HKUST Independent Project CSIT 6910

Ford-HKUST Conservation and Environmental Research Grants

REPORT

Integrated Vehicle Health Management (IVHM) for Passenger Automobiles

Approach to Efficient Operation, Maintenance and Knowledge Dispersion.

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Table of Contents

1. Brief Description

Integrated Vehicle Health Management (IVHM) Systems have been employed extensively in the fields of Aerospace and Aviation. The concept of IVHM was originally said to have been introduced by NASA in a 1992 paper, placing IVHM technology as the highest priority technology for present and future NASA space transport missions.

IVHM is the collection of data relevant to the present and future performance of a vehicle system, and its application to enhance operational decisions, maintenance actions and subsequent business performance. A vehicle system here can refer to anything from spacecraft, aircraft, submarine, tanks, trucks, or even cars. But what is being proposed in this project is developing an IVHM application tailored for the segment of passenger cars. With the combined processing of the diagnostic and prognostic data obtained from various sensors and systems monitoring the required components – invaluable information can be obtained relevant to the operation and maintenance of the automobile.

Prompting users with alerts, updates, and granting access to a continuously available schematic representation of the vehicle status can benefit them to making conscious and aware driving decisions. Such technology collaborated with innovative applications of mobile technology, wireless communication, Human-Computer Interaction (HCI) and engaging User Experience (UX) can change the current user-automobile equation. It can empower users, augmenting their underlying knowledge of important automobile technology, and encouraging environmentally conscious & energy saving actions.

For example, regular updates on the energy consumption and emissions of the automobile during automobile waiting at the traffic signals can be tracked and presented to the user, highlighting the wastage of resources. Similarly, tyre pressure can be monitored, and in the case of deviation this can be presented to the User along with its problem dependencies. A transparent and in-depth view of automobile condition along with intelligent-assist systems can enable users to make better operational decisions – in terms of usability of the vehicle in a scenario, or efficient driving methods, adding to the safety and improving the life of the vehicle.

IVHM tightly connected to mobile devices can provide personalised operational instructions. Such personalised knowledge dispersion can be used to encourage efficient automobile use in addition to generating better technical understanding.

IVHM data relayed to a central service centre can be used to pre-emptively prepare for appropriate actions and replacement components. This knowledge will be received much before fault occurrence. Such an approach will not only improve the efficiency of the process but also help reduce logistic and inspection costs. IVHM systems have been proven to reduce fault ambiguity, reduce repair times and reduce wasteful removal of serviceable components.

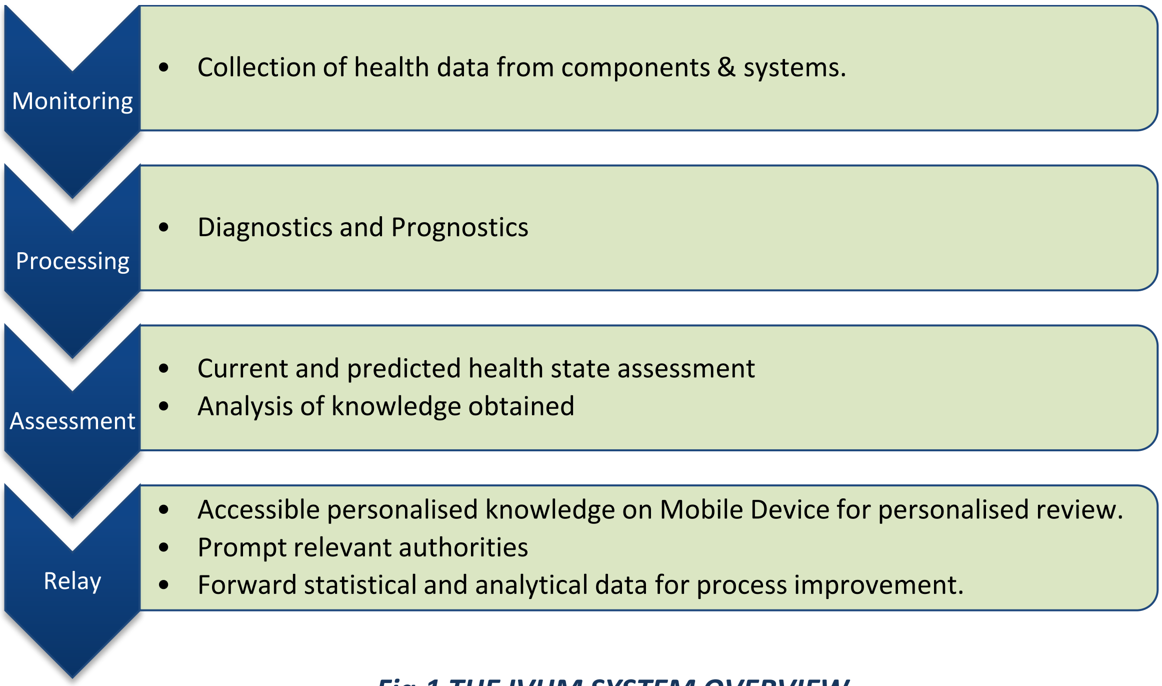

Fig.1 THE IVHM SYSTEM OVERVIEW

2. Overview of Project

The Scope of the project is defined by the problem areas of IVHM Applications for passenger automobiles. The focus was to demonstrate the potential offered by such technology to promote environmentally conscious & efficient operation of passenger automobiles.

This project aimed to demonstrate the potential benefits offered by the effective representation of the relevant automobile data using current mobile technologies.

The project did not focus in detail upon the underlying sensors and signal processing hardware, although it was necessary to understand their working to render successful results.

A proof of concept was implemented for demonstrating the underlying technologies. Making use of the easily available sensors built into most low cost “Smart Phones”, we were able to sense vehicle behaviour and report it to the User.

3. Proof of Concept & Motivation

Fig.2 SMART PHONE DOCKED ON COCKPIT

An application running on a "Smart Phone" device having built-in accelerometer and GPS receiver is used to track vehicle idling behaviour.

In the case the behaviour is inefficient; it is reported back to the user by setting off a sounded alarm.

An excerpt from **CAP 611 Motor Vehicle Idling (Fixed Penalty) Ordinance ,** as provided in the Hong Kong Legislation Gazette.

Under the Motor Vehicle Idling (Fixed Penalty) Ordinance (the Ordinance) (Cap. 611), the driver of a motor vehicle is prohibited from causing or permitting any internal combustion engine ("ICE") which forms part of a motor vehicle to operate for more than three minutes in aggregate within any continuous sixty-minute period while the vehicle is stationary ("idling prohibition"), unless an exemption applies. A driver3 who contravenes the idling prohibition may be issued with a Penalty Notice requiring him or her to pay a fixed penalty of HK$320. Traffic Wardens and Environmental Protection Inspectors are empowered to enforce the law.

Fig.3 EPD POSTER ADVERTISING THE BAN ON VEHICLE IDILING

The above mentioned ban since introduced in the year 2011 has faced severe criticism. Of course, such a ban has been extremely hard to enforce, as there are several problems that haven to be taken into account,

I. Counting the minutes the vehicle is Idling, since it came into rest.
II. Accuracy of the counting; who is counting in the first place? Currently it is up to the law enforcer's watch.
III. How efficiently can such behaviour be monitored or can the driver be warned? Currently it resembles a cat and mouse game.

4. Methodology and Related Information

In order to track the Idling behaviour of the Vehicle it is necessary to be able to tell if,

I. The engine of the vehicle is ON or OFF?
II. Is the vehicle moving or is stationary?
Leading to the most important question in our scenario,
III. Since how long has the vehicle been stationary while the engine was in the ON state?

To be able to answer the above question accurately we need to employ sensors rather than rely on the law enforcer ability. Also to promote a pre-emptive approach to solve the problem, such tracking must to be user-motivated.

Hence, we employed the use of the easily available and built-in sensors of a mid-range “Smart” mobile handset.

Hong Kong ranking 8th in the smart phone penetration rate at 62.8%, we could easily rely on the ubiquitous availability of these devices.

I. Hardware & Software Employed

I. HTC One X Smart Phone
II. OS – Android 4.2.2
III. Built-in Accelerometer
IV. Built-n GPS

In order to answer the questions listed above, various underlying sensors of the smart phone are employed.

II. Determining Engine Status

An internal combustion engine produces power using the extremely rapid pressure pulse of burning air fuel mixture above the piston. These powerful pulses of energy cause the engine to vibrate in response. Engine designers do their best to make these forces cancel out to minimize vibrations. But, no matter how well the designer does his job, he cannot eliminate all inherent vibrations in an engine. These vibrations sink through to the cockpit of the vehicle, which all of us can easily notice when the engine of the vehicle is ON.

Hence, if we can detect the nature of vibrations produced at the cockpit, we can determine if the engine is ON or OFF.

i. Accelerometer

According to the Android Sensor’s Overview, *an Accelerometer measures the acceleration force in m/s^2 that is applied to a device on all three physical axes (x, y, and z), including the force of gravity.*

Traditionally, accelerometers have been frequently employed to detect and measure vibrations. In fact, vibrations are often represented in units of G (9.8 m/s^2, acceleration due to gravity of the earth).

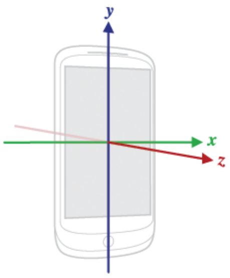

Fig.4 COORDINATE SYSTEM USED BY ANDROID API

ii. Solution

In our application we employ the built-in accelerometer provided in our smart phone, to measure the vibrations of the engine, read at the cockpit of the vehicle. The accelerometer determines the acceleration applied to the device, including the force of gravity. Using the X, Y and Z components of the acceleration as detected by the accelerometer we can calculate the magnitude of vibration at any instant as,

$$A = \sqrt{(A(x)^2 + A(y)^2 + A(z)^2)}$$

The application requires to be initially trained with sample acceleration values for both in ON and OFF states. Such training has to be performed for every new vehicle.

Since the sample acceleration values collected over X seconds, vary significantly for the ON and OFF states. This variation is presented by the Standard Deviation of the Samples, computed as,

$$SD = \sqrt{\frac{(A(t) - \bar{A})^2}{n}}$$

Since $\mathbf{SD_{ON}}$ and $\mathbf{SD_{OFF}}$ vary significantly, the final status of the engine in LIVE mode is determined by computing the SD of the incoming live data in a bucket of **W** samples (current use case W=7 i.e. roughly every 1.4s). Next the distance of this result from the $\mathbf{SD_{ON}}$ and $\mathbf{SD_{OFF}}$ values is calculated using the Euclidean Distance formula,

$$d(SD_W, SD) = \sqrt{(SD_W - SD)^2}$$

Classification is done by comparing,

$$d(SD_W, SD_{ON}) \; vs. \; d(SD_W, SD_{ON})$$

Further, in order to sensitise the system towards ON data, we apply a Weight < 0, on the $\mathbf{SD_{ON}}$.

ON	**ON**	**OFF**	**OFF**	**ON**	**ON**

Fig.5 VOTE LIST OF SIZE L = 6, DEMONSTRATING RESULT "ON"

Final result of engine state being ON or OFF is computed by forwarding the classification obtained into a vote list of length L values (Fig.5). The majority vote determines the final status of the engine as **ON** or **OFF**.

III. Tracking Vehicle Movement

In order to answer the second question, whether the vehicle is in motion or is stationary, we could instead track the position of the mobile phone which was docked in the car cockpit.

Again, most entry level smart phones provide in-built GPS sensor functionality and hence we could rely on this feature.

i. GPS

GPS stands for Global Positioning System technology and was introduced much earlier in 1973. Over the past few years GPS has become a must have feature on every smart phone, providing easy navigation and position tracking services to users. It is a space based satellite navigation system that provides location information, anywhere on Earth where there is unobstructed line of sight to 4 or more GPS satellites.

The usage of this feature does not rely on any data packet usage, and works by exchanging signals directly with GPS Satellites, and hence can be used easily without any subscriber charges.

ii. Solution

Android API provides access to GPS features using the LocationManager API.

The LocationManager fires events every time the Location of the Device changes based on two parameters,
minTime – The minimum time interval between location updates in milliseconds
minDistance – The minimum distance between location updates in meters

We utilised these events to determine if the vehicle is moving or stationary.

A continuous count-down timer is utilised for this purpose which is set at an initial T seconds. Every time the counter runs out to below 0 seconds the **Not Moving** State is set, and the timer is reset to T seconds.

On every Location Change event, the count-down timer is reset to T seconds, and the State is set to **Moving.**

This value of T seconds is very small to the extent of about ~4 seconds, which is more than suitable for our application, and is much more reliable than the abilities of the law enforcement officer.

IV. Idling?

The final and most important question to be answered – "Is the Vehicle Idling?" can easily be answered now, based on the above two results.

If the vehicle is **Stationary & Engine ON** then it is Idling.

As soon as such behaviour is detected the user is warned by a message that the warning timer is starting. As said, a warning timer is started which counts down $\mathbf{T_W}$ seconds (In case of HK this could be 180 seconds ~ 3 minutes).One the Timer $\mathbf{T_W}$ has elapsed a warning alarm is sounded prompting the user to either turn off the engine or to drive and move the vehicle in order to stop the alarm. As said, the application again monitors for state changes either **Engine OFF**, or **Moving** to stop the alarm.

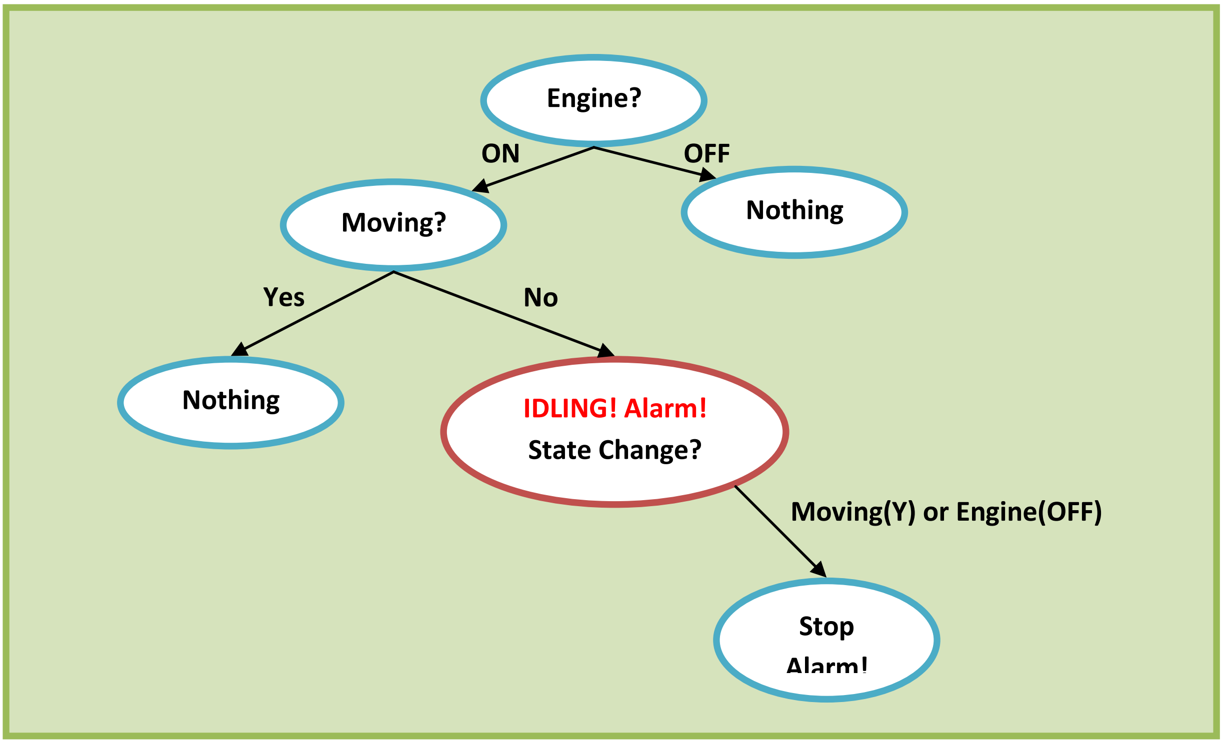

Fig.6 FLOW CHART OF THE DECISION PROCESS

5. Demonstration

The application is built for the Android OS, to run on any device fulfilling the basic requirements of providing,

I. Accelerometer
II. GPS

The User Interface of the application is split into 3 Tabs,

I. Train

a. Provides a Radio Button Group of ON and OFF, and a Train Button.
b. The user is expected to Train the Application for both ON and OFF states.
   i. Phone must be docked on the Vehicles cockpit.
   ii. Application Opened.
   iii. Train Tab selected.
   iv. In case of OFF, the user must select OFF and press Train Button to train the device for OFF state. The user will be prompted when the step is complete.
   v. In case of ON, the user must first turn on the Vehicle's engine. Next the user must select ON and press Train Button to train the device for ON state. The user will be prompted when the step is complete.

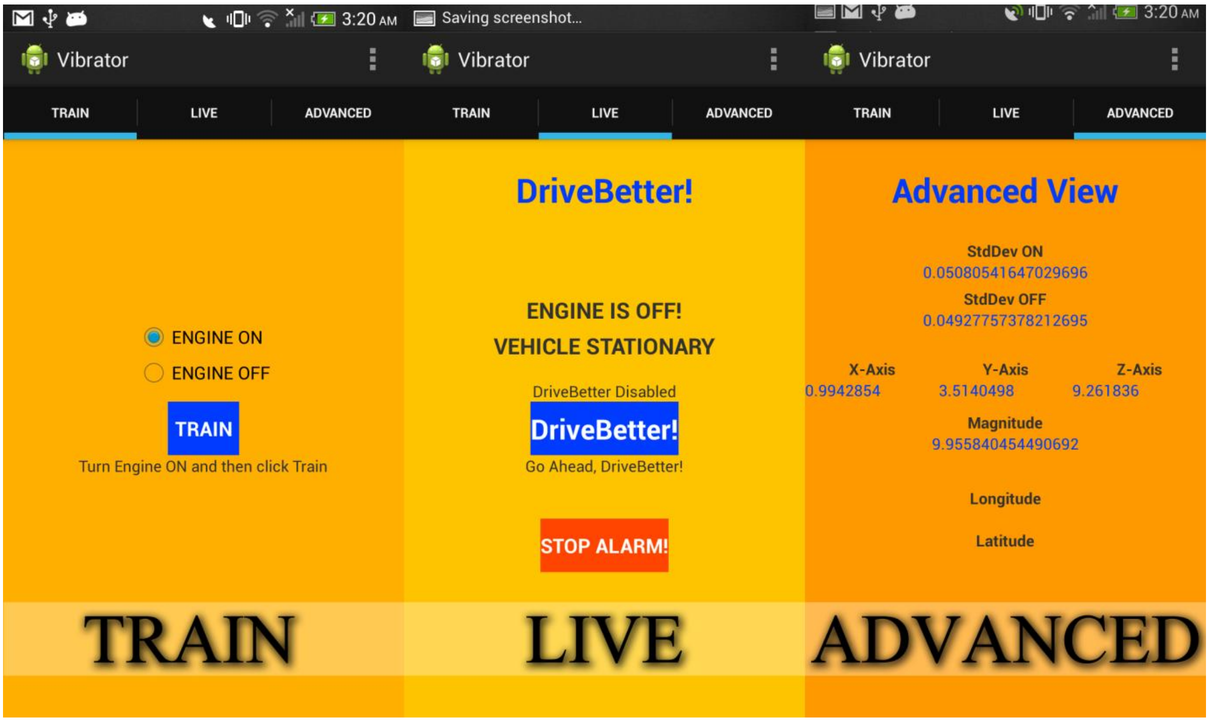

Fig.7 UI SCREENS OF THE 3 TABS (FROM LEFT TO RIGHT)

II. Live

a. Provides a Run("DriveBetter") Button and a Stop Alarm Button.

b. When the User presses the Run Button the Application is in its live mode, and is now tracking the behaviour of the vehicle. It will sound the Alarm if the User Idles for more than $\mathbf{T_W}$ seconds.
c. In order to Stop the Alarm, apart from Moving the vehicle, or turning off the engine, the user can press the Stop Alarm Button.
d. It also provides the status of the Engine, and the Vehicles Movement as detected by GPS.

III. Advanced

a. This tab provides advanced data such as,
   i. Live Accelerometer readings.
   ii. Standard deviations recorded by Training the Application, $\mathbf{SD_{ON}}$ and $\mathbf{SD_{OFF}}$.
   iii. Current Longitude and Latitude, if detected by the GPS.

6. Future Work

The application successfully demonstrates the ability to determine vehicle idling behaviour, Warn the user and also record this information.

This information can be further analysed and processed to reveal and represent trends in the vehicle usage. Such knowledge can be employed to provide the user, relevant feedback on his Driving patterns, so that a positive change can be made.

Also this information can be forwarded to the respective authorities in order to assess and determine vehicle use trends, and also to enforce efficient driving practises. As demonstrated, the mobile application can successfully perform the Monitoring and Processing Stages of IVHM lifecycle. Relay of this data to the various authorities for assessment is future work.

Better representation of the information and a convenient User Experience can motivate users to pre-emptively make changes in their vehicle use patterns. Positive feedback given to the users will further encourage change.

The application also needs to be ported to various other smart phone platforms.

7. Conclusion

Efficient vehicle operation and maintenance can be promoted by use of ubiquitous and easily available mobile and sensor technologies. Useful knowledge dispersion can be successfully employed to trigger positive operation behaviour by users.

As demonstrated by this Proof of Concept, low-cost and ubiquitous technology was used to encourage change in the user's operation behaviour. Such a concept can be applied to promote efficient parking, gear change, tyre maintenance, lane change etc. and can contribute to overall efficiency of vehicle usage and maintenance.

Such an approach also promotes user awareness, and hence relies much more on user motivation.

An IVHM can be implemented for passenger automobiles using the services provided by smart phones and tablets, which can entirely change the experience of vehicle operation as well as provide tremendous opportunities for efficient operation.

8. References

Benedettini, O., Baines, T.S., Lightfoot, H.W., and Greenough, R.M. State-of-the-art in integrated vehicle health management. *Proc. IMechE Vol. 223, Part G: J. Aerospace Engineering*, 2009, 157-170.

National Aeronautics and Space Administration (NASA). Research and technology goals and objectives for integrated vehicle health management (IVHM). Report NASA-CR-192656, October 1992.

The 15 Countries with the Highest Smartphone Penetration, Mashable, August 2013.
http://mashable.com/2013/08/27/global-smartphone-penetration/

Lloyd Johnson, THEORY: Reciprocating Engine Vibration.
http://www.dssmicro.com/theory/th_recip_vibs.htm

What is GPS?, Library Of Congress.
http://www.loc.gov/rr/scitech/mysteries/global.html

Android Developer Training.
http://developer.android.com/training/index.html

Transport Department, HKSAR.
http://www.td.gov.hk/en/home/index.html

Time to rethink law on Idling engines, The Standard, Hong Kong, September 2012.
http://www.thestandard.com.hk/news_detail.asp?we_cat=5&art_id=126522&sid=37560464&con_type=1&d_str=20120918&fc=2

9. Minutes

I. Minutes of the 1st Project Meeting

Date: 24 Sep. 2013 (Tuesday)

Time: 7:00 pm

Place: Rm. 3512

Attending: Chhabria, Jitesh Surendar

Dr. David Rossiter

Absent: None

Recorder: Chhabria, Jitesh Surendar

1. Approval of minutes

This is first formal group meeting, so there were no minutes to approve.

2. Discussion Items

Things to do

- Background Research (Papers, Publications, Web Resources)
    - Vehicle Technology
    - Sensors
    - Environmental Impact
    - Computer Technology
    - Communication Technology
    - User Experience
    - Service/Maintenance Potential
- Discuss Final Output and Demo Methodology
- Implementation Techniques
- Discuss Timelines

3. Meeting adjournment and Next meeting

The meeting was adjourned at 3:40 PM. The next meeting will be held in October.

II. Minutes of the 2nd Project Meeting

Date: 17 Oct. 2013 (Thursday)

Time: 10:20 AM

Place: Rm. 3512 / Car Park

Attending: Chhabria, Jitesh Surendar

Dr. David Rossiter

Absent: None

Recorder: Chhabria, Jitesh Surendar

1. Approval of minutes

The minutes of the last meeting were approved without amendment.

2. Discussion Items

Things to do

- Identify classification(ON/OFF) algorithm
- Demonstrate & validate accelerometer sensor data.
- Collect accelerometer data for tweaking.

3. Meeting adjournment and Next meeting

The meeting was adjourned at 10:40 AM. The next meeting will be held in November.

III. Minutes of the 3rd Project Meeting

Date: 7 Nov. 2013 (Thursday)

Time: 10:30 AM

Place: Rm. 3512 / Car Park

Attending: Chhabria, Jitesh Surendar

Dr. David Rossiter

Absent: None

Recorder: Chhabria, Jitesh Surendar

1. Approval of minutes

The minutes of the last meeting were approved without amendment.

2. Discussion Items

Things to do

- Test classification algorithm in Dr. Rossiter's Car.
- Test classification algorithm in Prof. Gibson Lam's Car.
- Test GPS sensor.
- Collect accelerometer data for tweaking.

3. Meeting adjournment and Next meeting

The meeting was adjourned at 11:00 AM. The next meeting will be held in December.

IV. Minutes of the 4th Project Meeting

Date: 22 Nov. 2013 (Friday)

Time: 04:15 PM

Place: Car Park

Attending: Chhabria, Jitesh Surendar

Dr. David Rossiter

Absent: None

Recorder: Chhabria, Jitesh Surendar

1. Approval of minutes

The minutes of the last meeting were approved without amendment.

2. Discussion Items

Things to do

- Test run for classification algorithm
- Record data for tweaking and outliers

3. Meeting adjournment and Next meeting

The meeting was adjourned at 04:40 PM. The next meeting will be held in the following week.

V. Minutes of the 5th Project Meeting

Date: 26 Nov. 2013 (Tuesday)

Time: 10:30 PM

Place: Rm. 3512 / Car Park

Attending: Chhabria, Jitesh Surendar

Dr. David Rossiter

Absent: None

Recorder: Chhabria, Jitesh Surendar

1. Approval of minutes

The minutes of the last meeting were approved without amendment.

2. Discussion Items

Things to do

- Demonstrate changes.
- Test run in Dr. Rossiter's car.
- Test for both GPS + accelerometer sensors, yielding final results.

3. Meeting adjournment and Next meeting

The meeting was adjourned at 11:00 PM. The next meeting will be held on December 4th.

VI. Minutes of the 6th Project Meeting

Date: 4 Dec. 2013 (Wednesday)

Time: 1:30 PM

Place: Rm. 3512

Attending: Chhabria, Jitesh Surendar

Dr. David Rossiter

Absent: None

Recorder: Chhabria, Jitesh Surendar

1. Approval of minutes

The minutes of the last meeting were approved without amendment.

2. Discussion Items

Things to do

- Demonstrate application.
- Present final report.

3. Meeting adjournment and Next meeting

This is the Final meeting.