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Remote sensing applications in precision farming for mapping research farm boundaries

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Abstract
The development and implementation of precision farming have been made possible by combining the Global Positioning System (GPS) and Geographical Information System (GIS). A field study was carried out to measure the research area of the Department of Farm Machinery and Power Engineering at Punjab Agricultural University, Ludhiana, with the help of two GPS modules for collecting more precise data and comparing it with the ground truth data measured by measuring tape. Out of measuring the area of 15 plots by two GPS systems, ± 5% variation as compared to the actual ground truth measurements was observed in nine fields. The variation of 5-20% was observed due to measuring a very small area by the GPS and more variations were observed due to the interruptions in network signals near the wall side area, trees on boundaries, and farm structure. It can be concluded from the present study that variation in measuring the area of a particular field will be less for measuring more area having less interruption of buildings, trees, etc. so that the GPS may catch more number of satellite signals.

Keywords: Precision farming, farm boundaries, sensing applications

Introduction

The increasing complexity of the world, pressure on natural resources, degradation of the environment, and the security of citizens require maps to display a wide range of information. Precision farming (PF) empowers the coupling of real-time data collection with accurate position information, leading to the efficient handling and study of large amounts of geospatial data. GPS-based applications in PF are being used for planning, field mapping, soil sampling, tractor guidance, crop scouting, variable rate applications of herbicides/ pesticides/ fertilizers, and yield monitoring (Chekole, 2014) [2]. GPS also allows farmers to work in less visibility conditions and adverse weather *viz*. rain, dust, fog, and darkness. It is also beneficial for accurate navigation for specific locations in the field, year after year to collect soil samples or monitor crop conditions (Ajai, 2002) [1].

GPS equipment manufacturers have developed several tools to help farmers and agribusiness entrepreneurs make more productive and efficient results in their precision farming activities. The accuracy of GPS devices allows farmers to create maps with precision for field areas, road locations, and distances between points of interest (Heywood *et al.* 2006) [3].

The global positioning system is an earth-orbiting Satellite based system that provides signals anywhere on or above the earth, 24 hours a day, around the year, irrespective of weather, and that can be used to determine the precise time and the position of a GPS receiver in three dimensions. GPS together with a coordinate system and GIS produces a map and the map facilitates navigation (Tyler, 2002) [8].

Key features of GPS

1. The basis of GPS is triangulation more precisely trilateration from satellites
2. A GPS receiver measures distance using the travel time of radio signals.
3. To measure travel time GPS needs very accurate timing which is achieved with some techniques.
4. Along with distance, one needs to know exactly where the satellites are in space.
5. Finally, one must correct for any delays, the signal experience as it travels through the atmosphere.

GPS Elements

GPS has 3 parts: the space segment, the user segment, and the control segment. The space segment consists of a constellation of 24 satellites, each in its orbit, which is 11,000 nautical miles above the Earth (Yoshimura and Hasegawa, 2003) [7]. The user segment consists of receivers, which can be held in hand or mounted in the vehicle. The control segment consists of ground stations (six of them, located around the world) that make sure the satellites are working properly as shown in Fig. 1.

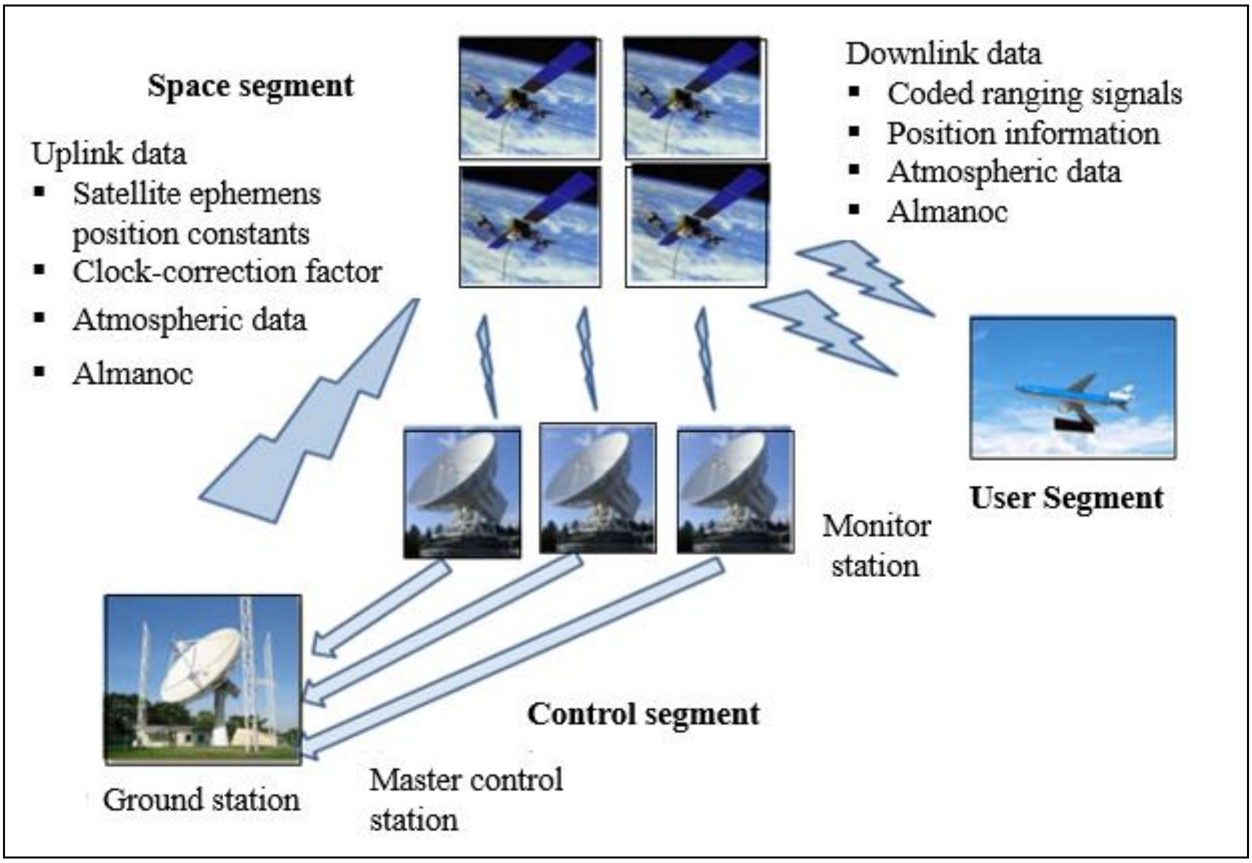

Fig 1: Space and control segments

Differential GPS (DGPS)

The basic idea is to locate one or more reference GPS receivers at known locations in user's "vicinities and calibrate ranging errors as they occur. These errors are transmitted to the users in near real-time. The errors are highly correlated across tens of kilometers and many minutes. The use of such corrections can greatly improve accuracy and integrity. To increase the accuracy of positioning, Differential-GPS (D-GPS) was introduced. The idea is as follows: a reference station is located at a known and accurately surveyed point (Mark *et al.* 1999) [4]. The GPS reference station determines its GPS position using four or more satellites. Given that the position of the GPS reference station is exactly known, the deviation of the measured position to the actual position and more importantly the measured pseudo range to each of the individual satellites can be calculated. The differences are either transmitted immediately by radio or used afterward for correction after carrying out the measurements.

GPS error sources

Satellite clock

GPS position calculations, as discussed above, depend on measuring signal transmission time from satellite to receiver; this, in turn, depends on knowing the time on both ends. NAVSTAR satellites use atomic clocks, which are very accurate but can drift up to a millisecond (enough to make an accuracy difference). These errors are minimized by calculating clock corrections (at monitoring stations) and transmitting the corrections along with the GPS signal to appropriately outfitted GPS receivers (Sigrist *et al.* 1999) [5].

Upper atmosphere (ionosphere)

As GPS signals pass through the upper atmosphere (the ionosphere 50-1000km above the surface), signals are delayed and deflected. The ionosphere density varies; thus, signals are delayed more in some places than others. The delay also depends on how close the satellite is to being overhead (where the distance that the signal travels through the ionosphere is the least). By modeling ionosphere characteristics, GPS monitoring stations can calculate and transmit corrections to the satellites, which in turn pass these corrections along to receivers. Only about three-quarters of the bias can be removed, however, leaving the ionosphere as the second largest contributor to the GPS error budget.

Receiver clock

GPS receivers are equipped with quartz crystal clocks that are less stable than the atomic clocks used in NAVSTAR satellites. Receiver clock error can be eliminated, however, by comparing the times of arrival of signals from two satellites (whose transmission times are known exactly).

Satellite orbit

GPS receivers calculate coordinates relative to the known locations of satellites in space, a complex task that involves knowing the shapes of satellite orbits as well as their velocities, neither of which is constant. The GPS Control Segment monitors satellite locations at all times, calculates orbit eccentricities, and compiles these deviations in documents called ephemerides. An ephemeris is compiled for each satellite and broadcast with the satellite signal. GPS receivers that can process ephemerides can compensate for some orbital errors.

Lower atmosphere

The three lower layers of the atmosphere (troposphere, tropopause, and stratosphere) extend from the Earth's surface to an altitude of about 50 km. The lower atmosphere delays GPS signals, adding slightly to the calculated distances between satellites and receivers. Signals from satellites close to the horizon are delayed the most since they pass through the most atmosphere.

Multipath

Ideally, GPS signals travel from satellites through the atmosphere directly to GPS receivers. In reality, GPS receivers must discriminate between signals received directly from satellites and other signals that have been reflected from surrounding objects, such as buildings, trees, and even the ground. Antennas are designed to minimize interference from signals reflected from below, but signals reflected from above are more difficult to eliminate. One technique for minimizing multipath errors is to track only those satellites that are at least 15° above the horizon, a threshold called the "mask angle."

Multipath errors are particularly common in urban or woody environments, especially those with large valleys or mountainous terrain, and are one of the primary reasons why GPS works poorly or not at all in large buildings, underground, or on narrow city streets that have tall buildings on both sides. If you have ever been geocaching, hiking, or exploring and noticed poor GPS service while in dense forests, you were experiencing multipath errors (Kizil and Tisor 2011) [9].

Material and Methods

The present study was conducted in the Research Farms of the Department of Farm Machinery and Power Engineering, Punjab Agricultural University, Ludhiana. The field was measured in various segments concerning the field numbers and various crops grown in the respective plots. The aerial view and layout plan of the field is presented in Fig. 2 and Fig.3 respectively. There were multiple trials on some major crops like paddy, sugarcane, maize, moong, basmati, turmeric, etc. were carried out at farms while collecting the data. The different crops were categorized and measured separately.

Instrumentation

Two GPS modules shown in Fig. 2 and Fig. 3 were used in these studies which are available in the department. Both modules were supplied by Trimble Works on Terrasync with a possible error limit of 5 m. For measuring ground truth data, the field area was measured using a measuring tape of a length of 100 m with a least count of 1 cm (Ravi and Jagadeesha, 2002) [6]. The aerial view and layout of Farm of Research Farms of the Department of Farm Machinery and Power Engineering are shown in Fig. 4 and Fig. 5.

Fig 2: GPS-1

Fig 3: GPS-2

Fig 4: Arial view of research farms of the department of farm machinery and power engineering

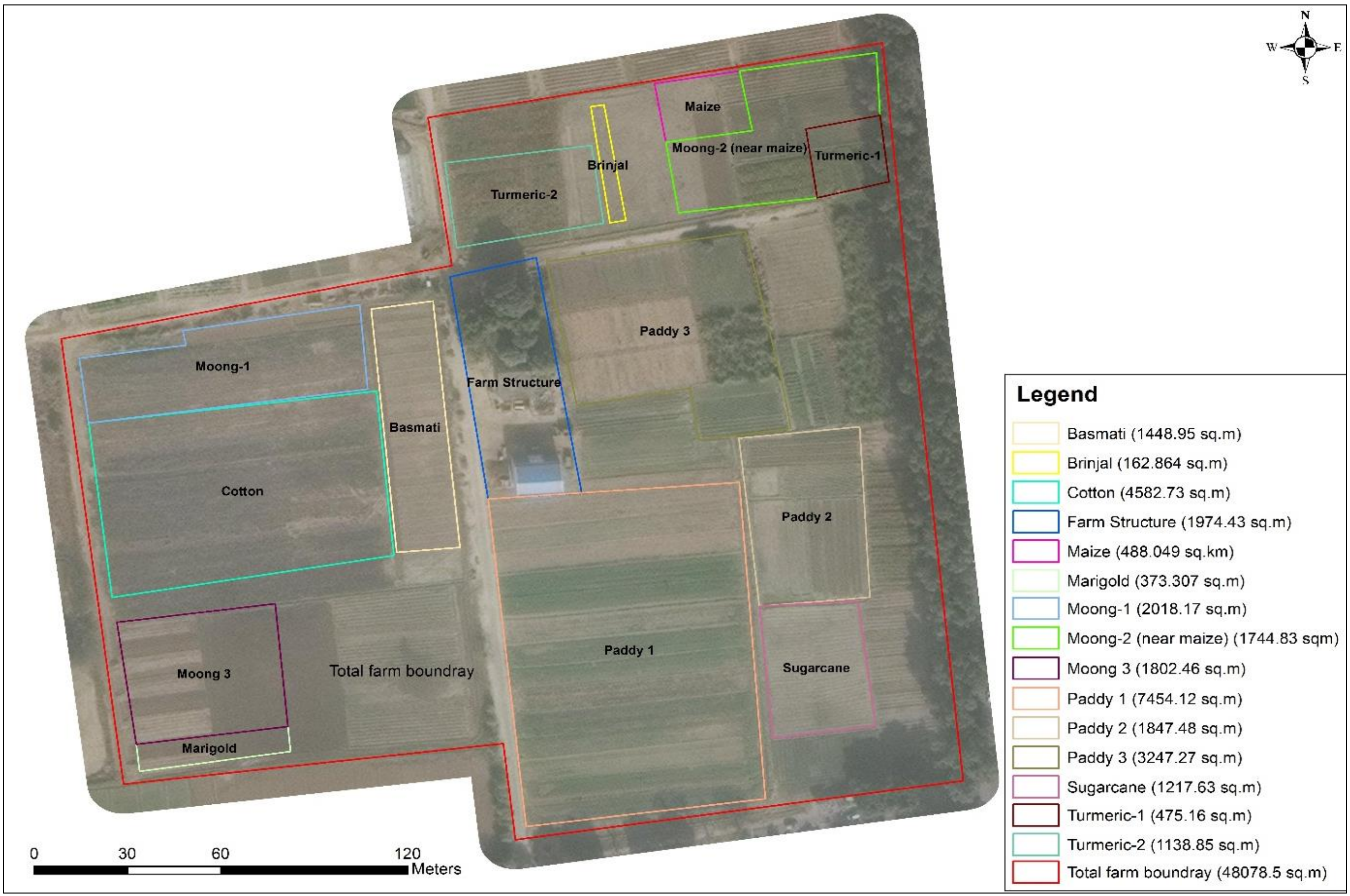

Fig 5: Layout of farm for farm machinery and power engineering

Results and Discussion

The area measured by various GPS and ground truth measurements are presented in Table.1. The ground truth area measured manually was about 30100 m^2, whereas the area measured by GPS-1 and GPS 2 was 299331 and 29012 m^2. It has been found that the total area measured by GPS-1 was 2.55% less than the ground truth measurement, whereas the 3.4% less area was measured by GPS-2 as shown in Table 1.

Table 1: Estimation of the area measured by GPS-1 and GPS-2 as compared to the ground truth data of the research farm

Field Number	Description of crops grown in the respective fields	Area measured by GPS-1, m^2	Area measured by GPS-2, m^2	Ground truth measurement area, m^2	Percent difference of GPS-1 as compared to ground truth measurement,%	Percent difference of GPS-2 as compared to ground truth measurement,%	Percent difference of GPS-1 as compared to GPS-2,%
F-1	Paddy-1	8729.01	8519.79	8244.00	5.88	3.35	2.40
F-2	Paddy-2	1731.80	1732.17	1767.00	-1.99	-1.97	-0.02
F-3	Paddy-3	3360.84	3554.99	4535.54	-25.90	-21.62	-5.78
F-4	Sugarcane	1307.51	1298.44	1260.00	3.77	3.05	0.69
F-5	Turmeric-1	434.39	454.08	540.60	-19.65	-16.00	-4.53
F-6	Turmeric-2	1206.36	1062.28	1089.25	10.75	-2.48	11.94
F-7	Maize	484.73	518.96	422.40	14.76	22.86	-7.06
F-8	Brinjal	165.92	196.83	234.30	-29.18	-16.00	-18.63
F-9	Moong-1	1835.73	1810.62	1826.00	0.53	-0.84	1.37
F-10	Moong-2	1779.75	1826.33	1852.50	-3.93	-1.41	-2.62
F-11	Moong-3	2044.89	1891.56	1872.90	9.18	1.00	7.50
F-12	Basmati Paddy	1529.28	1657.94	1584.60	-3.49	4.63	-8.41
F-13	Cotton	4648.43	4232.44	4590.00	1.27	-7.79	8.95
F-14	Marry Gold	386.35	318.51	333.33	15.91	-4.45	17.56
F-15	Farm Structure	1731.14	1829.39	1800.00	-3.83	1.63	-5.68
	Total	31376.13	30312.93	30099.92	4.24	0.71	3.39

Variation in measuring area by GPS-1 as compared to ground truth measurement

Out of a total of 15 fields, a variation of about ± 5% area as compared to ground truth measurement was measured in the seven fields i.e. F-2, F-4, F-9, F-10, F-12, F-13, and F-15. The results revealed that as compared to the actual area, this GPS observed 19.65%, 25.90%, and 29.18% less area in the field numbers F-5, F-3, and F-8 respectively, as shown in Fig. 6. However, more area was observed in the number of the field; F-6, F-7, and F-14 at 10.75%, 14.76%, and

15.91% respectively. This may be due that the area of F-7, F-8, and F-14 plots are very small, and the error may be more by measuring the area by GPS. The reason for the variation in field numbers, F-3 and F-5 might be due to the interruptions in the network signal of satellites near the wall side area, trees on boundaries, and farm structure.

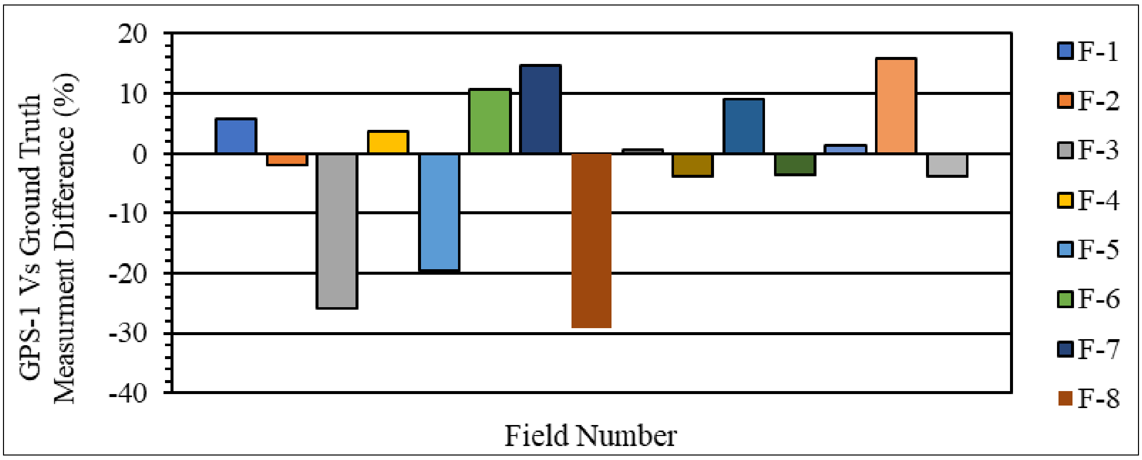

Fig 6: Variation in measuring area by GPS-1 as compared to ground truth measurement

Variation in measuring area by GPS-2 as compared to ground truth measurement

The GPS-2 observed a variation of ± 5% in nine fields, *viz.* F-1, F-2, F-4, F-6, F-9, F-10, F-11, F-12, F-14 and F-15 as compared to ground truth measurement. About 16% less area was measured each in the field number F-5 and F-8, whereas about 22% less area was observed in the field number F-3 as shown in Fig. 7. It has also been observed that about 23% more area was measured in field number F-7 as compared to actual measurements. The reasons for variation in these fields are the same as observed by GPS-1.

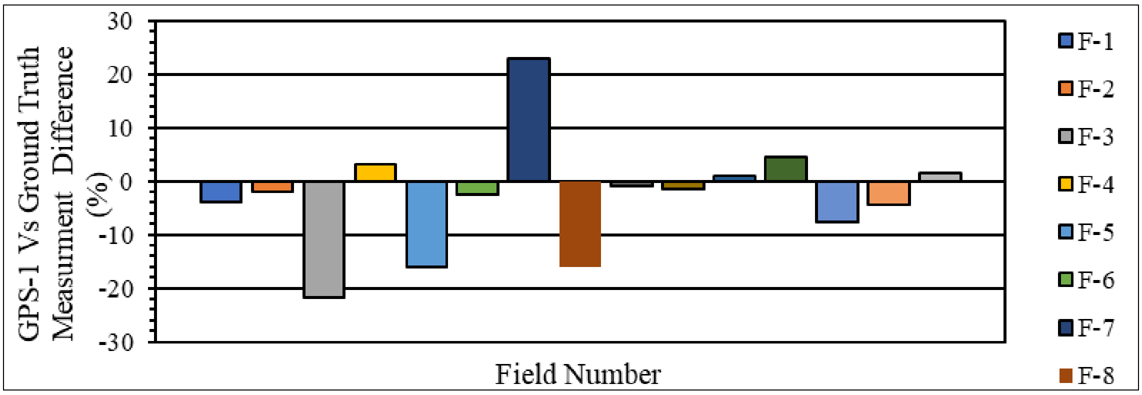

Fig 7: Variation in measuring area by GPS-2 as compared to ground truth measurement

Variation in measuring area by GPS-1 and GPS-2

A variation of ±5% was observed in 8 plots, whereas 5-10 percent more area was measured by GPS-2 as compared to GPS-1 in the field number, F-3, F-7, F-11, F-12, F-13, and F-15. About 12 and 17% more area was measured by GPS-2 in the fields F-6 and F-14 as shown in Fig. 8. About 19% less area was measured in field number F-8 by the same GPS. The variations may be due to the measuring of small areas by the GPS systems.

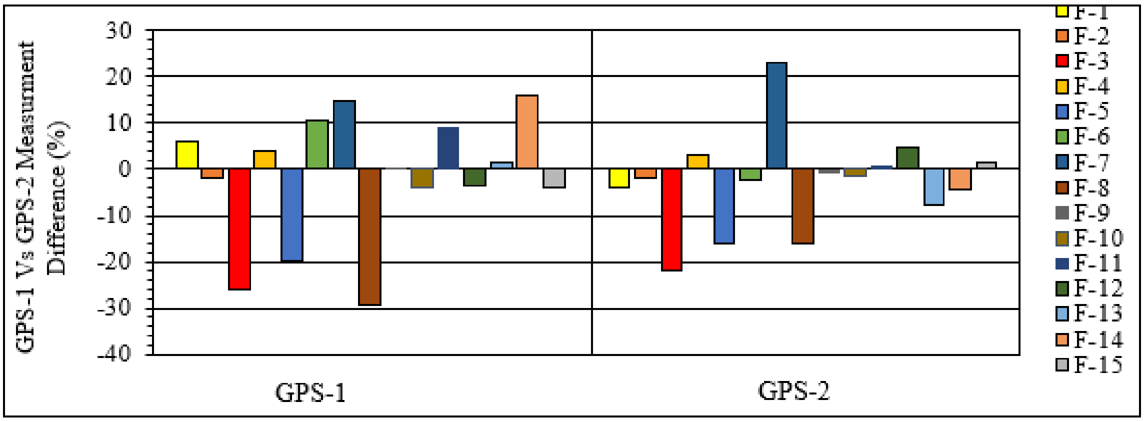

Fig 8: Variation in measuring area by GPS-1 and GPS-2

Conclusion

Out of measuring the area of 15 plots by two GPS systems, ± 5% variation as compared to the actual ground truth measurements was observed in ten plots. The variation of 5-20% was observed in the plots due to measuring a very small area by the GPS and more variations were observed due to the interruptions in network signals near the wall side area, trees on boundaries, and farm structure. It can be concluded from the present study that variation in measuring the area of a particular field will be less for measuring more area having less interruption of buildings, trees, etc. so that the GPS may catch more number of satellite signals.

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