Computers and Electronics in Agriculture 135 (2017) 208–215

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Original papers

Multi-camera surveillance systems for time and motion studies of timber harvesting equipment

Marco Contreras *, Rafael Freitas, Lucas Ribeiro, Jeffrey Stringer, Chase Clark

Department of Forestry, College of Agriculture, Food and Environment, University of Kentucky, United States

ARTICLE INFO

Article history:
Received 6 July 2016
Received in revised form 31 January 2017
Accepted 6 February 2017
Available online 21 February 2017

Keywords:
Forest operations
Skid-trail locations
Skidding cycle time
Productivity and costs

ABSTRACT

We evaluated the feasibility of using a multi-camera security system to conduct time and motion studies. It was installed on a John Deere 540G cable skidder and connected to the skidder's battery for continuous recording with minimal effort and intervention. After recording the skidder's work for eleven experimental skidding cycles, time stamped video footage was visually inspected to obtain time consumption of work tasks, which provided for accurate calculation of total cycle times and delays. Several advantages of the security camera system including quick and non-invasive installation, large memory storage, transferability, resistance to weather elements, and the capacity to capture different views, offer a great potential for this method to be adopted as a reliable approach to accurately conduct time and motion studies. Along with distance and gradient information for skid-trail segments, we also explored the influence of gradient on travel time for loaded and unloaded skidding. There is a need for future studies to formally explore this relationship and develop more detailed cycle time equations that explicitly take into account skid-trail gradient for individual segments.

1. Introduction

Time and motion studies are essential for determining machine cost and productivity of forest harvesting equipment. During the past several decades, numerous studies have been conducted for individual harvesting machines, harvesting methods, and harvesting systems (Kosir et al., 2015; Olsen and Kellogg, 1983; Worley et al., 1965). Data collected via traditional stopwatch methods have been useful for measuring time consumption of different work tasks and estimating productivity (LeDoux and Huyler, 1992; Olsen and Kellogg, 1983). However, these traditional methods are labor intensive and only sample work tasks (Nuutinen, 2013). Even with advances in video technology, manual methods are prone to observer error in recording work task time and require the presence of researchers on site, which can influence operator behavior (Parker et al., 2010; de Hoop and Dupre, 2006; Wang et al., 2003).

Recent developments in time and motion studies include the use of global positioning system (GPS) technology and automated methods to extract time consumption of individual work tasks (Strandgard and Mitchell, 2016; Hejazian et al., 2013; Odhiambo, 2010). Despite the perceived benefits of recording work tasks automatically, there are several limitations associated with the use of GPS-based approaches. Unreliable satellite signal strength is common, particularly in steep and dissected terrain often associated with forestry operations. Even in the absence of canopy cover, positional accuracy and time estimates can be impacted (McDonald and Fulton, 2005). Also, GPS-based approaches are not able to capture variables that have a significant impact in cycle time and productivity such as payload. Because of these shortcomings there is a need for alternative approaches. Although recognizing work tasks and measuring time consumption is possible with GPS data (de Hoop and Dupre, 2006; McDonald and Fulton, 2005), this process could likely be improved with the aid of cameras.

Limitations of manual and GPS-based data collection methods can potentially be addressed using video-based recording. Video technology has been used to address a number of aspects of forestry work including validation of advanced manual recording methods (Wang et al., 2003), quantification of productivity and worker exposure to hazards during manual felling activities (Parker et al., 2010), evaluating relationships between harvester felling time and tree diameter (Nakagawa et al., 2007), operator and equipment interactions (Gellerstedt, 2002), evaluating machine utilization rates (Wang and Haarlaa, 2002), and developing time and productivity models (Nurminen et al., 2006). These studies show that the use of video cameras can effectively minimize observer errors and their influence on operator behavior.

* Corresponding author.
E-mail addresses: marco.contreras@uky.edu (M. Contreras), drummis44@gmail.com (R. Freitas), lri235@uky.edu (L. Ribeiro), stringer@uky.edu (J. Stringer), chase.clark@uky.edu (C. Clark).

http://dx.doi.org/10.1016/j.compag.2017.02.005

They can be attached to individual workers and/or machines, eliminating the need for researchers to be present on site during data collection. The ability to pause and replay video recordings facilitates accurate identification of individual work tasks and precise timing (Parker et al., 2010; Gellerstedt, 2002; Ovaskainen et al., 2006).

Comparison of GPS and video-based approaches reveals distinct advantages of the latter. The most important is the ability to visualize and record individual work tasks that are not easily identifiable using GPS positional data (Nurminen et al., 2006; Wang and Haarlaa, 2002; Gellerstedt, 2002). Visualization may also provide for more accurate interpretation of movement patterns and recognition of work tasks that can create or contribute to variation in work times, for example irregular skidding cycles in timber harvesting operations (McDonald and Fulton, 2005). While video-based monitoring has been used in time and motion studies associated with forestry operations there was not a focus on describing and evaluating video capture methodologies. As a result there is little information on camera characteristics and video processing techniques, making replication difficult. Additionally, most previous studies used digital cameras which have limited storage capacity and battery life, effectively limiting the amount data collected (Parker et al., 2010).

Security camera systems commonly used for surveillance can be used to addresses these limitations. It is common for these systems to have a significant storage capacity, multiple channels (cameras), high-quality recording definition, and wireless capability. The most common systems have eight synchronized cameras, indicating usefulness in capturing multiple views and facilitating recognition of work tasks. They also have storage capacity sufficient for several weeks of continuous recording, are widely available and relatively inexpensive (400–1000 US $). This study was designed to determine the feasibility of using a readily available consumer grade, security camera system to conduct a skidding cycle time and motion study. In addition, we explored the influence of skid-trail gradient on skidding time using information along an existing 1.1 km skid trail.

2. Methods

2.1. Security camera system and installation

A Swann® 8-channel, 8-camera indoor/outdoor high-definition DVR surveillance system was used in this study. The system is manufactured for do-it-yourself installation and use in residential and business applications and is available through retail outlets making it widely available and relatively inexpensive. The system was installed on a John Deere 540 cable skidder. The 110-voltage, 42-watt potency system was coupled to a power inverter (Wagan 2016–6 700 W) connected to one of the two 12-volt batteries in the skidder. The inverter provided a potency of up to 700 W of alternating current that could be accessed by two outlets. Fig. 1 shows a diagram of the cameras-DVR-inverter-battery connections as well as the monitor used for adjusting camera angles during the installation process. Four cameras were attached to the external metal mesh of the skidder cab and were positioned to capture views on both sides of the machine, as well as the front and back (Fig. 2). To minimize obstructions in the operator's field of view, cables connecting cameras to the DVR were routed along the cab corners to a padded plastic box that was placed behind the operator's seat. The plastic box contained the DVR and the inverter, from which a connection was run to the battery enclosure outside the cab behind the operator. Prior to installation, in the desktop user interface the system was setup to record when power was available.

2.2. Skid-trail and loads description

We selected an existing 1.1 km constructed skid-trail at the University of Kentucky's Robinson Forest (37°28′23″N - 83°08′36″W), with elevation ranging from 419 to 465 m.a.s.l. laid out in an area with 45% average terrain slope (Fig. 3). We surveyed the skid-trail by measuring horizontal distance and gradient between 21 flags. Flags were placed at changes in gradient and/or direction along the skid-trail to examine the effect of skid-trail gradient on skidding travel time. Five logs of varying weight were used for the test (Table 1). These logs were cut two days before skidding near the existing skid-trail and their weight was estimated based on their dimensions and species using Timson (1972) study. In order to use the same logs for consecutive turn cycles and minimize unused time, a skidding cycle was defined as an empty trip from the landing (flag 1 in Fig. 3) along the looped skid-trail and back, followed by the loaded trip along the looped skid-trail. Skidding cycles were conducted with different load sizes starting with one cycle with five logs totaling 9.68 tons, followed by five cycles with four logs (7.59 tons), and five cycles with three logs (5.22 tons). The eleven cycles were determined as sufficient for evaluating the potential for security video systems to measure cycle times and the work tasks and variables that can affect cycle time.

2.3. Time consumption

The time stamped video-feed from the four cameras was visually inspected in the camera systems desktop user interface to measure time consumption for each work task with a precision of one second. We defined six work tasks and two delay elements for skidding cycles (Table 2). Time consumption for traveling unloaded and loaded was also recorded for each skid-trail segment. A segment was defined as the distance between successive flags (Fig. 3), and time consumption was measured when the flag was captured in either side camera. Fig. 4 shows the view from the four cameras and the moment when a flag comes into view on a side camera. Lastly, total cycle times were used to calculate skidder productivity in terms of scheduled machine hour, which considered delays, and productive machine hours, which omitted delays.

3. Results

The installation of the camera system, which ensures the positioning of the four cameras facilitated the identification of work tasks, required approximately 30 min. The skidder operator initiated recording with the inverters on/off switch. The camera system was able to continuously record uninterrupted video of the eleven skidding cycles totaling 7.83 h (7 h 49 min 29 s). Reviewing the video manually to identify individual work tasks and measure time consumption as well as measure travel time by skid-trail segment required 14.6 h.

Although the skidder's maximum drawbar pull at peak torque for first gear is almost 15 tons (Simonson and Horcher, 2002), the skidder was not able to pull the five-log load (9.68 ton) at flag 14 (Fig. 3). This was likely due to a combination of factors, including the presence of a sharp turn on the skid-trail, wet soils conditions, steep skid-trail gradient, and relatively low velocity, all of which resulted in tire slippage and halted the skidders forward movement. One of the logs was unhooked and the four remaining logs (7.59 ton) were used to complete the cycle. The four-log load was used for the next five cycles. During cycle six, a log slid off the skid-trail at Flag 4 and had to be unhooked. The skidder then continued with three logs (5.22 ton) and picked up the unhooked log