An EPICS-in-IEEE initiative: learners of St Alban's College and students of the University of Pretoria seek earth observation solutions through air-quality microsensing

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***Abstract*—This paper describes the design and implementation of a microsensor-based air-quality monitoring system intended for earth observations. Traditionally, air-quality monitoring systems are limited to centralized or static sites and thus obtain a limited amount of data for estimation of hazardous air pollutants. The system in this paper was designed to improve the shortcomings experienced by traditional air-quality monitoring systems. The system uses the wireless sensor network (WSNs) nodes to sense and transmit selected ambient air-quality parameters to a sensor sink, which relays these parameters to a data terminal where final data processing is completed and the user interface is situated.**

The project development team that was involved in the design comprised a senior undergraduate student at the University of Pretoria and a group of eight grade-11 secondary-school learners from St Alban's College, a boys' high school situated in Pretoria, South Africa. While the undergraduate final-year student designed an analogous system by first principles, the secondary-school learners used educational air-quality microsensor off-the-shelf components. The learners used an Android-based input/output sensor node to communicate to a mobile phone, which managed the upload to a Google drive folder. As a secondary outcome, the educational air-quality microsensor systems developed through this undertaking would serve as an educational tool for improving the public understanding of air-quality, including a new national air-quality act in South Africa. This project was completed as an endeavor of Engineering Projects In Community Service (EPICS) in IEEE.

Keywords - Wireless sensor nodes; Sensor sink; Data terminal; Google Cloud

I. INTRODUCTION

Wireless sensor networks have recently gained much attention in the field of earth observation research because of their ability to allow interactions between users and the environment. When these networks are compared with conventional wired communication networks, wireless sensor networks do not have physical infrastructure that restricts the topology. These networks take advantage of simple wireless communication and minimal computational tools to form networks which allow low-cost hardware to be densely and pervasively deployed. This low-cost hardware which is deployed is characterized by sensors that gather information about the physical environment and transmit the data collected to the controllers that are used as computational tools located at a sensor sink. The sensor sink acts as a gateway to the internet or data terminal used in the network.

The sensors used are usually mounted on tiny, autonomous and low-power devices called nodes. A WSN consists of a wireless communication unit, a microcontroller with a storage device for processing and data storage, a sensing unit and a power source [1]. When deployed, WSN nodes operate in harsh environments for extended periods. This requires individual nodes to be designed in such a way that power consumption can be kept to a minimum. Consequently, this requires a processing unit to be utilized efficiently, such that the communication unit is activated only when needed for transmission of data, processing and storage. Thus the communication unit is the most critical device in the design of a WSN.

The system designed in this paper aims to utilise low-cost hardware that can be used by consumers of various economic classes, but also in industrial and mining environments.

The work has been undertaken as an endeavour of Engineering Projects In Community Service (EPICS) in IEEE, which seeks vertical academic integration, among others, between preuniversity and university students / IEEE student members.

II. Background to 2012 Air-quality microsensor Project

Following the success of the EPICS-in-IEEE projects in [2] and [3], another project was initiated at the University of Pretoria in 2012. The project was aimed at developing mobile devices as sensor nodes for air-quality monitoring. The project was limited to measurements of ambient air-quality parameters with reference to the South African National Environment Management: Air Quality Act (NEM: AQA) specifications, measuring gas concentration above the AQA ambient air threshold levels [4]. To demonstrate the concepts illustrated for the purpose of this work, two gases were selected: nitrogen dioxide (NO_2) and sulphur dioxide (SO_2).

The project engaged a senior undergraduate student at the University of Pretoria and a group of eight grade-11 secondary-school learners from St Alban's College, situated in the vicinity of the University. The senior undergraduate student designed low-power WSN nodes by first principles and the secondary-school learners used commercial off-the-shelf (COTS) components.

III. WSN Nodes - design

Figure 1 shows the low-power WSN node that was designed by first principles.

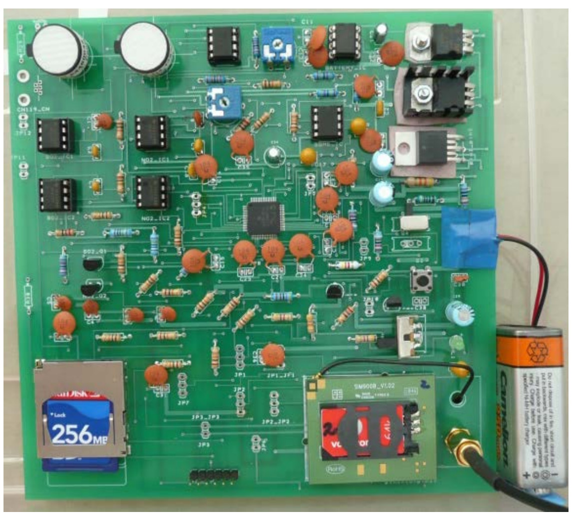


Figure 1. A prototype WSN node printed circuit board (PCB)

The node consists of the gas sensors, a microcontroller unit (MCU), a secure digital (SD) card and a global system for mobile communication/general packet radio service (GSM/GPRS) module as the main components of the node.

Different COTS gas sensors were investigated to find sensors which would be applicable for use in this paper. Several COTS gas sensors exist, including the heating semiconductor, nondispersive infrared (NDIR), light-emitting diode (LED) and electrochemical gas sensors. The latter gas sensors were chosen for this work. These sensors generate a current which is linearly proportional to the gas concentration and have an advantage over all sensors listed above as they are small, low in cost and have a longer lifespan.

The nodes design required a general purpose 32-bit MCU with a universal asynchronous receiver/transmitter (UART), universal serial bus (USB) and serial peripheral interface (SPI). The MCU used for a node was also used for the sensor sink as described in the following section. The UART was needed to interface the MCU with the GSM/GPRS module and the SPI was used to interface the MCU with the SD card. The USB was required for the sensor sink power supply.

The node design was intended to minimize power consumption. Thus the components that built up the WSN nodes do not consume an amount of power which requires a large power supply. In view of this, a readily available 9-V cell was considered. Figure 1 also shows the 9-V cell used to power a node.

A. *Results: Gas sensor's outputs*

Figure 2 shows the sensor's outputs when the PCB in Figure 1 was exposed to NO_2 and SO_2 that were produced at a local university laboratory.

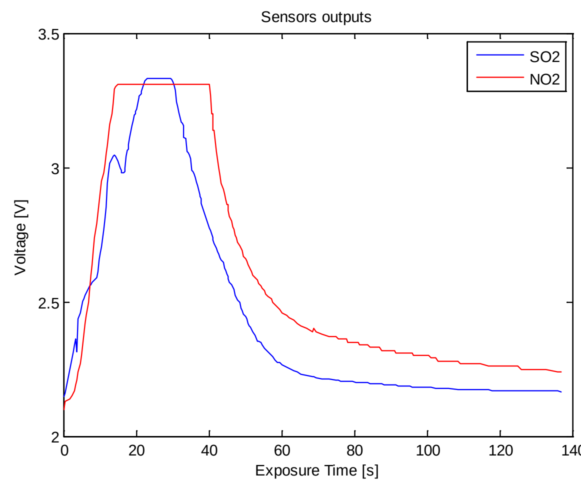


Figure 2. Gas sensor's outputs

While the gases that were made in the laboratory seemed to provide the expected results, the SO_2 sensors seemed to have cross-sensitivity with NO_2. This outcome was investigated further to evaluate the SO_2 sensors separately and it was found that the experiment used to make the NO_2 in a laboratory had some impurities that affected the SO_2 sensors. This outcome was followed up to test the presence of the SO_2 in the experiment that was used to make the NO_2 gas. The test yielded negative results, indicating that the SO_2 sensors could be picking up some impurities that could not be determined.

B. *Results: expected battery life of the WSN node*

Figure 3 shows the graph that shows the expected battery life of the WSN node.

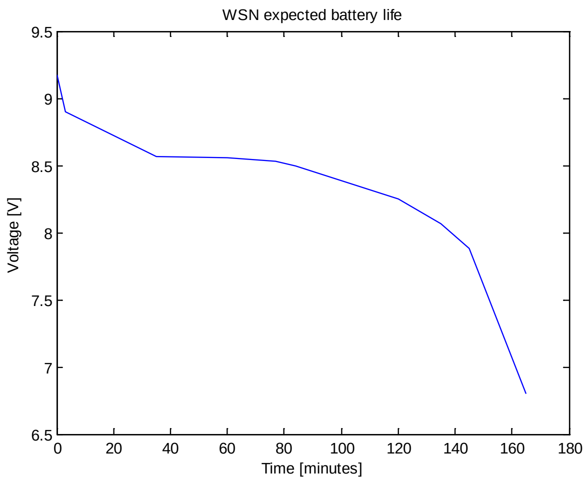


Figure 3. The graph that shows the expected battery life of the WSN node

The battery life of a node was investigated to address a design challenge of the project. The primary engineering challenge was the low power management of a node. Specific characteristics of the nodes such as power consumption had to be considered because power consumption of an individual node differs depending on its type and this represents a challenge when ways are sought to maximize the nodes' lifetime [5]. The node battery life was found to be 165 minutes (2 hours 45 minutes). This low WSNs battery life was due to the GSM/GPRS modules that were used. These modules require a 4.2-V power supply that can sink 2 A of current when transmitting. The minimum current consumed by these modules is 1.2 mA in sleep mode. The GSM/GPRS modules consume a considerably higher current than all components on a node PCB.

IV. Sensor Sink Design

Figure 4 shows a fully built sensor sink PCB which was designed to act as a gateway to the data terminal.

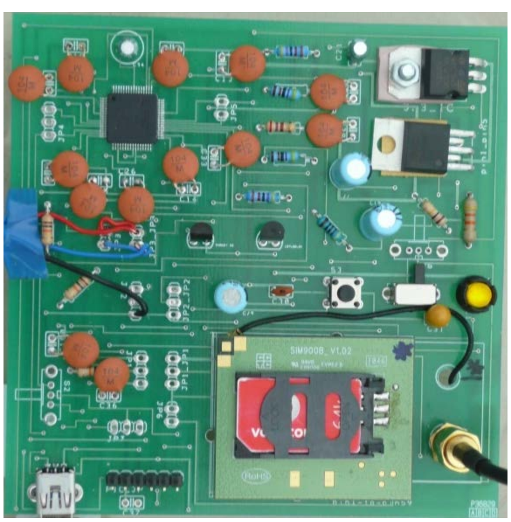


Figure 4. A fully built sensor sink PCB

The sensor sink design method was to replicate the WSNs design, with the exception of a power unit. The sensor sink was powered by a USB connection between the sensor sink and the data terminal. No design was required for the data terminal, only the graphical user interface (GUI) and database for the user to interact with the data terminal. A standard PC running on a 32-bit system was used to implement a data terminal.

A. Results: Data terminal GUI and database

Figure 5 shows a GUI that was designed using WYSIWYG web design software. This web-based GUI was designed to provide user-friendly interaction between the user and the system. The GUI also allows the user to navigate and display different data for different sensors from the system database, and accessible online.

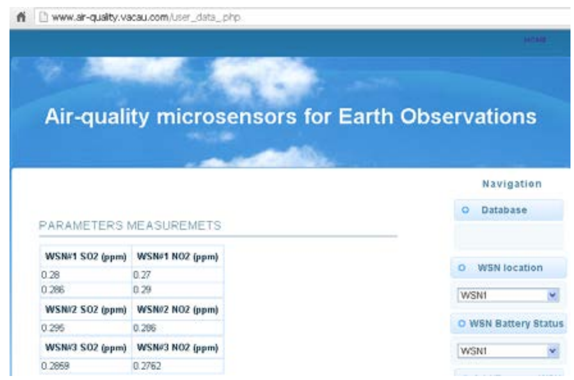


Figure 5. Web-based GUI that was designed

B. Results: WSNs approximate location query

Figure 6 shows a Google Maps application programming interface (API) indicating a successful WSNs approximate location query.

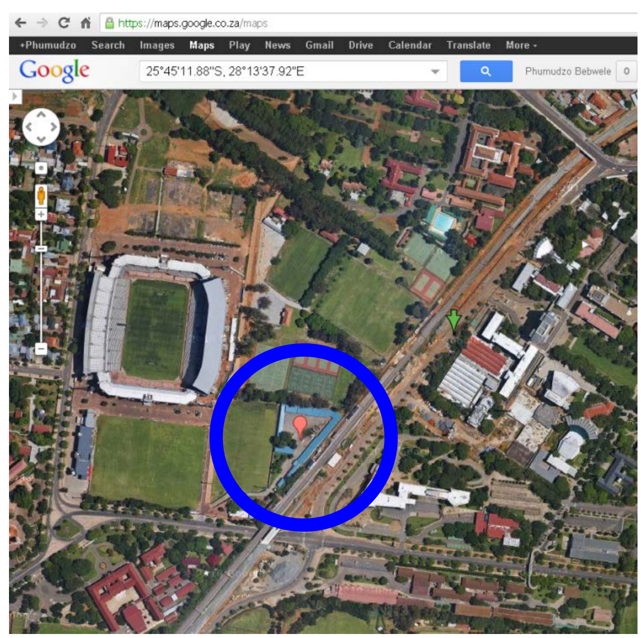
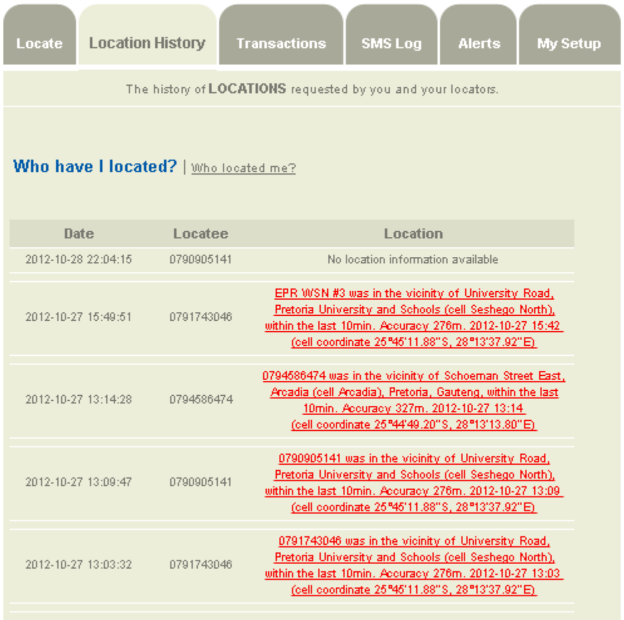


Figure 6. A Google Maps API indicating a successful WSNs approximate location query

The data terminal was used to query and locate the node's approximate location. Thus, the data terminal also served as a locator through a location-based service offered by Cellfind[1], which is a third-party wireless application service provider (WASP). The C-code-based implementation enabled unstructured supplementary service data (USSD), short message service (SMS) and an online interface.

Figure 7 shows the online interface with the location history that was generated when implementing the WSN's approximate location query.



Date	Locatee	Location
2012-10-28 22:04:15	0790905141	No location information available
2012-10-27 15:49:51	0791743046	EPR WSN #3 was in the vicinity of University Road, Pretoria University and Schools (cell Seshego North), within the last 10min. Accuracy 276m. 2012-10-27 15:42 (cell coordinate 25°45'11.88"S, 28°13'37.92"E)
2012-10-27 13:14:28	0794586474	0794586474 was in the vicinity of Schoeman Street East, Arcadia (cell Arcadia), Pretoria, Gauteng, within the last 10min. Accuracy 327m. 2012-10-27 13:14 (cell coordinate 25°44'49.20"S, 28°13'13.80"E)
2012-10-27 13:09:47	0790905141	0790905141 was in the vicinity of University Road, Pretoria University and Schools (cell Seshego North), within the last 10min. Accuracy 276m. 2012-10-27 13:09 (cell coordinate 25°45'11.88"S, 28°13'37.92"E)
2012-10-27 13:03:32	0791743046	0791743046 was in the vicinity of University Road, Pretoria University and Schools (cell Seshego North), within the last 10min. Accuracy 276m. 2012-10-27 13:03 (cell coordinate 25°45'11.88"S, 28°13'37.92"E)

Figure 7. An online interface with the location history that was generated when implementing the nodes approximate location query

When a node was registered on the network, the USSD reply to the sensor sink indicated the name of the node (EPR WSN #3 in Figure 7) and the location where the node was to be found. In this case, EPR WSN #3 was "in the vicinity of University Road, Pretoria University and Schools (cell Seshego North), within the last 10 minutes. Accuracy 276 m. 2012-10-27 15h42 (cell coordinate 25°45'11.88"S, 28°13'37.92"E)". Using the cell coordinate 25°45'11.88"S, 28°13'37.92"E, the location can be searched on the Google Maps API as shown in Figure 6.

V. Educational Air-Quality Microsensors Kits Design by St Alban's College Learners

To initiate the partnership between the University of Pretoria and the St Alban's College for the 2012 project, a first meeting was held at the St Alban's College where the undergraduate final-year student did a presentation to the learners. After this presentation, follow-up meetings were held to complete the project.

Figure 8 shows rough notes from a follow-up discussion following the first meeting at the St Alban's College. Figure 9 shows a photo taken when the learners were working on the project at the school.

[1] Cellfind is a South African location-based mobile services provider.

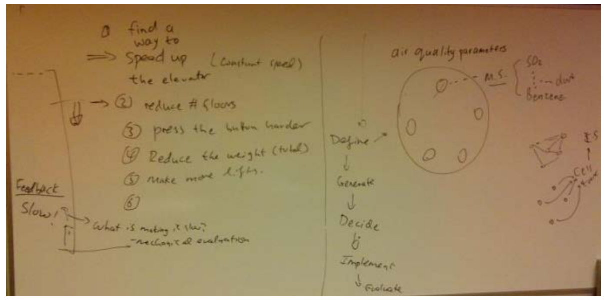


Figure 8. Rough notes from a follow-up discussion following the first meeting (the approach illustrates student *engagement*)

Figure 9. Learners working on the project at the school

The challenge of involving learners in the project was linking what they already knew and had learned in their individual school subjects with what was required from them during the design of these microsensor kits. It was vital to keep the difficulty of the project at a level that learners could handle in order to keep them motivated throughout the design process, but still challenge them to learn and broaden their knowledge.

When the project started, it leaned in the direction of devices that the young learners knew best, namely smartphones. The focus was placed on Android-based smartphones with an aim to develop open-source software. Most learners were familiar with the JAVA programming language which allowed for the above.

The project was divided into subsections to allow each learner to be responsible for his own section. These subsections can be seen in Figure 10. Little to no advice was given to learners relating to the specifications of each section. The students had to do their own research on what is available in their selected areas and had to report back to the whole group. From their feedback, a more detailed system design problem was formulated.

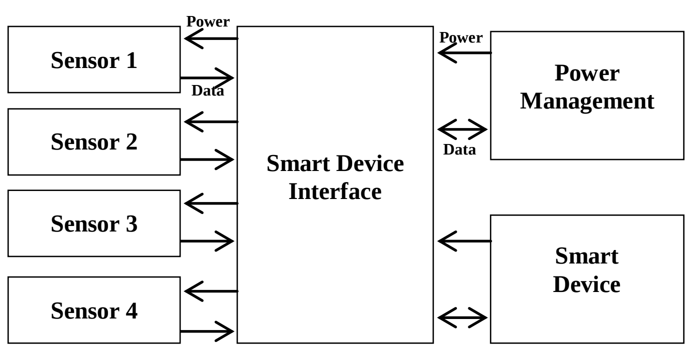


Figure 10. System diagram of the COTS-based air-quality sensing system

Figure 11 shows the Android IOIO board which was used as an interface between the microsensors and other electronic hardware, including the smartphone which was used. The IOIO interface consists of eight (8) analogue-to-digital converters (ADC), and various peripherals as well as the capability to provide a regulated 3.3-V and 5-V supply from a 5-V to 15-V source. The IOIO device communicates with the smartphone using either a USB connection or Bluetooth connection. The students were able to experiment both communication methods. All the IOIO functionality was controlled by a simple API that is freely available online. An open-source online forum that gives assistance on any IOIO problems makes this interface also ideal.

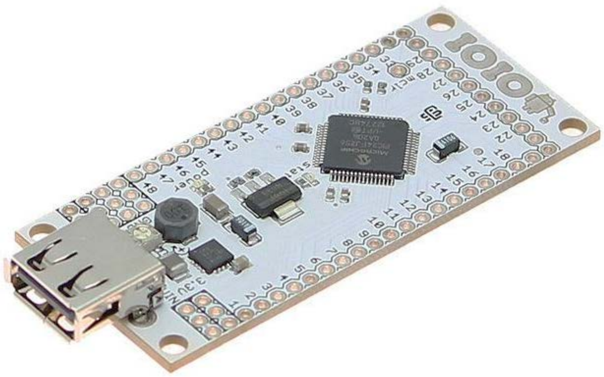


Figure 11. Android IOIO Interface board

Contrary to the university student's effort, the preuniversity learners selected a simpler and readily available carbon dioxide (CO_2) sensor. Figure 12 shows the CO_2 sensor which the learners used for testing the system. The sensor has three (3) data pins that give the measured CO_2 in parts per million (ppm), a controlled signal and a trouble signal. A controlled signal indicates the status of the CO_2 threshold levels and a trouble signal indicates when the sensor is faulty or fully functional.

Figure 12. Carbon sensor module

To investigate the use of renewable energy, the students also researched the option of using the iSense Solar Power Harvesting System as a power management unit. Figure 13 shows the iSense Solar Power Harvesting System that can produce a 5-V supply using a combination of photovoltaic (PV) cells and/or rechargeable batteries.

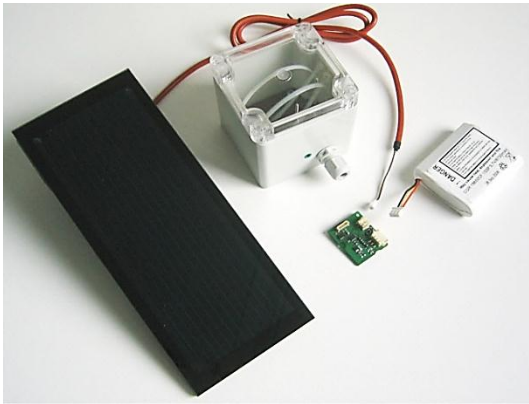


Figure 13. iSense Solar Power Harvesting System

The software pseudocode developed was kept simple and to minimum flow control, namely:

- Measure the gas sensor outputs.
- Write the measured data to a file that is stored on the smart device as part of a backup system.
- Upload the data file to Google Cloud (using Google drive) for remote processing.

The processing of the data was done at a remote location that also served as the central processing node of the sensors. These nodes (smartphones) were also enabled for global positioning system (GPS) location tracking. This allowed the learners to display the results visually using Google Maps. To this end, the learners were working on integrating the hardware, software and online components of the project.

The evaluation phase consisted of ten (10) sensors placed at remote locations near various schools and other polluted areas. Data was collected for further analysis and evaluation of the air-quality sensor nodes. This also created the opportunity for further involvement from communities as will be discussed later in this paper.

The challenges experienced during the development phase varied from time constraints to understanding basic engineering principles. The learners who were involved in this project were also involved in other compulsory and competing activities in their school programme. Finding time to focus on the project was therefore very difficult, which led to slow progress in the development of the microsensor nodes. The commitment of the learners to the project compensated tremendously for this problem. Understanding basic engineering principles is also a unique challenge. The educator (an electrical engineer) who was leading the learners was also available to assist the learners with solving more complex engineering problems. The aim of the educator was to help the learners to keep the design at a manageable level of complexity.

VI. Community Service

This project was intended to improve the public understanding of air-quality and encouraged learners to have a better perception of engineering. One previously disadvantaged high school (Modiri Technical School, Mamelodi, Gauteng, South Africa) was identified to further expand this community service. This identified school will be involved in the next system design phase of the project. Modiri Technical School has expertise that will complement the expertise of the learners of St Alban's College. This will strengthen the current learning collaboration between these two institutions. Other schools will also be used as locations for the testing nodes. This will create the opportunity for the learners of St Alban's College to share the importance of air-quality monitoring with learners as well as to share their experiences with learners in the hope of motivating them towards a career in engineering. In the pipeline is also the development of educational learning modules for primary schools as part of their school curriculum.

VII. Conclusion

This project was undertaken to design and implement a microsensor-based air-quality monitoring system that can be used for earth observations. The low-power WSNs and sensor sink were designed by first principles whereas a COTS-based approach was pursued by high-school learners. The former was designed by a senior undergraduate student at the University of Pretoria and the latter was developed by a group of eight grade-11 secondary-learners from St Alban's College. The project enabled verticial integration between the different levels of the national qualification framework (NQF) in South Africa.

Acknowledgment

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