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ANALYZING THE TRAVEL PATTERNS OF CONSTRUCTION WORKERS

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ABSTRACT

This paper describes a new framework and its algorithms of using frequent positioning data to entitle rapid learning among construction site managers and workers for safety. If collected accurately and in real-time, the location, speed, and trajectory of construction resources (e.g., workers, equipment, materials) can lead to important information regarding travel patterns. This information can then be shared among project stakeholders to improve work practices, e.g. the preconditions for safe construction operations. Additionally, the overall analyses of travel patterns on construction sites can help in the process of allocating resources more effectively to overall increase productivity and safety. Tracking and analyzing the paths of construction resources has multiple applications in construction and is not limited to important tasks such as monitoring the idle time of machines to reduce inefficiencies, tracking the path and location of materials to reduce search times, or signalling hazardous zones to workers to improve work zone safety.

KEYWORDS

Obstacle Detection and Avoidance, Path Planning, Safety, Tracking, Ultra Wideband, Work Zone

1. INTRODUCTION

In the period from 1995 to 2002, 802 workers in the United States' construction industry were fatally injured when struck by a vehicle or mobile equipment. 258 of these deaths were caused by the following construction vehicle types: Dump truck (41%), grading/surfacing machine (14.3%), excavation machine (6.5%), semi-truck (6%), other truck (14%), other machine (10.4%), and other vehicles/sources (7.7%) [1]. These statistics are alarming, since many passive safety tools (e.g., precautions and interventions such as jersey barriers and Internal Traffic Control Plans (ITCP)) and active safety tools (e.g., Proximity Warning Systems (PWS)) exist and aim to protect construction workers.

To solve this safety problem, the use of semi-automated and automated real-time project safety control in construction is not an illusionary vision any more. As far as the availability of technologies for measuring project performance indicators is concerned, a number of advanced technologies that are appropriate for onsite measurement are maturing, their accuracy and integrity are improving, and their costs are declining [2]. Among them are: Global Positioning Systems (GPS), Laser Detection and Ranging (LADAR), Vision Camera, Audio Technology, Radio Detection and Ranging (RADAR), Radio Frequency Identification (RFID), Ultra Wideband (UWB), and infrared heat and magnetic sensors. A more detailed technical discussion on the benefits and limitations can be found in Navon and Sacks [3]. Teizer et al. [4] has conducted experiments using Ultra Wideband (UWB) technology in the object cluttered construction environment.

This paper presents preliminary research efforts using emerging technology and data processing to improve safety training and education, and provide workers and safety personnel with the tools to prevent incidents pro-actively.

2. BACKGROUND

In a review of scientific literature and relevant Fatality Assessment and Control Evaluation (FACE) investigations, safety data analysis demonstrate that "road construction workers were as likely to be struck by a construction vehicle (48% of cases) as by a passing motorist" [5]. Contributing factors include: Lack of knowledge about specific risk factors, insufficient evaluation and adaptation of intervention technologies and newly developed approaches used in other industries, lack of adequate guidelines, particularly for controlling vehicle and worker movements inside the work zone, and lack of educational and training resources for non-English speaking workers. For these reasons, research objectives have been identified to coordinate vehicle/equipment movement inside the work zone and to develop measures for preventing workers-on-foot from being struck by motor vehicles and equipment:

- Focus on blind areas around construction vehicles and equipment, e.g., area around a vehicle or piece of construction equipment that is not visible to the operators, either by direct line-of-sight or indirectly by use of internal and external mirrors.
- Limit exposure of workers-on-foot to construction traffic.
- Reduce hazards for equipment operators, e.g., running over people, materials, striking other equipment and vehicles, rollovers, and contact with utilities.
- Develop exposure monitoring system(s), e.g., evaluating peed control, night work.
- Evaluate injury prevention measures.

3. METHODOLOGY

It is commonly known that the overall safety culture of a company depends on the executive commitment, a formal and informal safety system, operation personnel, and safety best practices and methods in place to prevent mishaps. Accident investigations integrated with the science of human behaviour and the identification of specific contributing factors involved demonstrate a significant lack of real data that often prevents valid assessment of human error causes. In advance of human factors, investigators receiving training in the science of human behaviour before joining an investigating team, it might become essential to assist existing practices in place with the following methodology [6]:

- Use of existing and emerging technology as neutral data collection tool designed within a human error analysis process.
- Automate validation, and interpretation of employee baseline capabilities to assess supervisors' or workers' behaviours, in addition to cognitive skills, in areas of critical thinking, leadership, and problem solving.
- Develop pro-active technology for real-time hazard warning.
- Improve training, educational tools, and methods within a framework of human error principles.

As a result of today's practices, this research tries collecting unrecorded data, processing and analyzing data, visualizing information to all stakeholders (workers, supervisors, managers, etc.), and implementing new knowledge into the training procedure. Frequent positioning data of construction resources (worker's path) is collected and processed using the following algorithms. Although obstacles can be detected by many technologies, safe travel paths may depend on accurate historical data of previously recorded safe paths. These safer paths can then be used to allow for the continuous detection of obstacles and of safe routes.

4. ALGORITHMS

Detecting construction obstacles automatically is a major challenge and is critical for the safety of workers on a construction site. An intelligent method is presented that allows for the detection of obstacles based upon the path the construction resources take. Once obstacles are detected safer routes can be planned.

A lot of work has been accomplished in the field of path planning. Pendragon and While proposed the safe navigation of robots through the tessellation of obstacles [7]. By growing a virtual bubble around each obstacle, a robot can always keep a safe distance to the obstacle(s). Since this technique does not help further in identifying the shortest path between two points, different techniques based on artificial intelligence for path planning were identified. Morad et al. identified the travel path by defining the environment as a collection of complex states which can be solved using a set of operations [8]. Although these "out-of-sequence" modelling technique can avoid obstacles, it does not identify shortest paths.

Similarly, many literature sources pre-identify obstacles for planning robot routes. For obstacle avoidance, many algorithms find convex hulls that are computationally intensive and use recursion to identify holes/hulls within the given distribution [9]. In Dehne et al., a randomized convex hull detection algorithm is introduced that operates successfully in a three-dimensional (3D) space [10].

To find the shortest path in a given plane, Dijkstra's single-source shortest path algorithm for graphs can be applied.

A combination of the two discussed approaches (convex hull algorithm to identify the obstacles in the path; shortest path algorithm to identify the shortest path between two points) has been developed. The following paragraphs will describe the developed algorithm in mite detail. Experiments and results will be presented for obstacle detection, identification, and avoidance using UWB positioning data.

5. EXPERIMENTS AND RESULTS

Different sensors exist to collect positioning data [3,4]. Experiments with UWB technology collected real-time (up to 60Hz) three-dimensional location data of workers, their tag ID, and time stamp. The goal of the experiments was to validate the developed obstacle detection, avoidance, and path planning algorithms.

Step 1: Considering construction resources (incl. workers) navigate in 3D, the space is divided into an occupancy grid with cube sizes of 0.1m x 0.1m x 0.1m [6].

Step 2: A counter in each cube records the number of times a tag ID was present in the particular cube. For example, each time a worker and his/her UWB tag enter the same cube, the counter increments by 1.

Step 3: The frequency of visits to each cube can be visualized in a colour-coded image. Analyzing colour-coded travel patterns has the potential to optimize the navigation of resources and make them safer (see Table 1).

Table 1. Colour Coding of Cubes

Cube Visits	Cube Colour	Safety
0	White	Very Low
1	Dark Orange	Low
2-8	Light Orange	Medium
9-20	Yellow	High
>20	Green	Very High

As an example, Figure 1 represents the frequency of visits in each cube for paths taken by multiple workers. The more frequently travelled path is in green, the least traversed path is in dark orange. Cell with no visits are white.

Based on field observations, workers generally avoid hazards. It can be assumed that the travel path is safe when the more often it is travelled. Cubes that have a higher frequency of "being visited" are safer and may offer a path that allows higher speeds, thus making the operation more productive than before. In other words, a high likelihood of a safe path would result in "green", where as "dark orange" results in a low safety rating. "White" cells that have never been visited result in an unknown and potentially hazardous area. As a result, the frequency of cube visits can become a safety indicator.

Step 4: Since "white" cubes automatically are categorized as obstacles, the next step is to identify obstacles in the frequency plot (see Figure 2). A basic area-growing approach is used to group all connected white cubes into single objects (obstacles). The developed algorithm correctly identified all obstacles by assigning an individual number to each obstacle. In addition, the algorithm identifies dimensional values to each object, such as the number of cells contained by the obstacle, its width, and height. Results and dimensions of the identified obstacles are illustrated in Figure 2 and Table 2.

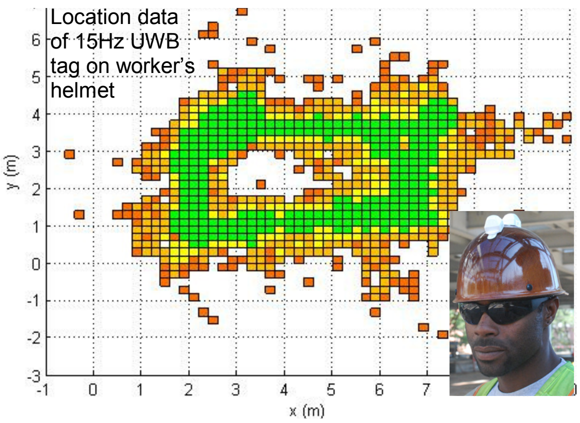

Figure 1. Plan view of Circular Travel Path

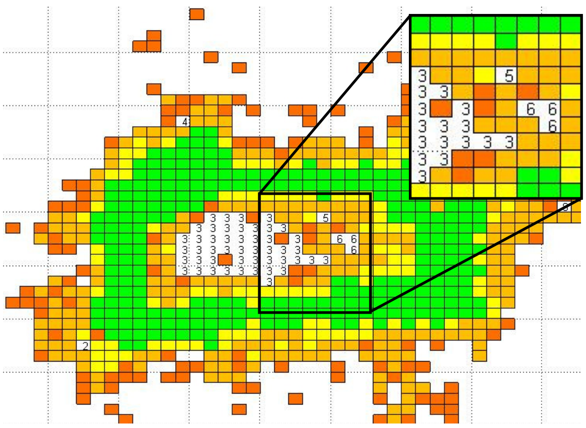

Figure 2. Obstacle Identification

Table 2. Dimensions of Detected Obstacles

Obstacle ID	Cells in Obstacle	Obstacle Width [m]	Obstacle Height [m]
1	2074	10.6	10.6
2	1	0.2	0.2
3	47	2	1.2
4	1	0.2	0.2
5	1	0.2	0.2
6	3	2	2
7	1	0.2	0.2
8	1	0.2	0.2

Step 5: After detecting the obstacles, the next step is path planning. Given two random points A and B in the graph, the objective is to:

1. Determine the shortest path from A to B avoiding the obstacles.
2. Determine the path from A to B avoiding obstacles and with the fewest possible directional changes.

In Figure 3 three potential paths from A to B are illustrated. Path I is the path from A to B by going around the obstacle (dashed lines, points 0 to 24). Path I might involve the longest path as well as most directional changes. Path II shows the shortest path from A to B involving the least number of directional changes. In addition, Path III maintains a safe distance to the obstacle.

To keep a safe distance a convex hull algorithm identifies the obstacle contours and encompasses the obstacle with a convex polygon. To minimize directional changes, the slope curve of changes based on the distance to the obstacle origin ("0") is calculated.

A change of slope occurs at every corner of the obstacle (in Figure 3, points: 0, 4, 8, 9, 12 and 18). For the outer boundary points, the angle of deviation is always greater than 180°, and for inner boundary points it is always less than 180°. For example, the angle of deviation at points 4, 9, 12 and 18 is greater than 180° and the angle of deviation at point 8 is less than 180°. This important feature is used in identifying the outer boundary points of an obstacle. In addition to the boundary, the convex hull assumes a fixed threshold (distance *d*) to maintain a safe distance to each object. The blue boundaries in Figure 6 demonstrate that all eight objects have been classified and displayed using polygonal shaped boundaries (with obstacle one being the large white area surrounding the worker's travel path).

The developed algorithms have been verified in other data sets where the path of the worker varied. Results to a worker walking in an "Eight" are illustrated in Figures 6 and 7. Dimensional results are presented in Table 3.

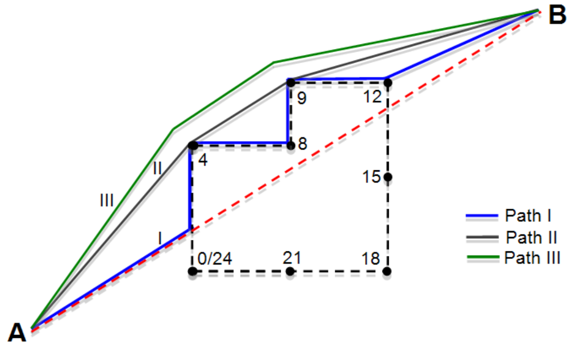

Figure 3. Path Planning

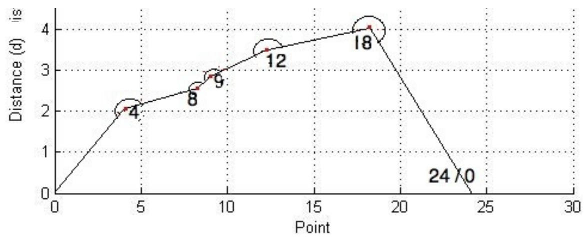

Figure 4. Slope Changes

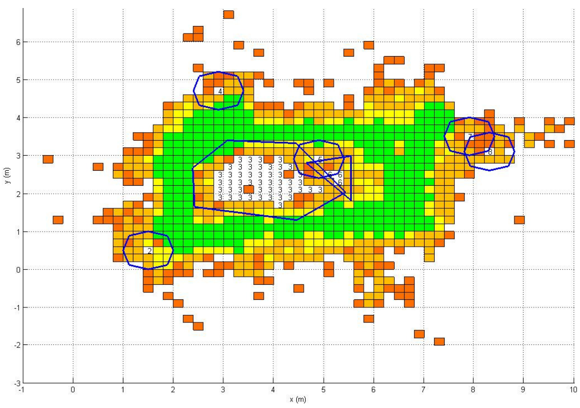

Figure 5. Outer boundaries of obstacles

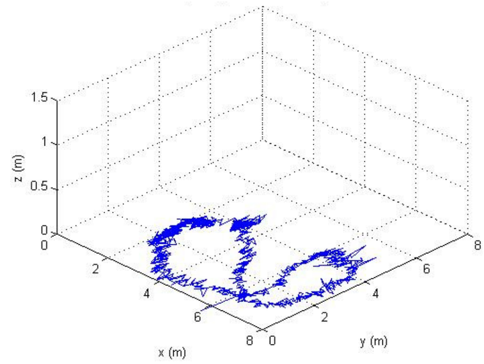

Figure 6. Path of a worker in the experiment

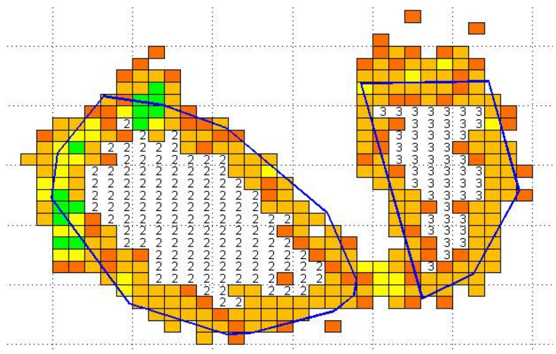

Figure 7. Outer boundaries of obstacles

Table 3. Dimensions of detected obstacles

Obstacle ID	Cells in Obstacle	Obstacle Width [m]	Obstacle Height [m]
1	2438	10.6	10.6
2	127	2.8	3
3	51	1.2	2.6

6. CONCLUSIONS

Emerging Ultra Wideband technology allowed collecting spatial data of the trajectory of construction workers. The presented and developed algorithms are capable of locating and identifying obstacles, and determining their dimensional values. This new information can be used for safe path planning efforts. Multiple application areas in construction can benefit from this approach and in particular the envisioned semi- or automated navigation of robots. Future research will go beyond analyzing the travel patterns of workers and will focus on identifying work patterns among construction resources (workers, machines, and materials) to overall increase efficacy and safety.

7. ACKNOWLEDGMENT

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