# Final Measurement and Verification Report for I&T Trial Project

Application of Gait Analysis

I&T Project No. : P-0071
I&T Wish No. : W-0151
I&T Solution No. : S-0093

E&M InnoPortal

EMSD

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## Purpose of the Project and Target Deliverables

To promote healthy workplace habits, the Electrical and Mechanical Services Department (EMSD) would like to encourage the staff on using staircase by holding a stair climbing campaign in the organization. However, violation of campaign rules are difficult to monitor with existing applications. To facilitate innovation and technology development, EMSD engaged a company to utilize gait analysis for

(i) identity authentication; and

(ii) accurate step counting.

## Project Description

In this project, Lambda Sense Limited (LDS) worked with EMSD to conduct a Stair Climbing Campaign in June 2019 (from 1st to 30th of June). In this Campaign, LDS customized a Mobile App for this purpose on both Android and iOS Smartphone platforms, respectively.

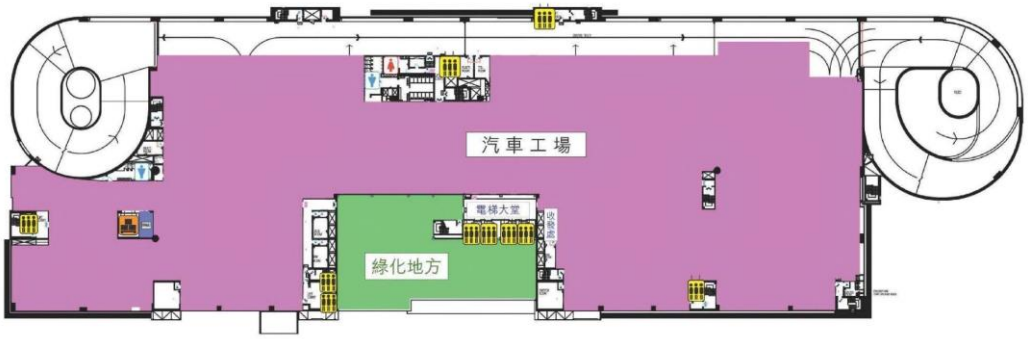
After the campaign finished, a summary of the participant's performance would be generated, and sent to the EMSD.

## Trial Site

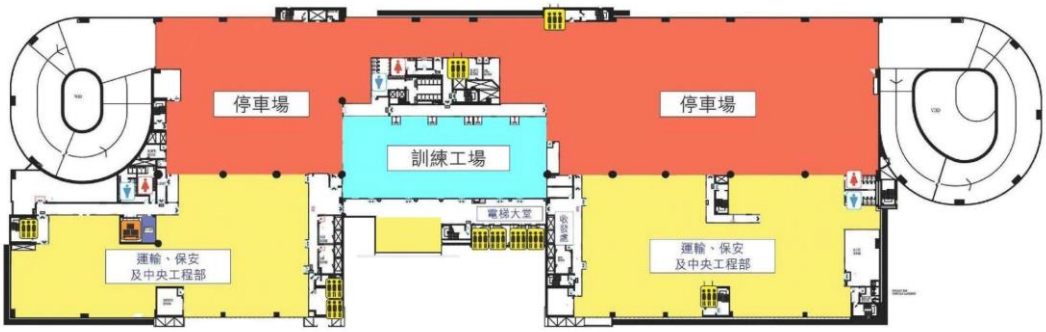
The EMSD Headquarters Building, from Ground Floor to 7/F (i.e. entire building).

## 機電工程署新總部大樓
## 一樓平面圖


## 機電工程署新總部大樓
## 二樓平面圖

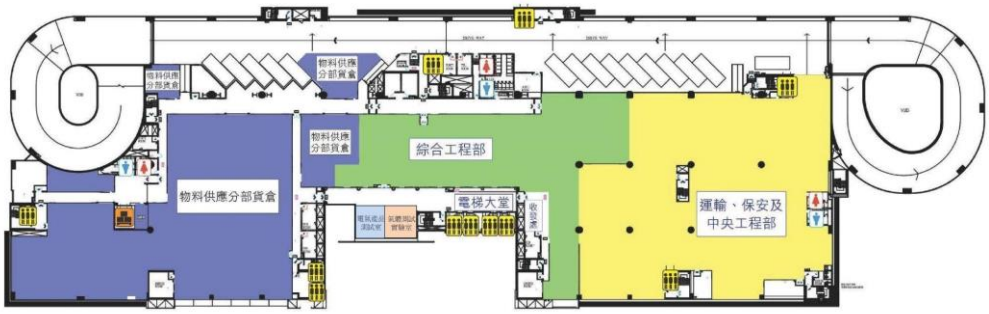



## 機電工程署新總部大樓
## 三樓平面圖

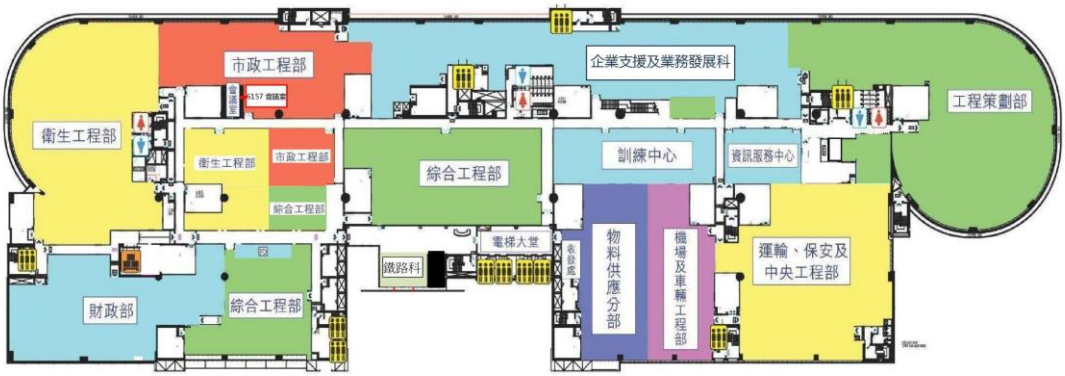


## 機電工程署新總部大樓
## 四樓平面圖


## 機電工程署新總部大樓
## 五樓平面圖




## 機電工程署新總部大樓
## 六樓平面圖



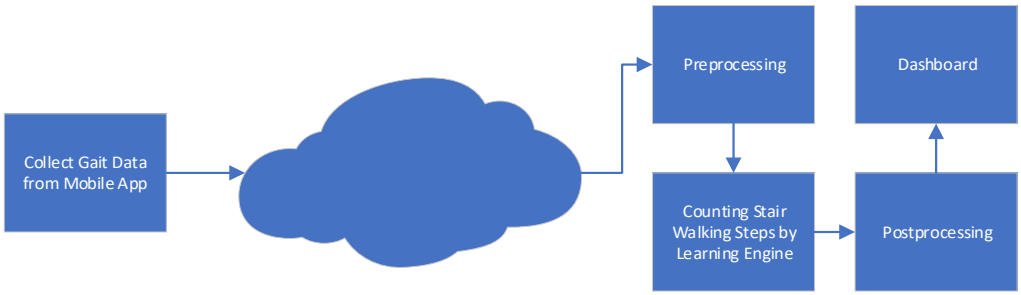

## Type of Equipment/ Installation/ Technology Adopted

Analysis of Cross-platform mobile device sensors data

Both Android smartphones and Apple iPhones were used as the client device for collecting the Gait data (eg. accelerometer data), and the collected data was sent to the Cloud by WiFi for further analysis.

Cloud-based Processing / Deep Learning

After the Google Cloud receives the data, the Pre-process module will process the data using techniques such as reformatting, data extraction, data normalization, etc. The Counting Stair Walking Steps Engine (a Deep Learning Engine) will then be triggered to recognize the steps of upstairs and downstairs for each participant profile. The result will be passed to the Post-processing module which will be used for scoring, and then displayed on the Management Dashboard.




Google Cloud

## Trial Timeframe

The trial was carried out between 28 February 2019 and 30 June 2019. Both upward climbing and downward climbing gait patterns were recorded in this trial.

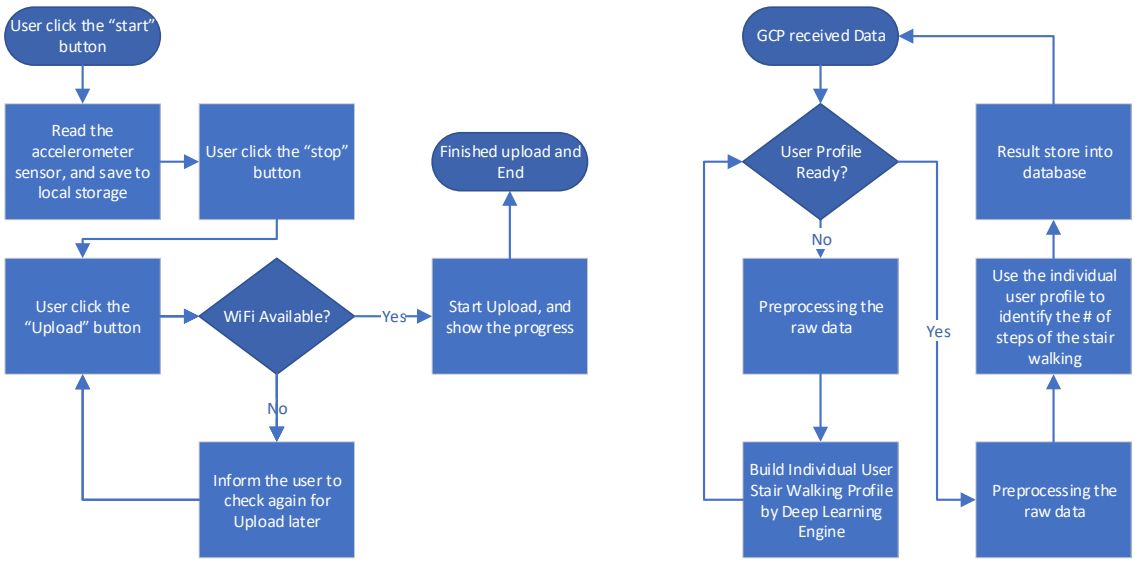
## Name and Background of I&T Solution Provider

The EMSD has commissioned Lambda Sense Limited (LDS), an IT Startup focusing on the products and services development for enhancing daily life based on Machine Learning technology, to customize a client App for mobile on both Android and iOS platforms for Gait Authentication and Identification by People Gait Pattern, as well as to enhance the Gait Analysis Learning Engine running in the Cloud to recognize People upstairs and downstairs Gait Pattern.

## Details of Implemented Trials

I. Methodology and Applicable Standard

(i) Initial Operation Model




The initial planning to collect gait data from the participants and to build their individual profile was shown on the above diagram on Design A Operation.

Participants are required to:

1. Turn on the Mobile App, and start the gait data collection simultaneously.

2. After the gait data collection, participant will need to upload the data to cloud through WiFi network (mobile network will be declined to avoid consuming participant's Mobile Data).

The project team had conducted a trial on data collection and individual profile building before the official launch. After a week, we were aware that collecting enough data from each individual member may not be easy. Only 2 participants had given enough data to build their own individual profile successfully. Building individual profile based on individual data, others' data couldn't be used for building others own individual profile.

(ii) Improved Operation Model

Hence, Design-A operation has been refined to Design-B operation as shown below.

Due to insufficient data being collected from individual participant, the Deep Learning Engine was changed from learning individual profile to building a shared profile (Shared Stair Walking Profile) with inputs from existing data pool.

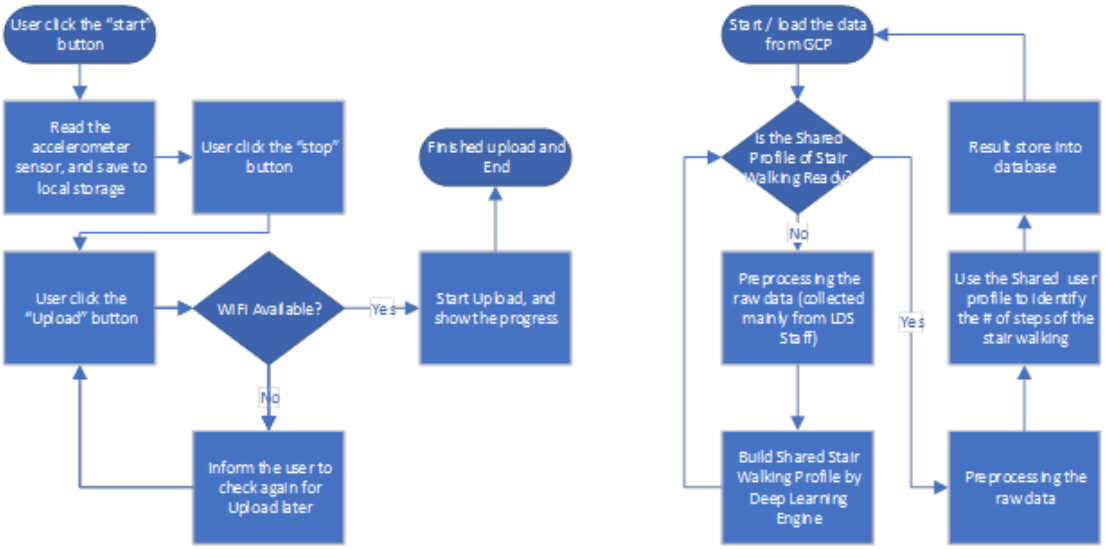
The adjustments to Design-A:

1. Design-A: based on individual Stair Walking Profile to identify the identity of each participant.

   Design-B: not to target on identifying the participant's ID, as individual will have their own PID signed during log-in.

2. Design-A: matching the participant's upstairs and downstairs pattern by their own Stair Walking profile, and count the steps taken.

   Design-B: match the participant's upstairs and downstairs pattern to the Shared Profile as to improve accuracy and other types of sensor, e.g. barometer, will be compared to support the counting of the steps of Stair Walking.




Below diagram showing the raw data of up and down stair collected by accelerometer. As mentioned in above flow chart.

(iii) Data Collection

Then, EMSD would assign some of HQ staffs to participate the campaign. Each participant was assigned a 4 digits Random Number as his own unique identifier. For the privacy consideration, this 4-digit Number would not associate to any identity of the participant. Hence, LDS wouldn't be able to know the true identity of the participant, e.g. name, staff ID, etc.

After 1st of June, the mobile App started to count the steps of up and down stairs. The participant had to manually upload the steps data to the LDS online service in GCP. The reason why participant uploading the data manually was because of avoiding using the participant's personal mobile data service, and let the participant to decide when he wanted to upload the data to the cloud for further processing.

Once the LDS online service received the data from the participant, the pre-processing modules will be triggered for some executions, e.g. segmentation, feature extraction, etc. After finished, the result would be the input of the Learning Engine. The learning engine would try to recognize the up and down stair pattern from the input, and increased the counter of step for each individual participant in the Database.

(iv) Cloud based Machine Learning

1. User profile database

- Below information will be stored under the profile:
    - User ID, i.e. Staff ID
    - Last login
    - On/offline Status
    - Historical Steps (stair only) data
    - Ranking
    - Location of the data stored in the Cloud Bucket

2. Data Re-formatter
    - Reformat the raw data collect into a suitable format for further processing and learning
    - Output file (per user) will be transferred into the Cloud Bucket
    - Reformat will be activated once new data being uploaded by the users.
3. Machine Learning Classifier
    - A Classifier will be built based on the data collected during the trial weeks to extract the steps of each user.
    - Output file (per user) will be transferred into the Cloud Bucket
    - Classifier will be activated once new data being reformatted by the Data Re-formatter.
4. Downstairs/upstairs Counter
    - It will be used to measure how many steps for each user per day
    - Result will be stored in the user's personal profile under the cloud
5. Report Generator Module
    - The Module will export a monthly result in excel format and email to the project team.
    - Raw Content includes
        - PID

- Date (30 days per PID)
- Steps

II. Measurement and Verification Activity Details

The step count result of each participant was showed on the app through the FireBase Real-time Notification Service (now is part of the Google Cloud Platform's service). In the meanwhile, the results would be stored in the cloud Database, which scheduled to generate a daily, and weekly log file, and sent to the management team of EMSD.

Before launching the program, below Measurement and Verification was conducted.

We took below data from a building, and ran the data through the same pre-processing module, as means of validating the process.

(1) We walked from 20/F to 22/F and then walk back to 20/F.

(2) We then took a lift from 20/F to ground. Then we walked in the open area at ground floor for a while.

(3) Then we took the lift from ground floor to 17/F.

(4) We then walked from 17/F to 20/F.

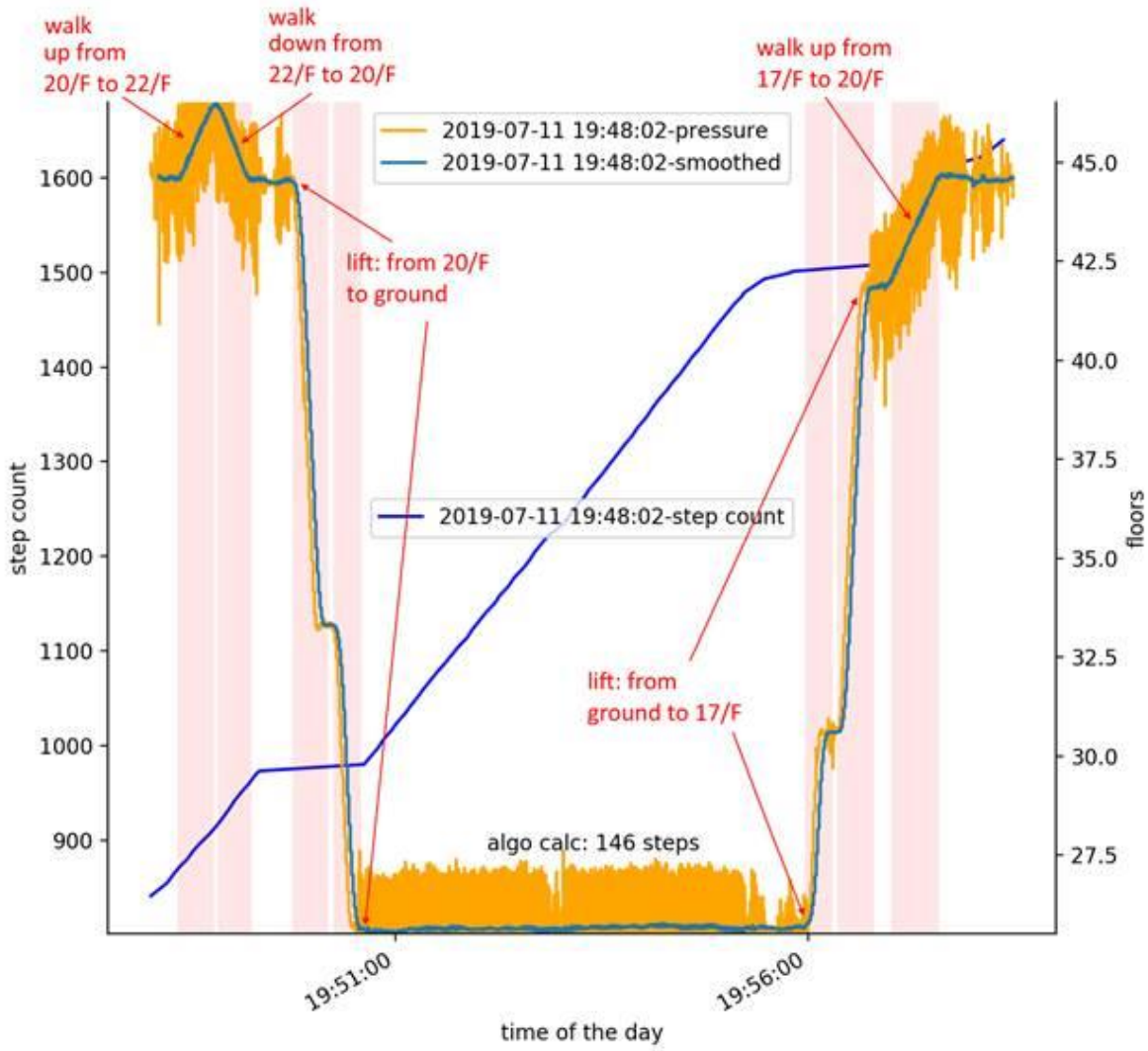
The estimation shown in the table below match well to the reality. The floors numbers match well, but the step count recognized is slightly on the high side.

| start | end | duration | climbed | floors | recognized stairs climbed | stairs per floor | stairs per second | | |
|---|---|---|---|---|---|---|---|---|---|
| 19:48:21 | 19:48:48 | 0:00:27 | up | 1.9 | 41 | 21.8 | 1.5 | good match: 2 floors up | walk |
| 19:48:51 | 19:49:15 | 0:00:24 | down | -1.8 | 47 | 26.0 | 2.0 | good match: 2 floors down | walk |
| 19:49:45 | 19:50:11 | 0:00:26 | down | -11.2 | 0 | 0.0 | 0.0 | total 19 floors down, close match; | |
| 19:50:15 | 19:50:35 | 0:00:20 | down | -7.7 | 0 | 0.0 | 0.0 | actual: 20 floors down by lift | lift |
| 19:55:58 | 19:56:18 | 0:00:20 | up | 4.9 | 0 | 0.0 | 0.0 | total 16 floors up, close match; | |
| 19:56:21 | 19:56:48 | 0:00:27 | up | 11.2 | 0 | 0.0 | 0.0 | actual: 17 floors up by lift. | lift |
| 19:57:01 | 19:57:35 | 0:00:34 | up | 2.6 | 58 | 22.7 | 1.7 | good match: 3 floors up | walk |

There should be 18 stairs per floor, but the estimation gave slightly higher at

21.8 to 22.7.

The stairs per second is between 1.5 to 2.0 stairs per second, which seems reasonable.

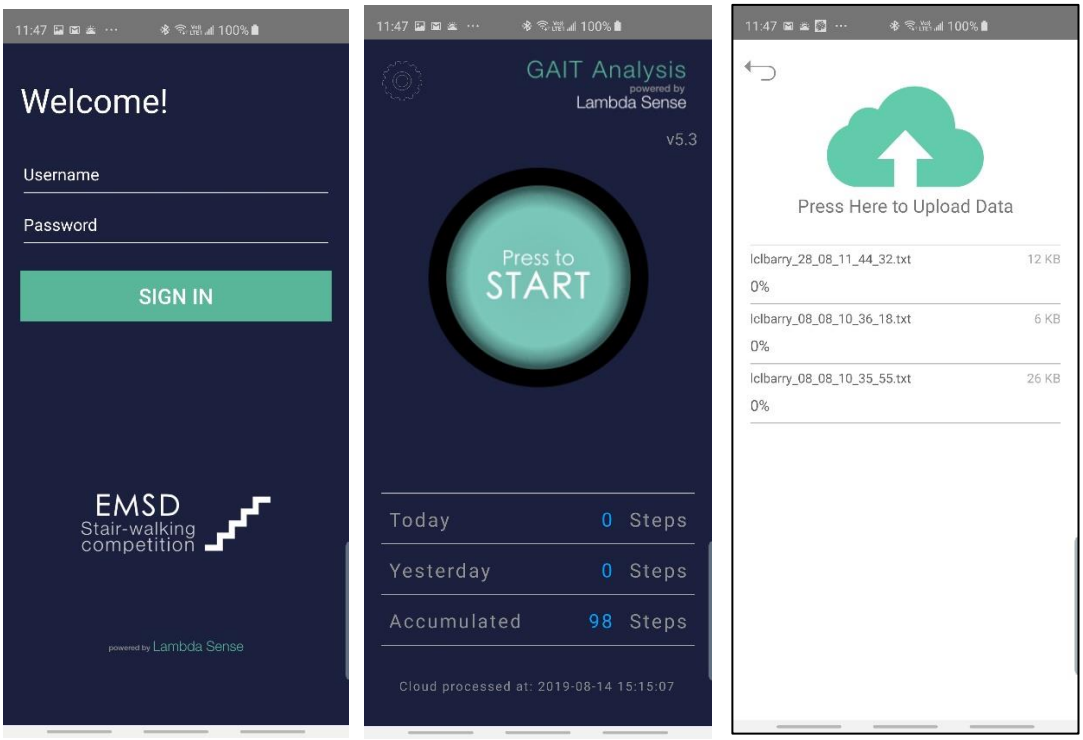



## Summary Results and Analysis

I. Pre and Post-installation Comparison

A mobile application was deployed for the steps-counting during the campaign, instead of the commonly available mobile applications.

Mobile App:




1. The Mobile App supports both iOS and Android platforms. Participants will download the app from:

   - Android Play and Apple Store from LDS account, or
   - From Websites of LDS

2. User Interface of the Client App

   a) App Home Page

      (i) Login Account and password

      (ii) LDS will pre-generate 500 set of 4 digits ID (Participant ID, PID) with Password pair for EMSD

      (iii) EMSD will assign the PID to the staff, and keep a record of the mapping between the Staff ID and the PID

   b) Personal Home Page

      (iv) After login successfully, the users will be directed to their personal home page indicating today steps, yesterday steps and the accumulated steps.

      (v) Click start to collect gait data and stop to end data collection.

c) Data upload page

(vi) After ending data collection, a data file will be created automatically and click to start upload data to the cloud.

(vii) Upon data upload completion, a message "Your Data has been successfully Uploaded" will appear on the display.

(viii) Only if WiFi connection is available or there is data pending for upload, the Upload Button will be functional.

(ix) In case WiFi connection is not available or no data is pending for upload, the Upload Button will be dimmed.

| Data File | WiFi Connection | Data Status | Upload Button |
|---|---|---|---|
| Ready | Ready | Upload | Click to activate |
| Ready | No Connection | Upload | Dimmed |
| No file | Ready | No Upload | Dimmed |
| No file | No Connection | No Upload | Dimmed |

(x) Participants need to click the Upload Button for data upload. If participant doesn't upload the data file within a day, there might be more than one data file stored under the mobile phone. Participants are allowed to upload all available data files at a time.

(xi) Data files will be displayed according to the record date under the personal dashboard.

Mobile App Properties:

1. The App will run in the background at all the time.
2. Timer will be set and start to collect the accelerometer data from 8am to 6pm every working day.
3. The collected data will be stored locally in the mobile phone, and users need to upload the data files to cloud.
4. The GPS sensor will be switched on automatically but no location data will be collected. The purpose of such a setting is to keep the App on live or the mobile Power Management module will stop the App.
5. To better manage the storage, only the data of active activities will be saved. No data will be saved if the mobile phone is in stagnant.

6. Power consumption is kept to a minimum and the actual usage will be recorded during the trial week (starting from 7th January 2019).

7. Two teams of participants have been deployed during the Trial weeks:

   - One team to collect the upstairs and downstairs data to train the Model

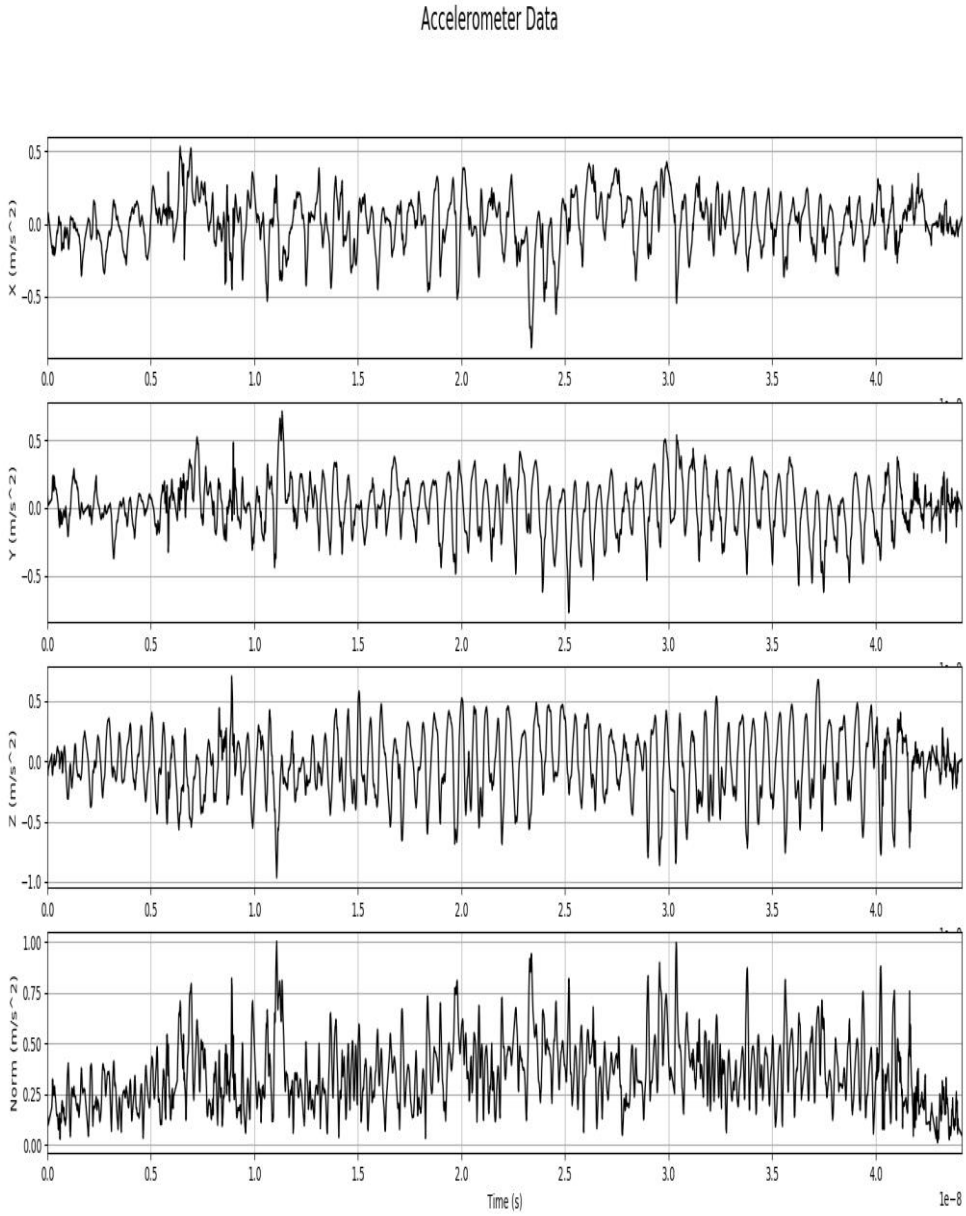
   - Another team to collect a full day data for testing

II. Key statistics/ Figures/ Infographics to Support the Results

Sensors Data Collected from various devices

| PID | Devices Type | Total Steps | Active Days | Day of Max | Average / Active Days | Problem in collected data set |
|---|---|---|---|---|---|---|
| 0103 | HUAWEI MHA-L29 | 282 | 8 | 282 | 35 | 8 days of record uploaded, but only 1 day has effective steps recognized |
| 0105 | Samsung SM-A730F | 54,870 | 21 | 5256 | 250 | Too high of counts in the MAX day |
| 0109 | iOS device | - | 2 | 0 | - | |
| 0112 | BullittGroupLimited S61 | 145,585 | 15 | 32512 | 2,167 | Too high of counts in the MAX day |
| 0115 | LGE LG-H930 | 187 | 3 | 72 | 24 | |
| 0122 | iOS device | 487 | 1 | 487 | 487 | |
| 0126 | iOS device | 1,727 | 18 | 263 | 15 | |
| 0128 | Samsung SM-N9600 | 2,336 | 3 | 1236 | 412 | |
| F000 | iOS device / Samsung SM-G9500 | 1,157 | 6 | 400 | 67 | |
| L000 | iOS device / Samsung SM-G9500 | 98 | 4 | 82 | 21 | |
| M000 | Samsung SM-G9500 | 159 | 3 | 159 | 53 | |
| P000 | Sony E5563 | 65 | 2 | 65 | 33 | |
| R000 | Samsung SM-N9500 | 550 | 2 | 490 | 245 | |

Collected Accelerometer Data from a device




III. Analysis of M&V Results to Address the Target Deliverables

Observations based on the above trial weeks results:

1. Data size from each PID (participants) is not sufficient.

2. Cross checked with the PIDs, below devices are consistently accurate on the steps counted.

    - iOS device

    - Samsung SM-N9600, N9500, G9500

3. Especially for iOS device, G9500, and N9500, these devices were used for collecting data to building the Shared Stair Walk Profile.

## Conclusion and Way Forward

Accuracy of the stair walking share profile (Design B) for some PIDs is not sensitive enough, if those PIDs did not provide necessary datasets of his star walking style in the training stage, as it was found that stair walking patterns varies when checking the data manually.

Time taken for one cycle from PIDs (participants) varied from 1 to 2.5 sec. The assumption is that the participant started walking upstairs in full power for the first cycle and after few more cycles, the participant started to get tired and thus it took a longer time to complete one cycle. Hence, the root cause is that it was not able to collect sufficient datasets of the stair walking variances from the PIDs, and thus not able to give the Learning Engine to learn and build the stair walking share profile (model), which should have the knowledge of the stair walking variation. Additionally, the exhibited table and diagram showed the high accuracy, which was obtained from the LDS members, where their datasets mainly contributed to the training stage.

Alternatively, building individual profile of Stair Walking (Design A) is still a better option to improve the accuracy. The benefit and improvement will be significant.

It was found in the review stage that different device may vary the results on individuals. For the step recognition is based on Individual Learning Profile, Deep Learning Engine could accept minor tolerance.

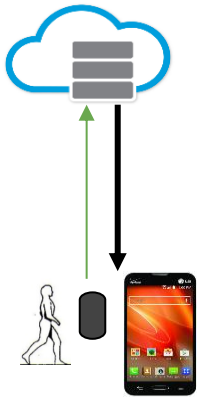
Data Size and Hardware variation

Generally, abundant personal data (i.e. including the various stair walking styles) is utmost important for building an individual's stair walking model. In the meanwhile, the control of the client hardware variation (e.g. the mobile phone version) is also critical to the success, as the sensor accuracy could be varied significantly from different models of smartphones. (The sensor accuracy from Apple iPhone is relatively consistent, whereas the sensor accuracy from different models of Samsung Smartphones is radically differed, respectively.)

Area of Improvement

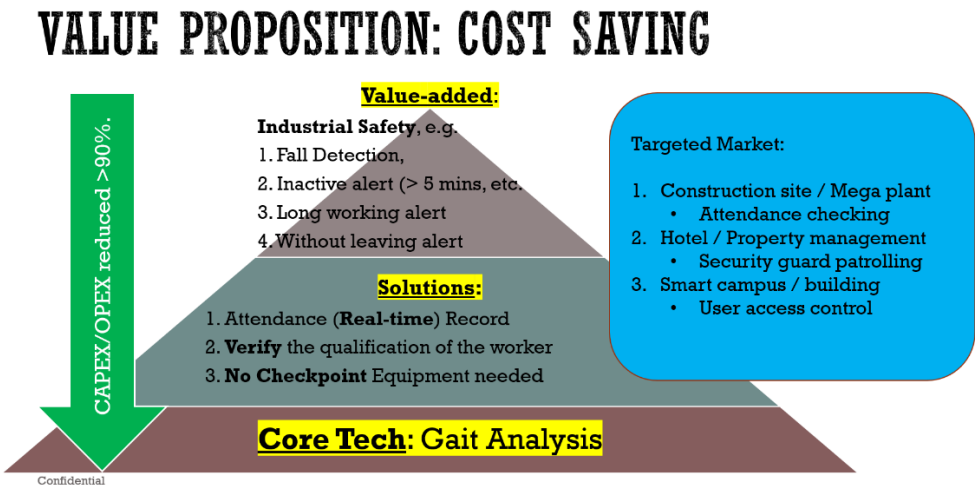
For the next App version, Training mode will be activated once the user login the App instead of having manual control on the start/ stop function for data

collection. Once the Cloud Engine collected enough data, it will stop the App to collect data and the training mode will be changed to execution mode.



There are 2 ways to start the data collection process, either by location (i.e. by GPS) or preset the time for auto-data collection. Moreover, a Walk Activity Recognition module will be introduced to the App in the next phase to collect only data on walking and send to the cloud for learning and training. Individual profile for each participant shall be built to ease the system's identification. To further improve the accuracy and consistency of data collection, only tested smartphones, smartwatch, and smartband shall be used for the gait analysis. Transfer Learning module will be implemented in the Cloud based Machine Learning Engine to reduce the amount of training data needed and knowledge management on individual profile.

On the other hand, with this Gait Analysis Platform, some value-added services can be provided, from the Industrial Safety perspectives. For example, some alerts messages will be generated, when the participant (or, mobile worker working inside a remote site) has accidental fall, or no activity for, say, > 5 mins, or, working too long, etc.




In spite of the result, the stair climbing campaign generated a lot of useful data, as well as the best practice and guideline on how to operate a similar Machine Learning based Gait ID, and event management experience for the startup in the future.

- END OF REPORT -

Digitalisation and Technology Division

Electrical and Mechanical Services Department

29 August 2019