CONSTRUCTION INDUSTRY COUNCIL
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S-HELMET: A PROACTIVE CONSTRUCTION SAFETY MANAGEMENT SYSTEM BASED ON REAL-TIME LOCALISATION

RESEARCH SUMMARY

Construction Industry Council

s-Helmet: A Proactive Construction Safety Management System based on Real-time Localisation

Research Summary

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FOREWORD

The fatality and accident frequency in Hong Kong construction industry had been declined but accident due to striking against fixed objects or by moving objects remained about 25% of total number of accident. It was necessary to make a break-through to enhance safety performance in this area.

While the construction site safety usually relies on the indication signs, barriers and personal protection equipment, a more proactive device can be helpful for providing warnings to workers before entering to a risky area. Hence, the Construction Industry Council (CIC) initiated the research by engaging a research team from The Hong Kong Polytechnic University to develop s-Halmet, which could be one of the innovative technology to reduce and avoid accidents in the construction site. The research team had successfully built a prototype based on the research study.

The research work presented in this report was funded by the CIC Research Fund, which was set up in September 2012 to provide financial support to research institutes/construction industry organizations to undertake research projects which can benefit the Hong Kong construction industry through practical application of the research outcomes. CIC believes that research and innovation are of great importance to the sustainable development of the Hong Kong construction industry. Hence, CIC is committed to working closely with industry stakeholders to drive innovation and initiate practical research projects.

The research work described in the report was carried out by a research team led by Prof. Jiannong CAO from The Hong Kong Polytechnic University. The project cannot succeed without the dedicated effort of the research team. I would like to thank to all who took part in this valuable work.

Ir Albert CHENG
Executive Director of Construction Industry Council

PREFACE

Construction site accidents account for nearly one fifth of all the industrial accidents in Hong Kong. This project aims to improve the construction site safety by providing a prototype of construction site management system that can monitor the real-time locations of workers and objects and provide alarm when the workers are approaching to the dangerous areas.

The Research Team would like to thank the Construction Industry Council for their financial support to this Research. Over the past 20 months, unreserved support, enduring guidance and constructive comments have been provided by colleagues of the Construction Industry Council. They have made this study possible and their generosity is hereby gratefully acknowledged.

In the summary of the final report, we will describe the research highlights, methodologies and findings of this project.

Prof. Jiannong CAO
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RESEARCH HIGHLIGHTS

Construction site accidents account for nearly one-fifth of all the industrial accidents in Hong Kong. It would be highly desirable to have a proactive safety management system for continuously monitoring workers' locations and automatically issue warning alarms. This research describes as s-Helmet, which is a system for construction safety based on the real-time localisation technique. In the s-Helmet, wireless tags are attached to safety helmets of workers and other moving objects to track their locations in real time. When a worker is moving near danger zones (e.g. edge of working platform, close to moving objects or electric discharge, etc.), the helmet will automatically issue an alarm to the worker as well as construction site coordinators. The results of s-Helmet show its great potential to avoid the construction accidents and its great impact on the construction safety in Hong Kong.

The s-Helmet is based on CSS-UWB (Carrier-based chirp spread spectrum- Ultra wide band) technology, which is suitable for construction site environment due to its high accuracy, low latency, large communication range, and ease of deployment. However, applying this CSS-UWB technology directly into the localisation for mobile objects faces many challenges including the interference, and the NLOS (non-line of sight) effect.

s-Helmet utilizes two localisation patterns: anchor-based localisation and relative distance. In the first pattern, anchor nodes deployed in the construction site will broadcast CSS-UWB pulses, which are received by nearby tags to determine its 3D location. However, only using the first approach is not sufficient to provide the real-time locations of all the tags. The construction site environment is complicated and it is common that the communication link between a tag and the nearby anchors can be lost. The relative distances of a construction worker to some dangerous zones (e.g. holes, electric discharge, moving vehicles) can be more useful. In other words, we only need to alarm a worker, who is near a danger zone. In this condition, we can simply deploy a number of anchor nodes in the danger zones and they will detect the relative distance to a worker wearing a s-Helmet. When a worker's distance to a dangerous zone is smaller than a threshold, alarms will be issued. This pattern is called as relative distance. This approach can help improve the performance of the s-Helmet.

The s-Helmet utilizes CSS-UWB transceiver as the localisation unit. In addition, an inertial measurement unit (MPU9150) which contains 3-axis accelerometers, a 3-axis gyroscope and a 3-axis digital compass is also included. The software of the s-Helmet consists of two parts: Software for tags / anchors and for the central server. The tags / anchor software part includes ranging protocol, communication protocol, and localisation algorithms. The central server software focuses on the graphical user interface.

To test the performance of our localisation system, localisation experiments were conducted in different conditions including both outdoor and indoor environments. In an open space like the P podium in The Hong Kong Polytechnic University (PolyU) and the square near the Hong Kong Coliseum. The minimum localization error is 0.6-0.8m and the maximum localization error is about 2-3.2m. In some complex areas, like the T core at the PolyU, and also in the indoor environment, the average localization error is about 1.8~2.3m, with the maximum error to be 3~3.5m. We have also carried out an experiment in a real construction site and the average location error is about 2.2m, with the maximum localisation error to be 3.1m.

We also discuss some import issues in the s-Helmet including the privacy issues, the responsibility issue, the acceptable range of the accuracy level of preventing accidents, the cost issue, and the health issue.

There are still some problems for the s-Helmet. We find through our tests that the packet loss rate of the s-Helmet can reach 8% in some conditions, especially in out-door environment due to the Non-line-of-sight effect and the wireless interference. In addition, the localization error of the s-Helmet in some conditions can reach more than 3 meters due to the NLOS effect. How to address these two problems is the future focus of this project.

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1 INTRODUCTION

1.1 Background

Construction site accidents account for nearly one-fifth of all the industrial accidents in Hong Kong. It would be highly desirable to have a proactive safety management system for continuously monitoring workers' locations and automatically issue warning alarms. This research describes as s-Helmet, which is a system for construction safety based on the real-time localisation technique. In the s-Helmet, wireless tags are attached to safety helmets of workers and moving objects to track their locations in real time. When a worker is moving near danger zones (e.g. edge of the working platform, close to moving objects or electric discharge, etc.), the helmet will automatically issue an alarm to the worker as well as the construction site coordinators. The results of the s-Helmet show its great potential to avoid construction accidents and its great impact on the construction safety in Hong Kong.

1.2 Aims and Objectives

The overall aim of this research is to improve the construction site safety by providing a prototype of construction site management system that can monitor the real-time locations of workers and objects, and provide alarm when the workers are approaching to the dangerous areas. The specific research objectives are:

(1) Review and analyze design issues of the s-Helmet.

(2) Design hardware localisation module based on Nanotran ranging techniques.

(3) Design and implement information fusion algorithms in the s-Helmet to integrate ranging information with accelerometers and gyroscopes.

(4) Design and implement mechanisms in the s-Helmet to realize real-time, scalable, long-term and robust localisation of construction workers.

(5) Develop backstage management software system for s-Helmet.

(6) Evaluate the results by simulation, laboratory testing and in-field deployment.

1.3 Scope

The scope of this research project includes developing the demo version of the real-time localization system and testing in some environments.

2 RESEARCH METHODOLOGY

The key for the s-Helmet is a high accurate localization system. In order to realize such a system, we have taken the following procedures.

Frist, we analyzed the requirements for the Real-Time Localization System (RTLS) systems that can be regarded as practical RTLS for construction site management. The localisation accuracy, the updating frequency, the scalability, and the system lifetime are the most important criterion for the s-Helmet.

Second, we carried out a comprehensive literature review on the existing works of in-door and out-door localisation techniques, especially those that can be utilized for construction site management. We realized that due to its high accuracy, low latency, large communication range, and ease of deployment, the UWB (Ultra Wide Band) technology using CSS (Carrier based Chirp Spread Spectrum)-UWB is suitable for construction site environment. However, applying CSS-UWB directly into the localisation site still have many challenges, including the problems of NLOS (Non-line-of-sight).

Third, we designed the hardware localization module based on Nanotran ranging techniques (see Fig. 1). The s-Helmet utilizes CSS-UWB transceiver as the localisation unit. In addition, an inertial measurement unit (MPU9150) which contains 3-axis accelerometers, a 3-axis gyroscope and a 3-axis digital compass are also included. The MPU9150 senses movement of the tag node. This extra information is utilized to improve localisation accuracy as well as decrease power consumption.

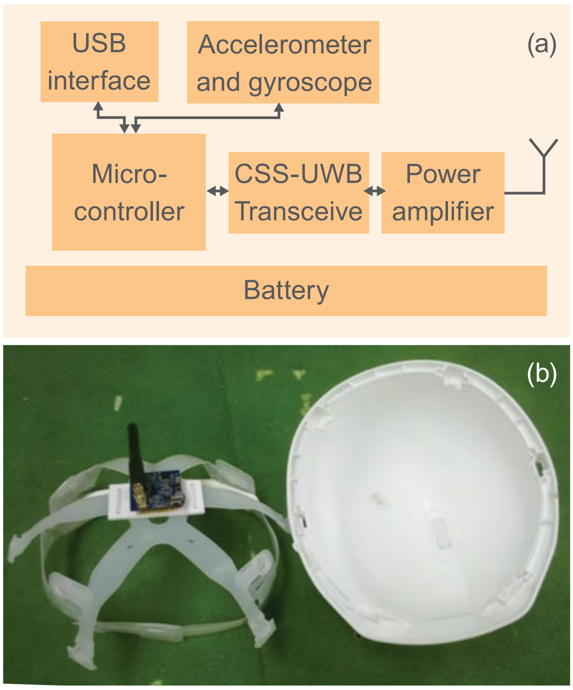

Fig 1 (a) The hardware design of the s-Helmet (b) The s-Helmet

Fourth, we designed and implemented information fusion algorithms in the s-Helmet to integrate ranging information with accelerometers and gyroscopes (see Fig. 2). In particular, we designed an orientation estimation module which fuses data from the compass, gyro, and accelerometer, to ensure high reliability and accuracy of user orientation. We also designed a step detection module to eliminate the accumulating error when using accelerometers. All the information mentioned above, along with the distances measured from Nanotran nodes, is integrated using the Kalman filter.

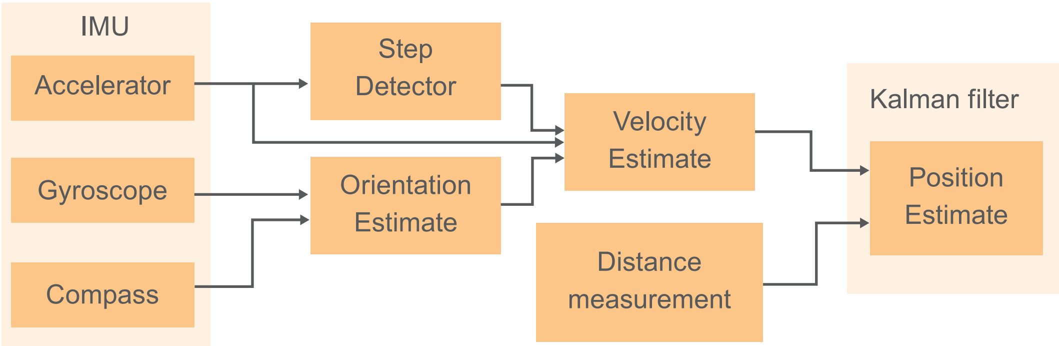

Fig 2 Localisation algorithm

Fig. 3 shows an application of this system in the construction site management. In this scenario, to prevent the occurrence of some accidents, the positioning of construction workers and the mechanical devices such as forklifts, cranes need to be delivered to a remote center in a real-time manner. To achieve this objective, a number of CSS-UWB anchors are deployed at different corners of the construction site, which will facilitate the communications with the tags. Each tracked object is attached with a CSS-UWB tag. The real-time location information of each tag will be transmitted to the nearby anchors (in the anchor-based localisation pattern), or to the nearby tags known their locations (in the tag-assisted localisation pattern). The information will then be forwarded to a remote management system to display the real-time locations.

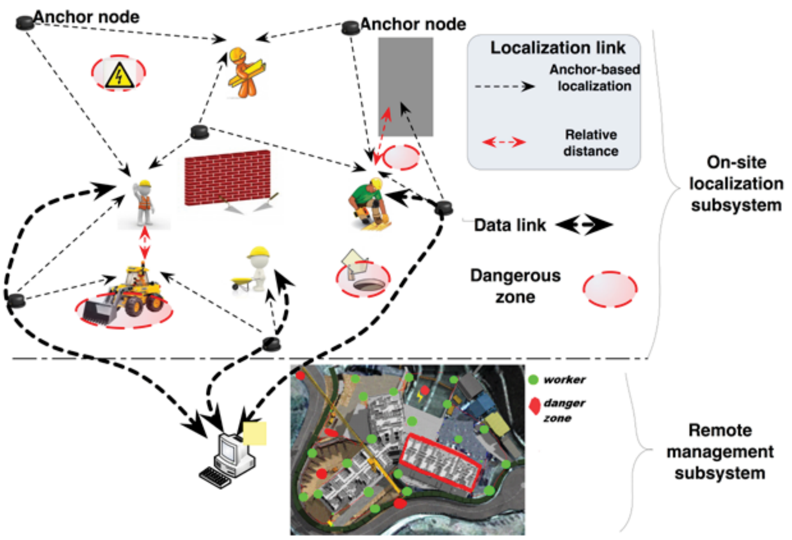

Fig 3 The overview of the RTLS to be developed

Fifth, we tested the Nantran ranging module and evaluated its accuracy, communication range, and reliability in different conditions including both outdoor and indoor environments, as listed below:

- We conducted the experiment near the P podium at the PolyU with the experiment area of 14x12m^2. The results showed that the mean outdoor localisation error was about 0.8m, with the variance to be 0.55m. The maximum localisation error in the whole experiment was about 2 meters.
- We conducted the experiment outside the Hong Kong coliseum. We placed four anchors at four corners of our experiment area. The experiment area was 40x15 m^2. The results showed that the average localisation error is about 0.6m, with the maximum localisation error to be 3.2m. In addition, we found that during the testing, some wireless packets were lost with packet loss rate of 7%.
- We carried out the experiment in the campus of PolyU, near the T core. The experiment area was 40x30 m^2. The experiment included 10 anchor nodes, 2 moving tag nodes, and a central server. The results showed that the average localisation errors for the two tags are about 2m and 2.3m respectively, with the maximum localisation error to be 3.5m and 2.8m.

- We conducted the indoor experiment in the PQ703 at the PolyU and placed four anchors at four corners of our experiment area with size of 9×6 m^2. The results showed that the average localisation error in this test is about 1.8m, with the maximum localisation error to be 3m.
- Finally, we carried out an experiment in a top floor of a construction site, Lin Tsui Estate, at the Lin Shing Road, Chai Wan. The testing area was about 16×21 m^2. We deployed four anchor nodes and one person was wearing the helmet and walking at a speed about 0.5m/s. Each test lasted about 2~3 minutes, and we carried out a total of 4 tests in the construction site. The statistical results showed the average location error in these four tests are 2.3m, 1.9m, 2.1m, and 2.7m, with the maximum localisation error to be 2.8m, 2.5m, 2.4m and 3.1m, respectively.

To summarize, we have carried out a number of tests in different scenarios including both outdoor and indoor environments. In an open space, the localization error was low to 0.6~0.8m, with the maximum localization error about 2~3.2m. In some relatively more complex areas and the indoor environment, the average localization error was about 1.8~2.3m, with the maximum error to be 3~3.5m. In a real construction site, and the average location error was about 2.2m, with the maximum localisation error to be 3.1m.

We summarized the potential problems of the s-Helmet and the potential solutions found during the experiments.

- Packet loss rate: We found through our tests that the packet loss rate of the s-Helmet can reach 8% in some conditions, especially in out-door environment. We believed that the solution was to leverage the information from sensors embedded in tags to localize itself without the assistance of anchors.
- NLOS(Non-line-of-sight) effect: We found that in a relatively open environment, the localization error was small but in more complex environments with many blocks and NLOS effects, the localization error increased to 2 meters or even higher. The NLOS effect could be alleviated if the role of anchor nodes can be partially replaced by nearby tags with known locations.

3 RESEARCH FINDINGS AND DISCUSSION

We have carried out a number of tests in different scenarios in both outdoor and indoor environments. In an open space like the P podium at the PolyU and the square near the Hong Kong Coliseum. The minimum localization error is 0.6~0.8m and the maximum localization error is about 2~3.2m. In some complex areas, like the T core at the Poly U, and also in the indoor environment, the average localization error is about 1.8m~2.3m, with the maximum error to be 3m~3.5m. We have also carried out an experiment in a real construction site and the average location error is about 2.2m, with the maximum localisation error to be 3.1m. The detailed experimental results are as follows.

1. Experiment 1: Outdoor Environment (small area)

The experiment in an open and small area is to test the performance of our s-Helmet in a generally ideal condition.

The experiment includes 4 anchor nodes, 1 moving tag nodes, and a central server. Four anchors were installed at each corners of experiment area and we calculated its position in advance. Coordinator anchor scheduled the tag with 1 second reporting period and measurements were refreshed in our GUI screen with accurate position. Tag could move anywhere in a cell, and would be displayed in a screen as real-time tracking. Low-power and highly efficient localisation were shown in our experiment.

We conducted the experiment near the P podium at the PolyU. We placed four anchors at four corners of our experiment area as shown in the Fig.4 (a). The experiment area was 14x12m^2. A person wearing the s-Helmet followed the predesigned traces at an approximately constant speed about 1m/s. The calculated position was sent to central server through a network coordinator which was one of anchor nodes using USB interface.

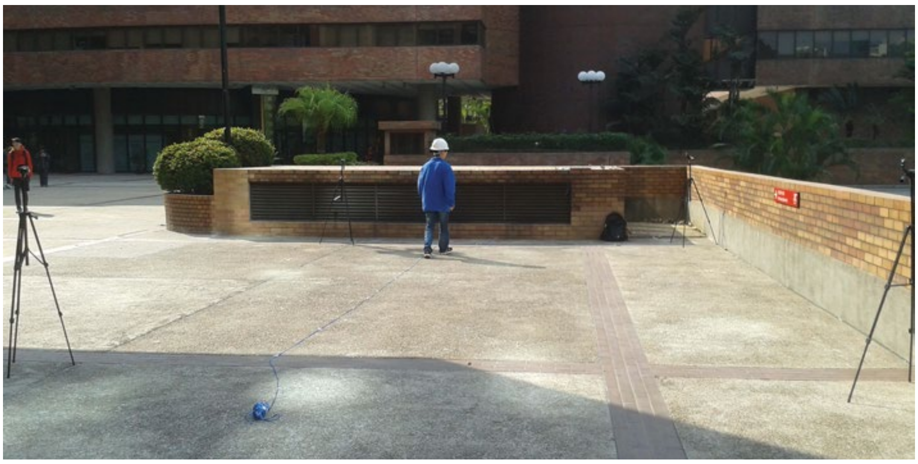

Fig 4(a) Outdoor experiment at the PolyU - Localisation Scenario

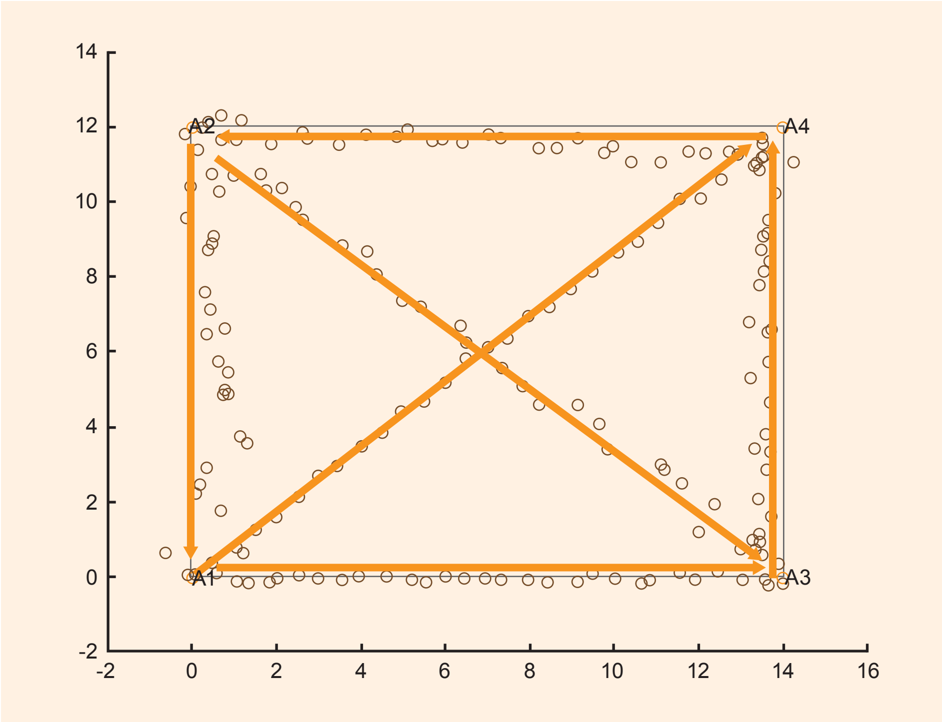

Fig 4(b) Outdoor experiment at the PolyU - Localisation Results

The experiment result is shown in Fig. 4 (b). The orange curves are the real traces and the locations of anchors are shown as A1~A4. The final locations determined are shown as brown dots in the figure. The results showe that the mean outdoor localisation error is about 0.8m, with the variance to be 0.55m. The maximum localisation error in the whole experiment is about 2 meters. The accuracy of the localization error will directly affect the performance of the s-Helmet in preventing a construction worker to walk in to a danger zone. For example, for a danger zone defined as a circle centered at (x,y) with radius R=2 meters, if the localization error is r=0.8 meters. Then the probability of false negatives (determining the worker is not in the danger zone but actually he is) is.

$$P_1 = \frac{r^2}{(r+R)^2} = 8\%$$

This results show that our system has a relatively high accuracy in open and small areas.

2. Experiment 2: Outdoor Environment (large area)

We conducted the experiment outside the Hong Kong coliseum. We placed four anchors at four corners of our experiment area. The experiment area is 40x15m^2. We attached one tag inside a safety helmet, and let a person wearing the safety helmet to follow the predesigned traces at a constant speed (Fig. 5(a)). The experiment results are shown in Fig.5(b). The orange curves are the real traces and the locations of anchors are shown as A1~A4. The final locations determined are shown as brown dots in the figure.

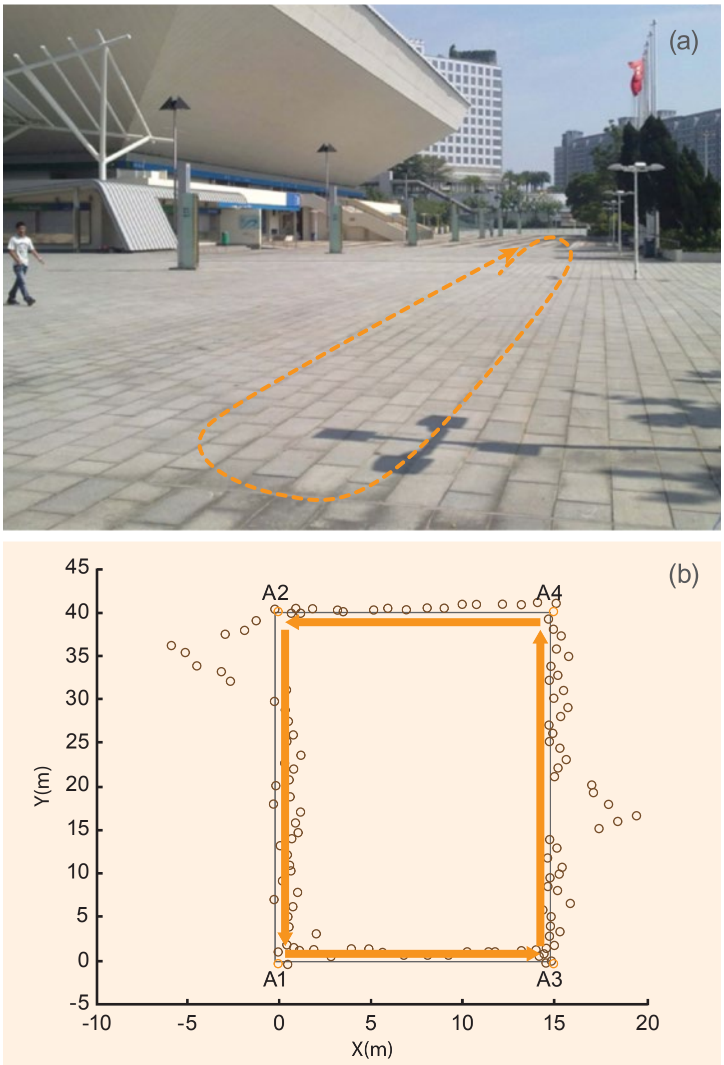

Fig 5 Outdoor experiment at the Hong Kong coliseum
(a) Testing scenario (b) Localisation results

The results showed that the average localisation error is about 0.6m, with the maximum localisation error to be 3.2m. In addition, we found that during the testing, some wireless packets are lost with packet loss rate of 7%.

3. Experiment 3: Outdoor Environment (multiple tags)

This experiment tried to demonstrate the performance of the system when multiple tags are localized at the same time. The experiment includes 10 anchor nodes, 2 moving tag nodes, and a central server. This experiment is carried out in the campus of the PolyU, near T core (see Fig. 6(a)). The experiment area is 40x30m^2. We adopted 10 anchor nodes due to complex environmental conditions. We found that the wireless communication in this area could be negatively affected by the NLOS effect. Therefore, we deployed 10 anchor nodes to ensure that wherever in any location within the area, the tag can receive signals from at least three anchor nodes. The experiment results were shown in Fig. 6(b). The orange curves are the real traces and the locations of anchors are shown as A1~A10. The final locations determined are shown as brown dots in the figure.

Fig 6(a) Outdoor experiment 3 at the PolyU -Testing scenario

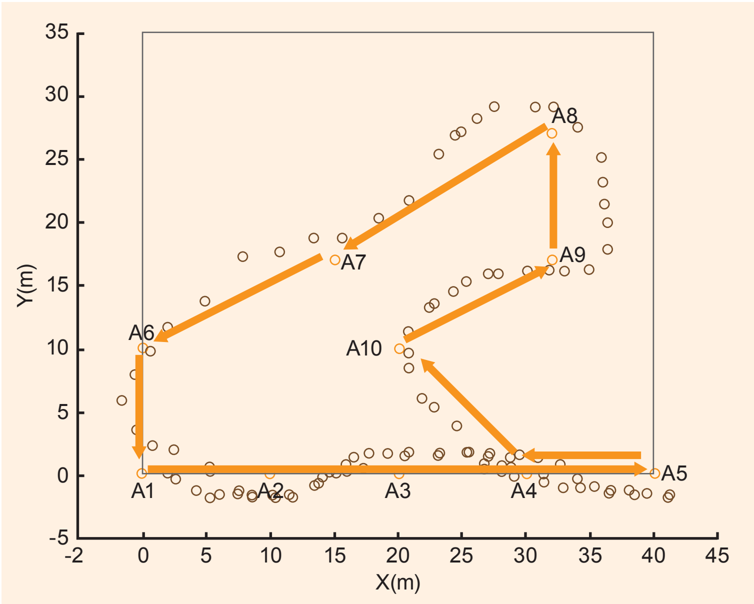

Fig 6(b) Outdoor experiment 3 at the PolyU - Localisation results

The results showed that the average localisation errors for the two tags are about 2m and 2.3m respectively, with the maximum localisation error to be 3.5m and 2.8m.

4. Experiment 4: Outdoor Environment (dangerous areas)

We conducted an experiment at the PolyU W core (shown in the upper figure of Fig. 7) to demonstrate the performance of the s-Helmet in the presence of dangerous areas. This area was about 28m×18m, and we deployed 5 anchor nodes in this areas. The tester wearing a s-Helmet walked at approximately 0.75m/s in this area, following the traces A-B-C-D (shown in the lower figure of Fig. 7). During the test, we set two fixed dangerous areas (one at location B and the other at location D). In addition, we also let another person serve as a moving dangerous area: when tester was near location C, this person approached to him and met the tester at location C. Note that at each of the three dangerous areas, an extra anchor node was installed at the center of the dangerous area and broadcasts CSS signal continuously. Here we utilized a hybrid strategy to issue an alarm: (1) We determine the absolute 3D locations of the tester. As the locations of the dangerous areas are pre-defined, we can calculate the distance between the tester and the dangerous areas. In this experiment, if the distance is smaller than 3 meters, an alarm would be issued. (2) The tag installed on the s-Helmet of the tester will receive the ranging data from the anchor nodes installed in the three dangerous areas. Then we adopted the two-level alarm strategy. When the tag finds that its distance to a dangerous area is shorter than 5m, a single alarm will be issued to the worker. No more alarm will be given unless the distance is shorter than the second threshold, which is set to be 3 meters.

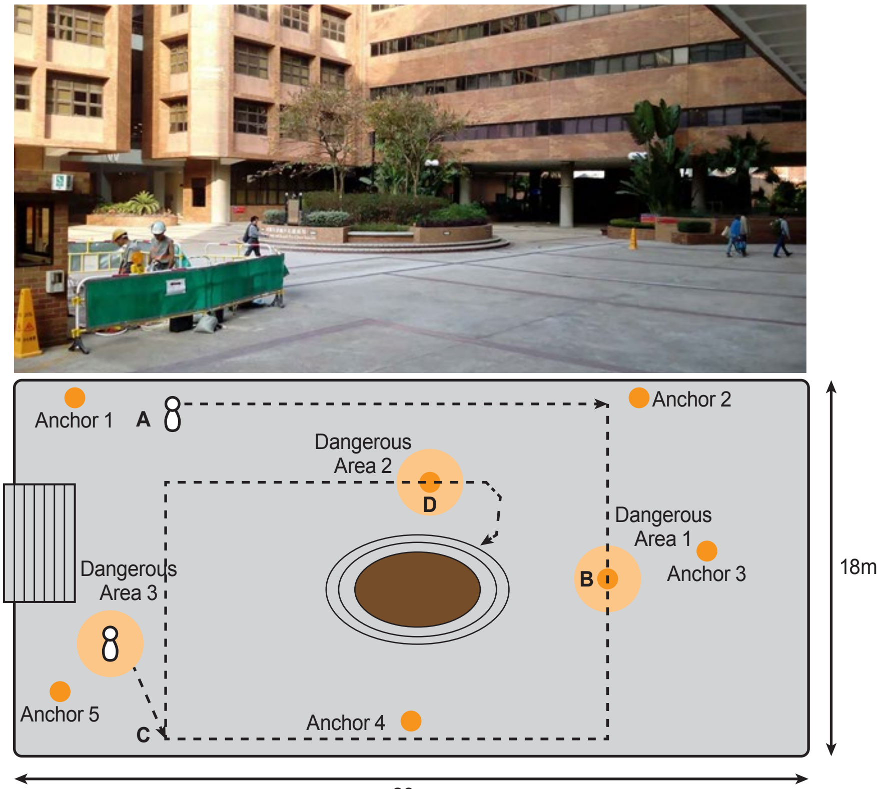

Fig 7 The experiment to test the performance of the system in the presence of dangerous areas

We carried out the experiment for 10 times. For a single experiment, we recorded the number of false positive alarms (an alarm is falsely issued when the person is not near a dangerous area) and false negative alarms (no alarm is issued when the person is near a dangerous area). Table 1 shows the testing results. In the 10 tests, the s-Helmet only missed an alarm in one test at dangerous area 2. It is because the wireless commutation was lost due to the crowed people nearby during at that time. The total false negative rate is 29/30=96.7%. For the 10 tests, we also recorded that 4 alarms were issued when the person was not in the dangerous area.

Table 1 Testing results for dangerous areas

	Dangerous area 1	Dangerous area 2	Dangerous area 3	Areas other than the dangerous areas
Number of alarm issued	10	9	10	4
Rate	False negative rate: 29/30			

5. Experiment 5: Indoor Environment

We conducted the indoor experiment at room PQ703 in the PolyU. We placed four anchors at four corners of our experiment area as shown in the Fig.8. The experiment area is $9x6m^2$. We attached one tag inside a safety helmet and let a person wearing the safety helmet to follow the predesigned traces at a constant speed. The trace is shown in Fig. 8(b) as the orange curves, which were the real traces and the locations of anchors were shown as A1~A4. The final locations determined were shown as brown dots in the figure.

Fig 8(a) Indoor experiment - Testing scenario

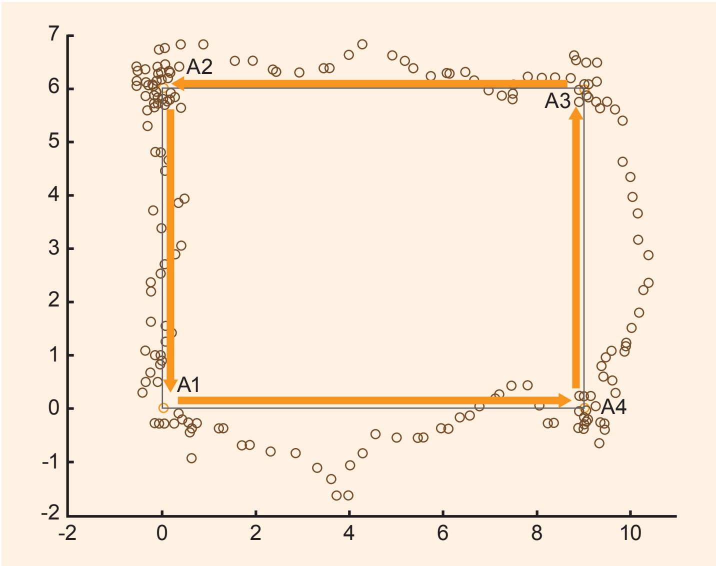

Fig 8(b) Indoor experiment - Localisation results

The results showed that the average localisation error in this test is about 1.8m, with the maximum localisation error to be 3m. In addition, we found that during the testing, some wireless packets were lost with packet loss rate of 2.2%.

6. Experiment 6: Testing in a construction site

We carried out an experiment on the top floor of construction site at Lin Tsui Estate, on the Lin Shing Road, Chai Wan. Fig. 9 shows the floor plan.

The testing area was about 16m(length)×21m(width). We deployed four anchor nodes shown as the red dots in Fig. 9. In this test, one person wearing the helmet walked at a speed about 0.5m/s. The red curve showed the walking track. Each test lasted about 2~3 minutes, and we carried out total 4 tests in the construction site. Fig. 10 showed some figures during the tests.

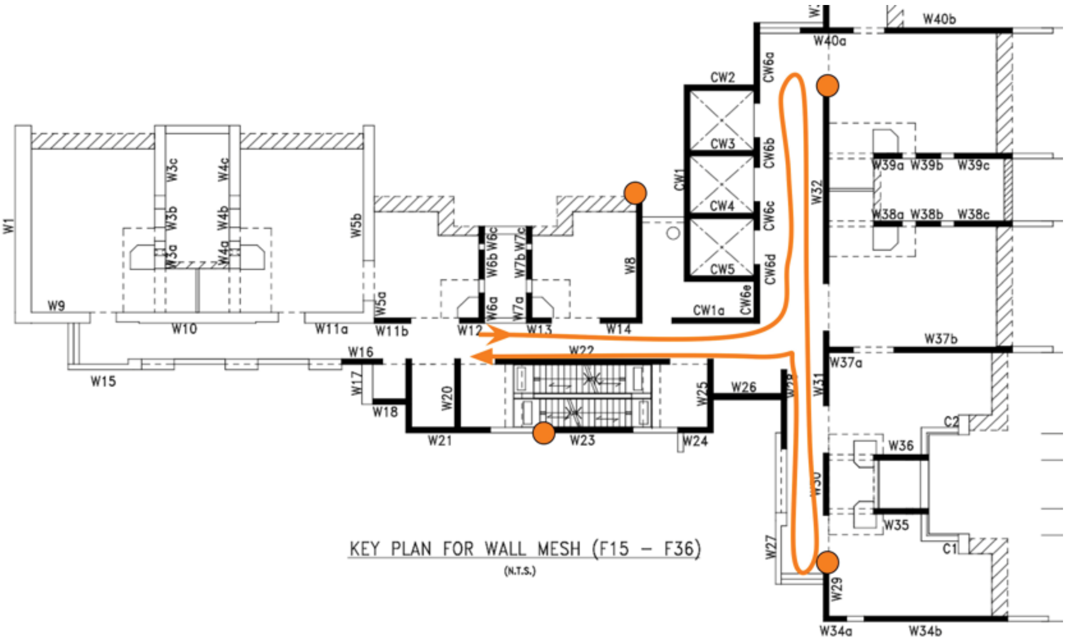

Fig 9 Floor plan in a construction site in Chai Wan

Fig 10 The routes during real tests

Fig. 11 shows the localization results in the four tests. Each brown dot is a localization point determined by the s-Helmet and the orange lines show the true traces. The average localization error in these four tests are 2.3m, 1.9m, 2.1m, and 2.7m, with the maximum localisation error to be 2.8m, 2.5m, 2.4m and 3.1m, respectively.

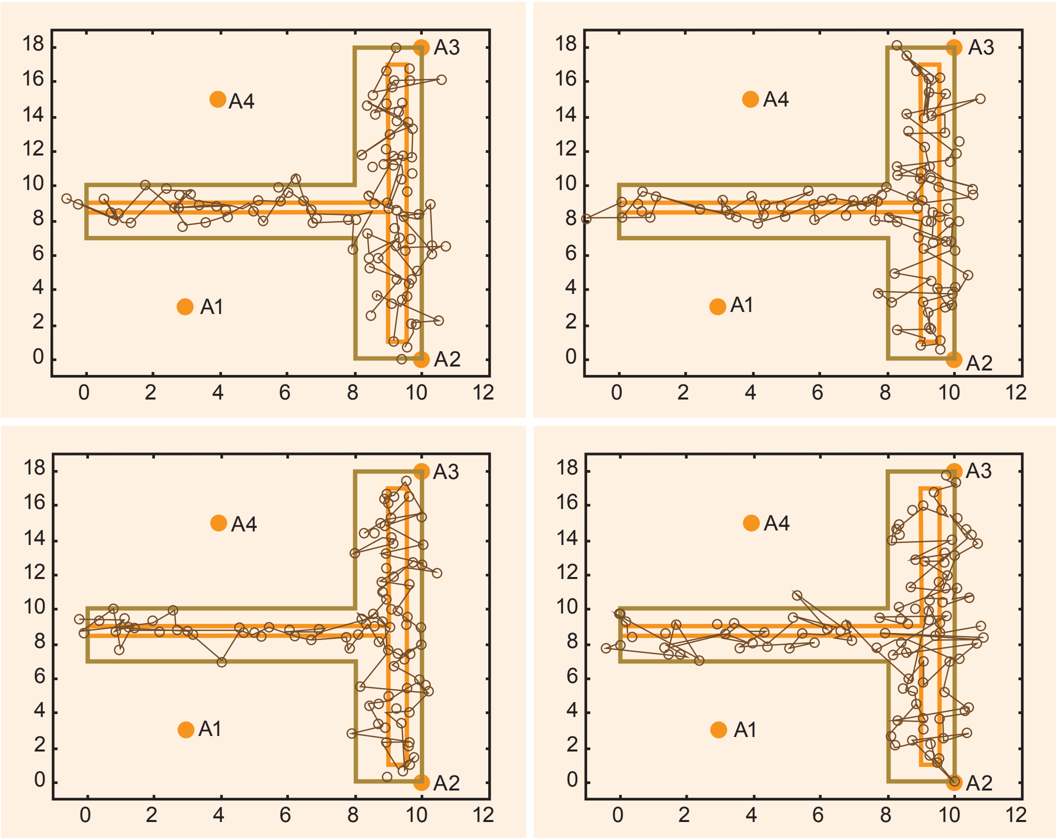

Fig 11 Localization results in the construction site

To improve the localization accuracy, adding the map information is a common approach. This process is generally called as map matching. The basic idea is to project the estimated localization to the nearest point on a path in the digital map. The objective of the s-Helmet is to provide timely and reliably alarm when the possible danger is likely to occur soon. If map-matching is adopted, the localization accuracy can be expected to lower down immediately. The consequence is that when the person is near the dangerous area, the map matching will cause the determined location points to be out of the dangerous areas. Therefore, in a construction site, it is more appropriate to determine the localization without using the map matching technique. Specifically, it is more advisable to not only determine the absolute locations of a construction worker, but also the relative distances of a construction worker to a dangerous area, which can further improve the utility of the system.

To summarize, we have the following research findings.

1. It is important to utilize relative localization strategy. We realized that although the localization algorithm can determine the absolute 3D locations of a construction workers, the relative distances of a construction worker to some dangerous zones (e.g. holes, electric discharge, moving vehicles) can be more useful. In this condition, we can simply deploy a number of anchor nodes in the danger zones and they will detect the relative distance to the s-Helmet users. When they are close to a dangerous zone, alarm will be issued.

2. It is important to utilized the information from inertial sensors to improve the localisation accuracy. Purely using the ranging information from the Nanotran nodes generally can only achieve high accuracy in an open and wide environment. This problem can be mitigated if the tag can collect some extra information from accelerometers, and gyroscopes (i.e. inertial sensors). The information from tags and the CSS-UWB technique can be integrated, through Kalman filter, to provide users more accurate location.

3. The deployment of anchor nodes is important to improve the accuracy. In real construction site, using a wireless localization system like s-Helmet will face more challenges than in an open space, due to the complex environment for wireless communications. The packet loss rate in the construction site is much higher than those obtained in PolyU and the Hunghom stadium. One possible solution is to place the anchor nodes higher in the construction site such that they have direct line-of-sight to the tags.

4. Map-matching technology should be used with caution. To improve the localization accuracy, adding the information of the map is a common approach. This process is generally called as map matching. The basic idea is to project the estimated localization to the nearest point on a path in the digital map. The objective of the s-Helmet is to provide timely and reliably alarm when a possible danger is likely to occur soon. If map-matching is adopted, the localization accuracy can be expected to lower down immediately. The consequence is that when the person is near the dangerous area, the map matching will cause the determined location points to be out of the dangerous areas. Therefore, in a construction site, it is more appropriate to determine the localization without using the map matching technique.

5. The radiation of the s-Helmet meets the safety requirement. Radiation could be a concern from contractors or workers when wearing the s-Helmet. Part of the radio waves emitted by the tag embedded in a helmet can be absorbed by the worker wearing it. The radio waves emitted by a tag is less than 100mw, which is less than 200mv~400mw in normal smartphones that have been commonly used. Therefore, we believe that our s-Helmet will not cause health issue to the construction workers.

4 RECOMMENDATIONS

Based on the research findings, we have the following recommendations for a localization system in a construction site:

1. Although the localization algorithm can determine the absolute 3D locations of a construction worker, the relative distances of a construction worker to some dangerous zones (e.g. holes, electric discharge, moving vehicles) can be more useful.
2. It is important to incorporate different types of information including ranging, accelerations, velocities to provide more accurate location.
3. It is important to improve the accuracy of the anchor nodes deployment. One suggestion is to place the anchor nodes higher in the construction site such that they have direct line-of-sight to the tags.
4. Although map-matching technology can significantly improve the accuracy of localization, it will cause the determined location point to be out of the dangerous area.

We summarize the potential problems of the s-Helmet and the future directions as below.

(1) Packet loss

We found through our tests that the packet loss rate of the s-Helmet can be high in some conditions, especially in out-door environment. There are two major reasons for the packet loss. (1) The Non-line-of-sight effect, which means that between the tag and the anchor, there are some other objects or human such that the communication between them is negatively affected. (2) Wireless interference with other tags and anchors nearby. Although we have designed contention less TDMA (Time Division Multiple Access)-based MAC (Medium Access Control) protocol, the inferences among nearby tags and anchors cannot be 100% avoided.

The packet loss can be partially addressed by increasing the transmission power of tags and anchors, but the price to pay is the higher energy consumption. We believe that a better way is to find an approach to realize accurate localization in the presence of packet loss. The obvious solution is to leverage the information from sensors embedded in tags to help to localize itself without the assistance of anchors. In our current s-Helmet system, we utilize the Kalman filter to improve the localization accuracy in the presence of ranging error. We believe that the same technique can be applied to solve the packet loss problem.

(2) High localization error in some testing scenarios

In a relatively open environment, the localization error is low but in more complex environments with many blocks and NLOS effects, the localization error increases to 2 meters or even higher.

The NLOS effect can be alleviated if the role of anchor nodes can be partially replaced by nearby tags with known locations. This idea is very simple, when a tag has already determined its locations, it will act like an anchor node by broadcasting ranging information with its locations. This approach can increase the number of sensor nodes that can directly communicate with each other and therefore the NLOS effect can be alleviated.

(3) Capability to track swarm of objects

When a swarm of objects in a small area need to be tracked, the UWB signals sent by the tags attached to workers can interfere with each other. This can result in many problems including large delay or packet loss, significantly downgrading the performance of the system. Moreover, the NLOS effect, which will decrease the accuracy of positioning, becomes more obvious in the presence of a swarm of objects since the CSS-UWB pulses used for positioning can be blocked, reflected when they are traveling between tags and anchors. If not handled well, this performance of the system can be significantly downgraded.

To solve the first problem, the timing of the tags sending the UWB signals need to be scheduled to decrease the un-necessary transmissions and collisions. For example, when the tag is at still or moving in a speed lower than 1m/s, the transmission frequency will be correspondingly decreased. Compared with the approach where the beacon signal of each tag is broadcast in a constant frequency, this mode can significantly decrease the number of un-necessary transmissions. The mobility of a tag can be determined by the tag itself, via evaluating the last few locations, or by the accelerometer embedded in the tag carried by the same object where the tag is attached.

To avoid the possible collisions or multiple re-transmissions, it is also advisable that nearby tags should schedule their timing for broadcasting the CSS-UWB signal. To achieve this goal, we should design an efficient scheduling scheme which combines the CSMA (Carrier Sense Multiple Access) and TDMA (Time-Division Multiple Access) accessing mode.

(4) The power consumption

The current battery cannot support a whole day operation. Therefore, the power consumption is still a problem for a practical system. To solve the problem, we have the following suggestions. (1) Adopt more powerful battery (2) utilize activity-aware power mechanism. The idea is to turn off the main power automatically when the s-Helmet detects a worker is not moving. (3) Design some energy-harvesting mechanism to obtain power from solar.

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