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A cost effective material tracking and locating solution for material laydown yard

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Abstract

In industrial construction, each fabricated material item such as a steel piece or a pipe spool is a unique building element. They are typically staged in a large laydown yard before final on-site installation. Manually tracking and locating each particular item in a large laydown yard can be very time consuming, and excessive man hours spent in this process can negatively impact on field installation activity and overall project performance. This study developed a robust and accurate yet cost effective material tracking and locating solution based on mature tracking technologies. The proposed solution features a handheld computer equipped with barcoding and GPS technologies for laydown yard material tracking and fast retrieval in a cost effective manner. The device scans item barcodes when the item is unloaded in the yard and, meanwhile, captures the GPS coordinates along with the item image, and stores these data in a central database. For material retrieval, material lookup through the database provides geographical location and images of an item, and navigation function gets the crew to the item in a shorter duration. To validate the accuracy of GPS and practicality of this solution, various handheld computing devices with built-in GPS functions were tested by comparing their GPS recordings against the true coordinates of selected geological survey benchmarks. The accuracy is measured by the distance between the true coordinates to the device-recorded coordinates using Vincenty's formula. A prototype system consisting of a mobile device and a software module was developed, and the achieved GPS accuracy is within 3 meters. While the proposed solution has the potential to significantly improve material tracking efficiency, its low initial and operating costs and robust performance make it practical to use in a wide range of projects.

Keywords: Automation; barcode; cost effectiveness; GPS; material tracking.

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1. Introduction

Industrial construction projects are challenged by the storage and handling of a large quantity of fabricated materials, each material item such as a steel piece, valves, fittings or a pipe spool is a unique building element. Effective material tracking requires not only the knowledge of what materials are currently present in a laydown yard, but also the ability to identify exactly where they are located for quick retrieval. Manually tracking and locating each particular item in a large laydown yard can be very time consuming. Excessive crew hours spent on locating and retrieving materials can have a significant impact on field installation productivity and overall project schedule performance. A CII study showed that the average time a crew spent manually locating fabricated items in a lay down yard was over 35 minutes [1]. On the other hand, a past case study indicated that effective material management has a benefit/cost ratio of over 5 to 1 in medium sized commercial construction projects [2].

The goal of this study is to design a balanced material tracking solution that provides adequate accuracy and robustness yet with low system cost and user-friendly setup. Such a solution is expected to improve the scalability of automated locating systems for projects of different sizes, while minimizing implementation efforts, thus resistance to changes. The sections below first reviews the current industry practice, followed by an examination of available tracking technologies. The hardware selection, accuracy testing and system development is then presented.

2. Current Industry Practice

As shown in Figure 1, in a typical industrial construction project, fabricated materials are tracked manually in this process [8]. To identify the location of a material item, the laydown yard is typically divided into a grid, and each grid section is identified by an alphanumeric location code, e.g. “5B.” The material item identification code (e.g. piece mark or tag) along with the grid location code are recorded manually after receiving in the yard, and then are later entered into the central material tracking database. If an item is moved during their storage in the laydown yard, the above process will be repeated to capture the item’s latest location. When an item is needed for field erection, the laydown yard crew will look up the item in the database for its identification and location codes. The crew will then manually search and retrieve the item in the grid location. As can be seen, this process involves manual collection of material data which can be tedious and error prone. More importantly, although the grid location code helps to find the approximate item location, it fails to pinpoint the exact location and still requires the crew to take the extra time to search for a specific item in a large grid section area, which is typically about 5,000 square feet. As mentioned previously, the CII case study (2008) found that this manual searching procedure can take more than 35 minutes [1].

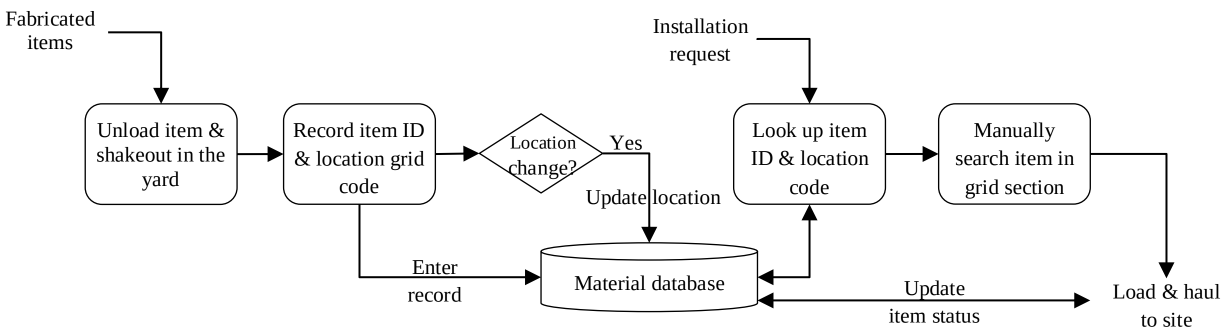

Fig. 1. Current practice in identifying and locating materials in laydown yards.

3. Available Tracking Technologies

Available material tracking technologies that have been considered by past studies include barcoding, global positioning systems (GPS), radio frequency identification (RFID), and ultra-wide band (UWB) locating. While these solutions provide material identification and locating capability, they are different in various aspects, e.g. accuracy, implementation and operating cost, instrument setup effort, level of automation, robustness, ruggedness, and practicality/scalability for projects of various sizes. For everyday field applications, the desired solution must mature, practical, efficient and cost effective.

Table 1 shows a comparison of these technologies. Barcoding has long been widely used by fabricators, and many owners require all fabricated items with bar-code label attached. Bar code readers can easily scan codes in the field of view and its low cost and reliability contribute to its widespread use [2]. A CII study attached an active RFID tag to each material item and a truck outfitted with a reader and GPS device drove around the yard while picking up RFID tag signals and strengths, based which an item’s rough location can be calculated. This approach automatically locates tagged items, but its implementation is limited by the extremely high cost (e.g. a tag can easily cost $25 or more), lack of equipment standardization, interference of metal to RFID data sensing, and risk of damage to tags during material handling. A Canadian study [3] used a GPS tagged camera to collect item piece marks as well as item location to assist item locating. The newer GPS tagging technology integrates GPS receiver and cellular/satellite communications to allow uniquely identifying a tagged object globally and broadcast its location remotely. However, for relatively low-cost large-volume construction material tracking, the very high cost and the risk of tag damages make GPS tagging a less attractive option. UWB is a short-range radio communication technology that can identify and locate items in both indoor and outdoor environments for sub-meter accuracy [4]. However, since UWB radio signal only works in a short range, a costly fixed array of receivers must be set up and calibrated for a specific site layout or whenever the layout is changed.

Table 1. List of devices used.

	Technology				
Function	Barcode	RFID	UWB	GPS Receiver	GPS Tagging
Identification	X	X	X	-	X
Locating (accuracy)	-	-	X (0.5m)	X (2-5m)	X (2-5m)
System setup	Tag and mobile reader	Tag, mobile or fixed readers	Tag, fixed sensor and hub network	GPS receiver and satellite	GPS tag and satellite
Availability					
▪ Cost range	Label ~$0.1 Reader ~ $100-500	Tag ~ $1- 50 Reader ~ $1k-5k	Tag ~ $5 Sensor & hub ~ $10k (estimated)	Receiver ~$200 Satellite signal free	Tag ~ $200-500 Satellite signal free
▪ Maturity	Already widely used by fabricators/required by owners	Research & newly commercialized in construction	Research/testing	Used for equipment tracking	Not widely used in construction

4. Proposed Solution

Considering low-cost large-volume construction material tracking, the key question is to tradeoff among competing needs and finds the most practical technical solution. Based on the above discussion, we propose to use a combination of barcoding and GPS for material identification and locating for the following reasons: (1) for material identification, barcodes are already widely applied by the industry and require no or minimal change to the current practice; (2) GPS has also been widely used for surveying and locating applications in construction, and it provides reasonable accuracy required for material locating; (3) both technologies enjoy relatively low cost, high level standardization, and good reliability for outdoor construction environments. It is expected to make material tracking solution more scalable for projects of varying sizes, while minimizing implementation efforts and costs, and thus resistance to changes. Although, a commercial product, Track’em [5], appears to be based on similar technologies, its actual usage and performance is not clear. Our solution is based on the most recent advancement of mobile computing to increase accuracy and efficiency while reducing system costs.

The proposed procedure is shown in Figure 2. When compared with Figure 1 current practice, areas of improvement in the proposed approach can be easily identified with the time-and-dollar sign. In the current practice, fabricated materials are received with barcodes already applied. A worker uses a handheld device equipped with a barcode reader and a GPS receiver to record an item's barcode, GPS location, and image. Item status data will be updated to the central material database through Internet. In case of an item being relocated, the above steps will be repeated to capture the latest location. A CII study found that about 20% items were moved to a different location [1]. This extra effort appears to be reasonable, especially comparing with the RFID and GPS solution which requires daily data collection and updating [1]. When an item is requested for field installation, the crew can search for the item in the database and retrieve its location. An onboard GPS will guide the driver to the laydown yard location to retrieve and load the item. These automated or semi-automated activities are expected to eliminate paper-based data collection, increase item locating accuracy, and substantially reduce item searching time.

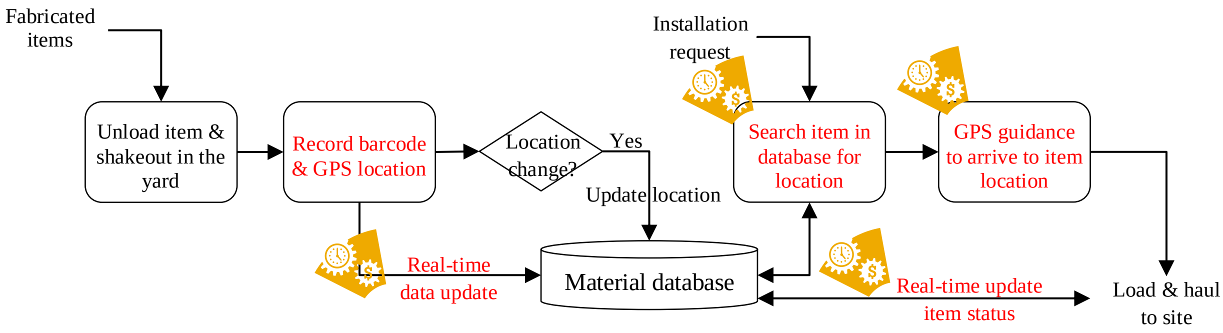

Fig. 2. Proposed practice in identifying and locating materials in laydown yards.

5. Hardware Selection

With the advancements in technology, the prices of handheld computing devices have fallen drastically and many of handheld computing devices are available in the market in the form of smartphones, tablets, personal digital assistants, etc. The basic requirements of our proposed approach include (1) a GPS receiver with real-time 3-meter accuracy or better; (2) an integrated bar code reader; (3) an integrated digital camera; and (4) wireless communication capability. A key requirement is the GPS accuracy since a higher accuracy will reduce the size of search area thus minimizing time required to locate an item. GPS devices or chips range from recreational, mapping to surveying grades. The accuracy range can fluctuate from 15 meters in the case of recreational/personal GPS units to less than 1 to 2 centimeters using survey-grade equipment with real-time kinetics and post-processing. Accordingly, the cost can go from $100 to over $40k. Our selection criterion is to balance the need of accuracy, portability, easy set-up, and cost. GPS survey equipment was not considered since it is not deemed to be practical to have equipment in the yard for the entire duration of a project. Custom integration of a handheld computer with a portable high-accuracy GPS and/or a bar coder reader is not user friendly since it requires a user to carry several individual devices that become cumbersome to use. The same is true for survey-grade handheld computers with sub-meter accuracy since they do not have built-in bar code reader. After a product search including various industrial models from Trimble and Motorola, Motorola MC75A was considered due to its 2-meter real-time GPS accuracy, integrated barcode reader and camera, and rugged design. In addition, the smartphones and tablets available in the current market offer similar capabilities with possibly lower GPS accuracy but larger display and more flexible options for software development and testing. It was determined that the accuracy of these computing devices to be tested in a real-world condition before final selection can be made. Several popular smartphone/tablet devices were included in the field test, as listed in Table 2, and they all feature built-in GPS, barcode reading, and digital imaging capability.

Table 2. List of devices used

Hardware	Operating system	GPS	Bar code reader	Camera	Wi-Fi & cellular data	Internal Memory
Motorola MC75A	Windows Handheld 6.5	YES	YES	0.3 MP	YES	1 GB
Sony LT26i	Android 4.4.2	YES	YES	12 MP	YES	32 GB
HTC one (M7)	Android 4.4.2	YES	YES	4 MP	YES	32 GB
Google Nexus 10	Android 4.4.2	YES	YES	5 MP	YES	32 GB
Apple iPad Air 2	iOS 8.1.3	YES	YES	8 MP	YES	16 GB

For efficient material tracking, reading barcodes and collecting GPS locations are the two most important tasks a hardware is required to perform. Barcoding is a mature technology, eliminating the need to test its accuracy. The quality of GPS chips however can fluctuate widely among handheld devices. The accuracy of GPS is influenced by various factors such as hardware, weather, and obstacles in the surrounding. Hence, there is a need to determine the accuracy of the candidate devices to validate their use for our purpose. The basic idea is to compare readings from candidate devices with known coordinates at survey benchmarks, as shown in Figure 3. The GPS units to be tested are placed directly over a surveyed benchmark whose coordinate is well established to an accuracy level of 1st order. The GPS data is then repeatedly collected in a regular time intervals, and the data set collected contains multiple readings from the same position using the same device. The position is recorded in a decimal degree format. The horizontal distance is then measured between the observed location coordinates and the known coordinates of the surveyed benchmarks. The average distance is used to characterize the GPS accuracy of a candidate device.

The first step is to identify and locate the geographical benchmark locations, these locations are available through the National Geodetic Survey (NGS) which establishes and maintains these benchmarks. Benchmarks in Houston, Texas were selected to conduct the experiments. The coordinates of these benchmarks can be accessed through the NGS Data Explorer [6]. In order to get a satisfactory results, only those points which were established with higher degree of accuracy can be used for accuracy testing. Four benchmarks were eventually selected.

Each candidate device was used at the four benchmarks situated at various locations in the City of Houston, and 50 readings were taken from each device at each benchmark. As shown in Figure 4, the barcode is setup near the surveyed benchmark resembling the barcode of a material item. It is placed near the benchmark at a distance of about 30 cm depicting a real case scenario. The selected device immediately above the survey benchmark is then used to scan the barcode while recording the GPS location.

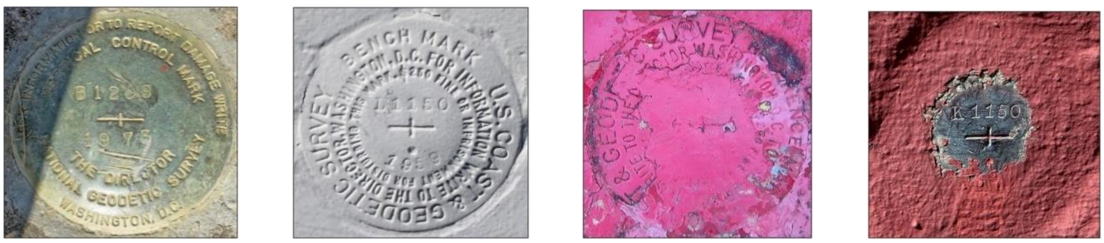

Fig. 3. Four selected benchmarks (from left to right: AW0201, AW2342, AW3222, and AW2340).

Fig. 4. The device, the benchmark and, the barcode.

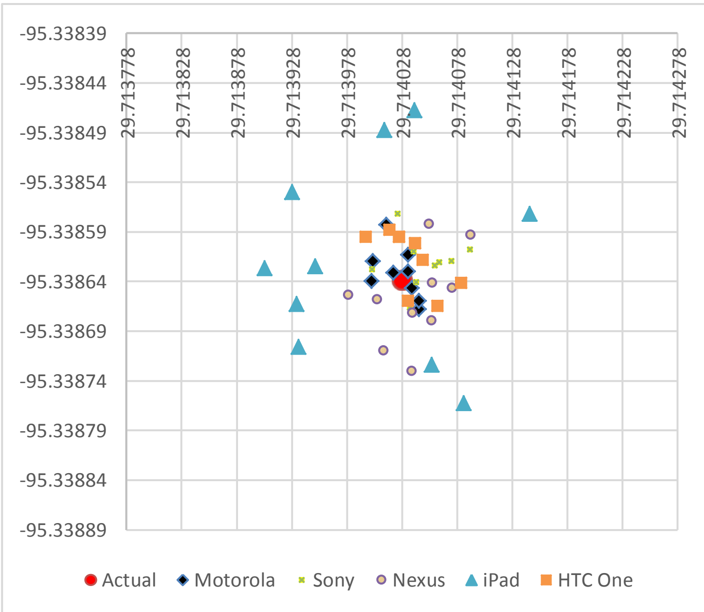

Fig. 5. Distribution of location points from various devices.

The distance between the observed coordinates of a selected device to that of the known coordinates at a benchmark is then measured. Smaller distance indicates higher accuracy and vice versa. Vincenty's inverse formula was used for this purpose. The Vincenty formula works by iterations, i.e. the calculation procedure is repeated until the change in the first approximation of the difference between two longitudes is negligible (e.g. 0.006 mm) [7]. The gathered GPS data was analyzed using a Vincenty's formula script implemented in MS Excel [8]. The distance between the obtained coordinates and the actual coordinates were measured and the average values were determined.

As shown in Figures 5 and 6, it can be observed that the accuracy of the candidate devices mostly vary between 3 to 5 meters and different devices achieved different accuracy levels. Motorola MC75A is more accurate than other devices and it is primarily designed for industrial barcode scanning and tagging purposes. As a result, the subsequent software was developed for this device on Windows Handheld platform.

6. Software System Development

The prototype software was developed by the authors using Visual Basic .Net with references to Windows Mobile SDK, Motorola's Enterprise Mobility Development Kit (EMDK), Microsoft SQL Server Compact Edition, and Bing Maps Platform API. Figure 7 show the various operations available in the application. Clicking on the store button will prompt the user to scan the barcode, and once scanned, the item identification code along with GPS location is captured and displayed. Optionally, a picture of the item can be taken to assist item retrieval. Clicking the search option will allow the user to search through previously scanned items and their location for retrieval with navigation assistance.

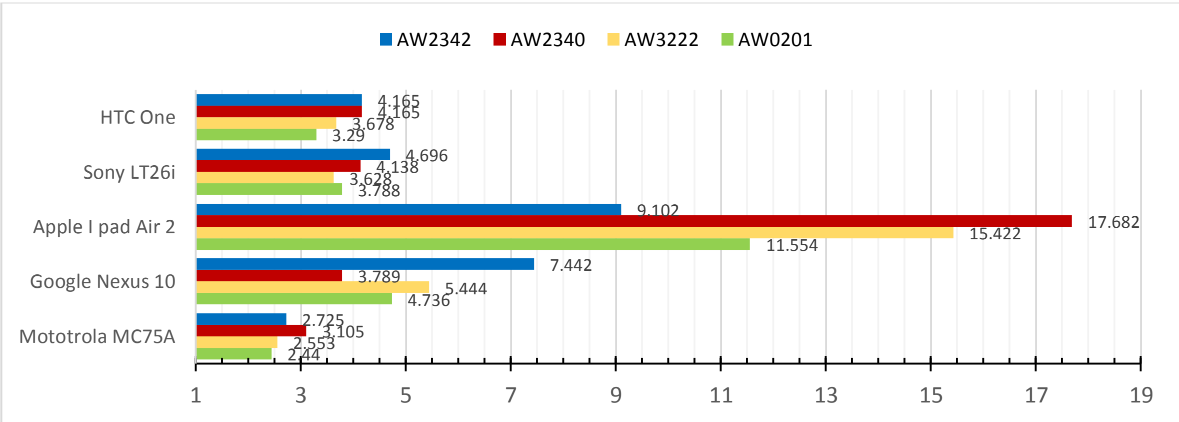

Fig. 6. Varying error levels in different devices (distance between device and benchmark in meters).

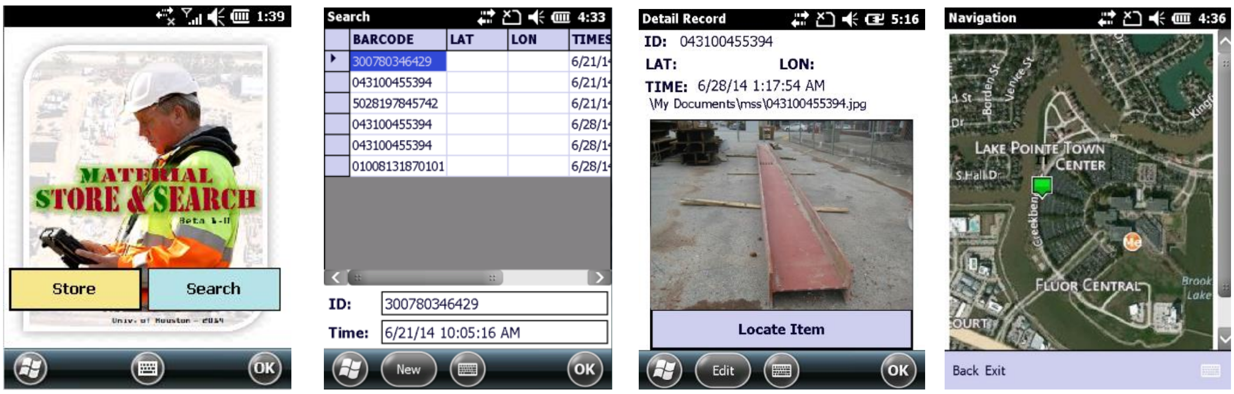

Fig. 7. System screenshots.

7. Cost-Benefit Analysis

To verify the cost effectiveness of the developed system, a cost-benefit analysis was conducted. The analysis is based on a typical crew setup, work hours, salary rates, and assumed annual work volume. On the cost side, the developed system essentially only requires handheld computers. We assume one crew equipped with two units for material receiving and retrieval with a total initial setup cost of approximately $5,000. To quantify savings, we assume the crew has three workers with an average hourly rate of $30. The crew works 52 weeks per year with 5 working days per week and 10 holidays, thus the total working days per year average at 250 days. For our study, an average of 12 minutes are required to locate and retrieve a material item. The crew was already required to scan bar code when receiving materials. Therefore, time required to automatically record GPS location and manually capture an item image is minimal and thus ignored in the subsequent analysis. The actual material retrieval time averages at 7 minutes. Considering a retrieval of 20 items per day a one-year project, the proposed system can save $150 per day or 41.7%. This translates to a yearly saving of $37,500, or a benefits/cost ratio of 7.5 to 1. This saving is expected to be even more significant for projects with longer duration. In comparison, as mentioned previously, a similar cost-benefit study collected data from two steel erection projects, and the objective was to analyze and compare the effects of material management practices on construction productivity performance. The results showed a benefits/cost ratio of 5.7.

8. Conclusion

This study developed a robust and accurate yet cost effective material tracking and locating solution based on barcoding and GPS. The prototype system consisting of a mobile device and a software module was developed, and the achieved GPS accuracy is within 3 meters. While the proposed solution has the potential to significantly improve material tracking efficiency, its low initial and operating costs and robust performance make it practical to use in a wide range of projects. Future field trails of the developed prototype on an actual construction project will help to determine the actual time saved and the practicality of this approach. Furthermore, a variety of new tracking technologies are being made available and more affordable, such as passive RFID, and they should be examined to cater the ever evolving needs of the construction industry.

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