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Estimating wheel slip for a forest machine using RTK-DGPS

Ola Ringdahl [a,*], Thomas Hellström [a], Iwan Wästerlund [b], Ola Lindroos [b]

[a] Dept. of Computing Science, Umeå University, SE-901 87 Umeå, Sweden
[b] Dept. of Forest Resource Management, Swedish University of Agricultural Sciences, SE-901 83 Umeå, Sweden

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Abstract

Wheel slip may increase the risk for wheel rutting and tear up ground vegetation and superficial roots and thereby decreasing the bearing capacity of the ground, but also reducing the growth of nearby standing forest trees. With increased slip, more energy is consumed for making wheel ruts in the ground, with increased fuel consumption as a result. This paper proposes a novel method for measuring slip in an uneven forest terrain with an 8WD forestry machine. This is done by comparing the wheel velocity reported by the machine and velocity measured with an accurate DGPS system. Field tests with a forestry machine showed that slip could be calculated accurately with the suggested method. The tests showed that there was almost no slip on asphalt or gravel surfaces. In a forest environment, 10–15% slip was common. A future extension of the method enabling estimation of the slip of each wheel pair in the bogies is also suggested.

Keywords: Forestry; Asphalt; Gravel; Sand; Snow; Terrain; Forwarder

1. Introduction

One of the major focuses in Swedish forestry is to decrease fuel consumption at forestry work [1]. Presently it is estimated that the average fuel consumption is 1.7 l/m^3 harvested wood from stump to landing at road side [2]. Usually this figure includes a harvester felling and bucking the trees, and a forwarder for the terrain transport of timber to the landing. However, in the work performed large masses are handled (trees or logs) and, thus, the machines are often heavy. Machine masses are especially high in the work of transporting trees or logs from the terrain to roadside landing points, as it is operational and fuel efficient to maximise payloads with good transport speed. At harvesting operation it is suggested that the forwarder fuel consumption could be decreased by improving the transmission chain. Another motive to look closer at the transmission chain is the concerns about soil damage at harvesting operation. One reason for this is the year around harvesting operation to supply the industry with timber. The expected more rainy periods and less frozen ground in north Europe due to climate change will increase soil moisture content and reduce the bearing capacity which in turn would increase wheel slippage. Good planning before harvesting should steer the operation towards better areas, but unexpected heavy rains can alter ground conditions very fast. Heavy axle loads and wheel slippage will create deep rutting and soil compaction and increase the fuel consumption [3–5]. Thus, there is generally a conflict between minimised soil disturbance and maximised operational efficiency.

Another reason to look at the transmission chain is to see if wheel slip could be avoided by having better load-adapted wheel propulsion [6,5]. Slip is defined as how the speed of the traction elements differs from the forward speed of the vehicle [7]. Most forestry machines are made for good mobility in uneven terrain, and the basic principles have been adopted by most machine manufacturers during the years. Now, with increased focus on trafficability, some of the previously accepted design principles can be questioned. Some slip is needed for good traction. On the other hand it is known that slip may

* Corresponding author.
E-mail address: ringdahl@cs.umu.se (O. Ringdahl).

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increase the risk for wheel rutting in the forest [8]. The slip may tear up ground vegetation and superficial roots and thereby both decreasing the bearing capacity of the ground floor but also reduce the growth of nearby standing forest trees [6]. With increased slip, energy is consumed for making wheel ruts in the ground with increased fuel consumption as a result [9].

It is relatively easy to measure the difference between the wheels' speed on even ground. This is used by many car manufacturers for slip control and traction control. Technical solutions for the same measurements in off-road forestry vehicles have also been suggested [10]. However, the rough off-road terrain makes the estimation of slip more challenging than for regular roads. Small obstacles, such as stumps and stones that have to be run over add extra distance to the travelled distance for each individual wheel, and the comparison to vehicle speed becomes more complex.

The main objective of the work presented in this paper was to develop and evaluate a method for measuring average slip in uneven forest terrain with an 8WD forestry machine with hydrostatic-mechanical transmission. Additionally, a method to measure and analyse slip of individual wheels is proposed. In a previous study, the forest machine's own data transmission measurement was used and combined with GPS-data for measuring mobility parameters [10]. We use a similar, but enhanced, technological approach specially adapted for slip measurements.

The paper is divided into two major parts. One part is a literature study of relevant work previously done in the area of wheel slip. The other part describes the developed method and contains a report on field studies carried out on a Valmet 830 forwarder to evaluate the method.

2. Background

To better understand the discussions later in the paper, this section contains a short background to satellite navigation systems and forest machine transmission.

2.1. Satellite navigation systems

Today, two different satellite navigation systems are available; the American GPS (Global Positioning System) and GLONASS (Global Navigation Satellite System) from Russia. These two systems are quite similar, and many GPS receivers are able to use the GLONASS signals as well, to increase the accuracy of the position estimation. The maintenance of the GLONASS system was neglected after the fall of the Soviet Union, but Russia has restored the system and currently (April 2012) 22 of 24 satellites are operational [11]. An advantage of GLONASS is better coverage at high latitudes (>60° North). A new system, Galileo, is under development in Europe but not yet in operation. The first two operational satellites were launched in October 2011, and the system is scheduled to be available to the public by 2014 [12]. The technology described below is common to all three systems with just minor differences.

Each GPS satellite transmits two carrier waves (denoted L1 and L2) modulated with ranging codes (Pseudo Random Noise, PRN) [13]. A standard GPS receiver measures the time-of-flight for the PRN-signals from 3 to 12 satellites. From the corresponding distances, and information about the exact location of each satellite, the position of the receiver can be estimated. Velocity and heading estimates are also possible to compute, based on the Doppler Effect on the signals from the satellites. The accuracy of the velocity estimates is about $0.1\ \mathrm{m\,s^{-1}}$. Basic GPS receivers have a position accuracy of around 15 m 95% of the time. An extended technology is differential GPS (DGPS) which has around 0.5 m accuracy [14]. This technique utilises two receivers; a base station located at a known position, and a moving receiver placed on, for instance, a vehicle. The base station is able to calculate the position error in the GPS-signal it receives, and can send correction data to the mobile receiver [13]. To get an even higher accuracy in the position, Real Time Kinematics DGPS (RTK-DGPS) can be used. This is an extension of DGPS where the two receivers use not only the ranging codes, but also the carrier waves. To calculate the distance to each satellite, the number of full periods of the carrier wave from the satellite to the receiver is required. This is referred to as solving the integer ambiguity, or getting a "fix solution". In addition to this number, the fraction of the last period, given by the phase of the wave, has to be calculated [15]. A non-stationary RTK-DGPS is capable of delivering positions with errors between 2 and 20 cm and headings with errors of less than 0.1° [16,17]. However, regardless of the GPS type, the technology has limitations that make a GPS system insufficient as the only position sensor for a forest machine. The most common problems involve obstruction of line-of-sight to satellites, multi-path problems and active jamming from other radio sources [14]. Therefore, a GPS system is often combined with *Inertial Navigation System* (INS) or odometry.

2.2. Forest machine transmission

One of the most commonly used machines in forestry is the forwarder (Fig. 1). A forwarder is used in the cut-to-length method to carry the cut timber from the forest to the roadside landing (for an overview of machine evolution see [18]). The carrying capacity is normally between 8 and 18 tonnes and commonly in Nordic forestry the machines have eight driven wheels (8WD), for improved comfort and mobility on soft ground. The machines have an articulated steering and to further improve mobility in rough terrain front and rear part has a connection that can pivot somewhat which enable the parts to move sideways rather independently of each other. During work, a forwarder normally drives at rather low speed in forest terrain; usually less than $1.3\ \mathrm{m\,s^{-1}}$ when driving unloaded and ca. $0.8\ \mathrm{m\,s^{-1}}$ when driving loaded [19].