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NOTE

A Flexible, Low-Cost Cart for Proximal Sensing

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ABSTRACT

Increasing interest in deploying multiple types of sensing instruments for agricultural plot-level observations has created a need for simple, high-clearance vehicles that can be easily maneuvered through crops while minimizing damage due to wheel traffic. We describe a simple cart built from a 2-m-wide by 1.2-m-long steel frame that was welded onto two bicycle frames at a height providing 1 m of vertical clearance. Instruments such as radiometers and infrared thermometers are attached to the frame via arms that are secured with U-bolts. A large, horizontal surface allows mounting data loggers, batteries, or computers. The cart is easily maneuvered by one person on level ground or by two persons on terrain with furrows, berms, or other obstacles. Design sketches and lists of materials are provided in an electronic supplement. The basic design is readily modifiable for different interrow spacings and sensor positions.

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Abbreviations: PSC, proximal sensing cart; SAE, Society of Automotive Engineers.

There is widespread interest in using electronic sensors and imaging tools to characterize crop growth and development, including responses to water deficits, heat stress, and nutrient deficits. Advances in instrument design and the realization that combining data from different instruments can increase the utility of a given dataset have led to a need for deploying instruments rapidly and consistently within research field plots (e.g., Munns et al., 2010; Furbank and Tester, 2011; White et al., 2012). Because the distance from the instruments to the crop surface is much shorter than in aerial or satellite remote sensing, this type of monitoring is best termed “proximal sensing” (Fussell et al., 1986). Various means for conveying instruments include push carts (Ruixiu et al., 1989), tractors (Rundquist et al., 2004; Andrade-Sanchez et al., 2012; Comar et al., 2012), and aerostats (Ritchie et al., 2010). For field spectroscopy, Milton (1987) emphasized the need to maintain radiometers at least 1 m above the canopy and to use a constant view geometry.

This technical note describes a simple proximal sensing cart (PSC) and associated instrument mounting system. The design reflects multiple criteria to make the cart suitable for crop research.

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Figure 1. View of the proximal sensing cart in a field of camelina. The cart was configured to carry two monochrome cameras and three infrared thermometers, the latter being positioned to provide forward, downward, and backward view angles.

A first consideration was that the cart should allow positioning individual instruments at different heights and lateral positions relative to centerlines of row crops. The second criterion was that assembly of the PSC should require only basic metal working skills (cutting, grinding, drilling, and welding) and use readily available materials. A third concern was that the cart should have an open frame so as to minimize effects of reflecting surfaces and shadows. The cart should also provide a surface for securing computers, data loggers, batteries, or other equipment.

CONSTRUCTION OF THE CART

The basic PSC consists of a rectangular frame welded onto two bicycle frames (Fig. 1). The frame measures approximately 200 by 115 cm and is constructed of 3.2 by 3.2 cm square steel tubing. The front of the frame consists of a 48 by 42 by 200 cm cage, which serves as the base for the instrument supports. The area behind the cage is partially covered with plywood to provide surfaces for mounting data loggers, battery packs, or other equipment.

The frame is attached to each bicycle via two supports, whose lengths were selected to provide 1 m of clearance between the frame and ground level. These joints receive more strain than other parts of the cart and are reinforced with T-shaped plates welded over the square and round (bicycle) tubing. The head angle, rake, and trail geometry of steering in bicycles is such that the steerable (front) wheels do not track the fixed wheels (i.e., as occurs with casters): regardless of direction of travel, the unrestrained wheels will turn sideways against the intended route. Therefore, the steerable wheels were welded in place allowing the PSC to travel in a straight line.

We made two types of instrument supports from 3.18 by 3.18 mm steel tubing. L-shaped arms can be used in a normal or inverted position and are anchored to the front or rear two crossbars (Fig. 2A). Straight or offset arms are supported from either the upper or lower pairs of crossbars (Fig. 2B). Variations in height of the straight or offset arms are obtained by mounting the arms either above or below the support and, in the case of the offset arm, by inverting the arm and/or mounting it on the upper or lower faces of the frame crossbars. All supports are fastened to the frame using pairs of square-end U-bolts that pass through a square four-hole bracket plate (Fig. 2C). Fine adjustments in positioning, especially to level sensors, are attained using shims made of hard sheet rubber or wood.

Instruments are mounted on short stubs (e.g., 15 cm long) of 2.86 cm square tubing that insert into the main support arms and are secured by two 6.4 by 50.8 mm bolts (Fig. 2D). To accommodate the mounting requirements of

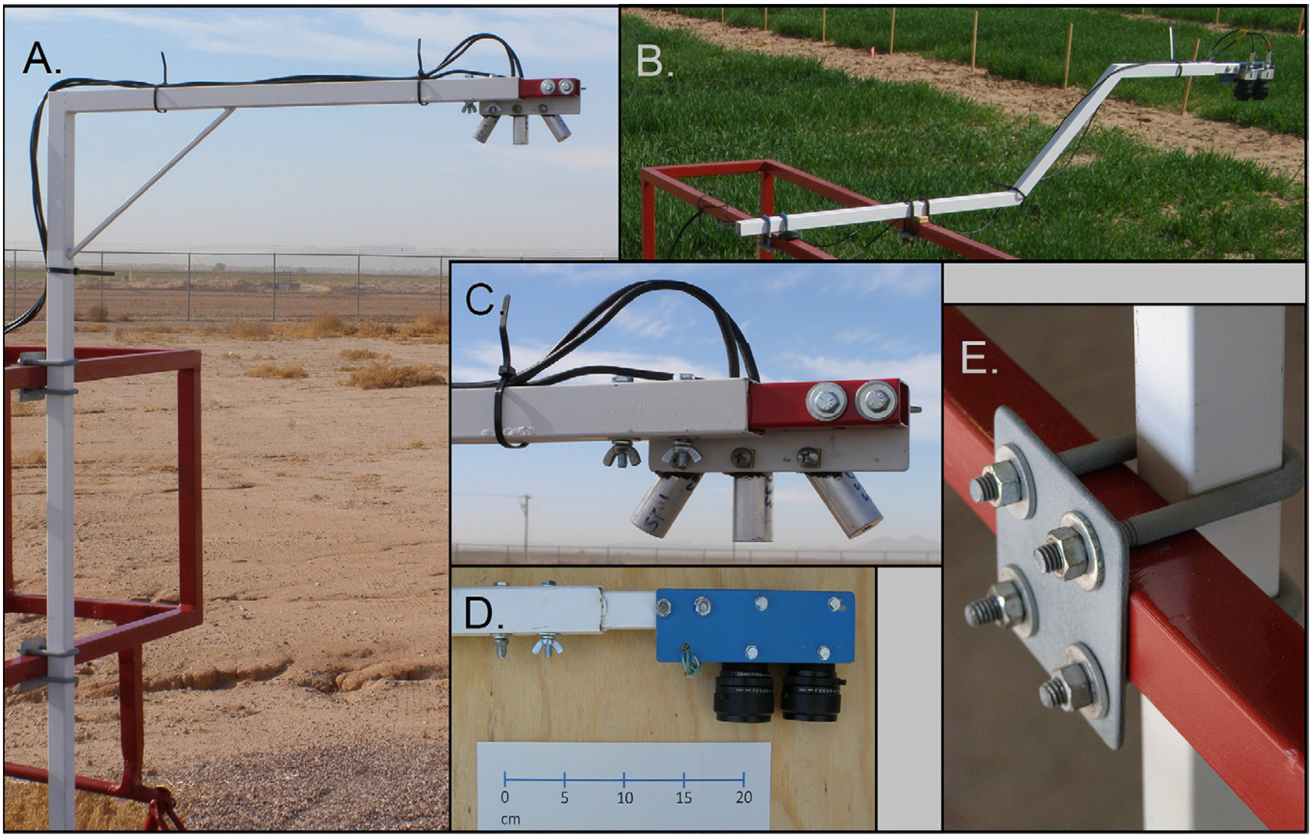

Figure 2. Examples of instrument mounting on the proximal sensing cart. A. L-shaped arm with three infrared thermometers. B. Offset arm with two digital cameras. C. Detail of support carrying infrared thermometers. D. Detail of support carrying digital cameras. E. U-bolt and plate assembly used to fasten the L-shaped arm to one of the horizontal frame members.

specific instrument housings, mounting plates are bolted or welded to the short stub sections of the smaller tubing.

Supplemental File S1 provides 1:24 sketches of the cart in English and SI units. A list of parts is also provided with additional notes on construction.

APPRAISAL OF THE CART

With two instrument support arms, our PSC weighs 40 kg. A single person can push the cart through a leveled field, including turning the cart by lifting the rear wheels and pivoting. For fields with furrows or irrigation berms, two people were used to avoid putting excessive strain on the cart while crossing irregular terrain. To follow a zigzag path through a series of field plots, we found that rather than turning the cart 180°, it was better to alternate pushing the cart forward and pulling it backward. This also conserved the position of the sensors relative to the sun and reduced time spent turning the cart. The cart has been used to deploy paired monochrome cameras, ultrasonic proximity sensors, infrared thermometers, and radiometers. A global positioning system (GPS) receiver is used to track the path of travel, allowing sensor data and images to be georeferenced and thus linked to individual plots. Data was logged primarily using CR1000 and CR3000 data loggers (Campbell Scientific, Inc.) at 1 and 5 Hz.

The PSC has been used in experiments involving winter cereals {bread wheat (*Triticum aestivum* L.), durum wheat [*Triticum turgidum* L. subsp. *durum* (Desf.) Husn.], and barley (*Hordeum vulgare* L.)}, camelina [*Camelina sativa* (L.) Crantz], and upland cotton (*Gossypium hirsutum* L.). The cereal and camelina studies used 20 cm interrow spacings. Minor difficulties were encountered in avoiding damage to border rows, and near maturity, plots with lodging were very difficult to navigate through. All wheats had a semidwarf habit and were short enough to allow the cart to pass over plots, but a two-row forage barley grew to over 1.2 m tall, which exceeded the 1 m clearance of the PSC. In a trial with 16 strips measuring 100 m each, a sensing run with no stops took approximately 75 min (including time to move from one strip to another), equivalent to an average speed of approximately 0.36 m s^{-1}. The cotton plots had a 1-m interrow spacing, and the cart was easily moved down the furrows. Readings were terminated when the cotton canopy was slightly taller than the PSC clearance. Overall, we suggest a minimum track width of 30 cm (distance between rows of plants) be provided.

The basic cart design is readily modified for different interrow spacings or to carry a boom that extends laterally over crops. Use of either telescoping or interchangeable cross-bracing would allow reconfiguration for different row spacings. Vertical clearance could be increased by raising

Table 1. Comparison of hand-held, cart, and tractor-based proximal sensing.

Characteristic	Hand-held	Cart	Tractor
Initial cost	Low	Low	High
Cost of operation	Moderate	Moderate	Moderate
Ease of maneuvering within field trials	High	Moderate	Low
Ease of maintaining a precise sensor height	Moderate	High	High
Ease of simultaneously deploying multiple sensors	Low	High	High
Ease of simultaneously deploying multiple sets of sensors over different rows	Low	Moderate	High
Ease of stop-and-go operation	High	High	Moderate
Maximum clearance	High	Moderate	Moderate
Risk of person or vehicle interfering with reflectance or thermometric sensor readings	Low	Low	Moderate
Risk of soil compaction	Low	Low	Moderate
Risk of damage to plants in a closed canopy	Low	Moderate	High
Ease of adjustment for different row spacings	High	Medium	Low
Ease of transport	High	Medium	Low

the cross braces and reinforcing the frame with diagonal bracing to reduce lateral flexing of the frame. Batteries and data loggers could be mounted low on the lateral frames to still allow access while lowering the center of gravity.

Various options could reduce the cart weight. For a narrower cart, smaller, lighter tubing could be used. Ruixiu et al. (1989) provide a diagram of a narrow, three-wheeled cart, and eliminating one wheel would further reduce weight, albeit also decreasing stability. Aircraft steel ("chromoly" or Society of Automotive Engineers [SAE] 4130) is stronger than the SAE 1040 steel we used, allowing use of thinner-walled tubing. Aluminum is lighter than steel but weaker, requiring use of thicker tubing (possibly partially negating potential weight savings). Other options would be to use round tubing and, possibly, thinner-walled tubing combined with more extensive diagonal bracing and reinforced joints. The various options merit consideration but transition PSC construction toward a more complex and costly process. Notably, aircraft steel and aluminum are more difficult to weld than SAE 1040 steel.

Mobility might be improved further if the cart had smaller rear wheels that pivoted like casters. In that case, the use of bicycle frames might provide no advantage in facilitating construction.

We transport the PSC on a light-weight trailer readily pulled by a pickup truck. A summary comparison of hand-held, cart, and tractor-based sensing is provided in Table 1.

Supplemental Information Available

Supplemental material is available at http://www.crops.org/publications/cs.

Supplemental File S1. Includes 1:24 scale sketches of the cart in English and SI units, a list of parts, and additional photos of the cart in use in the field.

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