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Daniel R. Unger
Arthur Temple College of Forestry and Agriculture, Stephen F. Austin State University, unger@sfasu.edu

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Daniel R. Unger[1]

[1] Arthur Temple College of Forestry and Agriculture, Stephen F. Austin State University, Nacogdoches, Texas, USA

Correspondence: Daniel R. Unger, Arthur Temple College of Forestry and Agriculture, Stephen F. Austin State University, Nacogdoches, Texas, 75962, USA. Tel: 1-936-468-2234. E-mail: unger@sfasu.edu

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Abstract

Undergraduate students pursuing a Bachelor of Science in Forestry (BSF) at Stephen F. Austin State University (SFA) attend an intensive 6-week residential hands-on instruction in applied field methods. The intensive 6-week instruction includes learning how to use the Global Positioning System (GPS) with a Garmin eTrex HCx GPS unit to accurately calculate area. Students were instructed how to assess the accuracy of their GPS collected waypoints by calculating the Root Mean Square Error (RMSE) comparing their GPS collected area measurements with instructor on-screen digitized area. Student's average area RMSE between digitized and GPS derived area was 0.015 hectares, whereas instructor's average area RMSE between digitized and GPS derived area was 0.015 hectares. Over 76% of students measured GPS area was within 5% of instructor on-screen digitized area. No difference between the students and instructors area RMSE of 0.015 hectares and high level of agreement between student measured GPS area and instructor on-screen digitized area: (1) indicates students receiving hands-on instruction in GPS applications can record accurate area measurements after only a limited 2 hour introduction; (2) the accuracy of the Garmin eTrex HCx GPS unit is not user dependent; and, (3) validates the interactive hands-on instruction methodology employed at SFA.

Keywords: accuracy, GPS, user, forest, RMSE

1. Introduction

Undergraduate students pursuing a Bachelor of Science in Forestry (BSF) degree within the Arthur Temple College of Forestry and Agriculture (ATCOFA) at Stephen F. Austin State University (SFA), Nacogdoches, Texas, focus on the management of natural resources from a multidisciplinary perspective. Students pursuing the BSF degree at ATCOFA include forestry, wildlife, and recreation majors. The mission of the BSF program within ATCOFA is to maintain excellence in teaching, research and outreach to enhance the health and vitality of the environment through sustainable management, conservation, and protection of natural resources. Students who decide to attend ATCOFA do so because they have chosen to pursue a career path based on three main items of concern where they can: make a difference, work outdoors, and use high end technology. To facilitate their career objectives undergraduate coursework within ATCOFA focuses on hands-on instruction, field exercises, and real-world applications. All students attend an off-campus residential 6-week hands-on intensive summer forestry field station in applied field methods focused on real-world applications

For students pursuing the BSF degree within ATCOFA knowing how to use a Global Positioning System (GPS) unit to derive the area of a specific site is crucial to the understanding and proper management of any natural resource. GPS is a satellite based navigation system that allows the user to identify the exact location of an object on the surface of the earth 24 hours a day in all weather conditions (Thurston, Poiker, & Moore, 2003). Surface objects are collected and categorized by their surface feature and represent either a point (e.g., tree, weather station, etc.), line (e.g., stream, river, hiking trail, etc.), or polygon (e.g., lake, clearccut, etc.) (Clarke, 2003; Heit & Shortreid, 1991; Lang, 1988). With the collection of a surface feature's location via GPS technology the exact area of a polygon can be extracted.

At field station students are trained on a consumer-grade GPS unit, the Garmin eTrex HCx (Garmin International Inc., Olathe, Kansas, USA), and representative of the type of GPS unit typically used by practicing natural resource managers within a forest environment. The use of a GPS unit in a forest environment presents many challenges (forest canopy blocks and degrades satellite signals and tree structure introduces multipath error) which the field station students are introduced to before collecting data in the field. Sigrist, Coppin, and Hermy (1999) found that canopy has a definite effect on horizontal and vertical positional accuracy and the relation appeared to be exponential; a small increase in canopy density resulted in a substantial increase in error. Yoshimura and Hasegawa (2006, 2003) found that horizontal positional accuracy and precision errors were highest in areas of dense canopy cover and lowest in areas of sparse canopy cover. Wing, Eklund, and Kellogg (2005) found that consumer-grade GPS receivers were accurate within 5 meters under open sky, 7 meters under young canopy, and within 10 meters under closed canopy in western Oregon. A study by Bolstad, Jenks, Berkin, Horne, and Reading (2005) confirmed those results with average errors of 6.5 and 7.1 meters under heavy forest canopy in Minnesota.

The first commercially available GPS unit, the Texas Instruments TI-411, was introduced in 1982. This GPS unit was barely portable, weighing 53 pounds and measuring 14.7” x 7.5” x 8.5”. The hardware retailed for $119 000 and post processing hardware and software cost another $19 000. The GPS unit was capable of tracking four satellites at a time and was theoretically accurate to 14 meters; when differentially corrected, it could be accurate to 2-5 meters. In 1989, Magellan introduced the world’s first consumer GPS unit, the NAV 1000. A rather large GPS unit by today’s standards, it measured 7.5” x 2.5” x 2” and weighed almost two pounds. It was a single channel receiver, capable of tracking only four satellites, was accurate to 30-45 meters, and cost nearly $2500. By comparison, the Garmin eTrex HCx released in 2006 measures 2.2” x 1.2”x 4.2”, weighs 5.4 ounces, is a 12 channel receiver and has a stated accuracy of less than 5 meters (Garmin, 2009).

Great strides have been made, and continue to be made, in the area of affordable consumer-grade GPS units. Advances in storage capacity, processing power, and display resolution have exponentially increased the power and capabilities of these devices. While sub-meter mapping grade and centimeter-level survey grade GPS devices are available for use in forest applications, they can be cost prohibitive, especially for many smaller companies. With the ability of many consumer-grade GPS units to incorporate real time SBAS (Satellite Based Augmentation System) signals such as WAAS (Wide Area Augmentation System), the opportunities for the use of such devices in forestry present themselves. Piedallu and Gegout (2005) tested three mapping grade and one consumer-grade GPS units and found that denser cover and bigger diameter stems caused a deterioration of accuracy. Zheng, Wang, and Nihan (2005) evaluated the static performance of a mapping grade GPS unit under three different canopy closure levels in the Pacific Northwest and found that canopy density can significantly affect the positional accuracy of GPS receivers at the $p = 0.01$ level. Rodriguez-Perez, Alvarex, and Sanz-Ablanedo (2007) evaluated four consumer-grade GPS receivers and indicated difference under varying forest canopy cover and found significant differences between the models.

2. Methods

At field station students were trained on a consumer-grade GPS unit, the Garmin eTrex HCx, representative of the type of GPS unit typically used by practicing natural resource managers. Field station is located at the Piney Woods Conservation Center (PWCC), a residential conservation center located adjacent to the Angelina National Forest on the shores of Sam Rayburn Reservoir approximately 15 miles south of Broaddus, Texas (Figure 1). PWCC can accommodate 128 people with sleeping quarters arranged in suites, two rooms sharing one bathroom. Two dining rooms are located at the lodge area, one seat 150 people; the other seats 70. Four meeting rooms are available for traditional academic instruction prior to taking the students outside for hands-on field applications.

Prior to going in the field to collect real-world area measurements with the Garmin eTrex HCx, students were instructed in a central classroom for 1 hour via traditional academic classroom instruction on basic GPS theory and how to use their Garmin eTrex HCx. Students were also instructed how to enable their GPS unit via WAAS to ensure that their GPS unit would collect data with real time correction. Once the GPS units were configured to be WAAS enabled the students were taken to the island in the central portion of PWCC to receive one-on-one faculty instruction on how to collect a waypoint (Figure 2).

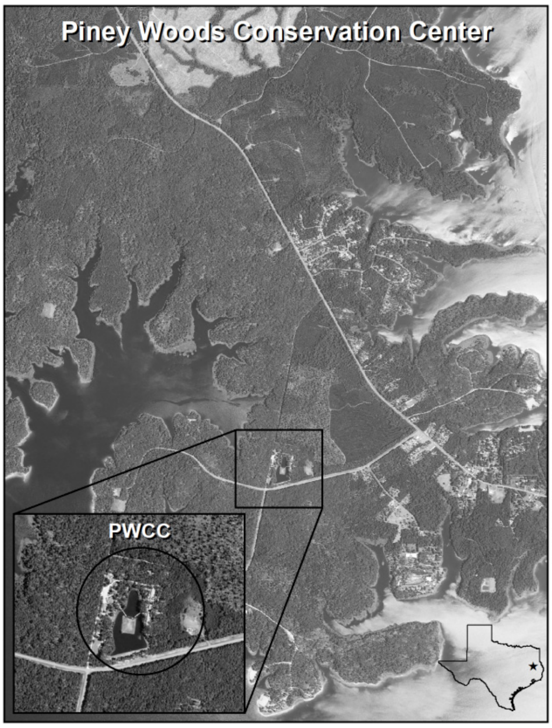

Figure 1. Location of Piney Woods Conservation Center adjacent to the Angelina National Forest

Figure 2. One-on-one faculty GPS instruction on the island at Piney Woods Conservation Center

A waypoint records the GPS derived real-world coordinates representing the actual location of each GPS unit. Students were also instructed how to collect waypoint location data in the UTM (Universal Transverse Mercator) coordinate system, the typical coordinate system required by most natural resource based entities. The island is the preferred place within PWCC for outside hands-on GPS instruction and represents a typical forest opening. The island provides a full view of the sky thereby minimizing multipath error making the initial introduction to students on how to use a GPS unit more effective (Figure 3).

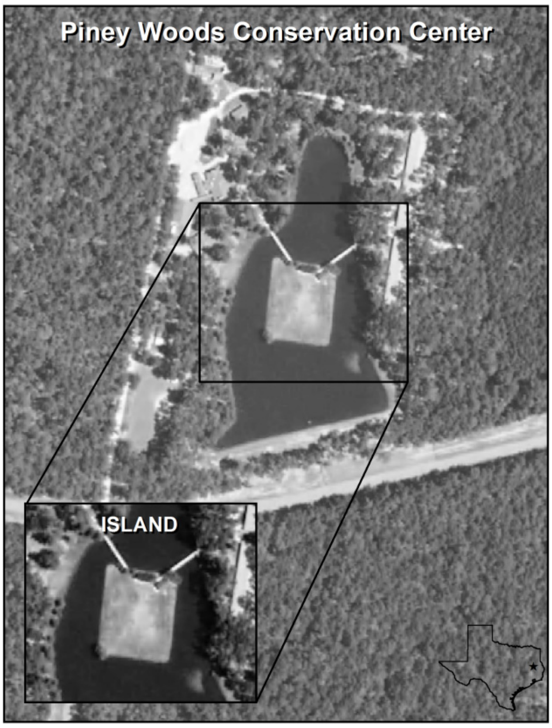

Figure 3. Island at Piney Woods Conservation Center used for GPS area measurements

Following waypoint data instruction, students then received one-on-one faculty instruction on how to use their GPS unit to interactively quantify area via a sequence of collected waypoints. Students were instructed how to identify a starting point for a GPS recorded track and asked to walk the perimeter of the island while receiving verbal instruction on how to save the island perimeter as a track resulting in an interactive calculation of area in the users preferred unit of measure (Figure 4).

Each student was supplied with their own GPS unit as it is imperative that each student performs the task individually to increase the effectiveness of their hands-on field training. Thirty students performed an area measurement of the island with no replications while an instructor with 17 years of experience in the spatial sciences performed an area measurement of the same island with a replication of 30 times for an evaluation of student accuracy and student-instructor accuracy comparison. The actual area of the island in hectares (mean = 0.323 ha, standard deviation = 0.006 ha, 10 replications) was derived by the instructor through on-screen digitization with ArcMap 10.0 (ESRI, Redlands, California, USA) using high spatial resolution digital imagery at 1.0 meters resolution as a backdrop (Table 1).

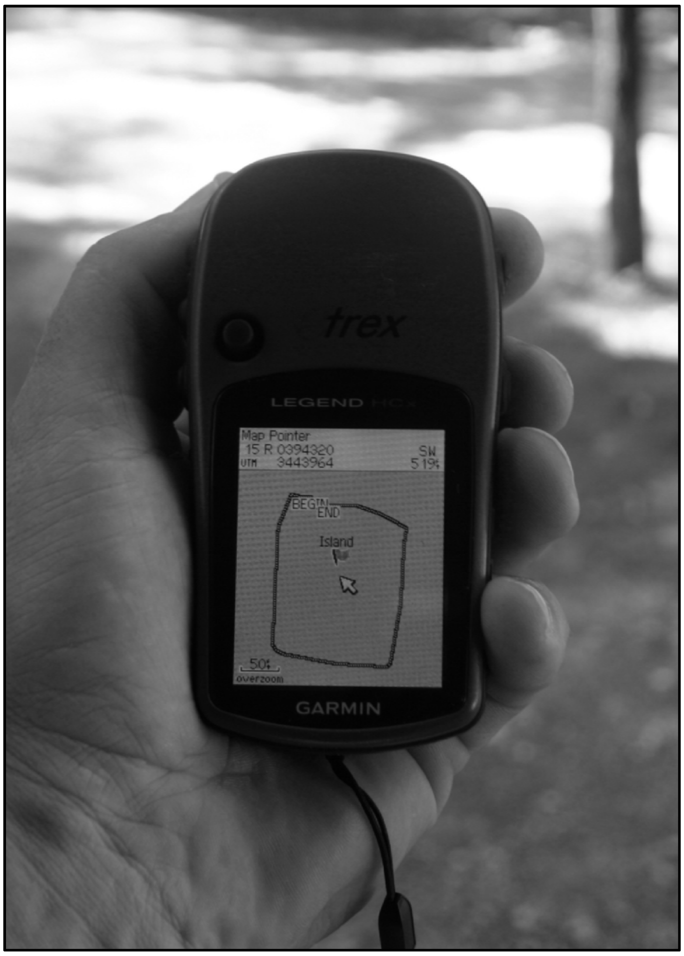

Figure 4. GPS recorded track on Garmin eTrex HCx GPS unit

Table 1. Instructor on-screen digitized area of the island in hectares for 10 replications

Replication	Island Area (hectares)
1	0.316
2	0.320
3	0.330
4	0.314
5	0.332
6	0.330
7	0.321
8	0.324
9	0.317
10	0.323
Mean	**0.323**
Standard Deviation	**0.006**

The accuracy of the student area measurements and the accuracy of the instructor area measurementswere assessed by calculating RMSEbetween each GPS measured area with on-screen digitized arearespectively (Equation 1). The student area RMSE was then compared to the instructor area RMSE for accuracy assessment.

$$RMSE = \sqrt{\frac{\Sigma\left(x_{Digitization} - x_{GPS\ Unit}\right)^2}{n}} \quad (1)$$

RMSE was utilized so the students could evaluate and quantify the effectiveness of their ability to acquire accurate real-world area measurements. An RMSE analysis was also used to assess if the accuracy of GPS derived area assessments is user dependent. Percent agreement between student measured GPS island area and instructor on-screen digitized island area was analyzed to evaluate the effectiveness of the one-on-one faculty instruction methodology.

3. Results and Conclusion

A summary of area errors by students and instructor can be found in Tables 2a and 2b. Area RMSE, a measure of the difference between GPS derived area and instructor digitized area, was 0.015 hectares for both the students and instructor respectively. Although the students and instructor GPS derived island area varied per observation resulting in observable area differences, absolute area differences and squared area differences per observation, calculated area RMSE was identical for students and instructor with a sample size of 30. The results indicate that although students and instructor measured GPS island area varied per observation, identical area RMSE between students and instructor validated hands-on instruction methodology when using consumer-grade GPS units for natural resource area measurement employed by ATCOFA faculty at SFA. No difference between the students and instructors area RMSE of 0.015 hectares respectively indicates that students receiving hands-on instruction in GPS applications can record accurate area assessments after only a limited 2 hour introduction to a consumer-grade GPS unit and that the accuracy of GPS derived area measurement using the Garmin eTrex HCx GPS unit, which is representative of the type of GPS unit used by a practicing forester, is not user dependent.

A summary of percent agreement between student measured GPS island area and instructor on-screen digitized island area can be found in Table 3. Student GPS derived island area measurements for 11 of 30 students (36.7%), 23 of 30 students (76.7%), and 29 of 30 students (96.7%) was within 97.5%, 95%, and 90% agreement with instructor on-screen digitized island area respectively. The high level of agreement between student measured island area and instructor on-screen digitized island area validates the interactive hands-on instructor methodology employed within ATCOFA.

Field forestry supervisors can have confidence that when hiring recent BSF graduates from a certified Society of American Foresters degree program such as ATCOFA that students have been introduced to geospatial technologies within a proven one-on-one instruction methodology designed to increase cognitive retention and can accurately record the area of a surface feature without concern for user dependent accuracy.

Table 2a. Student and instructor measured GPS island area and difference between student and instructor GPS island area and instructor on-screen digitized island area

Observation	Area Actual (hectares)	Area Student (hectares)	Area Instructor (hectares)	Difference Student (hectares)	Difference Instructor (hectares)
1	0.323	0.317	0.278	0.006	0.045
2	0.323	0.313	0.315	0.010	0.008
3	0.323	0.316	0.313	0.007	0.010
4	0.323	0.324	0.325	-0.002	-0.002
5	0.323	0.293	0.311	0.030	0.011
6	0.323	0.344	0.293	-0.021	0.030
7	0.323	0.324	0.297	-0.001	0.026
8	0.323	0.336	0.304	-0.013	0.019
9	0.323	0.334	0.333	-0.011	-0.011

10	0.323	0.300	0.332	0.022	-0.010
11	0.323	0.332	0.297	-0.009	0.026
12	0.323	0.328	0.317	-0.005	0.005
13	0.323	0.313	0.316	0.010	0.006
14	0.323	0.328	0.317	-0.005	0.006
15	0.323	0.332	0.317	-0.010	0.006
16	0.323	0.336	0.337	-0.013	-0.014
17	0.323	0.327	0.338	-0.004	-0.015
18	0.323	0.313	0.343	0.010	-0.020
19	0.323	0.304	0.329	0.019	-0.006
20	0.323	0.291	0.319	0.032	0.004
21	0.323	0.304	0.335	0.018	-0.013
22	0.323	0.332	0.323	-0.010	-0.001
23	0.323	0.324	0.317	-0.002	0.006
24	0.323	0.323	0.313	-0.001	0.010
25	0.323	0.288	0.314	0.034	0.009
26	0.323	0.317	0.336	0.006	-0.013
27	0.323	0.333	0.324	-0.010	-0.001
28	0.323	0.313	0.317	0.010	0.006
29	0.323	0.316	0.319	0.006	0.004
30	0.323	0.309	0.332	0.014	-0.009
			Mean	**0.004**	**0.004**
			SD	**0.014**	**0.015**

Table 2b. Absolute difference between student and instructor measured GPS island area and instructor on-screen digitized island area, squared difference between student and instructor measured GPS island area and instructor on-screen digitized island area, and RMSE for student and instructor measured island area

Observation	**Absolute Difference Student (hectares)**	**Absolute Difference Instructor (hectares)**	**Squared Difference Student (hectares)**	**Squared Difference Instructor (hectares)**
1	0.006	0.045	0.000	0.002
2	0.010	0.008	0.000	0.000
3	0.007	0.010	0.000	0.000
4	0.002	0.002	0.000	0.000
5	0.030	0.011	0.001	0.000
6	0.021	0.030	0.000	0.001
7	0.001	0.026	0.000	0.001
8	0.013	0.019	0.000	0.000
9	0.011	0.011	0.000	0.000
10	0.022	0.010	0.000	0.000
11	0.009	0.026	0.000	0.001
12	0.005	0.005	0.000	0.000

13	0.010	0.006	0.000	0.000
14	0.005	0.006	0.000	0.000
15	0.010	0.006	0.000	0.000
16	0.013	0.014	0.000	0.000
17	0.004	0.015	0.000	0.000
18	0.010	0.020	0.000	0.000
19	0.019	0.006	0.000	0.000
20	0.032	0.004	0.001	0.000
21	0.018	0.013	0.000	0.000
22	0.010	0.001	0.000	0.000
23	0.002	0.006	0.000	0.000
24	0.001	0.010	0.000	0.000
25	0.034	0.009	0.001	0.000
26	0.006	0.013	0.000	0.000
27	0.010	0.001	0.000	0.000
28	0.010	0.006	0.000	0.000
29	0.006	0.004	0.000	0.000
30	0.014	0.009	0.000	0.000
Mean	**0.012**	**0.012**	0.000	0.000
SD	**0.009**	**0.010**	**0.015**	**0.015**
	Absolute Error	**Absolute Error**	**RMSE**	**RMSE**

Table 3. Percent agreement between student measured GPS island area and instructor on-screen digitized island area stratified by number of students and percent of class

Agreement	**GPS Exercise**	
(percent)	**(number of students)**	**(percent of class)**
≥ 97.5	11	36.7
≥ 95.0	12	40.0
≥ 92.5	4	13.3
≥ 90.0	2	6.7
≥ 87.5	1	3.3

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