Portable Automobile Data Acquisition Module (ADAM) for Naturalistic Driving Study

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Abstract

In this paper, we present a non-intrusive, low-cost, portable Automotive Data Acquisition Module (ADAM) designed to gather naturalistic position, speed, acceleration and headway data based on two Raspberry Pi microcomputers, stereo cameras, GPS and IMU sensors. A prototype has been built with the ability to collect and store data. This prototype can be installed on the windscreen of a car without any interference to the safety of the car and driver. The naturalistic data collected is time-series data intended to be used to build driver models for human-in-the-loop control but may also be useful in human factors studies. One set of collected data is presented to show the performance of the device, and a validation study is performed to compare the collected range data with that from an instrumented vehicle.

Keywords: Naturalistic driving data, Stereo vision, Human factors

1 Introduction

For intelligent vehicle design, driver behaviour should be taken into account in order to evaluate the performance of the driver-vehicle system in terms of energy management, driving comfort, safety [1], etc. Hence, accurate knowledge of driver behaviour is vital in the design of future intelligent vehicle systems. To obtain driver models for prediction of driver behaviour, databases that include data such as speed, headway distance, and acceleration are needed. There are multiple ways to collect this kind of data, including driving in an instrumented vehicle [2] [3] or using a driving simulator [4]. And several vision-based driving datasets have been released, such as the Ford Campus vision and LIDAR data set[5], KITTI dataset[6], Cityscapes[7] and Oxford RobotCar dataset [8]. However, these datasets are all gathered from instrumented vehicles and focused mainly on autonomous vehicle research. However, the behaviour of drivers is inevitably different in these conditions than it is in natural driving when they drive their own cars.

Therefore we present a non-intrusive, low-cost, portable, Automobile Data Acquisition Module (ADAM) designed for the purpose of gathering naturalistic driving data, more specifically ego-vehicle position, velocity, and acceleration as well as the headway distance. This device was designed to collect data to be used as part of the G-ACTIVE project currently being carried out at the University of Southampton and Imperial College [9]. This paper includes details about the design of the device, including the configuration, sensors used, and data collection and processing techniques. Then the benefit of this device to human factors studies is explained. Finally, example data is presented and validation of the range data is carried out by comparison with the same data collected from an instrumented vehicle. It is also stressed here that the details of the device's design, as well as the data processing algorithms, are open to share freely within the academic community.

2 The ADAM Platform

As shown in Fig 1, the first prototype of ADAM has been built using two Raspberry Pi 3 Model B single board computers. The unit incorporates one Adafruit Ultimate GPS Module to record longitude and latitude as well as the speed. An Inertial Measurement Unit (IMU), which consists of a three-axis accelerometer, gyroscope, and magnetometer, is used to measure linear acceleration, angular velocity and vehicle heading. In addition, two Raspberry Pi cameras are installed in the front of the device to provide stereo vision capabilities.

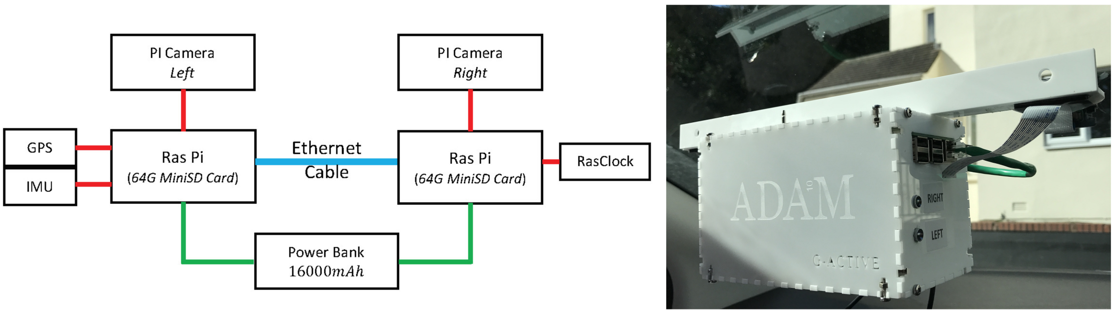


Figure 1: ADAM

2.1 Raspberry Pi

The Raspberry Pi 3 is the third-generation Raspberry Pi, which features a quad-core 64-bit ARM Cortex A53 clocked at 1.2 GHz. It also has four USB 2.0 ports and full size HDMI port for connecting keyboard, mouse and monitor, which makes the programming and troubleshooting of ADAM very convenient. A CSI camera port is used to connect the Raspberry Pi camera as shown in Fig 1. In addition, it provides a micro SD port for loading the operating system and storing data. In the prototype of ADAM, a 64GB micro SD card is installed. In addition, to avoid interference with the participants' vehicles, the two Raspberry Pi computers are powered by a 16000mAh dual port power bank which can support up to 2.4A current draw for each port. For clarity in the following sections, the Raspberry Pi connecting to the left Raspberry Camera is called the "left Raspberry Pi", and the other is called the "right Raspberry Pi".

2.2 Stereo Cameras

The range to the vehicle in front is crucial data for driver behaviour modelling. Hence two Raspberry Pi cameras are adopted to give stereo vision of the environment in front of the vehicle. As shown in Fig.2, two Raspberry Pi camera modules are installed on the top of the ADAM case via a 90 degree angle bar. The distance of between the two lenses are fixed as $30cm$.

The Raspberry Pi camera module has a Sony IMX219 8-megapixel sensor with the ability to taking high-definition video and still photographs. It is a leap forward in image quality, colour fidelity, and low-light performance in term of its price, which supports 1080p30, 720p60 and VGA90 video modes, as well as still capture.

Each Raspberry Pi camera attaches via a ribbon cable to the CSI port on the Raspberry Pi as shown in Fig 3a. In order to control the operation of the two Raspberry Pi camera, a script is written in Python based on the Picamera python library. When ADAM is powered on and the start button shown in 2 is pressed, two cameras will start recording videos simultaneously. The resolution of the video is 800×480 pixels and is captured at a rate of 30 frames per second. The videos are encoded using the h264 codec, stored in mp4 format, and have a maximum length of 5 minutes each.

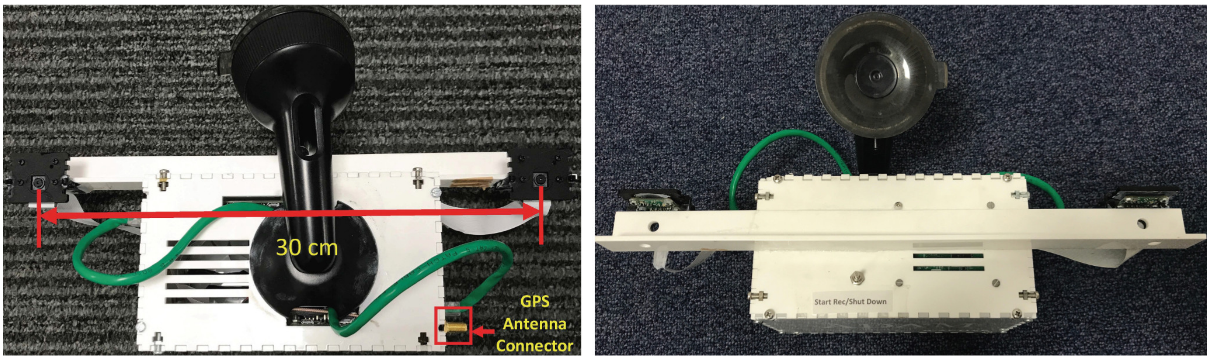


Figure 2: ADAM Stereo Cameras

2.3 GPS Module

In order to get the instantaneous location of the vehicle, an Adafruit GPS breakout is attached to the left Raspberry Pi as shown in Fig.1. The breakout as shown in Fig.3b is built around the MTK3339 chipset, a high-quality GPS module that can track up to 22 satellites on 66 channels, has an excellent high-sensitivity receiver (-165 dB tracking), and a built in antenna with only 20mA power usage during navigation.

As ADAM is installed inside the vehicle, an external antenna is used to ensure steady operation of the GPS. A python script based on the python GPS library is used to control the operation of the GPS and log the location data including longitude, latitude, altitude, speed and heading to a csv file with $1Hz$ updating rate.

2.4 Inertial Measurement Unit

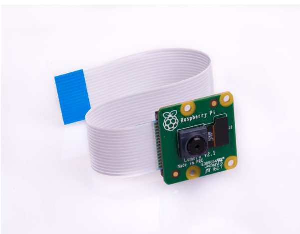
As shown in Fig.1, an inertial measurement unit (IMU) is attacked to the left Raspberry Pi to measures and reports on accleration, rotation, velocity, orientation and gravitational forces. The BerryIMU as shown in Fig.3c is chosen as it is specifically designed to interface with Raspberry Pi. The IMU sensor used on the BerryIMU is $LSM9DS0$, featuring a 3D digital linear acceleration sensor, a 3D digital angular rate sensor and a 3D digital magnetic sensor.

The BerryIMU communicates with the Raspberry Pi via a $i2c$ interface. Similarly to the GPS module, a python script based on the $LSM9DS0$ python library is written to configure the operation of the IMU and log data. The 3D linear acceleration sensor operates at $+/-4g$ scale with $100Hz$ data rate. The 3D magnetometer operates at $+/-12gauss$ scales with $50Hz$ data rate. The 3D gyroscope works at $2000dps$ with $50Hz$ data rate. The raw data of the three sensors is logged to a csv file.

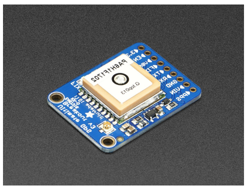
2.5 Time Synchronisation

As multiple sensors and cameras are adopted to capture different data of the vehicle, it is crucial to make sure all the logged data has a consistent time stamp. However, this is not a trivial task for Raspberry Pi as it don't have its own real-time clock, which means it can only synchronize time to external sources, such as the internet or external Real-time Clock (RTC) modules.

The initial plan was to install two Real-time Clock (RTC) modules to each of the Raspberry Pi. After carrying out some tests, it has been found out that the time difference between the two RTC modules can up to $0.1s$, which is insufficient for the synchronisation of the two videos from the left and right cameras as the frame rate is $30fps$. Hence, in order to address this issue, only one RTC module (as shown in Fig.3d) is attached to the right Raspberry Pi and a Stratum-1 NTP time Server is built on this Raspberry Pi. An enternet cable as shown in Fig.1 is used to connected two Raspberry Pis together. In this way, the left Raspberry Pi can synchronize time based on the information provided by the NTP time Server. In this way, the time difference between two Raspberry Pis has been reduced to few milliseconds.



(a) Raspberry Pi Camera



(b) Adafruit Ultimate GPS

(c) Berry IMU

(d) RasClock

Figure 3: ADAM internal hardware

2.6 The Enclosure

An enclosure was designed in AutoCAD and made by laser cutting High Density Polyethylene (HDPE). As shown in Fig.4, this enclosure includes six panels. Holes to install the sensors and Raspberry Pis are made on the top and bottom panels. On the left and right panels, open areas are left to access the USB ports and CSI camera ports. On the front and back panels, two square areas are open for access to HDMI ports and power sockets. To avoid the overheat of the Raspeberry Pi and sensors, ventilation slots are designed as well.

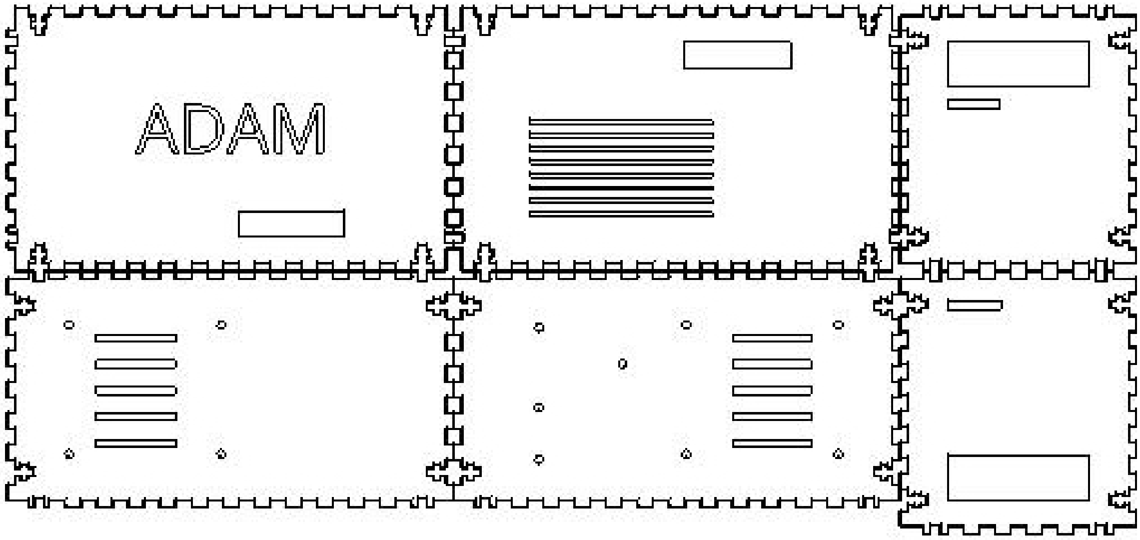


Figure 4: Laser cutter case

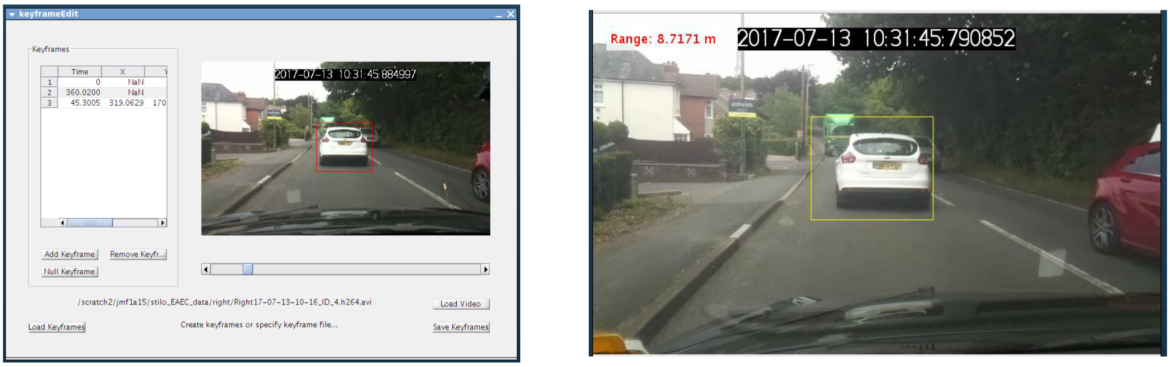
2.7 Installation and Operation of ADAM

As shown in Fig.2, there is a suction cup attached to the enclosure of the device which makes the installation very simple and avoid any damage to vehicles. Before data collection, ADAM is attached on the windscreen of a participant's car. After connecting the external GPS antenna and the power bank, ADAM will automatically power on. There are two LEDs to indicate the status of the left and right Raspberry Pi. When all the sensors are initialized, the LEDs will turn on which means ADAM is ready to collect data. Then the participant just needs to press the start button. All the sensors and camera will start to work and data logging will take place simultaneously. The participant can then perform their normal driving without interference from the device.

3 Headway Distance Post-processing

3.1 Estimation of Range

The stereo video captured from ADAM may be postprocessed in order to provide range information to other vehicles. To accomplish this, we designed an application within MATLAB that can be used to indicate the position and size of the lead vehicle in the captured video data (Figure 5a). Once the image location of the lead vehicle is provided, the range may be estimated by detecting corner features in the image from the left camera, matching them to corner features visible in the right camera, and computing the disparity in x-coordinates between the two images. These disparity estimates for each feature are



(a) user interface (b) result of processing

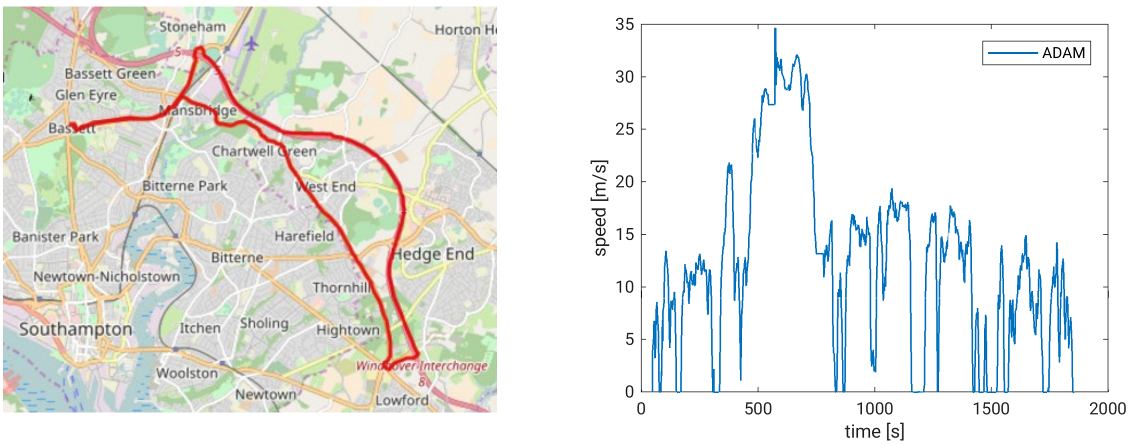
Figure 5: Processing of ADAM stereo video data

then averaged to produce a disparity estimate d for the vehicle and the range z may be calculated by the formula

$$z = \frac{fb}{d}$$

where f is the cameras' focal length and b is the distance between cameras. This process has been automated using functions from the MATLAB Image Processing Toolbox, and videos overlaid with the computed range and vehicle position were generated for validation (Figure 5b).

3.2 Validation of Range Data

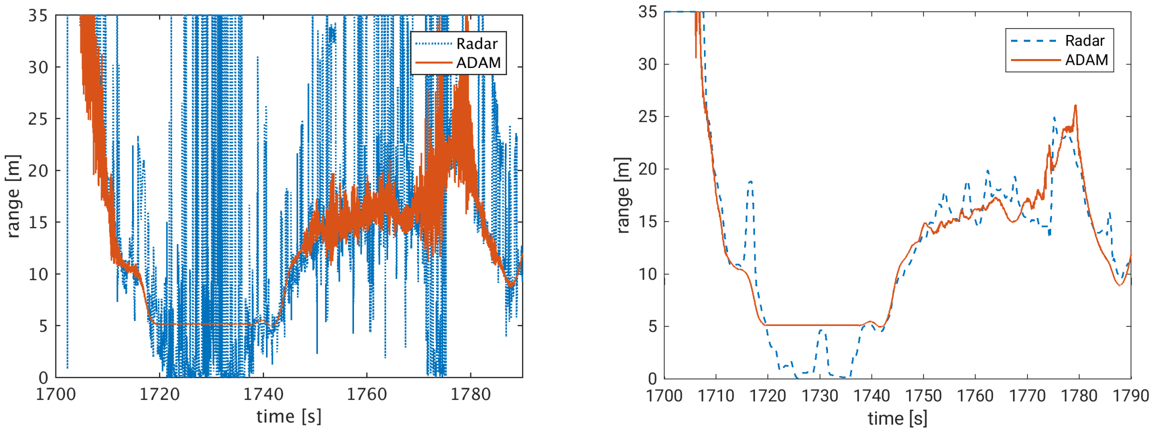


(a) driving route (b) speed profile

Figure 6: Driving route and speed profile for validation

To validate the range measurements provided by ADAM, we installed the unit in the University of Southampton instrumented vehicle, which is equipped with a front-mounted Doppler radar to measure the range and relative velocity of other vehicles. Data was collected during a 30-minute drive around the city of Southampton, starting and ending at the Boldrewood campus. The route is shown in Fig. 6a, which is based on the GPS data collected. In the meantime, the speed profile is shown in Fig. 6b.

Figure 7 shows a comparison between the range to a leading vehicle as measured with both ADAM and the front-mounted radar on the instrumented vehicle. Figure 7a shows the raw data gathered from each device, while Figure 7b shows the data after filtering. There is a sizeable amount of speckle noise on the radar signal which gives many isolated spikes above or below the correct value. This may be removed by a median filter with a window of 1 second, followed by a nonlinear filter that thresholds the derivative of the signal, although some erroneous values still remain in the filtered signal where the radar cannot track the target at short range (these are visible in Figure 7b between 1710 and 1740 seconds). The noise on the range data recovered from ADAM is persistent and approximately Gaussian, with a variance that increases with increasing range. This was reduced using a 3rd order Savitsky-Golay smoothing filter with a 1 second window.



(a) unfiltered range data

(b) filtered range data

Figure 7: Comparison of measured range with ADAM and IV radar

In a qualitative analysis, we found that the range reported by ADAM may become unreliable when driving on bumpy roads at high speed (as this causes vibration of the unit), and also under conditions of rapidly changing illumination (the lead vehicle may become over- or underexposed in the video, reducing the number of image features available for calculating depth). In other situations, we found that ADAM will typically track a target better than the radar for distances of less than 40m, as in Figure 7, and worse than the radar at larger ranges.

4 Benefit to Human Factors Study

The use of ADAM can provide significant benefit to Human Factors research exploring driving behaviours. By unobtrusively collecting everyday driving behaviours, drivers reaction to road events, such as junctions, road curvature and gradient changes, as well as interactions with other vehicles and road users, can be recorded and studied with no greater risk to the participants than would be encountered in daily life. Indeed, drivers are not required to engage in extensive on-road trials within instrumented vehicles, but rather engage in their normal behaviours, and their normal vehicle making the collected data high in ecological validity. With the use of ADAM, the potential for participants to display demand characteristics, whereby they modify their behaviour in order to perform in a way pleasing to the researcher, based on their perceived assumption of the researchers aims is greatly reduced. This is due to ADAM not interacting with the driver in anyway and not interfering with the driving task in any regard, in this way it is likely that the participants do not consider their behaviour under scrutiny.

Whilst the intrinsic use of the driver data can be used to develop generic mathematical and theoretical models, the recorded data can also be considered with reference to a variety of individual differences, including gender, age and driving experience. Consideration of the data in this regard will lead to a more holistic image of driver behaviours and a richer overall understanding. This knowledge is useful from both an academic perspective, but also of interest for those wishing to target and modify specific on road driving behaviours, for example as a basis to developing interventions to achieve greater ride comfort or greater fuel economy.

The ADAM device, due to its accurate time stamping of data can also be combined with multiple additional data sources to enhance its use as a human factors research tool. The use of eye tracking software [10], to detect a participants gaze direction and voice recorders, supporting the use of verbal protocol analysis, also know as think aloud research methods [11] are common place in driving based studies, and, when combined with the detailed recording from ADAM, can provide a rich picture of both the evolving road situation, and the drivers physical and psychological responses to events. In this regard, ADAM is of benefit both in terms its novel low cost approach, but also as a tool to support more established research methodologies.

5 Summary and Future Work

In this paper, a novel low cost, portable, driving data collection device called ADAM was introduced. The design process and the performance of the sensors installed are explained in detail. Furthermore, the benefits of this device to human factor studies has been discussed. One set of data has ben presented and used to validate the range information provided by ADAM. This range data was compared with the data from the front-mounted radar on the University of Southampton instrumented vehicle. The two data sources generally agree with each other, although we found that in various situations one will be outperformed by the other.

In the near future, a driving dataset will be set up based on processed data from ADAM. As part of the G-ACTIVE project, driver models will be established based on the data that have the ability to predict future driver behaviour. In the meantime, we are happy to share the experience of building ADAM and the collected data within the academic community.

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