at larger distance using video cameras or by virtual environment teleoperation [12] that relies on terrain data and recognition of objects and obstacles from the machine's sensor data, e.g. stereo camera, laser, radar.

[1] The practical reach limit for a full load may be shorter, however, depending on the weight distribution.

SPECIAL REQUIREMENTS OF THE SYSTEM

The purpose of studying biomass harvesting in simulator environment is to provide a tool for demonstration, experimentation and evaluation of new machine concepts and work methods. More specifically, the simulator should enable testing of: geometric corridor harvesting versus conventional multi-tree or single tree harvesting; stability, mobility and power consumption of the proposed machine; automation strategies; and design of human-machine interaction interfaces.

The scenario and machine concept described above implies the following special requirements for the virtual environment and simulator interface that are not automatically fulfilled with conventional systems: ***i)*** the virtual environment must support realistic contact and interaction contact between the machine and a large number of trees (up to 10 in a corridor and up to 50 in a pile); ***ii)*** forest representation and visualization from real or realistic forest stands; ***iii)*** realistic machine behavior – in the sense that time studies, stability, mobility, power consumption give reliable numbers with known uncertainty; ***iv)*** support for experimenting with human-machine interfaces, automation strategies and sensor simulation.

REALIZATION AND PRELIMINARY RESULTS

A simulator for the described scenario is realized with the following main components:

- simulation software – a simulation manager and integration of a number of code libraries
- hardware system – input devices, signal processing and display system
- visual and physical models of forest and vehicle
- vehicle and HMI module - vehicle control, automation, sensor simulation and human interaction interface

The 3D rendering and physical simulation system is realized using a state-of-the-art software framework, Colosseum3D [13]. This framework is built around a plugin system where the modules are accessed either through C++ and/or lua [14] scripting language. This makes it suitable for fast prototyping of interactive real-time virtual environments consisting of 3D rendering, sound and physical simulation. The main components in Colosseum3D for this application are the physics simulation engine Vortex [15] and the rendering toolkit Open Scene Graph [16]. Vortex is a simulation toolkit for real-time multibody dynamics with frictional contacts and its high functionality constraint library makes it suitable for visual interactive simulation of ground vehicles, machines and robots.

As for hardware system, the simulation is developed both for running on a demonstration laptop with a simple interface via keyboard and mouse, on portable simulator mounted in a portable case or in a full simulator environment – used in commercial training applications – for operator-in-the-loop evaluation of new machines, work methods and human-machine interfaces. The hardware components in the full simulator environment includes screen projection, authentic chair and joysticks from forest machine, see Figure 3.

Figure 3. The simulator environment. Image courtesy of Oryx Simulations.

Visual and physical models for a virtual test forest have been generated from data of real young dense forest stands [7] and is placed in a terrain model. Three tree types are included – pine, spruce and birch – and graphical models for these types with given size have been produced. The trees are simulated as rigid bodies of slender cylindrical geometry with mass and size according to the forest stand data file. Research for improving the dynamics of the trees is work-in-progress at the time of writing. Using recent results for constraint stabilization [17] the trees are made deformable with desired elasticity – an approach previously applied to wire systems [18]. With similar techniques we introduce deformable tree crowns for more realistic contact between tree-tree, tree-terrain and tree-vehicle that will allow large deformations, friction and locking with large sets of contacts. The purpose of this work is also to achieve better scaling of the computational time with the number of trees. The trees are attached to the ground using relative-position-relative-orientation constraint that is slightly relaxed. The visual model for the vehicle has been adapted from Ref. [10]. Physically, the vehicle is a rigid body system of approximately 15 elements connected via kinematic constraints ranging from elementary hinge constraints to more complex high-functionality constraints for vehicle suspension and transmission. There is a low-level interface for controlling the link velocities (or alternatively the joint force/torque in the links) and thereby the vehicle propulsion and motion of the crane and harvester head. The desired link velocity (or force/torque) is fed to the simulation physics engine.

High-level controls of automated motion patterns is currently under implementation. The controls can be linked either directly to the conventional interaction interface that is replica of what is found in forest machines today or to a automation module that computes motion trajectories from high-level commands. The high-level commands to be implemented are

- select a tree/corridor/strip road
- cut selected tree/corridor/strip road
- select pile (existing pile or position of new pile)
- move to pile

Selection of trees/corridors can in reality be made by projecting a laser pattern to the target. For virtual environment teleoperation [12] of the crane the selection can be made by a simple mouse interaction or any other suitable interaction device. We also plan to test eye and gaze tracking system [19] for high-level commands, e.g., for selecting trees and piles.

Figure 4. Snapshot from simulation. The machine is gripping several trees with a multi-tree harvester head.

The current results include a virtual environment of a forest stand in a terrain mesh, a virtual vehicle prototype and basic functionality that supports concept demonstration and development of the testing procedures. A snapshot from the virtual environment is displayed in Figure 4. A forest stand subjected for corridor harvesting is displayed in Figure 5. The virtual harvesting experiments will be conducted as time studies measuring the time consumption for a given area in a forest stand. The measuring unit is time (seconds) per biomass unit (kg). The total time consumption per unit mass is further divided in time for: producing a strip road, harvest a corridor/tree, move corridor/tree to pile, positioning the crane, moving the machine and "other". Evaluation is made by studying the effect of total time and process-divided time under variations of: harvesting technique (corridor, conventional multi-tree, single-tree), machine operation (manual, semi-automation), operator location (on machine, remote with direct visual contact, remote by virtual environment teleoperation). The operator interface as well as properties of the forest stand and terrain may also be varied to see the effect on time consumption.

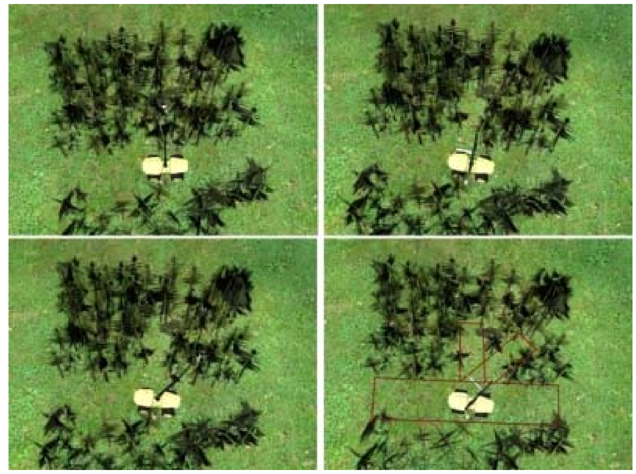

Figure 5. A sample forest stand subjected to corridor harvesting. A strip-road is produced (top left frame) and the harvester head is positioned, a first corridor is harvested (top right frame), the harvester head is re-positioned (lower left frame) and a second corridor is harvested (lower left frame)

DISCUSSION

We are applying simulator technology for developing, demonstrating and evaluating new machine concepts and work methods for ground vehicles, here focusing on harvesting in young dense forest stands. The system is flexible for building and altering the forest environment and vehicle design, and for experimenting with different control and HMI strategies. Current and future work is focused on implementing the high-level controls, make time-studies for the different harvesting methods and quantitative measuring of vehicle mobility and stability.

Current work also focuses on improving the physical simulation of tree-tree, tree-vehicle interaction to allow large number of trees in contact, flexibility and roughness of tree stems and crowns.

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