M7-029 Development of Wearable Robotic Arm Input for 5 DOF Articulated Arm Manipulator

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ABSTRACT

This paper presents experimental results from a new design of Wearable Robotic Arm Input (WRAI) to control the movement of an Articulated Arm Manipulator (AAM) having 5degree of freedom. SimMechanics and Virtual Reality toolboxes from MATLAB are used to model the AAM in order to assist an operator to monitor input signals from WRAI. Interactive 3D Virtual Reality and graphical information is achieved during simulation and experiment. The system being developed can be useful for future work in developing a medical device for the treatment of stroke patients or position teaching device for operators in industrial fields.

Keywords: 5 DOF Articulated Arm Robot, Wearable Arm Manipulator, SimMechanics, Virtual Reality

1. Introduction

Wearable Robotic Arm Input (WRAI) is a device that is worn on human's arm. The development of WRAI can have numerous valuable applications[1]. Biomedical area might use WRAI to observe the arm movement of stroke patients during a treatment. In industrial fields, arm manipulators are required to be controlled for its specific job. Programming to get arm manipulators best trajectory, sometime become a tedious job for the operator, therefore WRAI for position teaching is needed[2].

The purpose of this research is to develop WRAI for controlling an Articulated Arm Manipulator (AAM) having 5 degree of freedom. The AAM is installed on a rescue robot prototype as shown in Fig. 1. This research presents the AAM model based on WRAI movement connected to hardware interface using a modified USB game joystick.

The design of WRAI is focused on obtaining a better sinchronization between the joints on WRAI, the joints on the AAM and the virtual reality model of both WRAI and AAM. SimMechanics toolbox from MATLAB is used to generate 5 DOF AAM model for its kinematic movement.

The virtual reality technique is also used to generate the visualization of environmental condition.

2. Wearable Robotic Arm Input

The WRAI generates 5 output signals. It is worn on the right hand of an operator as it can bee seen in Fig. 1. Linear potentiometer is chosen as sensor devices, installed on each joint of WRAI. The WRAI in Fig. 1 was the early design of WRAI in which it had an auto extendable feature to keep the sensor stay on its initial position along exercise.

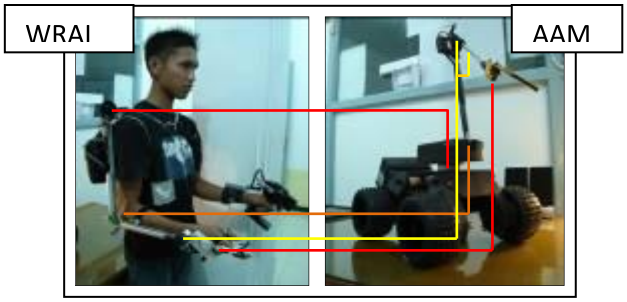
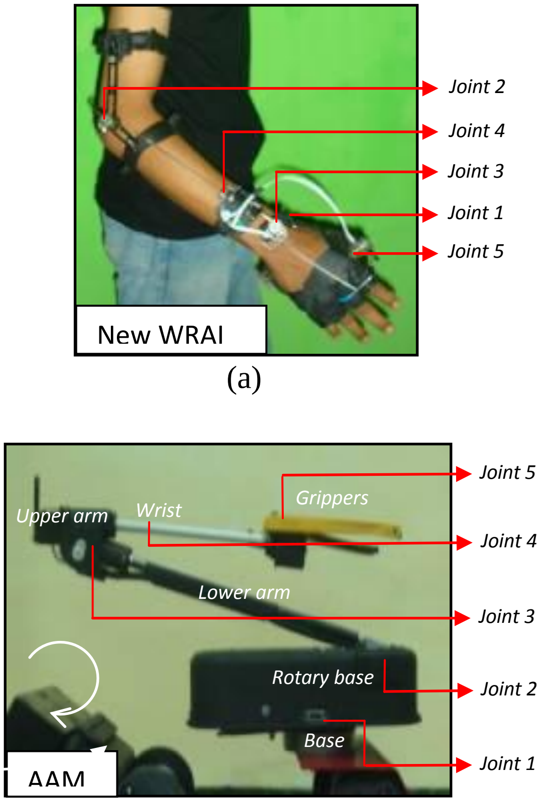


Figure 1. Early WRAI configuration controlled 5 DOF AAM on a Rescue Robot prototype.

The mechanical design on this early work of WRAI unfortunately prompted an avoidable rotational interference problems between two nearby joints. The difficulty in capturing hand kinematics is due to a relatively large number of degrees of freedom concentrated in a very small place[3] . An unexpected angular movement occured on another joint when one neighbor joint is rotated. An improved version of WRAI shown in Fig. 2 will be used for further analysis in this paper. Joint numbering in Fig. 2 explains the relation between the joints of WRAI and AAM. Joint 1 on WRAI controls the rotation of joint 1 on AAM, and so on.



(a)

(b)

Figure 2. (a) *New WRAI prototype with 5 output signals. (b) 5 DOF AAM installed on rescue robot.*

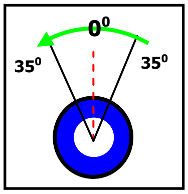


Figure 3: Saturation limit of potentiometer rotation

2.1 Interfacing and Synchronization

MATLAB software installed on a PC or a notebook reads the output signal from WRAI through a hardware interface built from a modified USB game joystick. MATLAB converted the signals automatically such that it can be accessed by using the Joys Stick Input block in

Simulink. Signals -1, 0 and 1 out from the Joys Stick Input block represents 0, 2.5 and 5 Volt consecutively.

The joystick has five linear potentiometers that their resistance can vary from 0 to 5KΩ causing voltage signal with the range of 0 to 5 Volt. The saturation limit of each potentiometer rotation is shown in Fig. 3, except for the potentiometer number 2, it can rotate along 70 degrees to yield the 0 to 5 Voltage range. The potentiometer number 2 for the joint 2 can accomodate 90^0 range of angular movement.

Standard terminology that classifies angular movement configuration of human's right hand[4], and its relation to AAM model are presented in table 1. WRAI, has an angular movement limitation. Therefore, when the WRAI is worn, the angular movement of human's hand joint is limited by the angular saturation limit of WRAI.

The values of angular movement limit for human's joint space (represented by WRAI), AAM model, and potentiometer (PotLim) are shown in table 2. Synchronization was needed and performed in Simulink using gain blocks such that the angular movement range for each of potentiometer and its related joint on the AAM model can be as wide as possible within their maximum allowable angular movement range.

Table 1. Relation between joint space of human's hand and AAM model

Joint	Human's hand	AAM
1	Radial/ Ulnar of Wrist	Rotary Base
2	Flexion/Extension of Elbow	Lower Arm
3	Flexion/Extension of Wrist	Upper Arm
4	Rotation of Forearm	Wrist
5	Flexion	Grippers

Table 2. Maximum angular movement occured on WRAI and AAM model

Joint	WRAI	PotLim	AAM
1	103^0	70^0	180^0
2	126^0	90^0	180^0
3	46^0	70^0	180^0
4	91^0	70^0	90^0
5	15^0	70^0	45^0

2.2 Implementation in Simulink

In Simulink the synchronization of rotation space between potentiometer signals and angular movements in AAM model follows the Eq. (1), in which the constant value of 1.64 is a conversion value between potentiometer and MATLAB signal acquisition result. The implementation of this synchronization in Simulink blocks is a simple gain adjustment as shown in Fig. 4.

$$K = \frac{\text{AAM}}{(\text{WRAI or PotLim})\ \text{x}\ 1.64} \qquad (1)$$

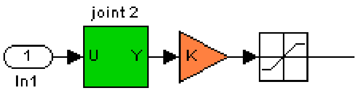
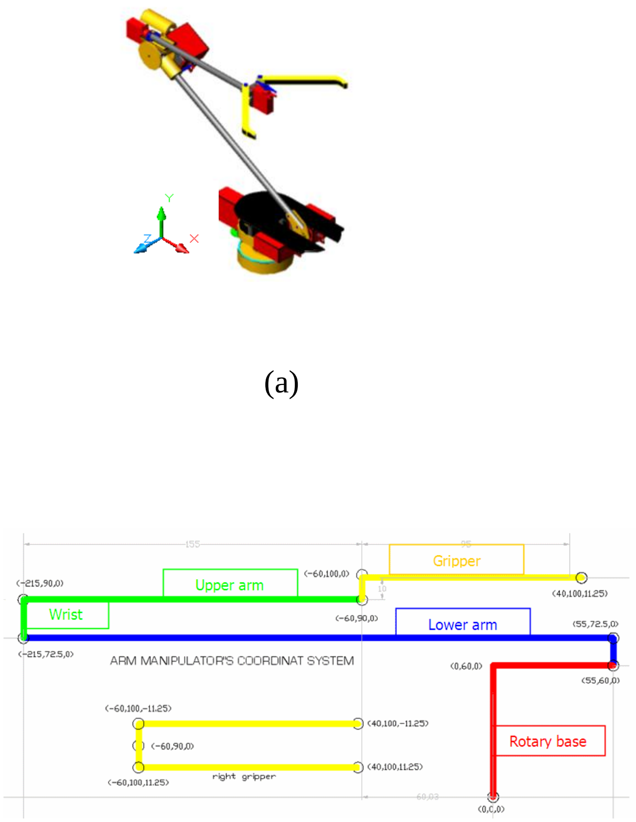


Figure 4. Simple gain adjusment

3. Articulated Arm Robot Model

Prototype of AAM shown in Fig. 5(a), created in AutoCAD, was converted into 3D SimMechanics and Virtual reality model, and then simulated using forward kinematic. To compute the position and orientation of the end of effector (EOF) on an arm manipulator is a static geometrical challenge[5]. Using SimMechanics, this challenge can be easily handled.



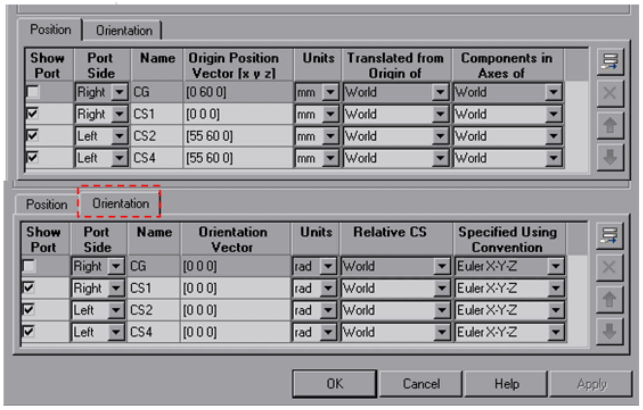
(a)

(b)

Figure 5. (a) 3D CAD model, (b) Arm dimension

3.1 CAD Model

AutoCAD is chosen to generate 3D model and geometrical model of AAM because it has enough requirements for 3D modeling. Few tutorials are available explaining how to use AutoCAD as an interface model for MATLAB. Position (x,y,z) and orientation of each joint is described in Fig. 5(b).



Show Port	Port Side	Name	Origin Position Vector [x y z]	Units	Translated from Origin of	Components in Axes of
☐	Right	CG	[0 60 0]	mm	World	World
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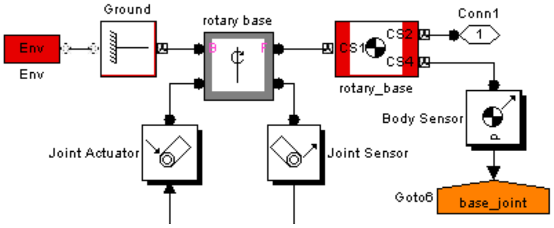
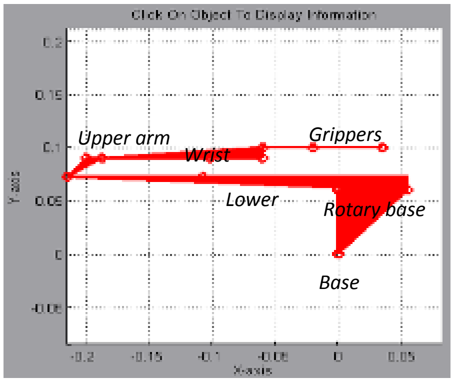
☑	Left	CS2	[55 60 0]	mm	World	World
☑	Left	CS4	[55 60 0]	mm	World	World

Show Port	Port Side	Name	Orientation Vector	Units	Relative CS	Specified Using Convention
☐	Right	CG	[0 0 0]	rad	World	Euler X-Y-Z
☑	Right	CS1	[0 0 0]	rad	World	Euler X-Y-Z
☑	Left	CS2	[0 0 0]	rad	World	Euler X-Y-Z
☑	Left	CS4	[0 0 0]	rad	World	Euler X-Y-Z

Figure 6. Input geometry of joint 2 (rotary base).



(a)



(b)

Figure 7. (a) Body model of joint 2 (rotary base),
(b) 3D machine body of AAM

3.2 SimMechanics Model

SimMechanics is a block diagram modeling environment that is available as one of Simulink toolbox. It can be utilized in engineering design and simulation of rigid body machines and their motions using the standard Newtonian dynamics of forces and torques [6]. To build SimMechanics body model, it is necessary to determine main dimensions of the prototype model. The 3D CAD model in Fig. 5(b) is then put into SimMechanics model shown in Fig. 6.

One important feature in building SimMechanics body is the conception of joint type selection between two bodies. Example of SimMechanics block diagram is shown in Fig. 7(a) depicting the modelling of joint 2 (rotary base). The overall result for the 3D body model of AAM using SimMechanics is shown in Fig. 7(b).

3.3 Virtual Reality Model

Virtual reality (VR) is a display and control technology that can envelop a person in an interactive computer-generated virtual environment. VR creates artificial worlds of sensory experience, or immerses the user in representations of real spatial environments that might otherwise be inaccessible by virtue of distance, scale, time, or physical incompatibilities of the user and the environment [7]. VR toolbox from MATLAB is chosen to build artificial environment of AAM model. In the VR model shown in Fig. 8, the AAM is pretended as part of manipulator in a Rescue Robot for Explosive Ordinance Disposal (EOD) application.

i	α_{i+1}	$\mathbf{a}_{i-1}$	$\mathbf{d}_i$	θ_i

Figure 8. Virtual environment of AAM on Rescue Robot is displayed through Orbisnap

The process of creating virtual model is as follows. AutoCAD generated drawing file *.dwg. This file needs to be converted into file *.3ds. Vrealm Builder, that is an embedded Virtual Reality Modelling Language (VRML) editor from MATLAB, can open file *.3ds, and save it to file *.wrl. VR toolbox called this file *.wrl and projected it into Orbisnap window as shown in Fig. 8.

4. SimMechanics Verification

SimMechanics model needs to be verified to prove its compatibility in generating a forward kinematic problem. Denavit-Hartenberg Parameter (D-H parameter) is a common technique to systematically present the relation between rotation and translation of connected joints on a manipulator and describe robot position and orientation [8]. D-H parameter variables are:

a = length of link
α = twist angle
d = offset distance
θ = joint angle

Applying the D-H parameter using a right-hand rule, the values of D-H model can obtained. Table 3 explains the D-H parameter for AAM model at initial condition. Verification was conducted by comparing the results between a manual computation that uses homogenous transformation matrix and the computation that uses SimMechanics.

1	-90	0	d_1	0
2	-90	a_2	0	90
3	0	a_3	0	-90
4	0	a_4	0	0
5	-90	0	d_5	180
6	90	a_6	0	0
7	0	0	d_7	0
8	-90	0	d_8	0
9	0	a_9	0	0
10	180	0	d_{10}	0

Table 3. D-H Parameter for AAM model

Referring to table 3, one case is given as an example here. Input angle variables on each joint of AAM are:

- *Rotary base* : 0^0
- *Lower arm* : 0^0
- *Wrist* : 0^0
- *Upper arm* : 0^0
- *Gripper* : 0^0

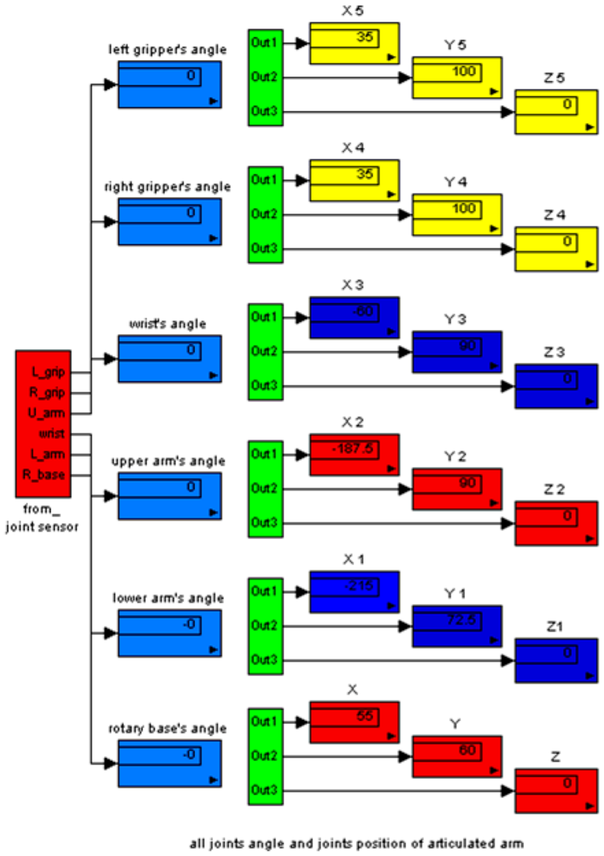


Figure 9. Simulink model of joint position as an example

Link-transformation matrix from joint 1 to joint 5 in Eqs.2 can be used to derive the coordinate position of end of effector (EOF) in the AMM model. The final values of this matrix is given in Eq. 5, whereas Fig. 9 displays the result of computation using SimMechanics. Both computation techniques show the same result. Therefore, SimMechanics model compatibility is valid.

$$ {}^{i-1}_{i}T = \begin{bmatrix} \cos\theta_i & -\sin\theta_i & 0 & a_{i-1} \\ \sin\theta_i \cdot \cos\alpha_{i-1} & \cos\theta_i \cdot \cos\alpha_{i-1} & -\sin\alpha_{i-1} & -\sin\alpha_{i-1} \cdot d_i \\ \sin\theta_i \cdot \sin\alpha_{i-1} & \cos\theta_i \cdot \sin\alpha_{i-1} & \cos\alpha_{i-1} & \cos\alpha_{i-1} \cdot d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2) $$

$$ {}^{7}_{8}T = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 11.25 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad {}^{8}_{9}T = \begin{bmatrix} 1 & 0 & 0 & 95 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3) $$

$$ {}^{9}_{10}T = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & -11.25 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{4} $$

$$ {}^{0}_{10}T = \begin{bmatrix} 1 & 0 & 0 & 35 \\ 0 & 1 & 0 & 100 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{5} $$

4. Experimental Testing of WRAI and AAM

Experimental testing was conducted by wearing the WRAI on the right hand of an operator. The WRAI was connected to a modified USB joystick plugged in to a PC with MATLAB installed as shown in Fig. 10.

VR toolbox allows the user to record a simulation process into a file video format. SimMechanics animation can also be viewed simultaneously. In this paper, the simulation was performed by giving the operator the task of taking an explosive object from its initial place somewhere in a cupboard and moving it to the ground. Results of this simulation were positions and angles of joints at each time steps presented in graphical plots, and video.

Graphical information during simulation process was obtained. The simulation and animation results are presented by the joint angles, and trajectories of AAM as shown in Figs. 11 to 15.

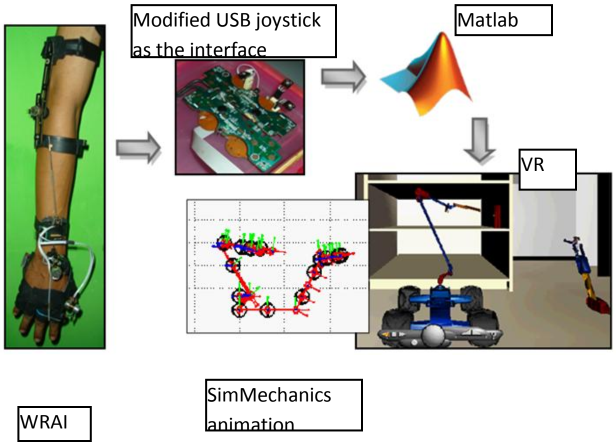
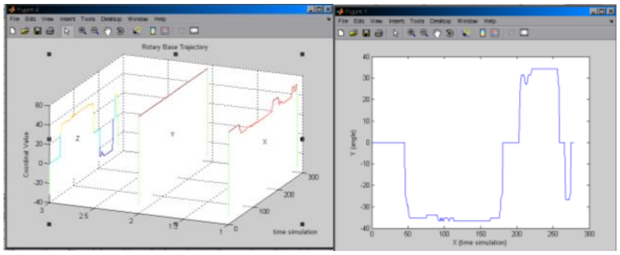


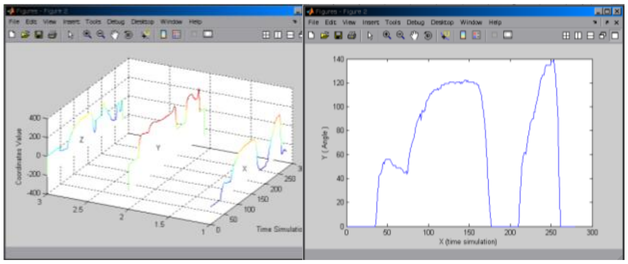
Figure 10. Apparatus setup



Trajectory

Joint angle

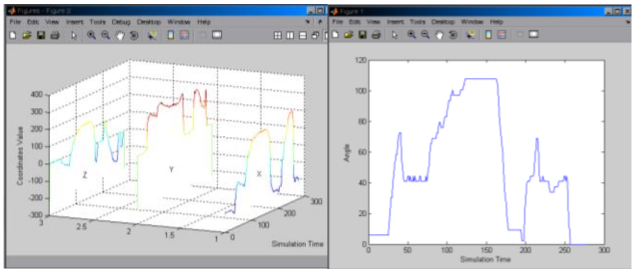
Figure 11. Plot of rotary base



Trajectory

Joint angle

Figure 12. Plot of lower arm



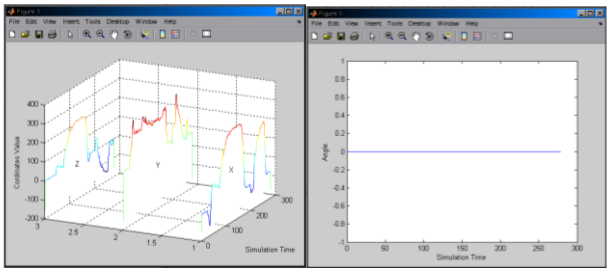
Trajectory

Joint angle

Figure 13. Plot of upper arm

5. Conclusions

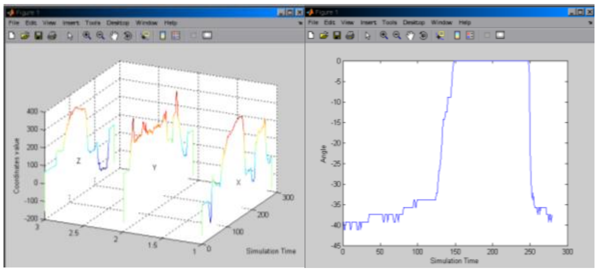
Working apparatus for simulating WRAI that can control an AAM model has been presented. Angular movement interference problem between can be eliminated. SimMechanics and Virtual Reality are powerful tools to model the virtual machine. Kinematics problem related to transformation of manipulator can be handled by SimMechanics. It eliminated time consuming matrix computation. In short, the combination of SimMechanics and Virtual Reality are very helpful to an operator for observing the behaviour of operator's command and machine response.



Trajectory

Joint angle

Figure 14. Plot of wrist



Trajectory

Joint angle

Figure 15. Plot of gripper

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