Palert
P Wave Alarm System
User Manual

- ✧ Version: 1.00 2010/04
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1. Features 6
2. Application Topology 7
3. Hardware information 8
3.1. Wiring 8
3.2. Information for LED Display 8
3.3. Digital Inputs Configurations 9
◎ Reset to Factory Setting 9
◎ Display IP Information 10
◎ Display The Last Earthquake Information 10
3.4. RTD (Real Time Data stream) Output Control 10
3.5. Parameters for Autoexec.bat 11
3.6. DOs Wiring and Characteristics 11
3.7. DIs Wiring 11
3.8. Installation 12
4. Parameters Setup 13
4.1. Parameters List 13
4.2. Parameters Description 17
◎Address 100, NTP Synchronal and Server Connected Flag 17
◎Address 101, Real-Time a Axis Acceleration 17
◎Address 102, Real-Time b Axis Acceleration 17
◎Address 103, Real-Time c Axis Acceleration 17
◎Address 104, Real-Time Vector Acceleration 18
◎Address 105, a Axis Offset 18
◎Address 106, b Axis Offset 18
◎Address 107, c Axis Offset 18
◎Address 108, Maximum Vector in Earthquake 18
◎Address 109, Real-Time Earthquake Intensity 18
◎Address 110, Maximum Intensity in Earthquake 19
◎Address 111, Earthquake Indicator 19
◎Address 112, LTA Ready Indicator 19
◎Address 113, Setup Parameters 19
◎Address 114, Time Zone 20
◎Address 115, STA Duration 20
◎Address 116, LTA Duration 20
◎Address 117, STA/LTA Trigger Threshold 20
◎Address 118, Operation Mode 20
◎Address 119, DI/Os Status 22

◎Address 120, Earthquake Event Sustained Duration.. 22
◎Address 121, PGA Watch Threshold 22
◎Address 122, Numbers Of Records For Offset Calculation................................ 22
◎Address 123 and 124, DOs Activated Setting 23
◎Address 125, PGV within 1 Second.. 23
◎Address 126, PGD within 1 Second.. 23
◎Address 127, Information for Last Earthquake 23
◎Address 128, Real-Time STA/LTA 23
◎Address 129, Maximum a Axis Acceleration in Earthquake 24
◎Address 130, Maximum b Axis Acceleration in Earthquake 24
◎Address 131, Maximum c Axis Acceleration in Earthquake 24
◎Address 132, Maximum a Axis Acceleration of Vector in Earthquake 24
◎Address 133, Maximum b Axis Acceleration of Vector in Earthquake 24
◎Address 134, Maximum c Axis Acceleration of Vector in Earthquake.................. 24
◎Address 135, PGA Trigger Axis 24
◎Address 136, Real-time a AXIS Velocity 24
◎Address 137, Real-time a Axis Pd 25
◎Address 138, Real-time a Axisτc 25
◎Address 139, Pd Trigger Status.. 25
◎Address 140, PGA Within 10 Seconds.. 25
◎Address 141, Earthquake Time – Year... 25
◎Address 142, Earthquake Time – Month.. 25
◎Address 143, Earthquake Time – Day 25
◎Address 144, Earthquake Time – Hour 25
◎Address 145, Earthquake Time – Minute 25
◎Address 146, Earthquake Time – Second... 25
◎Address 147, System Time – Year.. 26
◎Address 148, System Time – Month 26
◎Address 149, System Time – Day 26
◎Address 150, System Time – Hour 26
◎Address 151, System Time – Minute 26
◎Address 152, System Time – Second.. 26
◎Address 153, Set System Time – Year.. 26
◎Address 154, Set System Time – Month.. 26
◎Address 155, Set System Time – Day 26
◎Address 156, Set System Time – Hour 27
◎Address 157, Set System Time – Minute 27
◎Address 158, Set System Time – Second.. 27

◎Address 159, Real-time a Axis Displacement 27
◎Address 160, a Axis Displacement Warning Threshold 27
◎Address 161, PGA Warning Threshold 27
◎Address 162, Pd Warning Threshold 27
◎Address 163, Trigger Mode and Low Pass Filter Select 28
◎Address 164, Pd Watch Threshold 28
◎Address 165, Calibration Factor for a Axis at 0 g 28
◎Address 166, Calibration Factor for b Axis at 0 g 28
◎Address 167, Calibration Factor for c Axis at 0 g 29
◎Address 168, Calibration Factor for a Axis at 1 g 29
◎Address 169, Calibration Factor for b Axis at 1g 29
◎Address 170, Calibration Factor for c Axis at 1 g 30
◎Address 171~174, NTP Server IP 30
◎Address 175, Weekday 30
◎Address 176~177, TCP Server 0 IP 30
◎Address 178~179, TCP Server 1 IP 31
◎Address 180~191, Palert Network Address Setting 31
◎Address 192, Available Connections for Host 32
◎Address 193, Streaming Output Control 33
◎Address 194, Palert Modbus RTU Address setting 35
◎Address 195, Watch and Warning Period 35
◎Address 196, Maximum Acceleration within 1 Second 35
◎Address 197, a Axis Displacement Watch Threshold 35
◎Address 198, Earthquake Pre-Warning Register 36
◎Address 199, Palert Firmware Number 36
◎Address 200, Palert Serial Number 36
4.3. Modbus Related Information for Palert 36
4.4. Palert Operation Time Sequence 37
4.4.1. Power ON Time Sequence 37
4.4.2. Parameter Setting Time Sequence 37
4.4.3. Initialization Time Sequence 38
4.4.4. STA/LTA Trigger Time Sequence 38
4.4.5. Displacement, Pd, and PGA Trigger Time Sequence 39
Table 1. Earthquake Intensity Table, Central Weather Bureau, Taiwan. 40
Appendix 1. EEW Paper by Professor Yih-Min Wu., National Taiwan University 41

Revisions		
Date	Description	Author
20100418	The first edition 1.00	Ching
20100429	Some phrases correction	Ching
20100622	1. Streaming packet size is increased from 1100 to 1200 bytes. 2. Add DI/O status and EEW register in streaming packet. 3. Modify description for DI/O wiring. 4. Add quit program and FTP update description for address 113. 5. Add Pa, Pv and Pd in streaming packet. 6. Add streaming packet type 300, 1191 and 1192. 7. FTP server IP setting	Ching
20100913	Add earthquake maximum acceleration in streaming packet.	Ching
20100916	DHCP setup method changed	Ching

1. Features

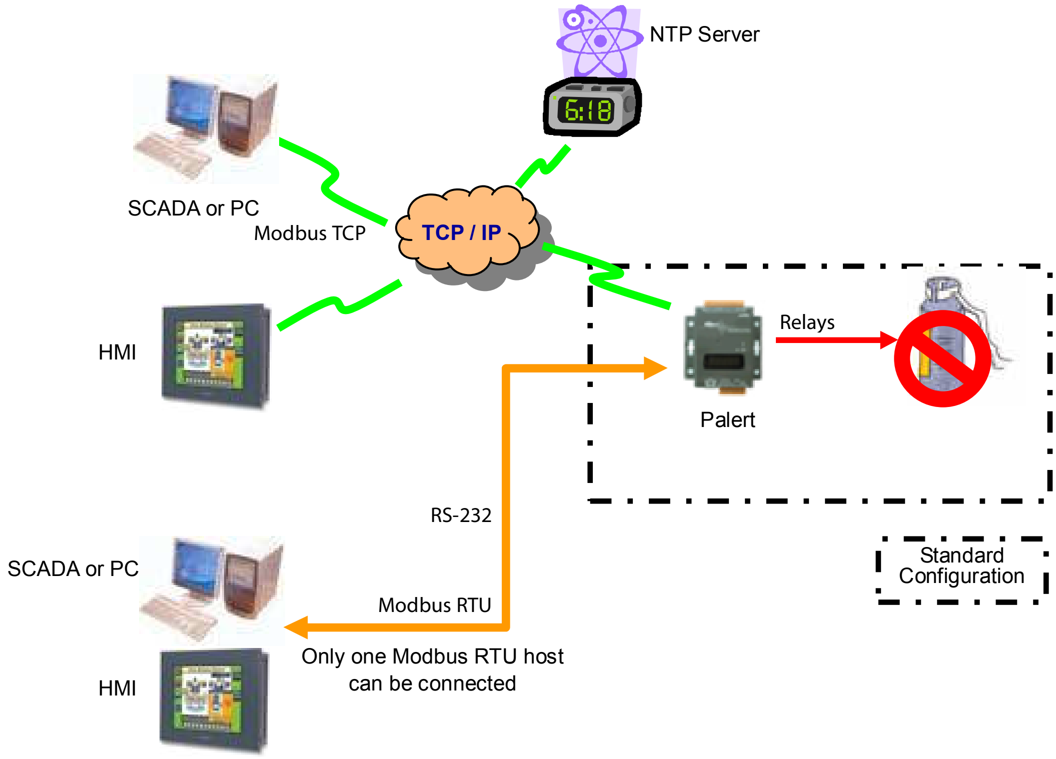
Palert, an advanced technology earthquake P wave alarm embedded Pd technology which is developed by Prof. Yih-Min Wu, National Taiwan University. Design to reduce earthquake damage that an alarm can be issued within 3 seconds after P wave is detected if following shock wave is destructive.

Offer four kinds of trigger algorithms Pd, PGA, Displacement and STA/LTA for detect earthquake. The Pd algorithm is developed by Prof. Yih-Min Wu. Please refer to related documents have been published. PGA stands for Peak Ground Acceleration. Palert offers 10 Hz and 20 Hz low pass filter which is selected by user to filter out high frequency components in signal generated by non-earthquake vibration. Component “a” is especially equips with real-time displacement calculation which is able to deploy displacement trigger algorithm in “a” axis. The conventional STA/LTA trigger algorithm is also available on Palert.

Intensity standards both for CWB (Central Weather Bureau, Taiwan) and China (GB/T-17742-2008) are available. Other useful earthquake information is stored and ready for retrieved in Palert. These include trigger time, maximum intensity, maximum acceleration for each component and maximum acceleration in vector. The powerful networking capability features streaming real-time data to hosts; automatically connect to up to 2 servers, NTP (Network Time Protocol) time calibration. With these networking functions Palert is a wonderful front end device for EEW (Earthquake Early Warning) system.

With PC utility it is possible to record earthquake data for research purpose and have voice warning if needed. Two outputs and supports industrial Modbus TCP/RTU communication standard which make Palert an ideal product for earthquake safety control in numerous applications.

2. Application Topology



3. Hardware information

3.1. Wiring

Pin Definition	Description
GND	Power Ground
Vs+	Power 10~30VDC 300mA
D2-	COM2, Modbus RTU (RS-485 D-)
D2+	COM2, Modbus RTU (RS-485 D+)
INIT*	For Service only. Please do not connect.
TXD1	COM1 TX
RXD1	COM1 RX
RTS1	COM1 RTS
CTS1	COM1 CTS
E1	Modbus TCP (10 / 100M Ethernet Port)
DO PWR	DC5V Output
DO0	Relay Output 0 (Photo MOS Relay, Form A) Normal Open , 0.6A/60VDC
DO1	Relay Output 1 (Photo MOS Relay, Form A) Normal Open , 0.6A/60VDC
DO COM	Common for Relay Output 0 and 1.
GND	0V
DI0	Digital Input 0 (LED display will show IP when grounding)
DI1	Digital Input 1(LED display will show last event information when grounding)
DI2	Digital Input 2 (RTD Output Mode)
DI3	Digital Input 3 (Reserved)

3.2. Information for LED Display

<u>Normal Status</u>

Display will illustrate three kinds of information periodically which are “YYYY.MM.DD WWW”, “hh.mm” and “.ss.”. It will blink if NTP synchronal function is enabled and Palert is unable to synchronize with NTP server.

YYYY : Year
MM : Month
DD : Day
WWW : Weekday
hh : Hour

mm : Minute

ss : Second

Earthquake Detected

Display will illustrate three kinds of information periodically which are maximum intensity, maximum acceleration and what kinds of earthquake trigger algorithms are set. If Palert is configured as CWB intensity based mode then the information is “IIIII”, “VVVV.V” and “P.d.A.t.”.

I : Maximum Intensity

VVVV.V : Maximum Acceleration in Gal Unit

P. : Pd Event Triggered

d. : Displacement Event Triggered

A. : PGA Event Triggered

t. : STA/LTA Event Triggered

If Palert is configured as GB/T 17742-2008 intensity based mode then the information is “I”, “VV.VVV” and “P.d.A.t.”.

I : Maximum Intensity

VV.VVV : Maximum Horizontal Acceleration in m/sec^2 Unit

P. : Pd Event Triggered

d. : Displacement Event Triggered

A. : PGA Event Triggered

t. : STA/LTA Event Triggered

Earthquake Pre-warning Information Sent by Server

When Palert is deployed as an EEW (Earthquake Early Warning) system front end device, it is possible sending EEW information to Palert in order to have earthquake pre-warning time for people. The information is “II.-99”.

II : Expected Intensity

-99 : Expected Earthquake Shockwave Arrival Time in Seconds.

Attention! This function is only available when Palert is connected to seismologic server which has advanced seismology program. Please consult your local distributor if you have EEW application requirement. User must be noticed to follow the individual countries earthquake dispatch regulations or laws.

3.3. Digital Inputs Configurations

◎ Reset to Factory Setting

Palert will restore all parameters to factory default setting if all four DIs are grounding.

◎ **Display IP Information**

When DI0 is grounding Palert will display IP information as “XXX.XXX.XXX.XXX” format.

◎ **Display The Last Earthquake Information**

Palert will display the last earthquake information when DI1 is grounding. The display format is described as below.

CWB Intensity Based Mode: “YYYY.MM.DD hh.mm.ss I.I.I.I.I VVVV.V”

YYYY : Year
MM : Month
DD : Day
hh : Hour
mm : Minute
ss : Second
I : Maximum Intensity
V : Maximum Acceleration in Gal Unit.

GB/T 17742-2008 Based Mode: “YYYY.MM.DD hh.mm.ss II VV.VVV”

YYYY : Year
MM : Month
DD : Day
hh : Hour
mm : Minute
ss : Second
II : Maximum Intensity
V : Maximum Horizontal Acceleration in m/sec^2 Unit.

3.4. RTD (Real Time Data stream) Output Control

When DI2 is grounding Palert will enable RTD output function. The data format is described as below.

Byte 1	Byte 2	Byte 3	Byte 4	Byte 5	Byte 6	Byte 7	Byte 8
0x0d	a High	a Low	b High	b Low	c High	c Low	0x0a

The data output serial port is determined by “autoexec.bat” file in Palert. The communication protocol is “9600, n, 8, 1”. Please refer to next section for more information about “autoexec.bat”. User must be noticed that all DOs will be controlled by RTD serial port and the data are raw without filtered. The DOs control commands are described as below.

	ON	OFF
DO0	#ON0#\r	#OFF0#\r

DO1	#ON1#\r	#OFF1#\r

\r stands for 0x0d

3.5. Parameters for Autoexec.bat

The parameter of “autoexec.bat” file for Palert is described as below.

Example: runexe 2

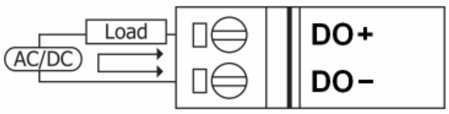
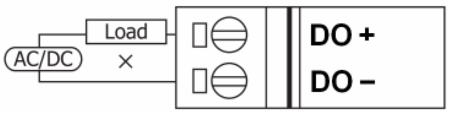
<u>Parameter 1</u>: Modbus RTU Port

Possible options are 1 or 2. RTD output function will be enabled when DI2 is grounding. The RTD serial port is automatically switched to the other port. For this example, Modbus RTU port is 2 and RTD port is 1.

Attention! The parameter should be maintained by professional with precise setting. Otherwise, it will cause Palert malfunction.

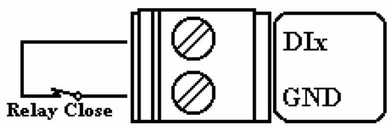
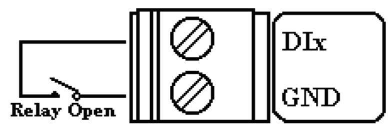
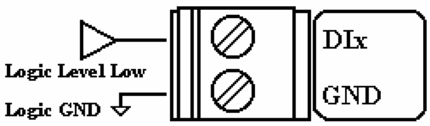
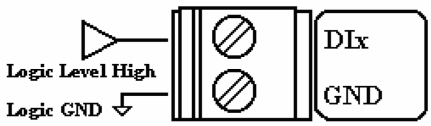
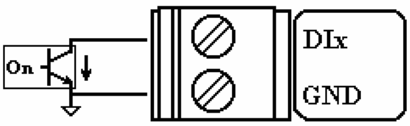
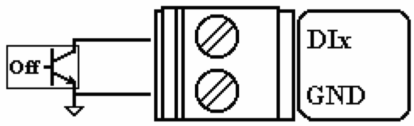
3.6. DOs Wiring and Characteristics

DO is acted just like a switch but with contact capacity as 60V 0.6A. Please refer to wiring diagram as below.

Output Type	Readback as 1	Readback as 0
From A Relay Contact	Relay On	Relay Off
		

3.7. DIs Wiring

Please refer to DI wiring diagram as below.

Input Type	ON State DI value as 1	OFF State DI value as 0
Relay Contact		
TTL/CMOS Logic		
Open Collector		

3.8. Installation

Due to the earthquake trigger algorithm Palert adapted that a axis should be installed as vertical component. It is recommended to have anti-impact transparent housing covered to avoid artificial impact. A backup battery is also good configuration to prevent power failure.

4. Parameters Setup

The parameters of Palert have been setup optimally. However, due to different installation location and background noise, some adjustments for parameters are necessary. Each function of Palert parameters are described as below.

Please notes that below address are zero based.

4.1. Parameters List

Palert Modbus Address Mapping Table (400XXX)			
Address	**R/W**	**Label**	**Description**
100	R	connection_flag	NTP Server Synchronal and Servers Connected Flag
101	R	a_axis	Real-Time a Axis Acceleration
102	R	b_axis	Real-Time b Axis Acceleration
103	R	c_axis	Real-Time c Axis Acceleration
104	R	vector	Real-Time Vector Acceleration
105	R	a_offset	a Axis Offset
106	R	b_offset	b Axis Offset
107	R	c_offset	c Axis Offset
108	R	vector_gal_max	Maximum Vector in Earthquake (Unit : gal)
109	R	intensity_now	Real-Time Intensity
110	R	intensity_max	Maximum Intensity in Earthquake
111	R	event	Earthquake Indicator
112	R	lta_flag	LTA Ready Indicator
113	W	data_changed	Setup Option (1 as Update, 2 as Write to EEPROM, 4 as Write IP Address Setting to EEPROM, 8 as Update System Time)
114	RW	time_diff	GMT Time Zone (Taipei is 8)
115	RW	sta_time	STA Duration (Unit : 100 ms)
116	RW	lta_time	LTA Duration (Unit : 100 ms)
117	RW	sta_lta_th	STA/LTA Trigger Threshold
118	RW	op_mode	GB/T 17742-2008 Mode, DO Control Mode, Intensity Calculated Standard, Servers Connection and NTP Enable, DHCP, Streaming Enable
119	R	DIO_status	DI and DO status
120	RW	event_time	Earthquake Event Sustained Duration (Unit :

Palert Modbus Address Mapping Table (400XXX)			
			second)
121	RW	pga_watch_threshold	PGA Watch Threshold (Unit: count)
122	RW	offset_records	Numbers of Records for Offset Calculation
123	RW	DO0_gal	DO0 Activated Setting (Unit : gal)
124	RW	DO1_gal	DO1 Activated Setting (Unit : gal)
125	R	PGV_1S	Peak Ground Velocity (Unit: 0.001 cm/sec)
126	R	PGD_1S	Peak Ground Displacement (Unit: 0.001 cm)
127	R	last_event	Information for Last Earthquake
128	R	sta_lta	Real-Time STA/LTA
129	R	a_maximum	Maximum a Axis Acceleration in Earthquake
130	R	b_maximum	Maximum b Axis Acceleration in Earthquake
131	R	c_maximum	Maximum c Axis Acceleration in Earthquake
132	R	vector_max_a	Maximum a Axis Acceleration of Vector in Earthquake
133	R	vector_max_b	Maximum b Axis Acceleration of Vector in Earthquake
134	R	vector_max_c	Maximum c Axis Acceleration of Vector in Earthquake
135	RW	pga_trig_axis	PGA Trigger Axis
136	R	pv_int	Real-Time a Axis Velocity (Unit: 0.001 cm/sec)
137	R	pd_int	Real-Time a Axis Pd (Unit: 0.001 cm)
138	R	tc_int	Real-Time a Axis τ_c (Unit: 0.001)
139	R	pd_flag	Pd Trigger Status
140	R	pga_10s	PGA Within 10 Seconds (Unit: count)
141	R	e_year	Earthquake Time – Year
142	R	e_month	Earthquake Time – Month
143	R	e_day	Earthquake Time – Day
144	R	e_hour	Earthquake Time – Hour
145	R	e_minute	Earthquake Time – Minute
146	R	e_second	Earthquake Time – Second
147	R	sys_year	System Time – Year
148	R	sys_month	System Time – Month
149	R	sys_day	System Time – Day
150	R	sys_hour	System Time – Hour

Palert Modbus Address Mapping Table (400XXX)			
151	R	sys_minute	System Time – Minute
152	R	sys_second	System Time – Second
153	RW	set_year	Set System Time – Year
154	RW	set_month	Set System Time – Month
155	RW	set_day	Set System Time – Day
156	RW	set_hour	Set System Time – Hour
157	RW	set_minute	Set System Time – Minute
158	RW	set_second	Set System Time – Second
159	R	displacement	Real-Time a Axis Displacement (Unit: 0.001 cm)
160	RW	disp_warning_threshold	A Axis Displacement Warning Threshold (Unit: 0.001 cm)
161	RW	pga_warning_threshold	PGA Warning Threshold (Unit: count)
162	RW	pd_warning_threshold	Pd Warning Threshold (Unit: 0.001 cm)
163	RW	trig_mode	Trigger Mode and Low Pass Filter Select
164	RW	pd_watch_threshold	Pd Watch Threshold (Unit: 0.001 cm)
165	RW	a_0g	Calibration Factor for a Axis at 0 g (Unit: 0.1 mg)
166	RW	b_0g	Calibration Factor for b Axis at 0 g (Unit: 0.1 mg)
167	RW	c_0g	Calibration Factor for c Axis at 0 g (Unit: 0.1 mg)
168	RW	a_1g	Calibration Factor for a Axis at 1 g (Unit: 0.1 mg)
169	RW	b_1g	Calibration Factor for b Axis at 1 g (Unit: 0.1 mg)
170	RW	c_1g	Calibration Factor for c Axis at 1 g (Unit: 0.1 mg)
171	RW	ntp_svr_ip1	NTP Server IP Address 1
172	RW	ntp_svr_ip2	NTP Server IP Address 2
173	RW	ntp_svr_ip3	NTP Server IP Address 3
174	RW	ntp_svr_ip4	NTP Server IP Address 4
175	R	week_day	System Time – Weekday
176	RW	server0_ip12	Server0 IP Address 1, 2
177	RW	server0_ip34	Server0 IP Address 3, 4
178	RW	server1_ip12	Server1 IP Address 1, 2
179	RW	server1_ip34	Server1 IP Address 3, 4
180	RW	IP1	Palert IP address
181	RW	IP2	Palert IP address
182	RW	IP3	Palert IP address
183	RW	IP4	Palert IP address

Palert Modbus Address Mapping Table (400XXX)			
184	RW	Subnet mask 1	Palert IP subnet mask
185	RW	Subnet mask 2	Palert IP subnet mask
186	RW	Subnet mask 3	Palert IP subnet mask
187	RW	Subnet mask 4	Palert IP subnet mask
188	RW	Gateway 1	Palert IP gateway
189	RW	Gateway 2	Palert IP gateway
190	RW	Gateway 3	Palert IP gateway
191	RW	Gateway 4	Palert IP gateway
192	R	sck_remain	Available Connections for TCP Host
193	RW	stream_output	Streaming Output Control
194	RW	rtu_address	Palert Modbus RTU Address
195	RW	light_sound_duration	Watch and Warning Period
196	R	vector_gal_now	Maximum Acceleration Within 1 Second (Unit: gal)
197	RW	disp_watch_threshold	a Axis Displacement Watch Threshold
198	RW	pre-alarm	Earthquake Pre-Warning Register
199	R	version	Firmware Number
200	R	serial_no	Palert Serial Number

4.2. Parameters Description

◎Address 100, NTP Synchronal and Server Connected Flag

bit 0

0: Palert not synchronize with NTP server.

1: Palert has synchronized with NTP server. The synchronal interval is 10 minutes and Palert will try to synchronize with NTP server every 10 seconds if last synchronization failed. The new connection will be established if there is no synchronization within 700 seconds.

Regarding the IP address setting for NTP server please refer to addresses 171 to 174.

bit 1

0: Indicate that there is no connection with server 0.

1: Indicate that connection between server 0 and Palert has established.

Regarding the IP address setting for server 0 please refer to addresses 176 and 177.

bit 2:

0: Indicate that there is no connection with server 1.

1: Indicate that connection between server 1 and Palert has established.

Regarding the IP address setting for server 1 please refer to addresses 178 and 179.

All functions mentioned above will only available when NTP or servers connection is enabled. Please refer to address 118 for related setting.

◎Address 101, Real-Time a Axis Acceleration

This address stores real-time a axis acceleration, unit in count. One gal is equal to 16.7184 counts. The throughput is 100 samples / second when connected up to 3 hosts in Ethernet environment.

◎Address 102, Real-Time b Axis Acceleration

This address stores real-time b axis acceleration, unit in count. One gal is equal to 16.7184 counts. The throughput is 100 samples / second when connected up to 3 hosts in Ethernet environment.

◎Address 103, Real-Time c Axis Acceleration

This address stores real-time c axis acceleration, unit in count. One gal is equal to 16.7184 counts. The throughput is 100 samples / second when connected up to 3 hosts in Ethernet environment.

◎Address 104, Real-Time Vector Acceleration

This address stores real-time vector acceleration, unit in count. One gal is equal to 16.7184 counts. The throughput is 100 samples / second when connected up to 3 hosts in Ethernet environment. The equation of vector is described as below.

$$Vector = \sqrt{a^2 + b^2 + c^2}$$

◎Address 105, a Axis Offset

This address stores a axis offset compensation value, unit in count, One gal is equal to 16.7184 counts. The zero point output of accelerometer will be affected by installation or some other issues. This value will only calculate at initialization. Palert equips automatic zero algorithm so it is no need to calculate offset after initialization.
Due to installation that a axis will face gravity so there is around -980 gal offset in this axis.

◎Address 106, b Axis Offset

This address stores b axis offset compensation value, unit in count, One gal is equal to 16.7184 counts. The zero point output of accelerometer will be affected by installation or some other issues. This value will only calculate at initialization. Palert equips automatic zero algorithm so it is no need to calculate offset after initialization.

◎Address 107, c Axis Offset

This address stores c axis offset compensation value, unit in count, One gal is equal to 16.7184 counts. The zero point output of accelerometer will be affected by installation or some other issues. This value will only calculate at initialization. Palert equips automatic zero algorithm so it is no need to calculate offset after initialization.

◎Address 108, Maximum Vector in Earthquake

This address stores the maximum vector acceleration in last earthquake, unit as gal. This value will be updated when next earthquake is detected.
This value will be calculated as horizontal vector (GB/T 17742-2008) or tri-axes vector based on the setting on address 118.

◎Address 109, Real-Time Earthquake Intensity

This address stores real-time intensity as grade from 0 to 7 based on CWB standard (Central Weather Bureau, Taiwan) or from 0 to 11 based on GB/T 17742-2008 standard (China). This number will only meaningful when earthquake indicator (address 111) is set. Palert calculates vector or absolute axes acceleration to determine equivalent earthquake intensity. Please refer to address 118 for related setting.

Due to there is no definition for intensity less equal 4 in GB/T 17742-2008. So Palert uses below levels do determine intensity.

1 : <= 0.008 m/sec^2

2 : <= 0.022 m/sec^2

3 : <= 0.080 m/sec^2

4 : <= 0.220 m/sec^2

◎Address 110, Maximum Intensity in Earthquake

This address stores the maximum intensity of the last earthquake, unit as grade form 0 to 7 based on CWB standard (Central Weather Bureau, Taiwan) or from 0 to 11 based on GB/T 17742-2008 standard. Please refer to address 118 for detail setting.

◎Address 111, Earthquake Indicator

Related bits of this address will be set correspond to earthquake detected by certain trigger algorithms; otherwise the value will be 0 when there is no earthquake detected by trigger algorithms.

When related bits are set, the time needed to clear these bits is defined at address 120.

bit 0: a axis Displacement triggered.

bit 1: Pd triggered.

bit 2: PGA triggered.

bit 3: STA/LTA triggered.

◎Address 112, LTA Ready Indicator

LTA stands for Long Time Average, which is average of vector in specified long time period. The opposing parameter is STA, which stands for Short Time Average. It will issue earthquake signal when STA divide LTA is great equal to STA/LTA threshold (address 117) and STA/LTA earthquake trigger algorithm is set (address 163 bit 3 is set).

Palert needs enough time to accumulate enough data for LTA calculation. This LTA Ready Indicator will become 1 when Palert LTA calculation is completed. In other word, Palert STA/LTA earthquake detecting algorithm can function only this Indicator is 1.

◎Address 113, Setup Parameters

Write proper value to this address to refresh Palert when change any parameters. The available setup options are described as below.

2 - Update and write parameters into EEPROM and force Palert to restart.

4 - Update and write Palert its own TCP/IP settings into EEPROM and force Palert to restart.

8 - Update and write system clock. Palert will use time information stored in addresses 153 to

158 to update system RTC.

128 – Force Palert to quit program and entering console mode. Caution! This procedure is only for firmware upgrade.

384 – Force Palert to upgrade firmware from SANLIEN FTP server.

◎Address 114, Time Zone

This address stores the GMT time zone information for NTP time calibration, for example, Taipei is GMT + 8. It is no function when NTP service is disabled.

◎Address 115, STA Duration

STA stands for Short Time Average, which is average of vector in specified short time period. The opposing parameter is LTA, which stands for Long Time Average. It will issue earthquake signal when STA divide LTA is great equal to STA/LTA threshold (address 117) and STA/LTA earthquake trigger algorithm is set (address 163 bit 3 is set).

This address represents the duration of STA in 100ms unit. The factory setting of this value is 20 which mean 2 seconds. The larger number the less false trigger is. The maximum value is 1 / 2 of LTA.

◎Address 116, LTA Duration

LTA stands for Long Time Average, which is average vector in specified long time period. The opposing parameter is STA, which stands for Short Time Average. It will issue earthquake signal when STA divide LTA is great equal to STA/LTA threshold (address 117) and STA/LTA earthquake trigger algorithm is set (address 163 bit 3 is set).

This address represents the duration of LTA in 100ms unit. The factory setting of this value is 800 which mean 80 seconds. The Larger number the more sensitive trigger is. The maximum number of LTA is 2000 which means 200 seconds.

◎Address 117, STA/LTA Trigger Threshold

Palert uses STA/LTA as one of earthquake detecting algorithms. It will issue earthquake signal (address 111 bit 3) when STA/LTA trigger algorithm is enabled (address 163 bit 3 is set) and STA divide LTA (Address 128) is great equal to this threshold (The factory preset value is 3). Regarding the DOs activities when earthquake signal is set please refer to address 123 and 124.

◎Address 118, Operation Mode

bit 0: Intensity calculation standard.

0: CWB (Taiwan) standard.

1: GB/T 17742-2008 (China) standard.

bit 1: GAS_mode

0: Standard DOs control mode. During this mode, The DOs turn on time will be determined by which algorithm is triggered. Please refer to addresses 120, 121, 123, 124, 161, 162, 163, 164 and 195.

1: DOs will only turn on for 2 seconds when earthquake signal is set. This is suitable for gas valve control.

bit 2: CWB Intensity calculation mode.

0: Intensity is calculated by maximum acceleration in axes.

1: Intensity is calculated by vector.

bit 3: Server 0 connection enable.

0: Disable server 0 connections.

1: Enable server 0 connections.

Palert supports 2 servers connection. By enable this function Palert could automatically connect to server 0 which are defined at addresses 176 and 177. This is very useful when Palert is installed at environment with no real IP. It is also the must function for EEW.

bit 4: NTP time calibration enable.

0: Disable NTP function.

1: Enable NTP function.

Palert equips NTP function which can automatically calibrate its system time every 10 minutes with NTP server which IP is specified at addresses from 171 to 174.

bit 5: DHCP client enable.

0: Disable DHCP client function.

1: Enable DHCP client function.

Warning, Once Palert got IP from DHCP server. There is a chance that user can not find correct Palert IP address to connect. To solve this problem, user could grounding DI0 and observe the IP information from LED display.

bit 6: Server 1 connection enable.

0: Disable server 1 connections.

1: Enable server 1 connections.

Palert supports 2 servers connection. By enable this function Palert could automatically connect to server 1 which are defined at addresses 178 and 179. This is very useful when Palert is installed at environment with no real IP. It is also the must function for EEW.

◎**Address 119, DI/Os Status**

The DI/Os status will be updated every second. High byte represents DIs and low byte as DOs. There are 4 DIs map from bit 8 to bit 11 and 2 DOs map from bit 0 to bit 1. It is also possible to use Modus DI and DO commands to read these DI/Os status which their addresses are begin from 100.

◎**Address 120, Earthquake Event Sustained Duration**

When earthquake is detected, Palert will enter earthquake operation mode. Below describe tasks performed during this stage.

a. Related earthquake trigger algorithm indicators will be set to 1 (Address 111).
b. Maximum acceleration, intensity and time will be update and store in real-time.
c. Determining of turn-on or turn-off for both two DOs when use only STA/LTA trigger algorithm.
d. Counting down the earthquake event duration timer. Timer will be reset if maximum acceleration occurred. Palert will return to normal operation mode when time is up. This address stores the timer value in second (The factory preset value is 30). Please refer to 4.4.4 earthquake time sequence.

◎**Address 121, PGA Watch Threshold**

This address stores PGA (Peak Ground Acceleration) watch threshold with unit in count. One gal is equal to 16.7184 counts. The recommend value is 67 counts (4 gals). An earthquake signal will be set when PGA triggers is enabled (address 163 bit 2) and PGA is great and equal to this threshold. DO0 also will be enabled during this stage. Please refer to address 123 and 124 for more detail.

◎**Address 122, Numbers Of Records For Offset Calculation**

This address stores the number of records to be averaged for offset calculation during initialization (The factory preset value is 200).

◎Address 123 and 124, DOs Activated Setting

These addresses store the activated acceleration threshold for DOs when there is only STA/LTA trigger algorithm enabled. The unit is gal and default setting for DO0 is 10 and DO1 is 50.

Please refer to the following table for more detail about DOs activity. The numbers with under line shown on this table are addresses.

	DO0		DO1	
DO Status / Trigger Mode	ON	OFF	ON	OFF
Displacement Trigger 163 bit 0	159 > 197	Timer = 195 High byte OR DO1 ON	159 > 160	Timer = 195 Low byte
Pd Trigger 163 bit 1	137 > 164	Timer = 195 High byte OR DO1 ON	137 > 162	Timer = 195 Low byte
PGA Trigger 163 bit 2	PGA > 121	Timer = 195 High byte OR DO1 ON	PGA > 161	Timer = 195 Low byte
STA/LTA Trigger 163 bit 3	112 = 1 AND 128 > 117 AND 108 > 123	Timer = 120 OR DO1 ON	112 = 1 AND 128 > 117 AND 108 > 124	Timer = 120

◎Address 125, PGV within 1 Second

This address stores the maximum real-time three axes PGV (Peak Ground Velocity) within one second. The unit is 0.001 cm/second.

◎Address 126, PGD within 1 Second

This address stores the maximum real-time three axes PGD (Peak Ground Displacement) within one second. The unit is 0.001 cm.

◎Address 127, Information for Last Earthquake

This address stores the last earthquake triggered information which is the copy of address 111.

◎Address 128, Real-Time STA/LTA

Palert uses STA/LTA as one of earthquake detecting algorithms. It will issue earthquake signal (address 111 bit 3) when STA/LTA trigger algorithm is enabled (address 163 bit 3 is set) and this value is great equal to STA/LTA threshold (address 117).

Regarding the DOs activities when earthquake signal is set please refer to address 123 and 124 for more detail.

◎Address 129, Maximum a Axis Acceleration in Earthquake

Palert will store the information for maximum acceleration during last earthquake. This address stores the maximum acceleration in a axis, unit in count. One gal is equal to 16.7184 counts.

◎Address 130, Maximum b Axis Acceleration in Earthquake

Palert will store the information for maximum acceleration during last earthquake. This address stores the maximum acceleration in b axis, unit in count. One gal is equal to 16.7184 counts.

◎Address 131, Maximum c Axis Acceleration in Earthquake

Palert will store the information for maximum acceleration during last earthquake. This address stores the maximum acceleration in c axis, unit in count. One gal is equal to 16.7184 counts.

◎Address 132, Maximum a Axis Acceleration of Vector in Earthquake

Palert will store the information for maximum acceleration during last earthquake. This address stores the a component acceleration in the maximum vector, unit in count. One gal is equal to 16.7184 counts.

◎Address 133, Maximum b Axis Acceleration of Vector in Earthquake

Palert will store the information for maximum acceleration during last earthquake. This address stores the b component acceleration in the maximum vector, unit in count. One gal is equal to 16.7184 counts.

◎Address 134, Maximum c Axis Acceleration of Vector in Earthquake

Palert will store the information for maximum acceleration during last earthquake. This address stores the c component acceleration in the maximum vector, unit in count. One gal is equal to 16.7184 counts.

◎Address 135, PGA Trigger Axis

This address stores the PGA trigger axis when PGA trigger is enabled and PGA earthquake signal is set. 1 as a axis triggered, 2 as b axis triggered and 3 as c axis triggered, 0 as none.

◎Address 136, Real-time a AXIS Velocity

This address stores the real-time a axis velocity which is integrated from a axis acceleration. The unit is 0.001 cm/second.

◎**Address 137, Real-time a Axis Pd**

This address stores the real-time a axis Pd, unit in 0.001 cm. There is a very high possibility when P wave is detected and Pd is great equal to 0.3 cm the following S wave will be very destructive (According to the research of Prof. Yih-Min, Wu. NTU.). Please refer to appendix 1 for more information about Pd.

◎**Address 138, Real-time a Axis τ_c**

This address stores the real-time a axis τ_c. Please refer to appendix 1 for more information about Pd.

◎**Address 139, Pd Trigger Status**

This address stores the Pd trigger algorithm working status.

bit 4: P wave detected.

bit 5: P wave detected.

bit 6: Pd is greater and equal to Pd watch threshold.

bit 7: Pd is greater and equal to Pd warning threshold.

◎**Address 140, PGA Within 10 Seconds**

This address stores the PGA within 10 seconds with unit in count. One gal is equal to 16.7184 counts.

◎**Address 141, Earthquake Time – Year**

This address stores the last earthquake happened time, year.

◎**Address 142, Earthquake Time – Month**

This address stores the last earthquake happened time, month.

◎**Address 143, Earthquake Time – Day**

This address stores the last earthquake happened time, day.

◎**Address 144, Earthquake Time – Hour**

This address stores the last earthquake happened time, hour.

◎**Address 145, Earthquake Time – Minute**

This address stores the last earthquake happened time, minute.

◎**Address 146, Earthquake Time – Second**

This address stores the last earthquake happened time, second.

◎**Address 147, System Time – Year**

This address indicates the Palert system time, year.

◎**Address 148, System Time – Month**

This address indicates the Palert system time, month.

◎**Address 149, System Time – Day**

This address indicates the Palert system time, day.

◎**Address 150, System Time – Hour**

This address indicates the Palert system time, hour.

◎**Address 151, System Time – Minute**

This address indicates the Palert system time, minute.

◎**Address 152, System Time – Second**

This address indicates the Palert system time, second.

◎**Address 153, Set System Time – Year**

Although Palert embedded with NTP function, user still could use addresses from 153 to 158 to set system time. This address stores the information for set system time, which is year. Palert will update its RTC (system time) by taking time information stored in addresses from 153 to 158 when address 113 is set to 8.

◎**Address 154, Set System Time – Month**

Although Palert embedded with NTP function, user still could use addresses from 153 to 158 to set system time. This address stores the information for set system time, which is month. Palert will update its RTC (system time) by taking time information stored in addresses from 153 to 158 when address 113 is set to 8.

◎**Address 155, Set System Time – Day**

Although Palert embedded with NTP function, user still could use addresses from 153 to 158 to set system time. This address stores the information for set system time, which is day. Palert will update its RTC (system time) by taking time information stored in addresses from 153 to 158 when address 113 is set to 8.

◎**Address 156, Set System Time – Hour**

Although Palert embedded with NTP function, user still could use addresses from 153 to 158 to set system time. This address stores the information for set system time, which is hour. Palert will update its RTC (system time) by taking time information stored in addresses from 153 to 158 when address 113 is set to 8.

◎**Address 157, Set System Time – Minute**

Although Palert embedded with NTP function, user still could use addresses from 153 to 158 to set system time. This address stores the information for set system time, which is minute. Palert will update its RTC (system time) by taking time information stored in addresses from 153 to 158 when address 113 is set to 8.

◎**Address 158, Set System Time – Second**

Although Palert embedded with NTP function, user still could use addresses from 153 to 158 to set system time. This address stores the information for set system time, which is second. Palert will update its RTC (system time) by taking time information stored in addresses from 153 to 158 when address 113 is set to 8.

◎**Address 159, Real-time a Axis Displacement**

This address stores the real-time a axis displacement, unit in 0.001 cm. It is double integrated from a axis acceleration and filter by 0.075 Hz high pass filter.

◎**Address 160, a Axis Displacement Warning Threshold**

This address stores a axis warning threshold, unit in 0.001 cm. The recommended setting is 0.35 cm. The earthquake signal will be set (address 111 bit 0) when displacement trigger algorithm is enabled (address 163 bit 0) and displacement (address 159) is great equal to this threshold. Please refer to addresses 123 and 124 for more information regarding to DOs activity during this stage.

◎**Address 161, PGA Warning Threshold**

This address stores PGA warning threshold, unit in count. The recommended setting is 418 counts (25 gals). The earthquake signal will be set (address 111 bit 2) when PGA trigger algorithm is enabled (Address 163 bit 2) and PGA is great equal to this threshold. Please refer to addresses 123 and 124 for more information regarding to DOs activity during this stage.

◎**Address 162, Pd Warning Threshold**

This address stores Pd warning threshold, unit in 0.001 cm. The recommended setting is 0.3 cm. The earthquake signal will be set (address 111 bit 1) when Pd trigger algorithm is enabled

(Address 163 bit 1) and Pd (address 137) is great equal to this threshold. Please refer to addresses 123 and 124 for more information regarding to DOs activity during this stage.

◎Address 163, Trigger Mode and Low Pass Filter Select

Palert equipped 4 kinds of earthquake trigger algorithm as below. The recommend trigger algorithms are Pd and STA/LTA.

bit 0: Displacement trigger enable.

bit 1: Pd trigger enable.

bit 2: PGA trigger enable.

bit 3: STA/LTA trigger enable.

bit 7: Low pass filter selector, 0 as 10 Hz, 1 as 20 Hz.

STA/LTA trigger algorithm is the only one needs to wait for the LTA flag is ready (address 112). Other trigger algorithms are able to detect earthquake right after offset calculation.

◎Address 164, Pd Watch Threshold

This address stores Pd watch threshold, unit in 0.001 cm. The recommended setting is 0.15 cm. The earthquake signal will be set (address 111 bit 1) when Pd trigger algorithm is enabled (Address 163 bit 1) and Pd (address 137) is great equal to this threshold. Please refer to addresses 123 and 124 for more information regarding to DOs activity during this stage.

◎Address 165, Calibration Factor for a Axis at 0 g

Palert is calibrated at factory already, so it is not recommend for user to change these calibration factors stored in addresses 165 to 170.

Address 165 stores the zero g calibration factor for a axis. Below describe the calibration procedures.

a. Align Palert a axis horizontally.
b. Write 0 to this address and force Palert into initiation.
c. Find out a axis offset value and write this value by 10 times. For example, write 102 into this address if offset value is 10.2 mg.
d. Check if offset value is near by 0.

Caution! Any change of this address may trigger earthquake signal, so please make sure Palert disconnect with other system before you make above procedures.

◎Address 166, Calibration Factor for b Axis at 0 g

Palert is calibrated at factory already, so it is not recommend for user to change these calibration factors stored in addresses 165 to 170.

Address 166 stores the zero g calibration factor for b axis. Below describe the calibration procedures.

a. Align Palert b axis horizontally.
b. Write 0 to this address and force Palert into initiation.
c. Find out b axis offset value and write this value by 10 times. For example, write 102 into this address if offset value is 10.2 mg.
d. Check if offset value is near by 0.

Caution! Any change of this address may trigger earthquake signal, so please make sure Palert disconnect with other system before you make above procedures.

◎Address 167, Calibration Factor for c Axis at 0 g

Palert is calibrated at factory already, so it is not recommend for user to change these calibration factors stored in addresses 165 to 170.

Address 167 stores the zero g calibration factor for c axis. Below describe the calibration procedures.

a. Align Palert c axis horizontally.
b. Write 0 to this address and force Palert into initiation.
c. Find out c axis offset value and write this value by 10 times. For example, write 102 into this address if offset value is 10.2 mg.
d. Check if offset value is near by 0.

Caution! Any change of this address may trigger earthquake signal, so please make sure Palert disconnect with other system before you make above procedures.

◎Address 168, Calibration Factor for a Axis at 1 g

Palert is calibrated at factory already, so it is not recommend for user to change these calibration factors stored in addresses 165 to 170.

Address 168 stores the 1g calibration factor for a axis. Below describe the calibration procedures.

a. Align Palert a axis vertically.
b. Write 10000 to this address and force Palert into initiation.
c. Find out a axis offset value and write this value by 10 times. For example, write 10208 into this address if offset value is 1020.8 mg.
d. Check if real-time value is near by 1 g.

Caution! Any change of this address may trigger earthquake signal, so please make sure Palert disconnect with other system before you make above procedures.

◎Address 169, Calibration Factor for b Axis at 1g

Palert is calibrated at factory already, so it is not recommend for user to change these calibration factors stored in addresses 165 to 170.

Address 169 stores the 1g calibration factor for b axis. Below describe the calibration procedures.

a. Align Palert b axis vertically.
b. Write 10000 to this address and force Palert into initiation.
c. Find out b axis offset value and write this value by 10 times. For example, write 10208 into this address if offset value is 1020.8 mg.
d. Check if offset value is near by 1g.

Caution! Any change of this address may trigger earthquake signal, so please make sure Palert disconnect with other system before you make above procedures.

◎Address 170, Calibration Factor for c Axis at 1 g

Palert is calibrated at factory already, so it is not recommend for user to change these calibration factors stored in addresses 165 to 170.

Address 170 stores the 1g calibration factor for c axis. Below describe the calibration procedures.

e. Align Palert c axis vertically.
f. Write 10000 to this address and force Palert into initiation.
g. Find out c axis offset value and write this value by 10 times. For example, write 10208 into this address if offset value is 1020.8 mg.
h. Check if offset value is near by 1 g.

Caution! Any change of this address may trigger earthquake signal, so please make sure Palert disconnect with other system before you make above procedures.

◎Address 171~174, NTP Server IP

Palert equipped with NTP function which could calibrate its system time via network time server. These addresses store NTP server IP information (Factory preset value is 192.43.244.18 which is time.nist.gov).

When these addresses are changed user must also write 2 into address 113 to effect the changes.

◎Address 175, Weekday

This address indicates the weekday of Palert system time. The number is from 1 to 6 stands for Monday to Saturday, 7 for Sunday.

◎Address 176~177, TCP Server 0 IP

Palert has ability to connect with servers automatically. This is an advantage for Palert at the site without real IP. It is also the must function for EEW system. When server 0 connections enable is set (address 118 bit 3). Palert will try to connect to server 0 at all time. The connection status will be indicated at address 100 bit 1. Palert will also send its serial number

in ASCII format to the server when connection is established.
These addresses store TCP server 0 IP information as the order ip1.ip2.ip3.ip4 as below.
ip1: Address 176 high byte
ip2: Address 176 low byte
ip3: Address 177 high byte
ip4: Address 177 low byte

When these addresses are changed user must also write 2 into address 113 to effect the changes.

◎Address 178~179, TCP Server 1 IP

Palert has ability to connect with servers automatically. This is an advantage for Palert at the site without real IP. It is also the must function for EEW system. When server 1 connections enable is set (address 118 bit 6). Palert will try to connect to server 1 at all time. The connection status will be indicated at address 100 bit 2. Palert will also send its serial number in ASCII format to the server when connection is established.
These addresses store TCP server 1 IP information as the order ip1.ip2.ip3.ip4 as below.
ip1: Address 178 high byte
ip2: Address 178 low byte
ip3: Address 179 high byte
ip4: Address 179 low byte

When these addresses are changed user must also write 2 into address 113 to effect the changes.
Server 1 IP address is also the FTP server IP for firmware upgrade. Once user writes 0x180 into address 113 will force Palert to upgrade firmware from FTP server.

◎Address 180~191, Palert Network Address Setting

These addresses store IP information for Palert. User must write 4 into address 113 when there is any change for these addresses.
The factory preset values are described as below.
IP: 192.168.255.1 (Address 180 to 183)
Mask: 255.255.0.0 (Address 184 to 187)
Gateway: 192.168.0.1 (Address 188 to 191)
User could ground DI0 in order to display Palert IP information from 7 segments LED. Please maintain Palert at steady status in case of Palert displays earthquake trigger information.
Attention! Improper network address setting may cause Palert malfunction.

◎Address 192, Available Connections for Host

Palert offers 3 TCP connections for host simultaneously. This address indicates remain connections.

◎**Address 193, Streaming Output Control**

Palert will stream out data packet continually every second when user writes 1 or 2 into this address. Palert will also send out one additional packet at the moment when below conditions is satisfied.

1. P wave is detected.
2. Exactly three seconds after P wave.
3. Pd great equal Pd watch threshold if Pd trig algorithm is enabled.
4. Pd great equal Pd warning threshold if Pd trig algorithm is enabled.

The packet data format is depending on the data 1 or 2. Palert will stop streaming when user writes 0 to this address. Please notice that these kinds of data packets are not standard Modbus protocol so it is not possible to be received by standard PLC. Streaming output is also the must function for EEW system. Regarding to the format of these packets data are describe as below.

Mode 1	Mode 2	Integer Number	Description (Value in parentheses indicate Modbus address)
		0	Packet type 1: Normal streaming packet 119: P wave streaming packet 300: Pd within 3 seconds after P wave 1191: Pd watch streaming packet 1192: Pd warning streaming packet
		1	Event flag (111)
		2	system time-year (147)
		3	system time-month (148)
		4	system time-day (149)
		5	system time-hour (150)
		6	system time-minute (151)
		7 (high byte)	system time-second (152)
		7 (low byte)	system time-10 msecond
		8	event time-year (141)
		9	event time-month (142)
		10	event time-day (143)
		11	event time-hour (144)
		12	event time-minute (145)
		13 (high byte)	event time-second (146)
		13 (low byte)	event time-10 msecond
		14	Serial number (200)
		15	Displacement watch threshold (197)

Mode 1	Mode 2	Integer Number	Description (Value in parentheses indicate Modbus address)
		16	PGV within 1 second (125)
		17	PGD within 1 second (126)
		18	PGA within 10 seconds (140)
		19	PGA trig axis (135)
		20	Pd warning threshold (162)
		21	PGA warning threshold (161)
		22	Displacement warning threshold (160)
		23	Pd flag (139)
		24	Pd watch threshold (164)
		25	PGA watch threshold (121)
		26	Intensity now (109)
		27	Intensity maximum (110)
		28	PGA within 1 second
		29	PGA axis within 1 second (138)
		30	τ_c (138)
		31	Trig mode (163)
		32	Operation Mode (118)
		33	Durations for watch and warning (195)
		34	Firmware version
		35 ~ 38	IP Address (180~183)
		39 ~ 40	Server 0 IP address (176~177)
		41 ~ 42	Server 1 IP address (178~179)
		43 ~ 46	NTP server IP address (171~174)
		47	Sockets remain (192)
		48	Connection flag (100)
		49	D I/O status (119)
		50	EEW register (198)
		51	Pd in a axis (137)
		52	Pv in a axis
		53	Pa in a axis
		54	Maximum vector in earthquake (108)
		55	Maximum a axis acceleration in earthquake (129)
		56	Maximum b axis acceleration in earthquake (130)
		57	Maximum c axis acceleration in earthquake (131)
		58	Maximum a axis acceleration of vector in earthquake

Mode 1	Mode 2	Integer Number	Description (Value in parentheses indicate Modbus address)
			(132)
		59	Maximum b axis acceleration of vector in earthquake (133)
		60	Maximum c axis acceleration of vector in earthquake (134)
		100	a axis Acceleration of Record 1
		101	b axis Acceleration of Record 1
		102	c axis Acceleration of Record 1
		103	Pd of Record 1
		104	Displacement of Record 1
		..	..
		595	a axis Acceleration of Record 100
		596	b axis Acceleration of Record 100
		597	c axis Acceleration of Record 100
		598	Pd of Record 100
		599	Displacement of Record 100

Notes:

a. Integer format is low byte at first and follow with high byte.

b. This streaming function is only available for Modbus TCP.

◎Address 194, Palert Modbus RTU Address setting

Factory preset value is 101. The possible number is from 1 to 255. Please write 2 into address 113 when there is change in this address.

◎Address 195, Watch and Warning Period

This address stores the watch and warning period for displacement, Pd and PGA trigger algorithms. High byte as watch time in second (recommended value is 10). Low byte as warning time in second (recommended value is 30).

◎Address 196, Maximum Acceleration within 1 Second

This address stores the maximum acceleration within 1 second, unit in gal.

◎Address 197, a Axis Displacement Watch Threshold

This address stores the displacement watch threshold for a axis, unit in 0.001 cm. The recommended value is 0.2 cm. The earthquake signal will be set (address 111 bit 0) when displacement trigger algorithm is enabled (address 163 bit 0) and real-time a axis displacement (address 159) is great equal to this threshold. Please refer to addresses 123 and 124 for more information regarding to DOs activity during this stage.

◎Address 198, Earthquake Pre-Warning Register

This address is designed for received EEW information from EEW server. High byte as predict intensity and low byte as remain seconds for shock wave arrive. When there are data write into this address, two DOs will be turned on and 7 segments LED will display intensity and count down seconds. It will display local earthquake information immediately if Palert detects earthquake later.

This function only available when Palert is integrated with EEW system and with seismologist supports. It is also important that the system must obey the individual countries regulations or laws for dispatch earthquake information.

◎Address 199, Palert Firmware Number

This address indicates the Palert firmware version.

◎Address 200, Palert Serial Number

This Address stores the serial number of Palert. User could change this serial number based on the application needed. The possible range is from 1 to 65535.

4.3. Modbus Related Information for Palert

Palert supports Modbus TCP and Modbus RTU simultaneously. ID will be 1 when connected by Modbus TCP. The Modbus RTU communication parameters is “19200, n, 8, 1”. Palert supports Modbus function 1, 2, 3, 6 and 16.

Example: Set STA as 2.5 seconds by using Modbus TCP.

2.5 seconds equal to 25 * 0.1 seconds, 25 = 0x0019. Function code is 6 and the register address is 114 = 0x0072 (Palert uses zero based system). The command set will be like this one as below.

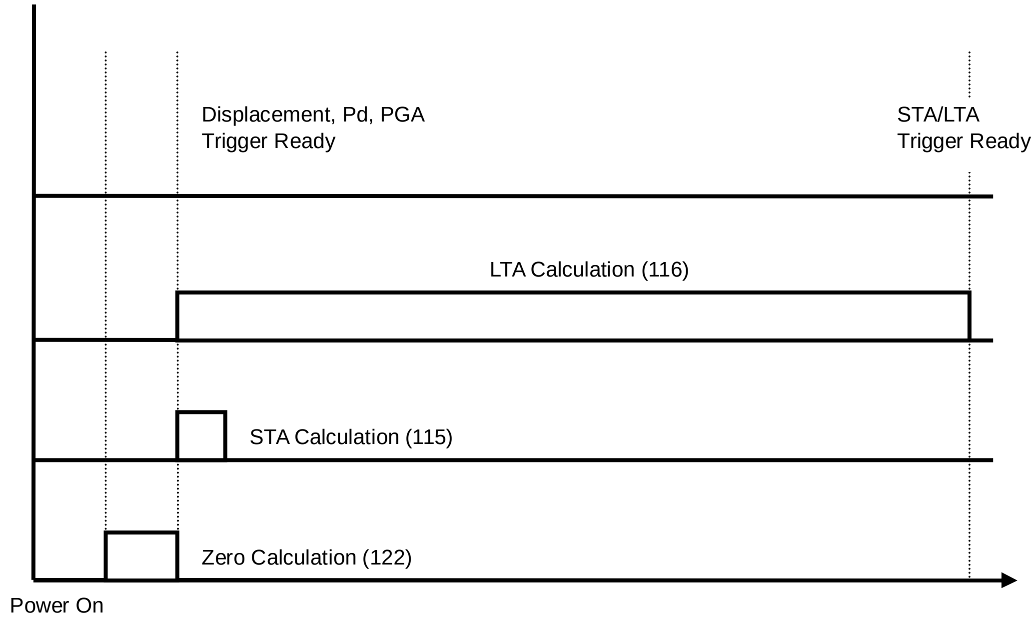
TID (hex)	PID (hex)	Field Length (hex)	UID (hex)	FC (hex)	Reg_Offset. (hex)	Value (hex)
0001	0000	0006	01	06	0072	0019

TID: Transaction Identifier; PID: Protocol Identifier (Protocol Length);

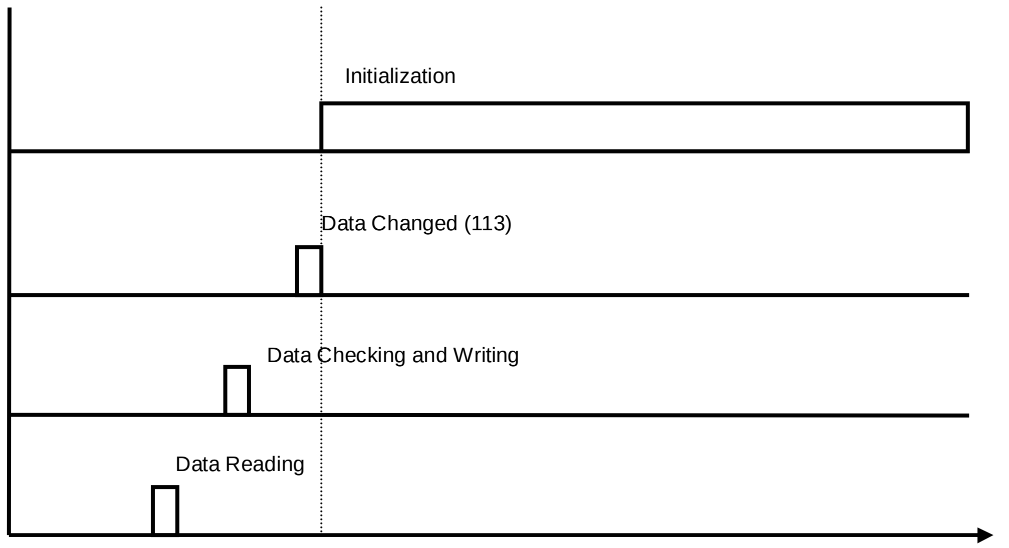
UID: Unit Identifier; FC: Function Code

4.4. Palert Operation Time Sequence

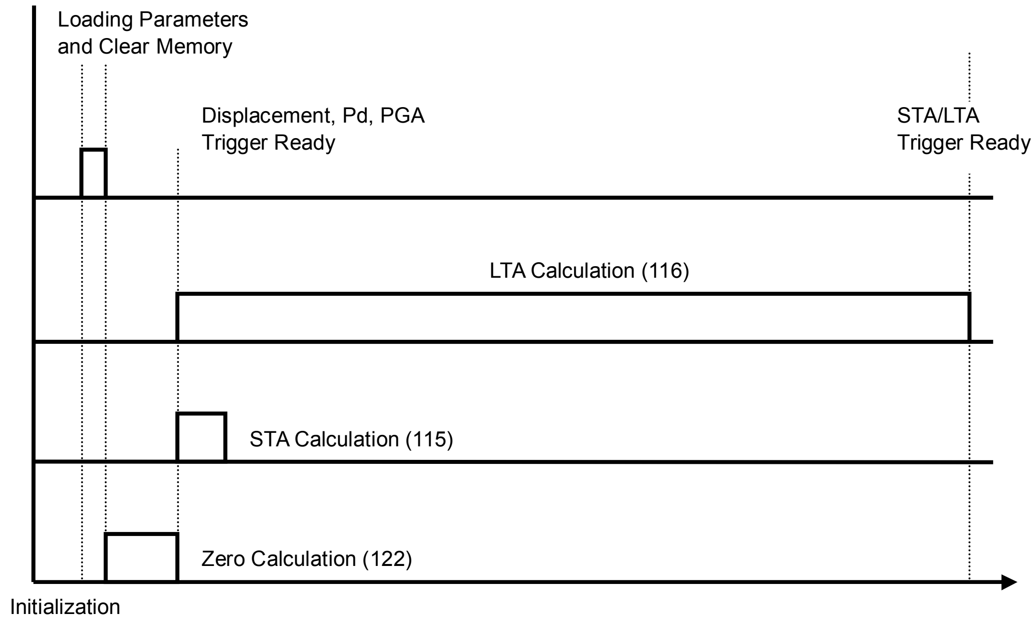
4.4.1. Power ON Time Sequence



4.4.2. Parameter Setting Time Sequence



4.4.3. Initialization Time Sequence



4.4.4. STA/LTA Trigger Time Sequence

4.4.5. Displacement, Pd, and PGA Trigger Time Sequence

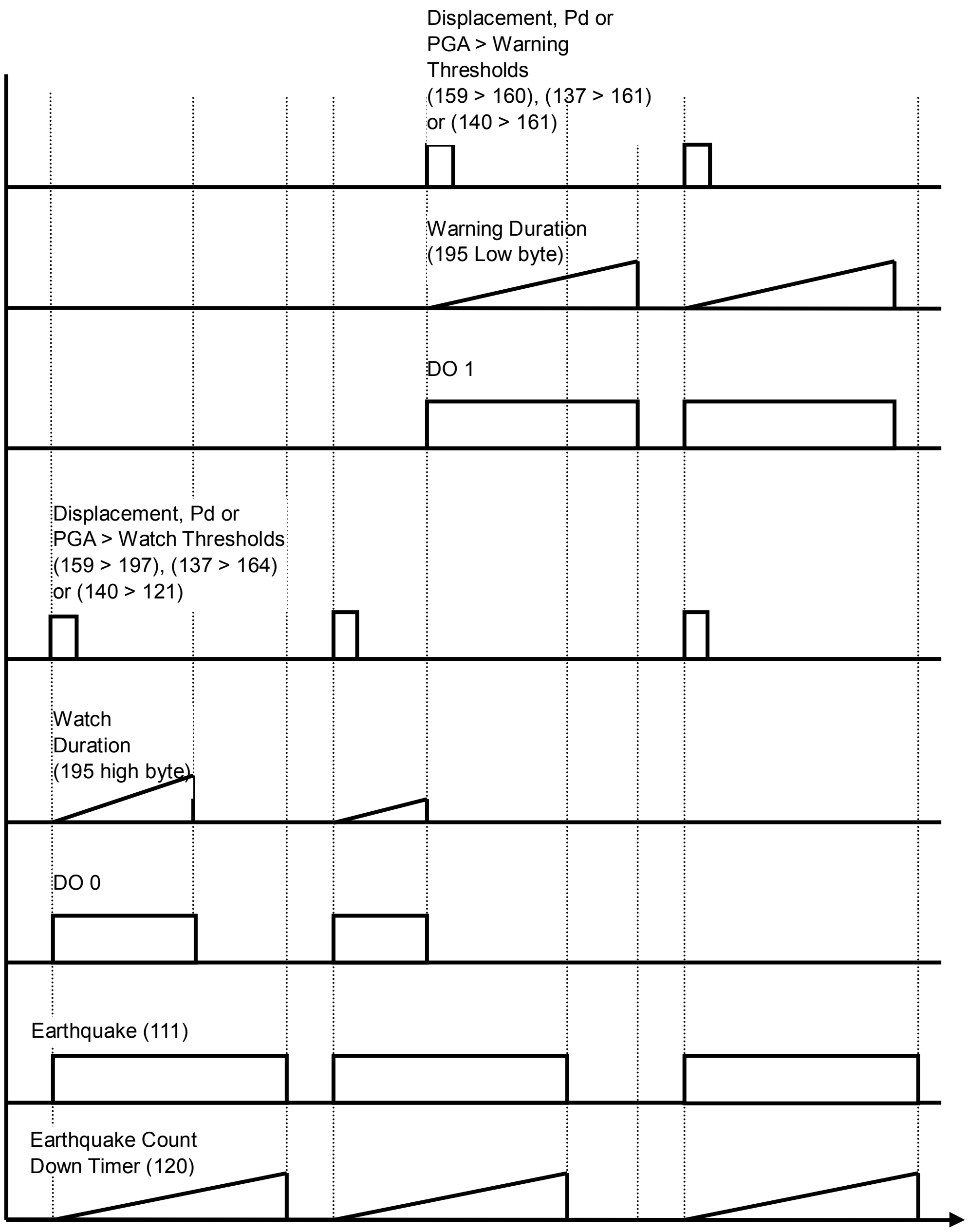


Table 1. Earthquake Intensity Table, Central Weather Bureau, Taiwan.

Intensity Scale		Range of Ground Acceleration	Effects on People	Effects Indoors	Effects Outdoors
1	Very minor	0.8~2.5gal	Felt only by a few people at rest, vibrates slightly.		
2	Minor	2.5~8.0gal	Felt by the majority of people. Some awakened from sleeping.	Hanging lamps and objects vibrate slightly.	Standing vehicles vibrate slightly, similar to being passed by a truck, but only lasts for a short time.
3	Light	8~25gal	Felt by nearly everyone, a few frightened.	Buildings shake; dishes, windows, and doors shake making sounds; hanging objects shake visibly.	Standing vehicles vibrate obviously; electric wires sway gently.
4	Moderate	25~80gal	Many people are quite frightened, looking for safe shelter. Most people are awakened from sleep.	Buildings rock noticeably; unstable objects topple over; heavy furniture moves; may cause slight damage.	Felt by drivers; electric wires sway obviously, felt by people walking.
5	Strong	80~250gal	Most people are considerably frightened.	Walls crack; heavy furniture may overturn.	Noticeably felt by drivers; some chimneys and large archways topple over.
6	Very Strong	250~400gal	People have trouble walking due to violent rocking.	Damage to some buildings; heavy furniture overturns; doors and windows bend.	Drivers have trouble steering; sand and clay blasts occur.
7	Great	400gal and above	People move with difficulty due to severe rocking.	Severe damage to or collapse of some buildings; almost all furniture moves or falls down.	Landslides and faults rupture occur; railway bend; underground lines break.

Note: 1gal = 1cm/sec*sec

Appendix 1. EEW Paper by Professor Yih-Min Wu., National Taiwan University.

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Full Research Paper

Development of an Earthquake Early Warning System Using Real-Time Strong Motion Signals

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Abstract: As urbanization progresses worldwide, earthquakes pose serious threat to lives and properties for urban areas near major active faults on land or subduction zones offshore. Earthquake Early Warning (EEW) can be a useful tool for reducing earthquake hazards, if the spatial relation between cities and earthquake sources is favorable for such warning and their citizens are properly trained to respond to earthquake warning messages. An EEW system forewarns an urban area of forthcoming strong shaking, normally with a few sec to a few tens of sec of warning time, i.e., before the arrival of the destructive S-wave part of the strong ground motion. Even a few second of advanced warning time will be useful for pre-programmed emergency measures for various critical facilities, such as rapid-transit vehicles and high-speed trains to avoid potential derailment; it will be also useful for orderly shutoff of gas pipelines to minimize fire hazards, controlled shutdown of high-technological manufacturing operations to reduce potential losses, and safe-guarding of computer facilities to avoid loss of vital databases. We explored a practical approach to EEW with the use of a ground-motion period parameter τ_c and a high-pass filtered vertical displacement amplitude parameter *Pd* from the initial 3 sec of the P waveforms. At a given site, an earthquake magnitude could be determined from τ_c and the peak ground-motion velocity (*PGV*) could be estimated from *Pd*. In this method, incoming strong motion acceleration signals are recursively converted to ground velocity and displacement. A P-wave trigger is constantly monitored. When a trigger occurs, τ_c and *Pd* are computed. The earthquake magnitude and the on-site ground-motion intensity could be estimated and the warning could be issued. In an ideal situation, such warnings would be available within 10 sec of the origin time of a large earthquake whose subsequent ground motion may last for tens of seconds.

Keywords: earthquake, early warning system, seismic hazard mitigation.

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1. Introduction

Because of the extreme complexity involved in the earthquake processes, reliable earthquake prediction is not currently possible (Kanamori et al., 1997). Present technological advances in seismic instrumentation and in digital communication and processing permit the implementation of a real-time earthquake monitoring system. From the point of view of seismic hazards mitigation, earthquake early warning (EEW) is becoming a practical tool to reduce the loss caused by a damaging earthquake (Kanamori et al., 1997; Teng et al., 1997; Wu and Teng, 2002; Allen and Kanamori, 2003).

The idea of an earthquake early warning system was proposed more than one hundred years ago by Cooper (1868) for San Francisco, California. About a hundred years later, Japan Railways Company designed an EEW system in 1965 and started operation in the following year (Nakamura, 1988). In the past decade, progress has been made towards implementation of earthquake early warning in Japan, Taiwan, Mexico, Southern California, Italy, and Romania (e.g., Nakamura, 1988; Odaka et al. 2003; Allen and Kanamori, 2003; Horiuchi et al, 2005; Wu et al., 1998, 1999, 2006, 2007; Wu and Teng, 2002; Wu and Zhao, 2006; Espinosa-Aranda et al., 1995; Zollo et al, 2006; Böse et al., 2007). In particular, the systems developed at the National Research Institute for Earth Science and Disaster Prevention (NIED) (Horiuchi et al., 2005) and the Japan Meteorological Agency (JMA) (Kamigaichi, 2004; Tsukada et al., 2004) were integrated in June, 2005. The system was successfully activated during the 2007 Noto Hanto (Peninsula) and the 2007 Niigata Chuetsu-Oki earthquakes, and provided accurate information regarding the source location, magnitude and intensity at about 3.8 s after the arrival of *P* wave at nearby stations. Thus, it provided early warning before arrival of strong shaking. Currently, there are many seismic networks using real-time strong motion signals for earthquake monitoring (Wu et al., 1997, 2000, 2001; Hauksson et al., 2001). In this paper, we describe the τ_c and *Pd* methods developed for earthquake early warning purposes.

2. τ_c and P_d method

Determinations of magnitude and the strength of shaking from the initial P wave are two important elements for earthquake early warning. Strength of shaking can practically be represented by peak gound acceleration (PGA), peak ground velocity (PGV), and peak ground displacement (PGD). Figure 1 shows a strong motion record of a $M_w6.6$ earthquake in Japan. Generally, strong motion signal represents acceleration, and after once and twice integration the signal can be coverted to velocity and displacement. PGA, PGV, and PGD are the peak values of the three components. In real-time operation, velocities and displacements are recursively filtered with a one-way Butterworth high-pass filter with a cutoff frequency of 0.075 Hz for removing the low frequency drift during the first integration process.

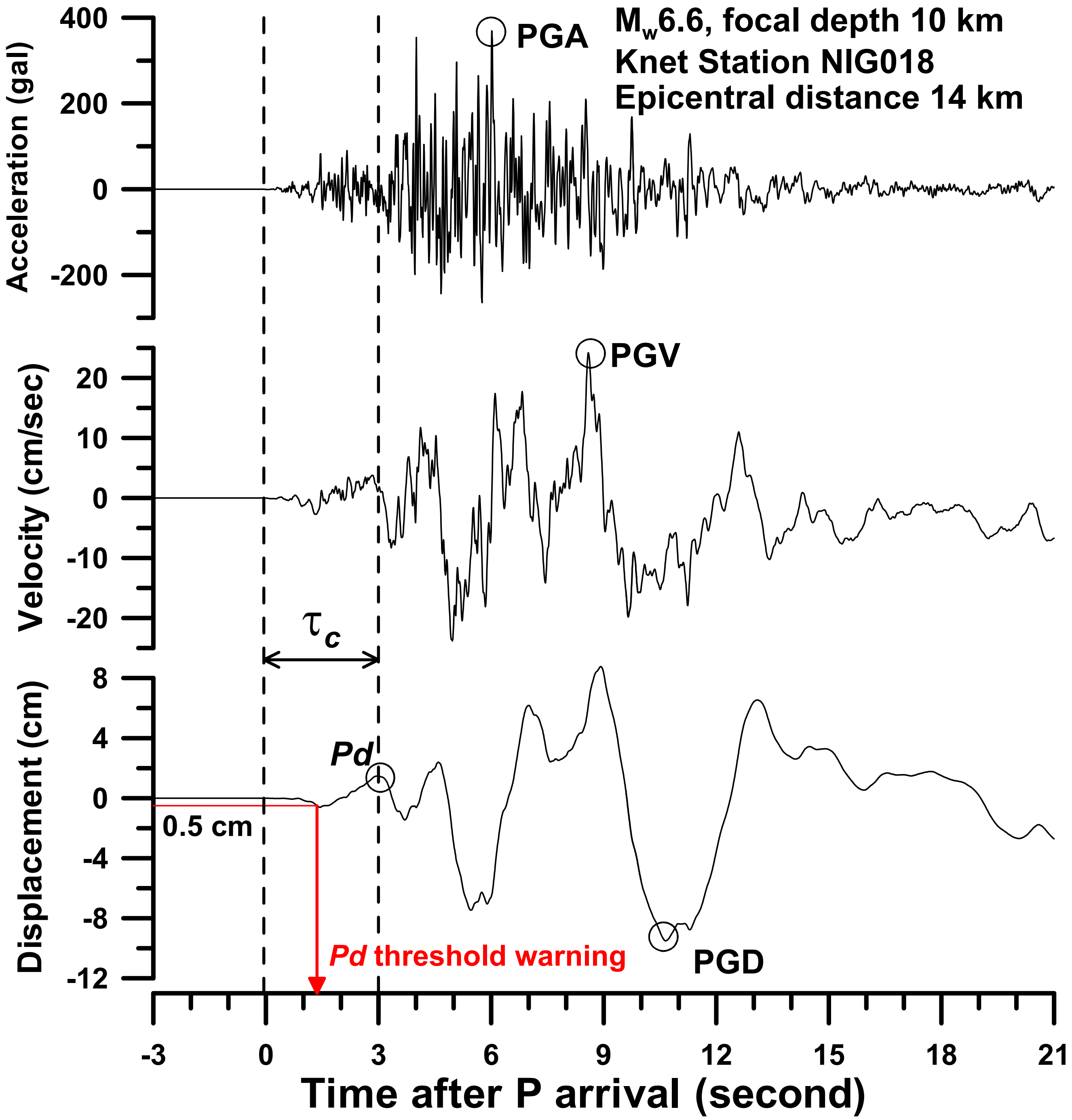

Figure 1. Vertical component acceleration, velocity and displacement seismograms for the 2007 Niigata Chuetsu-Oki earthquake, at the nearest stations, NIG018 (Δ=14 km). A ground-motion period parameter τ_c and a high-pass filtered displacement amplitude parameter P_d are determined from the initial 3 sec of the P waveforms.

An earthquake excites both P and S waves. The S wave carries the major destructive energy, and the smaller amplitude P wave precedes the S wave by the time equal to the 70% of the P-wave travel time to the station. The initial portion of the P wave, despite its small and nondestructive amplitude, carries the information of the earthquake size, and estimation of the earthquake size from the P wave provides information about the strength of shaking to be brought by the following S wave. Using *P* wave information to estimate the strength of S wave destructive shaking is a principal concept of EEW.

One of the major elements of EEW is to determine the earthquake magnitude rapidly and reliably. To determine the size of an earthquake, it is important to determine whether the earthquake rupture has stopped or keeps growing which is generally reflected in the period of the initial motion. Small and large events generally cause short and long period initial motions, respectively. The method developed by Nakamura (1988) attempts to use the period averaged over some time window. Kanamori (2005) used the following procedure which is modified from the method used by Nakamura (1988). The ground-motion displacement, $u(t)$, and velocity, $\dot{u}(t)$, from the vertical component record are used to compute the following ratio *r* by

$$r = \frac{\int_0^{\tau_0} \dot{u}^2(t)dt}{\int_0^{\tau_0} u^2(t)dt} \tag{1}$$

where the integration is taken over the time interval $(0, \tau_0)$ after the onset of P wave. In a series of previous studies (Wu and Kananmori, 2005a, 2005b, 2007; Wu et al., 2006; 2007), τ_0 is set at 3 s. Using Parseval's theorem,

$$r = \frac{4\pi^2 \int_0^{\infty} f^2 \left|\hat{u}(f)\right|^2 df}{\int_0^{\infty} \left|\hat{u}(f)\right|^2 df} = 4\pi^2 \left\langle f^2 \right\rangle \tag{2}$$

where $\hat{u}(f)$ is the frequency spectrum of $u(t)$, and $\left\langle f^2 \right\rangle$ is the average of f^2 weighted by $\left|\hat{u}(f)\right|^2$. Thus,

$$\tau_c = \frac{1}{\sqrt{\left\langle f^2 \right\rangle}} = \frac{2\pi}{\sqrt{r}} \tag{3}$$

can be used as a parameter representing the average period of the initial portion of the P wave. τ_c approximately represents the P wave pulse width which increases with the magnitude and can be used to estimate the event magnitude.

Another important element of EEW is to estimate the strength of S wave shaking at a site from the initial P waves at the same site. Wu and Kanamori (2005a) showed that the maximum amplitude of a high-pass filtered vertical displacement during the initial 3 sec of the P wave, *Pd* can be used to estimate the PGV at the same site. When $Pd \geq 0.5$ cm, the event is most likely damaging. τ_c and Pd are the two basic parameters used for EEW in this approach.

Wu and Kanamori (2005a, 2005b, 2007), and Wu et al. (2006, 2007) applied this method to EEW in southern California, Taiwan, and Japan by determining τ_c and Pd. Figure 2 shows a good linear trend between τ_c and M_w determined from the Japan, Taiwan, and southern California records. τ_c values of 54 events for which at least four measurements are available for each event are shown in this figure. The potentially damaging earthquakes with $M_w > 6$ all have $\tau_c > 1$ sec. The regression with errors in both coordinates of M_w and τ_c results in relationships

$$\log \tau_c = 0.296 M_w - 1.462 \pm 0.122 \text{ and}$$
$$M_w = 3.373 \log \tau_c + 5.787 \pm 0.412 \quad (4)$$

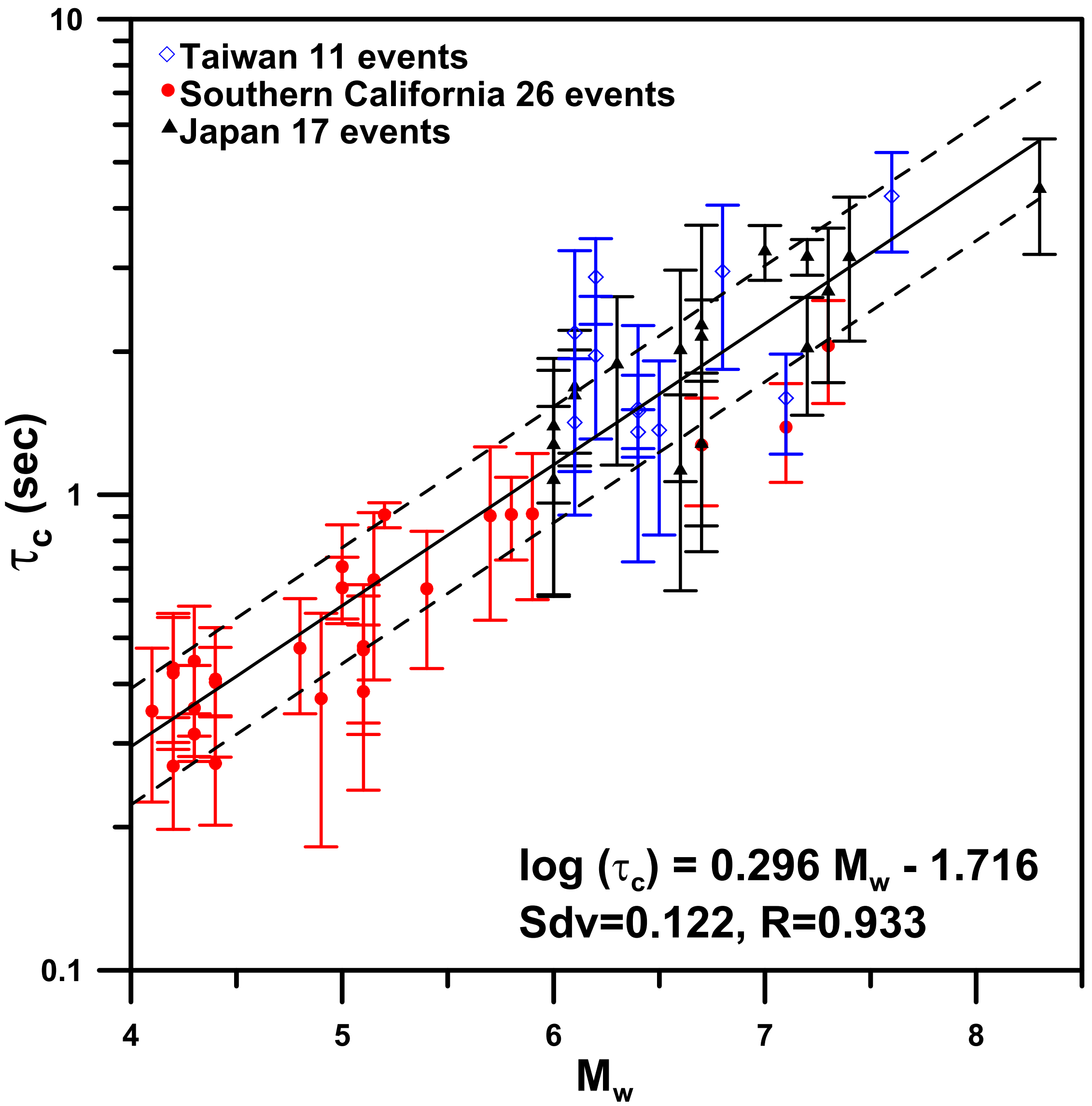

Figure 2. τ_c estimates for 54 events using the nearest stations for Japan (black triangles), southern California (red solid circles) and Taiwan (blue diamonds). Symbols show the event-average with standard deviation. Solid line shows the least squares fit and the two dashed lines show the range of one standard deviation.

The standard deviation of the estimate of M_w is 0.41 for all the events. This regression is based on the average τ_c for each event with at least four measurements.

Figure 3 shows the relationship between *Pd* and *PGV* for the 780 records with epicentral distances less than 30 km from Japan, Taiwan and southern California. We obtained a regression relation

$$\log(PGV) = 0.920 \log(Pd) + 1.642 \pm 0.326 \text{ (}PGV\text{ in cm/sec and }Pd\text{ in cm)} \quad (5)$$

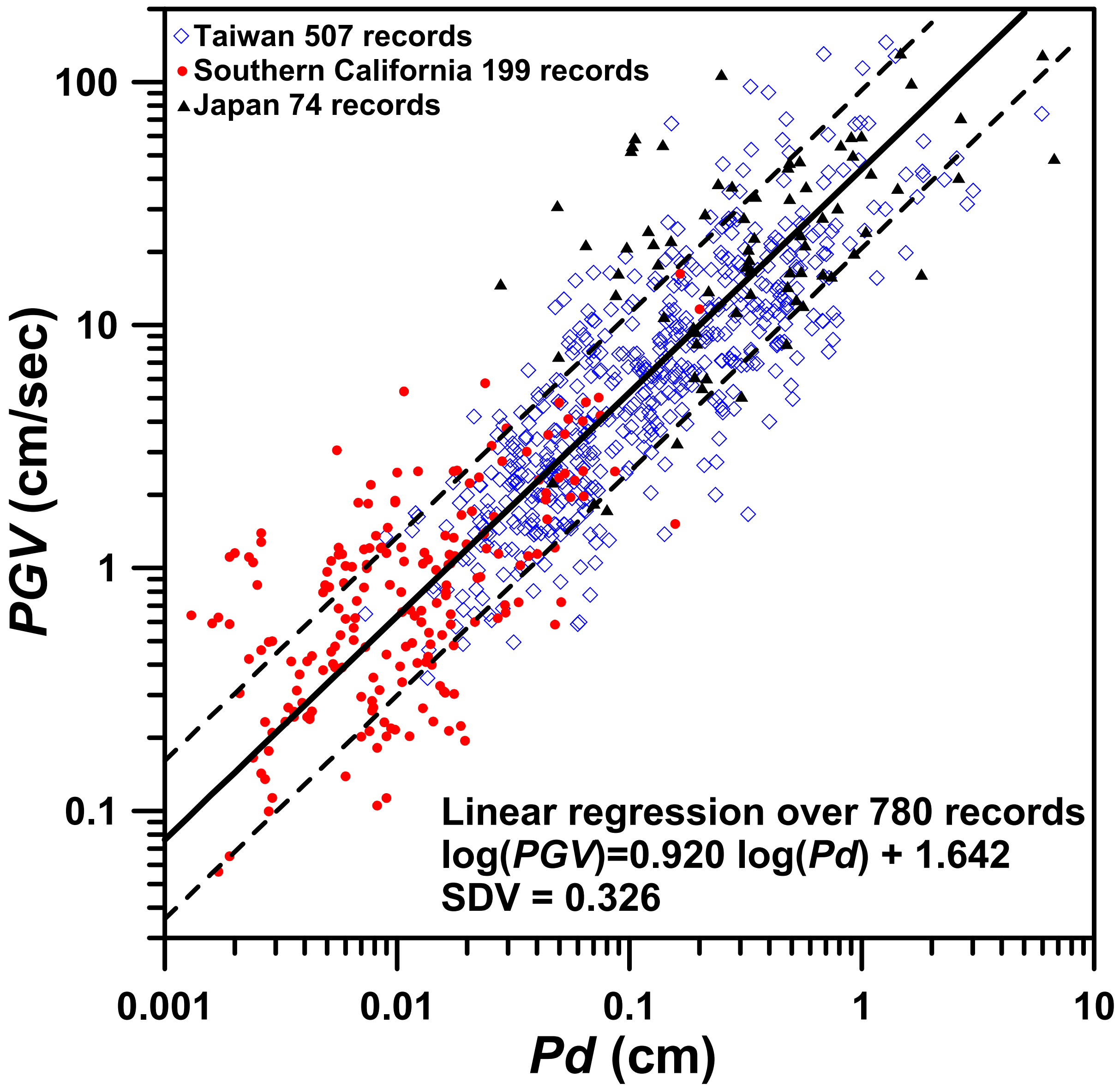

Figure 3. Relationship between peak initial three-second displacement amplitude (*Pd*) and peak ground velocity (*PGV*) for 780 records with the epicentral distances less than 30 km for Japan (black triangles), southern California (red solid circles) and Taiwan (blue diamonds). Solid line indicates the least squares fit and the two dashed lines show the range of one standard deviation.

Instrumental intensity scale for large events is defined with respect to *PGV* (Wald et al., 1999a, 1999b; Wu et al., 2003). Using these relationships, the shaking intensity can be estimated from a single station with a standard deviation of 1.0 unit of MMI scale or 0.6 unit of Japan and Taiwan intensity scale. Thus, the magnitude and shaking intensity can be estimated for EEW purposes 3 sec after the P arrival is detected (Allen, 1978). If τ_c > 1 sec and *Pd*>0.5 cm at a site, then the potential of a damaging earthquake striking this site is high (Wu and Kanamori, 2005a, 2005b, 2007; Wu et al., 2007).

3. Discussion and conclusions

From our experience with the Japan, Taiwan and southern California data, if *Pd* exceeds 0.5 cm, the PGV at the site most likely exceeds the damaging level, i.e., 20 cm/s. One possible approach for faster warning is to monitor *Pd*, and issue a warning as soon as it has exceeded 0.5 cm. As shown in Figure 1, for the 2007 Niigata Chuetsu-Oki earthquake, at the nearest stations, NIG018 (Δ=14 km), the threshold value of *Pd*=0.5 cm was reached at 1.36 s from the arrival of P wave. If we issue a warning at a threshold of $Pd \geq 0.5$ cm, a warning will be issued at 1.36 s after the P arrival and several seconds before the occurrences of PGA and PGV. This type of early warning approach will become effective especially for close-in sites where warnings are most needed.

For any warning system, reliability is always important and it is desirable to have redundancy built in the system to make it more robust. In this paper, we explore the feasibility of using several early warning methods to increase the speed and reliability of early warning. In these methods, the information from the initial part (up to a few seconds) of P wave is used to estimate the magnitude and the strength of the impending ground motion at the same site. In view of the success of the Japan, Taiwan, and Mexico warning systems, we believe that further enhancement of the system like the one described here is worthwhile to make the overall system faster, more reliable, and robust.

Currently, MEMS (Micro Electro Mechanical Systems) acceleration sensors are well developed for a wide range of applications from air bag systems, detecting industrial vibrations, and strong motion recording (Holland, 2003). MEMS sensors are miniature sensors made in wafer fabrication facilities similar to semiconductor foundries. Many types of commercial MEMS accelerometers exist and they are inexpensive. Those accelerometers could be used for EEW purposes with the concept described in this paper and are useful for future seismic hazard mitigation.

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