POSITION MEASUREMENT ASSISTED BY PSO AND 360-DEGREE IMAGES

Walter W. Chen, Zhe-Ping Shen, Hung-Chi Chen, and Jian-An Wang

Department of Civil Engineering, National Taipei University of Technology

1 Sec. 3 Chung-Hsiao E. Rd., Taipei 106, Taiwan
Tel: +886-2-27712171 Ext. 2628; Fax: +886-2-27814518
E-mail: waltchen@ntut.edu.tw, fishfishfishgoo@gmail.com, s1226888@gmail.com, petera23p@yahoo.com.tw

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Abstract: The terms geolocating or georeferencing is usually used to characterize the process of determining the location of an object in space with respect to a coordinate system. This study illustrates the use of ultra-high resolution 360-degree images and Particle Swarm Optimization (PSO) to determine positions of field objects. The process is similar to triangulating with cell towers using three circles of known radii. However, instead of knowing the distances to the desired objects, all that is known in this study are the angles between objects. Without knowing the bearing of North, imaginary rays of lines emitting from the locations of three cameras were used. Their triangles of intersection were analyzed by the technique of PSO to minimize the total lengths of the triangle sides. The best possible solution determined in this way represents the most probable positions of the objects. This technique was tested at a Taipei landslide site in the Muzha area, and specialized programs were written in Fortran to facilitate the computation. The results showed promising potentials of this methodology in field investigation work in rough terrains.

1. INTRODUCTION

The terms geolocating or georeferencing is usually used to characterize the process of determining the location of an object in space with respect to a coordinate system. The object itself can be a geological feature, a landmark, a street address, or an event of interest. The location determination occurs across a range of spatial scales depending on applications. From three dimensional triangulation with satellites to triangulating a cell phone with cellular towers, the need to determine locations seems to rise daily. For field researchers, the need to record the locations of objects of interest and convey this spatial information to others seems to also grow rapidly. In this study, a landside site was examined for its mechanism of sliding. During the early phase of investigation, it was found that a significant amount of information can be obtained from the tilting of trees on the slope. However, due to highly undulating topography, eGPS (enhanced GPS) signals were not available and RTK (Real Time Kinematic) results were not reliable for measuring the locations of tilting trees. Therefore, this study attempts to develop an alternative and innovative method to measure the object locations in the field. This method does not require access to expensive surveying equipment and experienced operators. With only the aid of ultra-high resolution 360-degree images and Particle Swarm Optimization (PSO), positioning of field objects can be done routinely and efficiently.

2. EXPERIMENT
2.1 Study site

The study site is a landslide triggered by heavy rains brought by typhoons Kalmaegi and Sinlaku in 2008, and is located in the Muzha area of Taipei City as described in [1, 2, 3, 4]. Even after the major sliding in 2008, the slope was not stable, and it raised the interest of researchers to investigate the creeping of the slope by monitoring tilt trees growing on the slope. Since the study site is situated in a valley with poor satellite reception and cell signals, it was necessary to devise an alternative method to determine the locations of the trees in a quick and swift manner in order to simplify the field work and the data acquisition process. Fig. 1 shows an aerial photograph of the study site after grading and the removal of large debris. Individual trees can be seen on the upper-left side of the image. A plot to the right of the trees was set up to test the technique described in this study.

2.2 PSO

Particle Swarm Optimization (PSO) is an artificial intelligence technique developed by Eberhart and Kennedy [5, 6] to locate the optimum value in arbitrary n-dimensional space. It has the form like the follows:

$$v_i = w \times v_{i-1} + c_1 r_1 (pbest - x_{i-1}) + c_2 r_2 (gbest - x_{i-1}) \qquad (1)$$

where x = position in n-dimension, v = velocity, i = iteration number, w = inertia weight, c_1 = 2, c_2 = 2, and r_1, r_2 are random number in the range of (0...1). Eq. (1) is usually used with a certain number of "birds" or "particles" to perform search in the pre-defined space like a swarm of birds searching for food. Along with this formulation, an object function is needed to evaluate different positions visited by the birds. New locations of search are determined by the following equation:

$$x_i = x_{i-1} + v_i \quad (2)$$

A total of m birds or particles may participate in the search. The optimum or best solution is found swiftly and efficiently because of the exchange of information between the particles. At the end of each iteration, every particle will update its own pbest (best solution experienced by the particle) and share it (along with the location of pbest) with other particles. Gbest (best solution experienced by the entire group of particles) is also updated by comparing the available solutions one by one. Particles will move toward the centroid of the data-pair formed by pbest and gbest.

2.3 Panorama

At the study site, seventeen bamboo sticks were placed at random locations and hammered into the ground to represent "objects of interest." A Gigapan robotic camera mount was used with a Canon S95 camera to take 360-degree panoramic images at three locations marked as 1, 2, and 3 in Fig. 1. A total of 108 photos (36 by 3) were taken at each position, and each photo had 2816 by 2112 resolution. Each set of the 108 photos were then stitched together using Gigapan Stitch to create a 360-degree panoramic image. Each resulting ultra-high resolution images has roughly 642 mega-pixels. Afterwards, the images were imported into an image software, and the bamboo sticks were marked and numbered from 1 to 17 as shown in Figs. 2, 3, and 4. Since an image spans 360 degrees, the angle between any two bamboo sticks can be calculated as follows:

$$angle = N_P / T_P \quad (3)$$

where N_P = number of pixels between two bamboo sticks, and T_P = the total number of pixels in the image in the horizontal direction. These angles will be used to generate imaginary rays of lines emitting from the locations of the 3 cameras. Their intersections determine the locations of the bamboo sticks. In order to be consistent, bamboo #1 was used as the reference (0 degree). The angles of the other 16 bamboo sticks were measured counterclockwise from bamboo #1. Notice that the order of individual bamboo sticks is different in each of the three images, and the images shown are not full 360 panoramas.

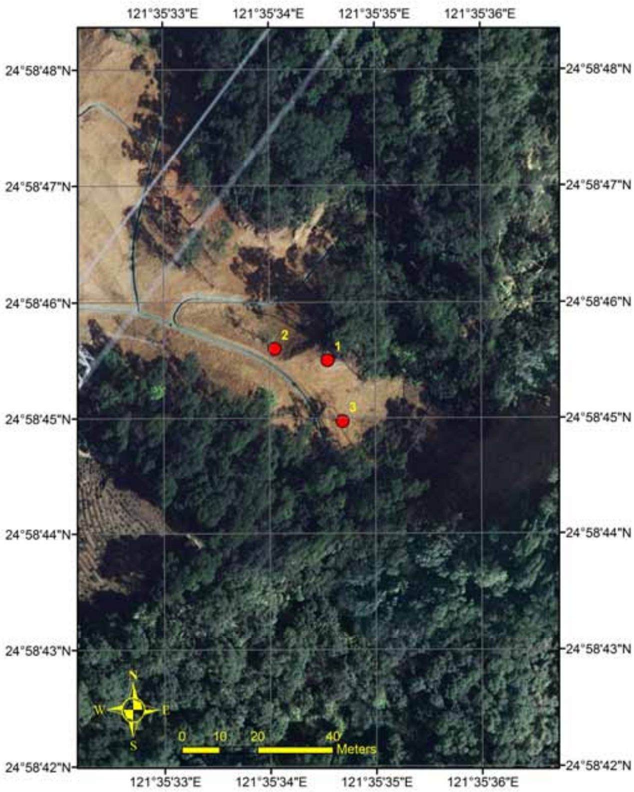

Fig. 1. Aerial photo of the landslide site analyzed in this study.

Fig. 2. Marked and numbered bamboo sticks at the study site as photographed from location #1 shown in Fig. 1.

Fig. 3. Marked and numbered bamboo sticks at the study site as photographed from location #2 shown in Fig. 1.

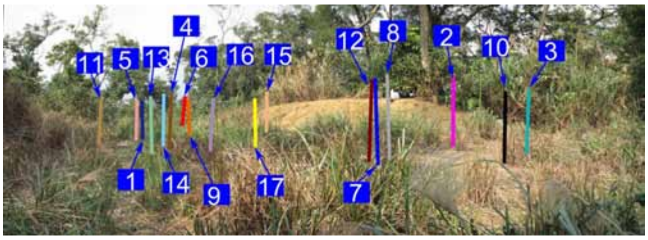

Fig. 4. Marked and numbered bamboo sticks at the study site as photographed from location #3 shown in Fig. 1.

3. PROGRAM DEVELOPMENT

The method to triangulate the locations of bamboo sticks is similar to that described in [7]. In order to find the intersections of imaginary rays of lines emitting from the 3 camera locations, a Fortran program was written following the flowchart shown in Fig. 5. At each of the 3 camera locations, the image was rotated until bamboo #1 was aligned with the positive x direction, and a circle of radius 1 was drawn. Then, points on the perimeter of the circle corresponding to the measured angles were determined. Rays of lines were constructed by drawing from the center of the circle to the points on the perimeter and beyond (as shown in Fig. 6). Intersections were then calculated for matched rays from 3 different circles. If everything goes well, each set of 3 matched rays of lines from 3 camera locations should intersect at the same point. However, since the bearing of North was not known and bamboo #1 was arbitrarily aligned to the positive x direction, the rays of lines generally would form a triangle instead of intersecting at the same point. In order to minimize the total lengths of the triangle sides, images at three locations (along with their rays of lines) were rotated independently until the best match can be achieved. Two different methods of rotating images are described and compared in the following section.

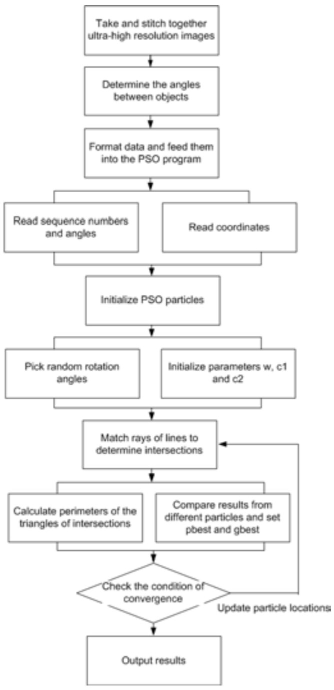

Fig. 5. Flow chart of the Fortran program developed to determine the best rotation angles of 3 images at 3 camera locations (PSO version).

4. COMPUTATIONAL METHOD

To find the best rotation angles, two methods were contrasted. First, a brute force method was considered. In this method, each of the three images would rotate from 0 to 360 degrees in 1-degree increment. At every possible combination of rotations, the total lengths of the triangle sides formed by intersecting rays of lines were computed. Since there were three independent rotations, the following number of computations was needed:

$$360 \times 360 \times 360 = 46{,}656{,}000 \tag{4}$$

The results obtained were summarized to find the minimum sum of lengths, and the answer was accurate to 1-digit. A Fortran program was written for this purpose. In addition, another program was developed to make use of the PSO technique. In this method, 10 "birds" were released to random locations in the 3D space *(x, y, z)* described by 3 rotation angles from 0 to 360 degrees. After being released, each bird would compute the total lengths of triangle sides at its location and exchange this information. Based on the information, individual bird then decided the next location to visit. The tendency was to fly to the best possible location but a random component was built into the formulation so that the actual destination was probabilistic. The reason for this random component was so that the birds would have opportunities to explore other locations where a better solution might exist. It is worth noting that normal PSO problems had rigid boundaries to define the space of exploration. Birds would be stopped at the boundaries in the x, y, or z dimension if they attempted to cross the boundaries. For this study, however; boundaries were not needed. Since x, y, and z represent angles of rotations, they could rotate more than 360 degrees or less than 0 degree (in the negative direction). All that was needed was to add or subtract 360 from the intended angle, and the result would be the same. In other words, birds crossed boundaries and disappeared on one side would re-appear on the other side.

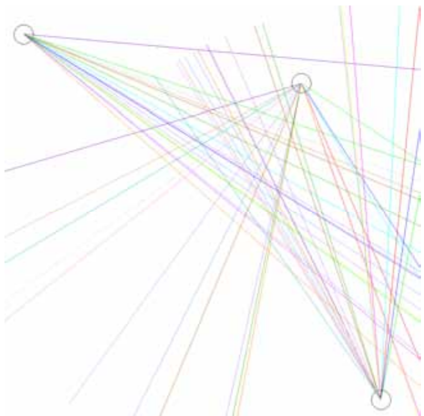

Fig. 6. Locations of bamboo sticks can be determined by rotating the rays of lines until each set of matching rays intersect at the same point. This figure shows one of the possible combinations of rotations.

5. RESULTS AND DISCUSSION

The computational results of the two methods are shown in Table 1. For the brute force method, the computation is expensive. Because of its exhaustive nature, it took about 47 millions iterations to determine the best angles of rotations to be 203, 333, and 126 degrees. On a computer with a dual-core Intel Celeron G530 processor (2.40 GHz), 4 GB of memory and the 64-bit Ubuntu 11.04 operating system, it took about 7,100 seconds or 2 hours to complete. The minimum sum of lengths is 96.716. As shown in Table 1, PSO can beat this answer in 13 seconds. The number of iterations needed is 36,982. The speed-up factor is:

$$7100/13 = 546 \tag{5}$$

The answers are accurate to at least 5 decimal points, and they have a very good agreement with those obtained by the brute force method. If the computation is allowed to continue, the answer will eventually converge to 91.771 after about 353,558 iterations and 126 seconds. The improvement of accuracy (total length) is about 5%. The convergence curve of the first 100,000 iterations is shown in Fig. 7. As shown in Fig. 7, the curve converges quickly at the beginning of the iteration process but slows down substantially afterwards. After about 37 thousand iterations, the values stay pretty much the same.

Table 1. Comparison of brute force method and PSO method.

method	Min. sum of lengths of triangle sides	# of computation	Best solutions	Time spent
Brute force	96.716	46,656,000	203 333 126	About 7,100 sec
PSO	96.414	After 36,982 iterations	202.34116 333.05945 124.73030	About 13 sec
	91.771	After 353,558 iterations	202.63654 333.17480 127.36497	About 126 sec

6. CONCLUSIONS

Unexpected needs frequently arise in the field to determine the location of objects of interest. If the study site is remote and the ground condition is poor, the task of positioning objects will not be trivial. This study illustrated a method of triangulating objects using only high resolution images and PSO. Comparing with the brute force method, the PSO solution is more than 500 times faster and more accurate. The error margin was about 2.78 m per triangle side, which is consistent with the precision of the hand-held GPS device (Garmin Dakota 20) used in the field to estimate the locations of the cameras. In addition to finding the optimum rotation angles to match the rays of lines, the PSO method also simultaneously determines the north direction without any prior knowledge of the direction in the field. Therefore, the combined use of 360 images and PSO showed promising potentials in field investigation work in rough terrains.

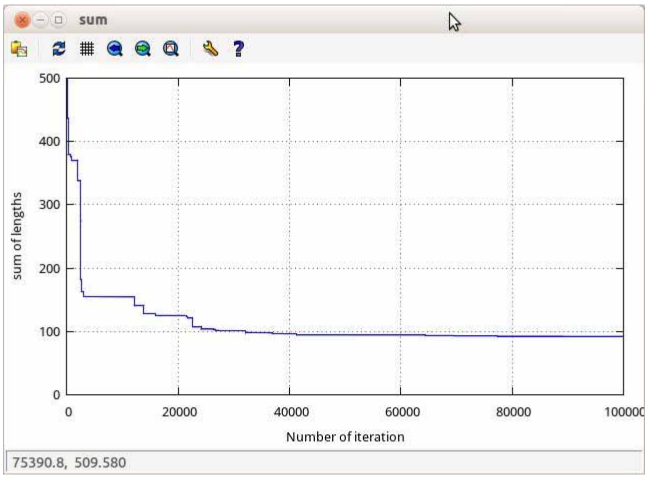

Fig. 7. Convergence curve of the PSO method.

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