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Computer Vision and Wireless Sensor Networks in Ambient Assisted Living: State of the Art and Challenges

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ABSTRACT

Due to demographic reasons, the percentage of elderly population in developed countries is rapidly increasing, thus leading to much bigger demand of alternative caring solutions such as Ambient Assisted Living (AAL). This paper presents the recent research trends in AAL, as well as the main challenges to its development. The paper focuses on two significant fields in AAL – computer vision and Wireless Sensor Networks (WSN), and provides details about the state of the art and challenges to research in these fields.

Keywords: *Ambient Assisted Living, fall detection, computer vision, Wireless Sensor Networks*

1. INTRODUCTION

There is a pronounced tendency towards gentrification of the population in developed countries. According to the results of the 2008 Eurostat, in 2015 the average demographic growth in the EU will become negative, and in 2060 30% of the EU countries population will be at or above 65 years old [1]. The situation is similar in Japan, the US, and Canada. This would lead to increased pressure on the social system and pension schemes as the working to non-working people ratio will drop. There will also be growing demand for care and health services and it is likely that hospitals, care providers and nursing homes will no longer have sufficient resources to respond to the increased needs of the elderly population.

This is the reason why the area of Ambient Assisted Living (AAL) is getting more and more important and a lot of research has been going on in this field in recent years. AAL could be interpreted as the distributed collection of intelligent systems (either implanted, body-worn, or embedded in the surrounding environment) that assist and monitor the elderly in their daily lives, thus assuring a better quality of life [2]. Quality of life is defined as the physical, mental and social well-being.

The purpose of this paper is to summarize the general directions in which AAL research efforts are concentrated, and to provide more detail into the areas of computer vision and wireless sensor networks focusing on their application in AAL systems.

2. GENERAL DIRECTIONS OF AAL-RELATED RESEARCH

As suggested by the AALIANCE consortium, the broad area of AAL could be separated into three subareas – AAL4persons, AAL@community and AAL@work [2]. This separation is presented at Fig.1.

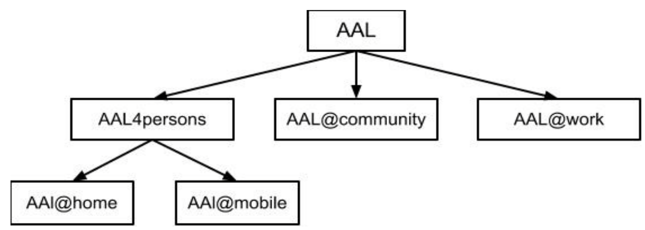

Figure 1: Separation of AAL into subareas.

AAL4persons is focused on assuring the personal health, rehabilitation and care of the elderly. It could be further subdivided into AAL@home, dealing with research and development of smart home systems, and AAL@mobile which is oriented towards providing care and insuring personal safety when the elderly people are on the move – e.g. when transferring between their home and a doctor or when visiting a friend, shops, etc.

AAL@community encompasses areas of research related to the position of the elderly in the society. Main effort in this field is the development of platforms that prevent the elderly from feeling lonely or isolated, providing them with means of social networking, entertainment and leisure activities. Another direction in this field is the provision of means to perform activities such as shopping which often become burden, especially for aged people who live on their own.

AAL@work refers to research in the area of aging at the work place and development of supportive solutions that ensure dignified transition from full-time work to retirement.

The main research focus in AAL are also determined by the technological areas that build up this highly multidisciplinary field [3, 4, 5]. Some of the fundamental technological areas integrated into AAL are presented at Fig. 2.

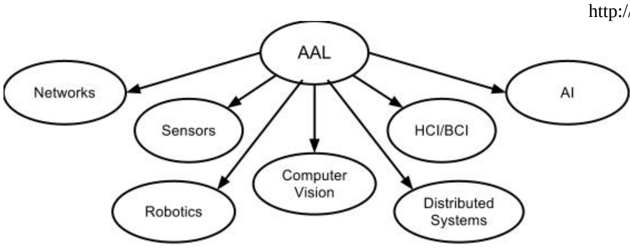

Figure 2: Technological areas in AAL.

AAL uses advances in computer networks and distributed systems, sensors, robotics, Human Computer Interfaces (HCI) and Brain Computer Interfaces (BCI), computer vision, audio and video processing, artificial intelligence (AI) and many more.

The objectives of AAL and the technologies it uses result in concentrated research in the following areas:

a. Fall detection and/or detection of helplessness

This is one of the main and most critical problems in AAL. The elderly are very frail and due to decreased functions of the locomotive and nerve systems, or to age-related diseases, they often have reduced stability, increased reaction time and moments of disorientation. This increases the risk of falls and subsequent injuries. Often the elderly aren't able to alarm that they have fallen and need assistance, they may lie on the floor for hours without help, and in many cases this could lead to long period of hospitalization or treatment, and in some cases even to death.

A lot of effort has been concentrated on creating a fall detector that would trigger an alarm on the event of a fall. The main requirements to the hardware and software implementation of such a fall detector are:

- Not to miss the event of a fall, i.e. very high sensitivity;
- To minimize the number of false positive alarms (the registration of a fall when there is no fall), i.e. high specificity.

The first requirement is logical as the aim of a fall detector in the ideal case is to register all falls. Moreover, as the fall could cause a condition of helplessness or even be life threatening, fast reaction to such events is crucial.

In the second case a high number of false positive alarms could compromise the system and to diminish the acceptance by the end users.

Different authors use different algorithms and sensors to detect the fall, the most often used being:

- accelerometers and/or gyroscopes [6-11];
- cameras – either wearable or static [12-17];
- smart floors [18,19];
- combination of several methods [20].

Despite all the research dedicated to fall detection, there still isn't a 100% reliable algorithm that catches all falls without issuing false alarms.

b. Activity classification

These teams' objective is to create a reliable classifiers of human actions and activities. The difference between action and activity is that the action is a simple movement or change in the posture of the user (e.g. gets up, lies, walks, etc.), whereas the activity could be a combination of several actions representing a complex higher level abstraction such as cooking, cleaning, eating, etc. Different machine learning techniques are deployed in these projects [21-23].

c. Location tracking

Location tracking is very important component of a tele monitoring system, especially for persons with any form of mental illnesses or dementia (such as Alzheimer disease). Different approaches for practical realizations exist [24], some of which use:

- radio frequency identification (RFID) [25];
- cameras [26];
- Multimodal approaches [27, 28].

d. Tele monitoring of vital parameters

The tele monitoring is important aspect of the health services provided by AAL. Parameters such as pulse rate, blood oxygen saturation, ECG are monitored [28]. Most often the sensors are wearable but this might impact the acceptance from the users. That is why efforts are focused on developing other contact-free means of obtaining the vital parameters' signals.

e. Sensor data fusion

All algorithms for monitoring, fall detection, activity recognition, etc., relying on only one data provider (sensor, camera, and microphone) have their own limitations and do not ensure 100% reliability. Sensor data fusion is the area which is focused on creating multimodal systems, which receive data from several providers and perform correlation or fusion upon it in order to increase the accuracy and reliability of the algorithms [20, 26, and 27].

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f. Development of innovative user interfaces

Some components of complicated AAL systems have to be interactive, e.g. in a social network the user should be able to communicate and set up the system. Given that the elderly are often reluctant to use computers, some novel interfaces should be developed which are better suited for their technical knowledge and abilities [29]. These may include but are not limited to:

- brain computer interfaces (BCI) [30];
- gesture recognition [31,32];
- speech recognition [33,34];
- intuitive touch screens or touch pads [34].

g. Wireless sensor networks (WSN)

Wireless sensor networks are essential component of AAL systems. All wearable sensors in the system are bound to be battery-powered and to transmit data wirelessly. Other environment embedded sensors and devices are also likely to transmit their data in a wireless fashion. There are several well established wireless standards such as Bluetooth, ZigBee, WiFi (IEEE 802.11) which are widely used in ALL systems. A lot of research has been conducted in the area of WSN but issues such as traffic optimization, network management, security and reliability are yet to be fully investigated and developed [35,36].

h. Social networks and Smart TVs

A lot of research efforts in AAL are focused on dealing with the technological challenges for having reliable and predictive functioning of the AAL system. But apart from their physical safety and security, the elderly need social communication, cares, and attention. This is especially valid in today’s and future's societies where the family members and care providers couldn't spare enough time to properly address these aspects of the care services to the elderly. Several projects work in the direction of development of social networks or Smart TV systems which would offer to their users a variety of social networking options as well as different kinds of entertainment and leisure activities [37, 38].

i. Robot assistance

Research in the area of robotics and creating a robo-companion is also taking place [39, 40]. The idea is that robots could serve dual purpose – on the one hand, they could monitor the user health state and behavior, on the other hand, they could act as social companion to reduce the level of loneliness. This area is a multi-disciplinary field of research on its own, with problems in the areas of mechatronics, signal processing, artificial intelligence, user acceptance etc., and currently is far from delivering a completely finished product.

j. Behavior determination

This area is focused on building a behavioral profile of the user and monitoring whether there are deviations from the model. Behavior determination is heavily based on activity recognition and location tracking as both are important aspects of the user's routine life. The objective of behavior-tracking systems is to detect atypical behavior which might be caused by decreased health status, progressing disease or emergency situation [41-43].

k. Standardization

One major problem in AAL is that because of the multidisciplinary nature of the area the research groups are somewhat scattered and they often create their own platforms or frameworks which lack interoperability. There are several projects (such as UnivresAAL) whose objective is to create a standardized and unified approach to developing AAL systems [44, 45]. The results of these initiatives are yet to be evaluated.

l. Modeling, simulation and verification

There are some teams dedicating their efforts to modeling and simulation of AAL systems and their verification [46-48]. This is a very difficult task due to the heterogeneity and complexity of these systems. So far, there is partial success reported in this field.

3. BARRIERS AND CHALLENGES TO AAL

AAL has a number of barriers and challenges that impede its development and more universal deployment. These could be summarized as: technological, ethical, legal and psychological challenges [49-51]. They are presented at Fig. 3:

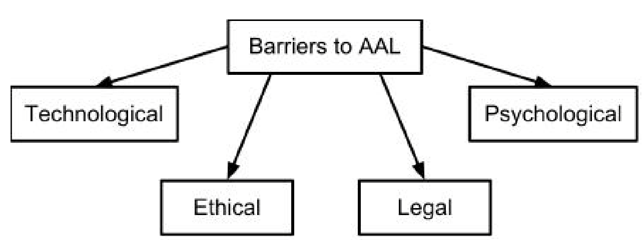

Figure 3: Barriers to AAL

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a. Technological

There are a lot of technological issues to AAL system developers – which systems and environmental sensors should be wired and which wireless; the accuracy and reliability of the critical systems; unmanned automatic operation and tele maintenance; ease of installation, configuration and use; interoperability and vendor independence; innovative and usable user interfaces, etc. [49].

Another major issue in AAL systems is the conflict between two contradictory requirements [2]:

- AAL systems have to offer applications and services in a user-centered way;
- a common application platform approach is needed.

b. Ethical

There are ethical issues in the development of AAL systems as well [52]. Most of them deal with the privacy of the users, especially when video processing is deployed. There are concerns about the security of information and who can access what information and under what circumstances.

Also, there are issues when the AAL systems are tested. Normally the systems are tested by volunteers who are most often young or middle-aged people. But the accuracy of these tests is influenced by the fact that the volunteers are active and healthy which wouldn't be the case of the real users of AAL systems. Of course, testing a fall detector on elderly people is ethically unacceptable but on the other hand, the tests with young subjects may not have the desired accuracy.

c. Legal

There are legal issues involved with AAL too, mainly due to the lack of standards and regulations [53]. There is no legislative base addressing the responsibilities of the manufacturers, service providers, support teams, and no regulation of the relationships between them, the users and the users' families.

d. Psychological

One of the most serious problems with AAL systems is the acceptance by the users [54, 55]. An AAL system would be useless if the user refuses to use it. Major issues here are the fear, reluctance or inability to use technology and the unclear evidence of real benefits of the AAL system.

4. USE OF COMPUTER VISION IN AAL SYSTEMS

Computer vision and image or video processing is deployed in almost all recent research in the area of AAL mainly due to the advances in the field of signal processing, the small prices of today's digital cameras and to the fact that the video signal is semantically rich in information for the user's condition. The main areas where video or image processing is used in AAL are [14]:

- Fall detection – cameras are used as a supplement to, or instead of, existing fall detection algorithms (accelerometer or motion sensor based, smart floors, etc.);
- activity monitoring – cameras are used in order to track simple actions or more complicated activities from the daily life of the users;
- security – this application often means video surveillance with the purpose of burglars or other kinds of unwanted visitors detection;
- Safety – keeping track of the person and weather he or she is well. This could mean tracking of people with dementia or other mental illnesses, etc.;
- tele monitoring of physiological parameters such as pulse.

Video or image capturing systems and their applications in AAL are a relatively recent research field and there are still a lot of challenges to be overcome [14]. The main groups of challenges are presented at Fig. 4:

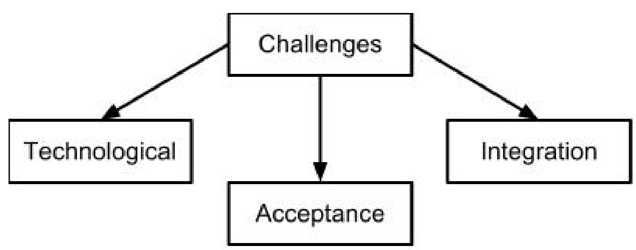

Figure 4: Computer vision challenges in AAL systems.

a. Technological Challenges

Even though the area of computer vision is well researched for many years, the application of computer vision in AAL systems with their particular requirements and needs is relatively new field. This means that there are still technological issues to be overcome such as:

- the choice of video or image processing algorithms – there is an on-going research in areas such as foreground-background subtraction, humans detection and segmentation, human shape features extraction, machine learning techniques and algorithms for action and activity classification, etc [14];

- the problem with occlusions – if the environment is full of furniture, there might be a need for several cameras;
- data fusion from multiple cameras;
- multi occupancy of the environment;
- presence of a pet such as a cat or dog, etc;

b. Acceptance Challenges

Acceptance is a very serious issue on the way of deploying video systems in AAL systems. The users are often very concerned that they will loose their privacy and as a consequence are reluctant to accept camera-based solutions in their homes. The way to resolve this issues is to process locally the video or images (i.e. to use smart cameras) and if possible to forward only alarms to other parts of the system which are accessible by careers; to use silhouettes and edges [56]; and most importantly to educate the prospective users, to explain that their privacy wouldn't be sacrificed. Another approach would be to deploy some kind of interactive communication with the assisted person (audio or light indication, signaling through a vibrating module) so that the video recording could be announced in advance and the user could have some time to react (e.g. turn off the video recording) [57]. This approach has the additional plus that it could minimize the negative effect of false positive alarms.

c. Integration Challenges

This challenge is related to the integration of the video processing subsystem with the other components of an AAL system. Issues here are the interfaces to the other parts of the system; the choice of where to process the sensitive information – locally or centrally; to ensure good protection of the sensitive information.

5. USES OF CAMERAS IN AAL

The uses of cameras in AAL systems could be divided into several groups, presented at Fig. 5. Most often they are deployed to detect falls [13,20,15-17,58,59] but in some applications they are used to ensure secure home [60] or detect 'significant' events [61].

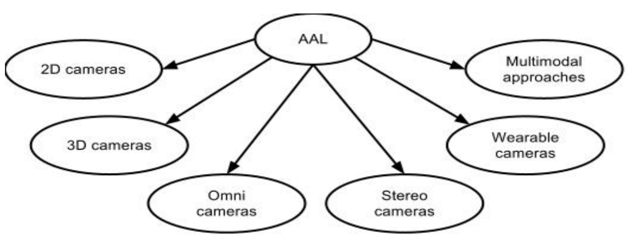

Figure 5: Cameras in AAL systems.

a. 2D cameras

2D cameras are the cheapest option as their prices have fallen dramatically over the last decade. On the down side it is difficult to extract reliable data for the purposes of AAL (e.g. fall detection) from only one source [16], and in most cases multiple cameras are deployed [13,15,16]. This comes at the price of complication of the processing algorithms.

b. 3D cameras

3D cameras are more expensive than 2D cameras but their benefit is that they provide more information about the position of the user's body in space and as a consequence only one camera might be sufficient for the purposes of the AAL application [58].

c. Omni cameras

Omni cameras provide 360° view of the space and are useful for fall detection or location tracking [14]. They are often positioned on the ceiling to provide a view on the entire room.

d. Stereo cameras

Stereo cameras deploy two lenses in order to provide stereo video signal which could be very beneficial to AAL systems which aim to detect falls [59]. The video processing algorithms in this case are more complex than for monocular cameras.

e. Wearable cameras

There are a couple of applications in AAL that deploy wearable cameras such as Microsoft's Sense Cam [60,61]. Wearable cameras aren't as suitable as other camera types for fall detection as they might move independently of the user and might fall with their lenses facing in an arbitrary direction. They are good for detecting risk zones in the user home [60] or to detect significant events in the user's daily life [61].

f. Multimodal approaches

Cameras are also used in conjunction with other sensors to obtain better precision of the selected algorithms, most often through data fusion [20].

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6. WIRELESS SENSOR NETWORKS IN AAL SYSTEMS

Wireless Sensor Networks is a very broad and relatively new scientific field combining research efforts in the areas of Sensor Technologies, Communications, Distributed and Embedded Systems, Information Technologies, etc. A WSN consists of a number of sensor nodes that transmit their data wirelessly to a gateway which forwards the data to a remote system. The gateway is also called a 'sink'. The measurements from the sensors might be processed locally before they are transmitted to the sink or the processing and aggregation of the data might be performed by the sink – Fig. 6 (a) and (b).

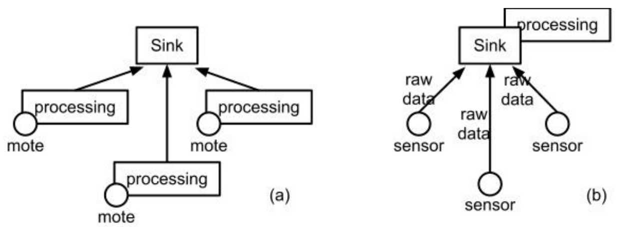

Figure 6: Wireless Sensor Networks: (a) local processing by the motes (b) centralized processing

In the Fig. 6 (a) the sensors are 'smart' – they have some limited processing and storage capabilities and are also referred to as 'motes' [62, 63]. They transmit the processed information to the sink. In Fig. 6 (b) the sensors are much simpler and transmit raw data directly to the sink. The trade off is that they put much heavier load on the wireless network infrastructure.

Sensors in WSN (irrespective of whether they are smart or not) could all send their data to the sink or be grouped in clusters of sensors. The cluster-based topology is more complex but might provide better traffic organization in larger WSNs with higher number of sensors. Every cluster has a cluster head which is a sensor node acting as a cluster coordinator. All the sensors in the cluster send their data to the cluster head and the cluster head forwards it to the sink. Both variants are presented at Fig. 7:

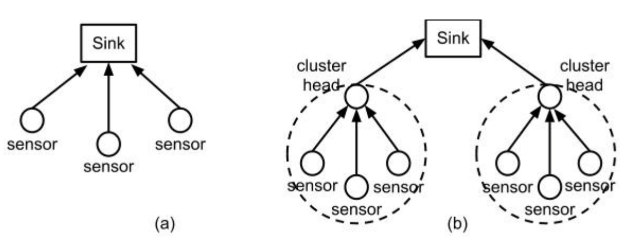

Figure 7: Wireless Sensor Networks: (a) all-to-one generic topology (b) cluster-based topology

The wireless standards and interfaces used in WSN are ZigBee and IEEE 802.15.4, Bluetooth, IEEE 802.11, SimpliciTI proprietary interfaces, cellular technologies [62].

All WNS applications put heavy constraints on the energy usage and resource allocation in the WSN but in healthcare applications there is also a demand for wearability, very high system reliability, quality of service (QoS), privacy and security [63,65]. Main areas of healthcare that benefit from development in the area of WSN are [63]:

- Monitoring in mass-casualty disasters;
- Vital signal monitoring in hospitals and nursery homes;
- At-home and mobile aging;
- Assistance with motor and sensory decline;
- Large scale in-field medical and behavioral studies.

In AAL the WSN is an omnipresent component. The network consists of all the sensors on the patient (the Body Area Network - BAN) and the ambient embedded sensors, and its structure is presented at Fig. 8:

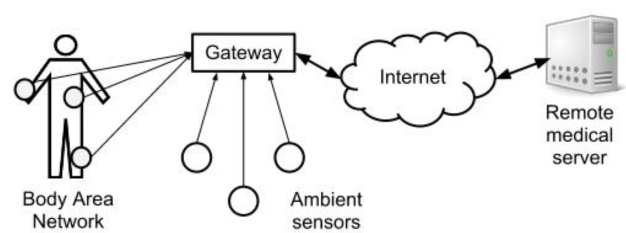

Figure 8: Wireless Sensor Network for AAL applications.

The body wearable or implanted sensors form a mobile cluster of sensor nodes (the BAN). The nodes in the cluster are also mobile in terms of the cluster – e.g. a wrist-bound heart rate sensor moves when the patient moves his or her arm, etc. [66]. It could be assumed that the ambient sensors are fixed and stationary nodes. There might be one or several sinks to provide for better reliability and latency control. Often the gateway(s) send data to a remote medical server over the Internet.

A very important issue in WSN for AAL applications is to ensure sufficient QoS for critical data. When the AAL system is designed, a model of the transmitted data should be created and there should be a clear distinction between critical and non-critical data. What data is critical depends on the concrete application – e.g. in a tele monitoring system the alarm generated by a fall detection is critical data. On the other hand the current location of the patient when creating a behavior profile is non-critical data. In applications such as tracking of patients with dementia, the location of the patient could trigger an alarm if the patient tries to leave the protected environment of his/her home or nursery home and in this case will be critical data. This shows that the requirements for QoS of a

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given sensor depend also on the current scenario under which the system is running [66, 67].

There are several approaches in order to provide adequate QoS and to ensure successful transmission of the critical data – measures might be taken on data link (MAC – Media Access Control) layer, network or transport layers [65-67].

a. Data Link Layer

Protocols responsible for ensuring access to the medium reside in this layer. As the sensors and devices deployed in AAL systems often come equipped with standard interfaces such as Bluetooth, ZigBee or WiFi, whose data link layer protocols are well described by the corresponding standard, it isn't always feasible to develop own protocols for enhanced QoS for critical data at this layer.

b. Network Layer

This layer is responsible for the routing of the data. A lot of efforts have been concentrated to develop routing protocols serving different purposes – energy efficiency, congestion avoidance, load balancing, general high QoS [68]. This looks like the most promising layer to work in the direction of priority optimized QoS routing protocols – a novel research in this area along with some overview of existing research is presented by Nabi et al. [66].

c. Transport Layer

There are measures that could be taken to ensure lossless transmission on this layer too. The idea is to work in the direction of ensuring total end-to-end reliability procedures, mainly at packet or event level [65].

Apart from ensuring the corresponding QoS for critical and non-critical data, there are other challenges and open research problems for WSN in healthcare applications [65, 69]:

- physical challenges - unobtrusiveness, energy of the batteries, bandwidth problems, effective data collection methods;
- energy efficiency at the data link layer;
- load balancing, congestion avoidance, rate control, data compression techniques at the network layer;
- congestion and flow control at the transport layer;
- producing meaningful information that could be translated into knowledge, coordination and organization of sensor data, self-learning at the application layer;
- Security, privacy, user friendliness, scalability, ease of deployment, etc.

6. CONCLUSIONS

There are a lot of challenges and open research questions to AAL and it would be impossible to encompass all of them in detail in a single paper. All the same, a brief summary of the AAL-related research topics, barriers and challenges to AAL systems was presented in this paper. A more detailed overview of the state of the art and the open research problems of computer vision applications and WSN in AAL were presented as well.

AAL is a relatively new and exciting research area and because of its multidisciplinary nature it presents a lot of challenges which need to be addressed by multidisciplinary teams. It is very probable that in the next several years we will witness a lot more research efforts in AAL-related areas which would hopefully lead to insuring better quality of life and dignified and independent living to the elderly and people with disabilities.

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