An FPGA-based chaos synchronisation classifier for estimation of peripheral vascular disease using photoplethysmography

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July 20, 2017

Peripheral vascular disease (PVD)

- PVD is a disease in which plaque builds up in the arteries that carry blood to head, organs, and limbs.
- This thesis focuses on PVD that affects blood flow to the legs and hands.

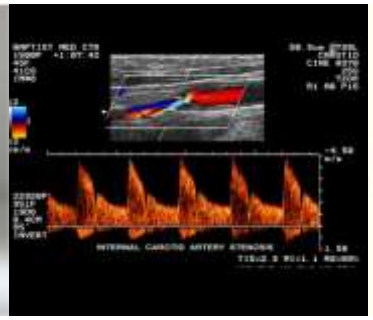
Risk Factor	Incidence Ratio (IR)	The numbers of patients in Taiwan	Mortality Rate (%)
hemodialysis	27.8%	>70,000	11%
diabetes	11%	>1,721,000	3.1%
smoking	9%	>4,500,000	16%
hypertension	10%	>4,300,000	3.2%

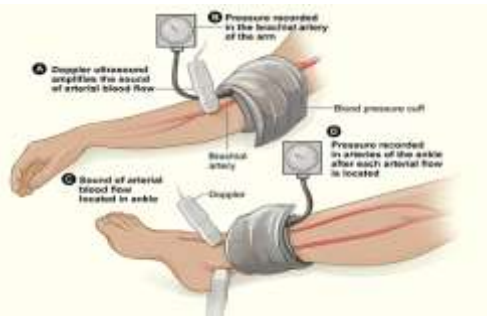
Source: National Health Insurance Administration (Taiwan)

Instruments

- Expensive instruments provide reliable techniques and high accuracy in clinical examinations.


Magnetic resonance angiography


Arterial Doppler

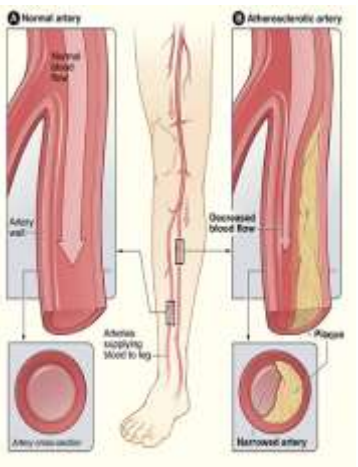

ABPI

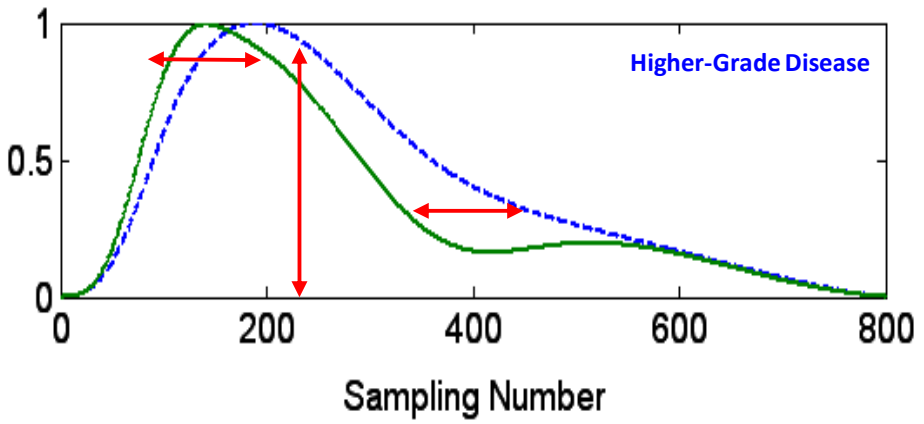
- However, these instruments are not suitably used in a non-clinical environment.

ABPI	Severity classification
>1.30	Non-compressible
0.91-1.30	Normal
0.41-0.90	Mild-to-moderate disease
0.00-0.40	Severe disease

Objectives of Study

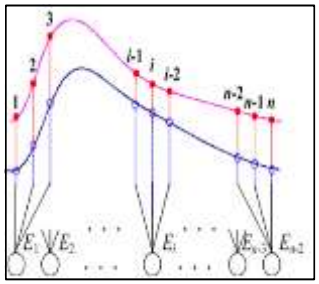
- To develop a portable PPG device based on Sprott system for evaluation of PVD
- To measure the bilateral difference PPG in the foot and finger
  - PPG → timing, amplitudes and shape
  - CS synchronisation → dynamic error
- To estimate the condition of microcirculation in patients with lower-limb PVD



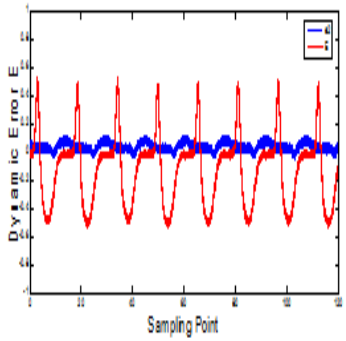


Signal processing flow chart

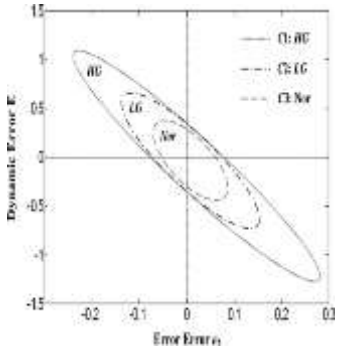
Sampling

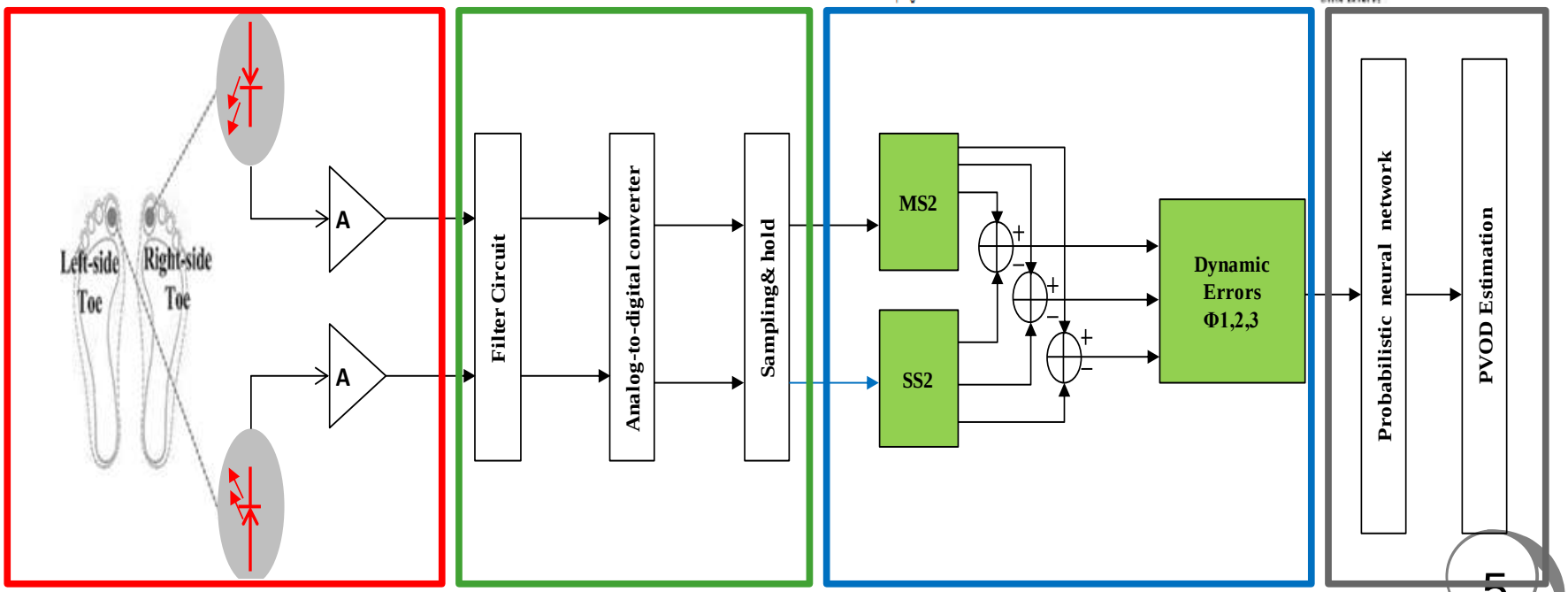


Dynamic Error



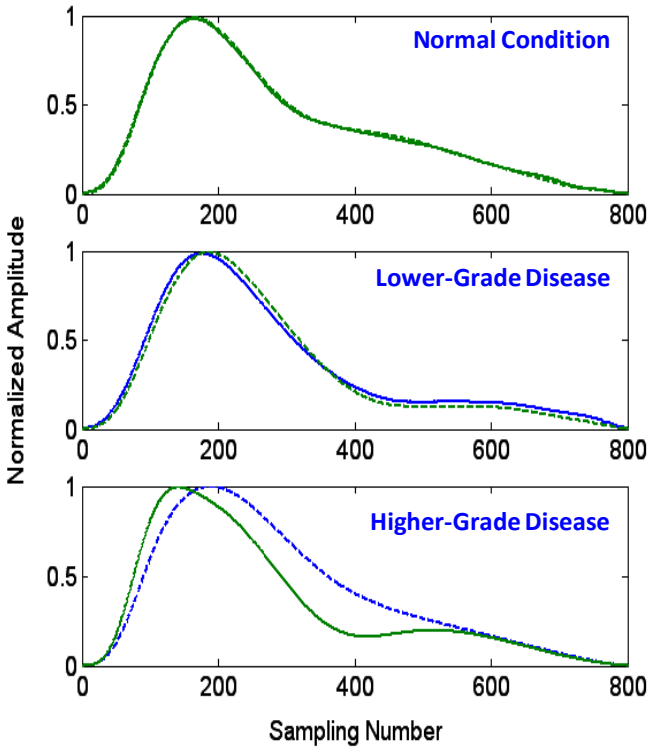
Butterfly patterns

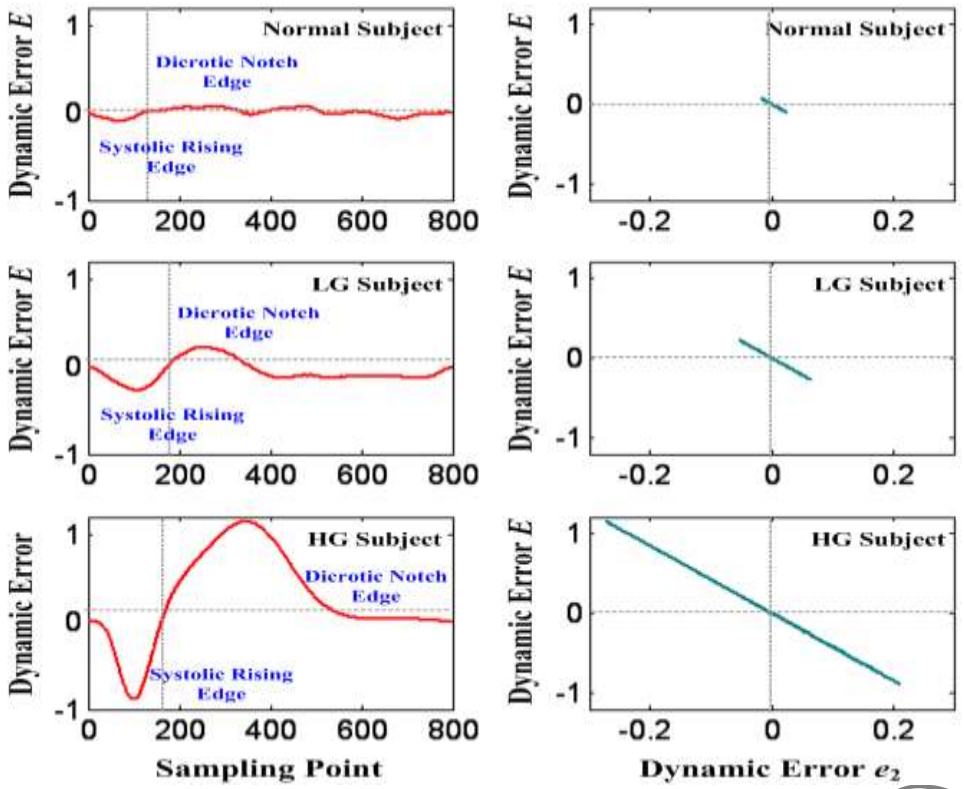




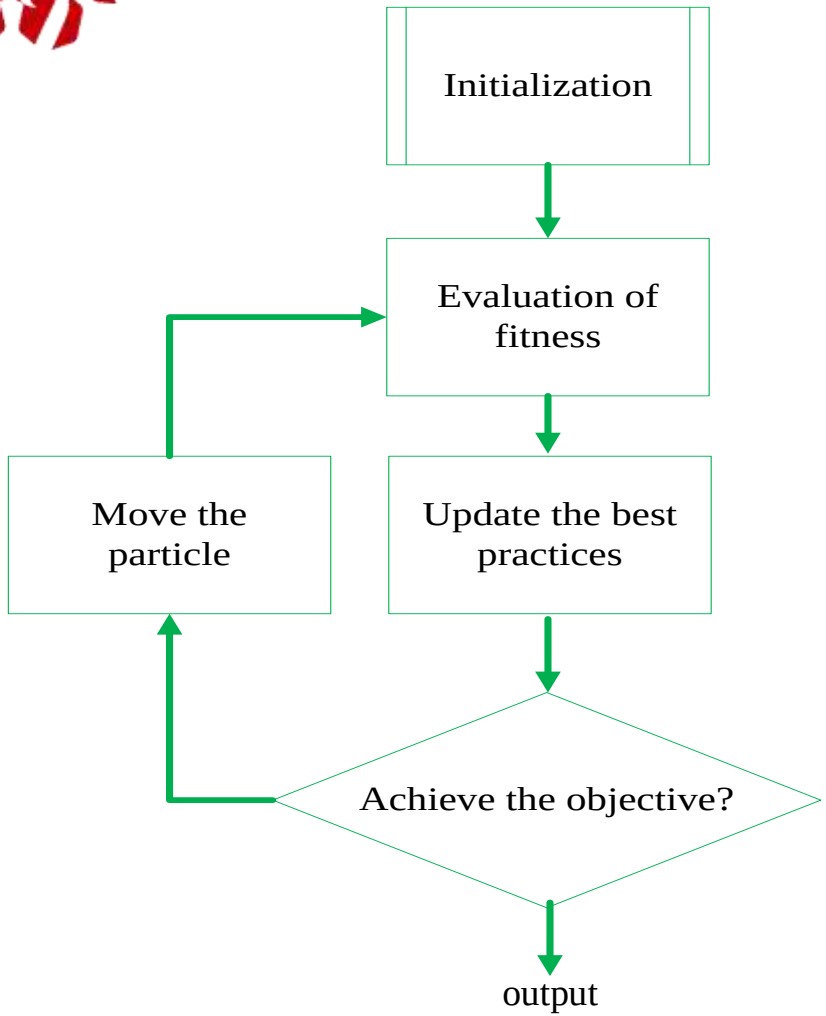
Chaotic motion of bilateral PPG signals

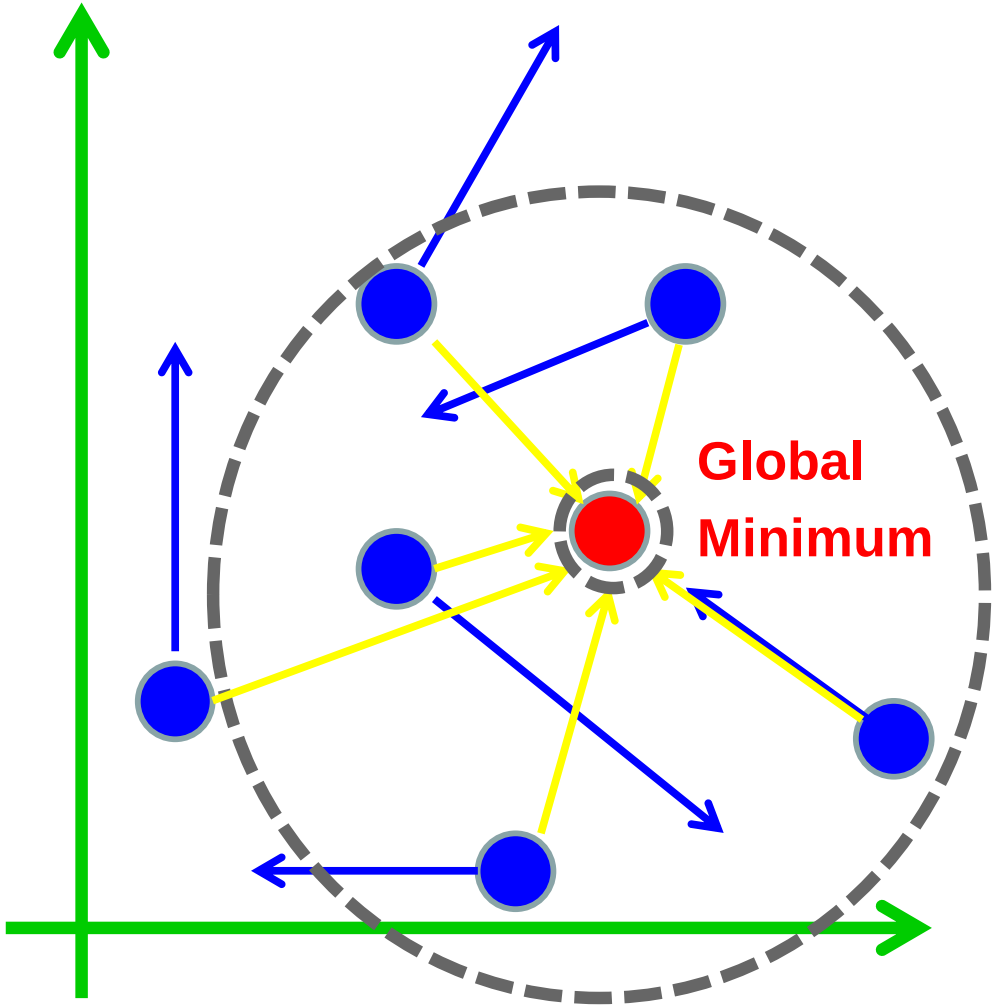
- We choose parameters a = 2 and b = 1 result in a stable CS attractor.





Particle swarm optimization

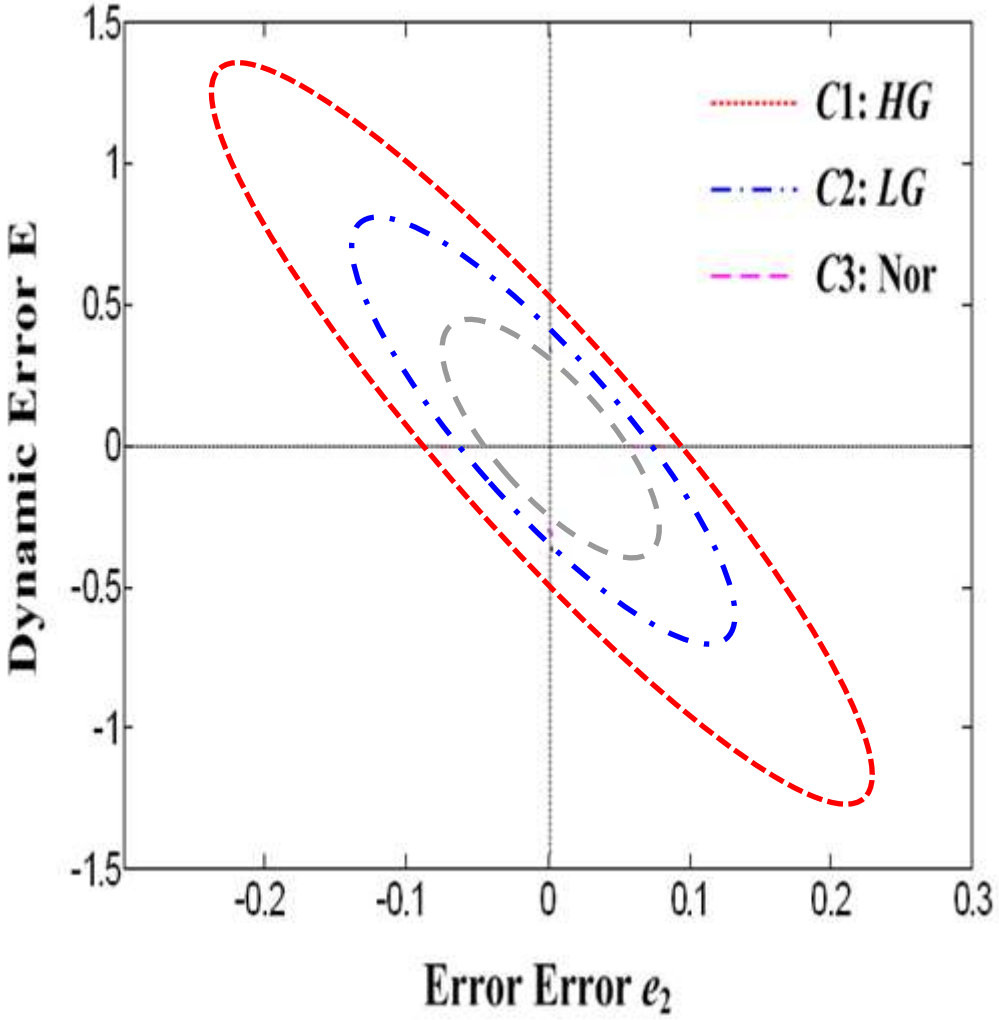




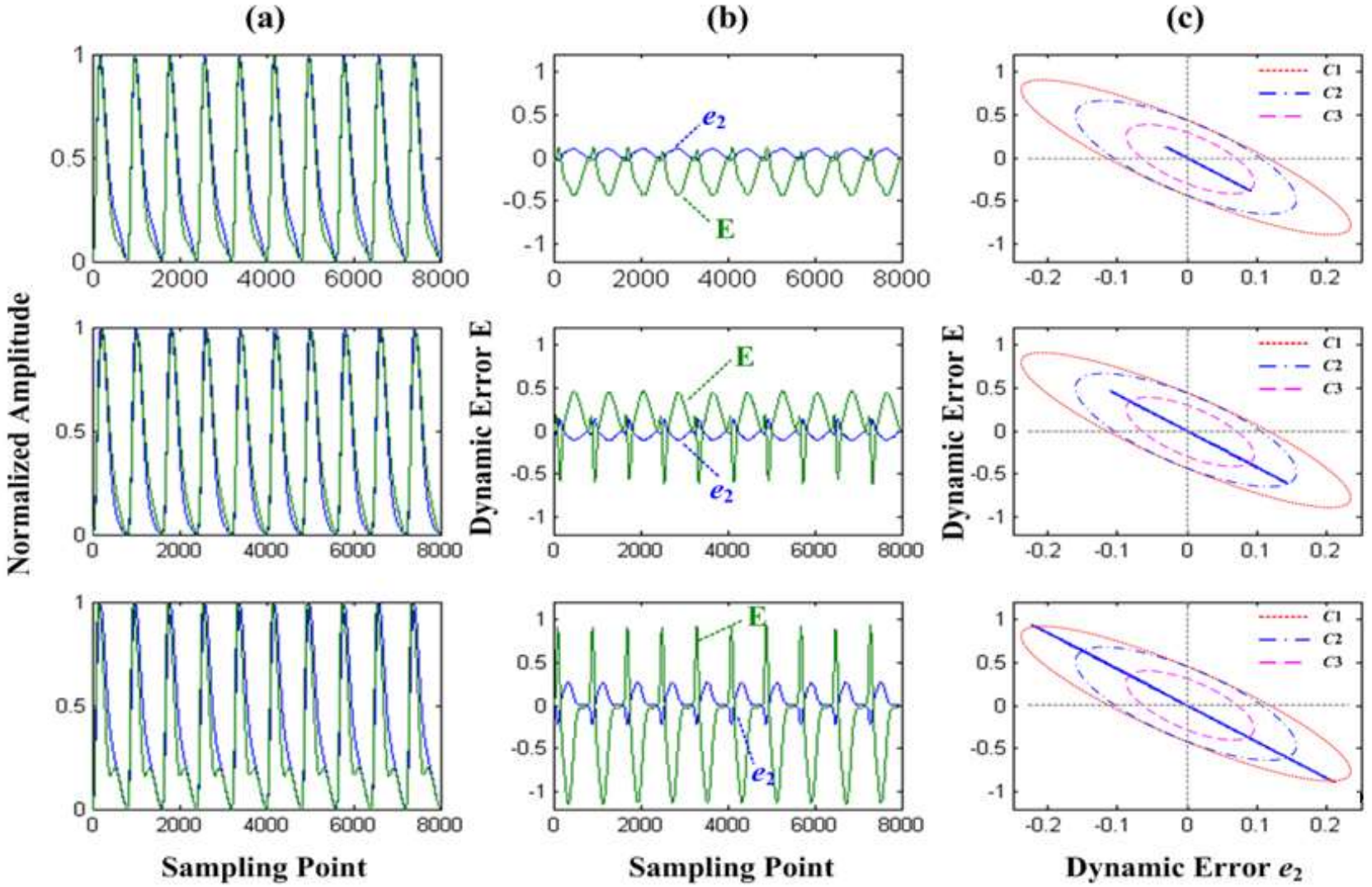
$$\Delta\sigma_g^{p+1} = \omega\Delta\sigma_g^p + c_1\, rand_1(\sigma best_g - \sigma_g^p) + c_2\, rand_2(\sigma best_g - \sigma_g^p)$$

Butterfly patterns within ellipse regions at E-e2 plane

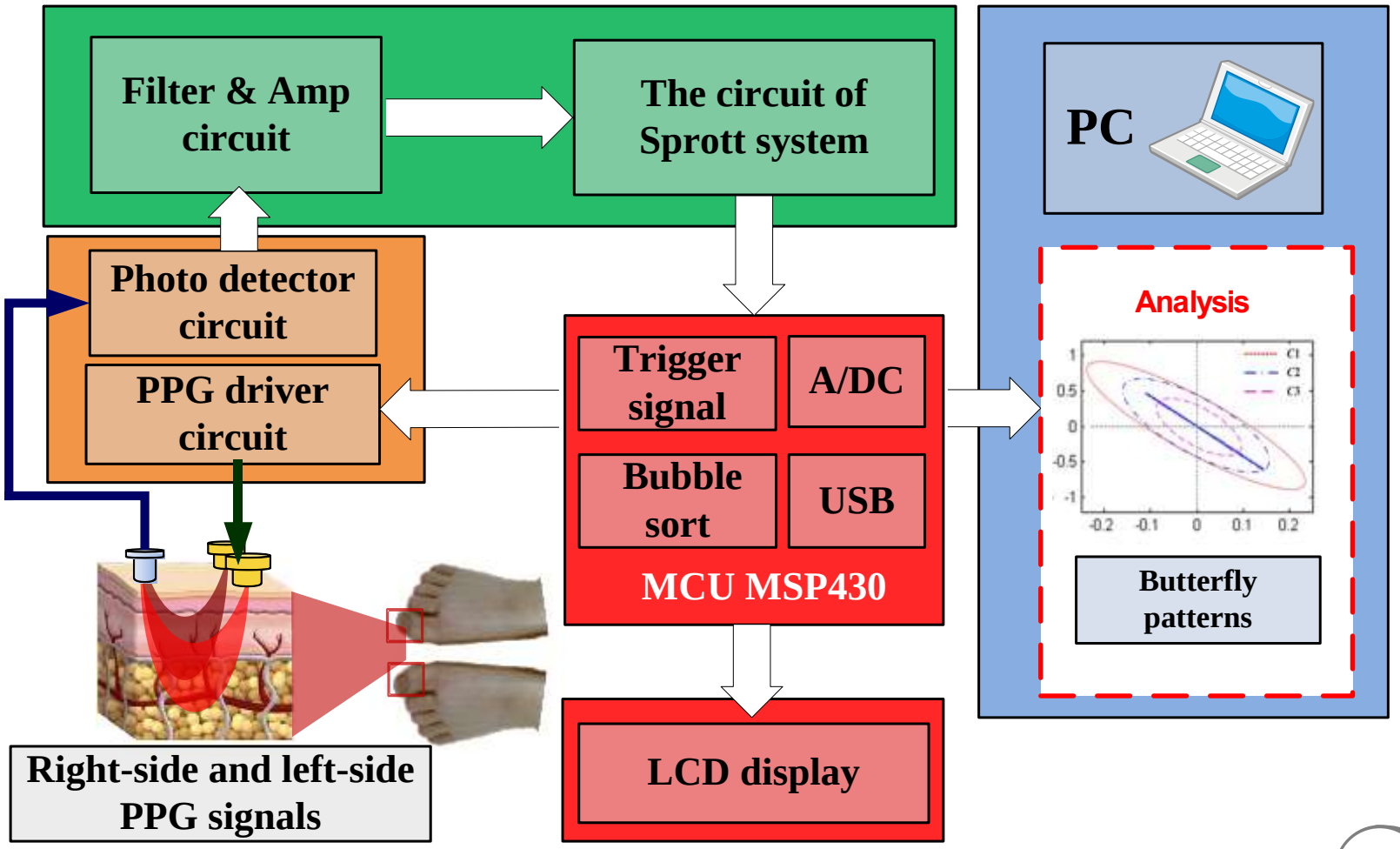
		NOR	LG	HG
Subject 01	E(1)	1	0	0
⋮	⋮	⋮	⋮	⋮
Subject 11	E(11)	1	0	0
Subject 12	E(12)	0	1	0
⋮	⋮	⋮	⋮	⋮
Subject 17	E(17)	0	1	0
Subject 18	E(18)	0	0	1
⋮	⋮	⋮	⋮	⋮
Subject 21	E(21)	0	0	1



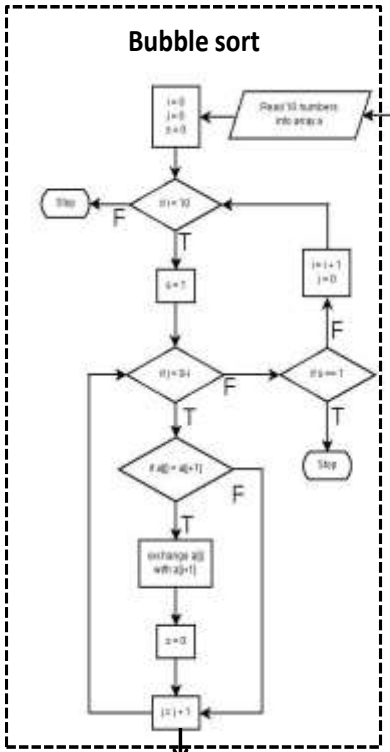
Butterfly patterns for normal, LG, HG subject

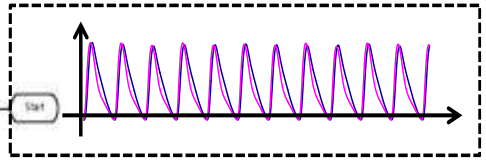


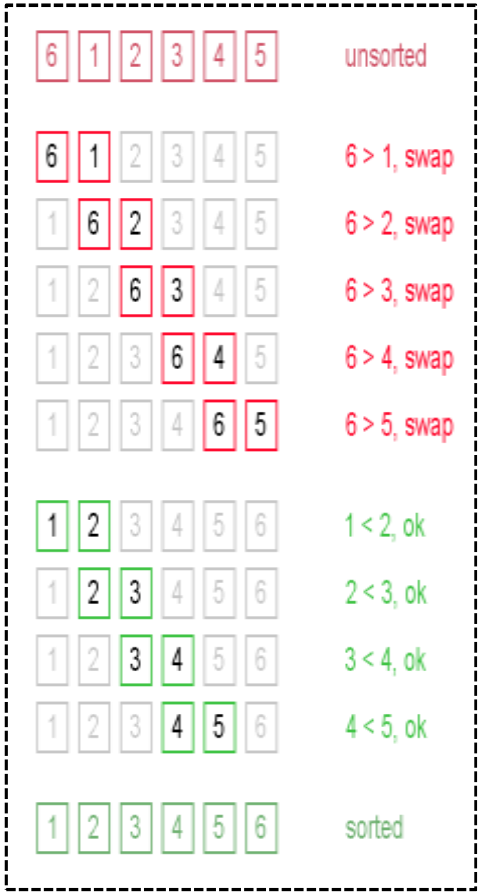
System Implementation

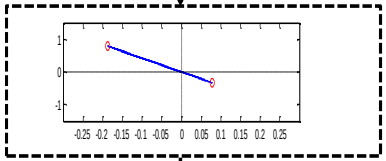


Bubble sort algorithm

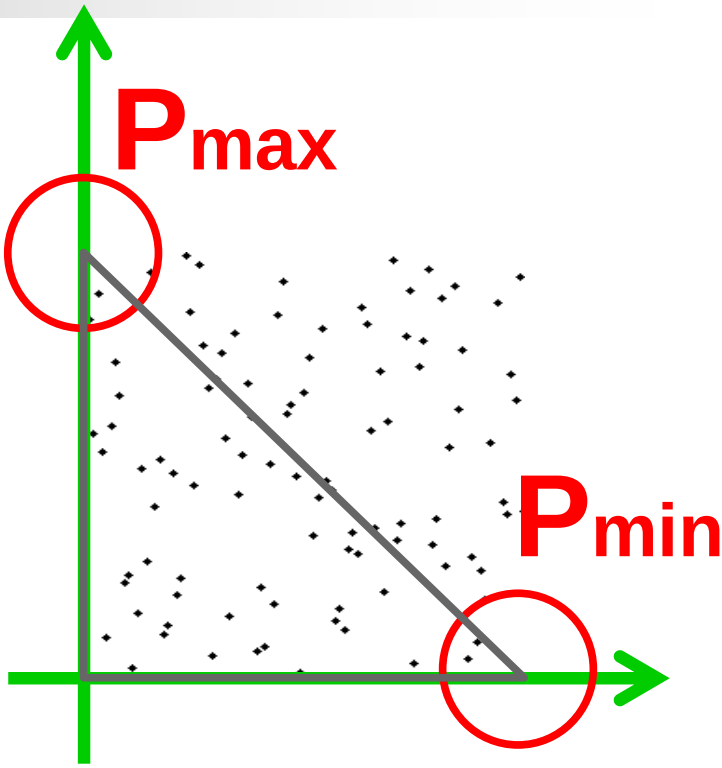






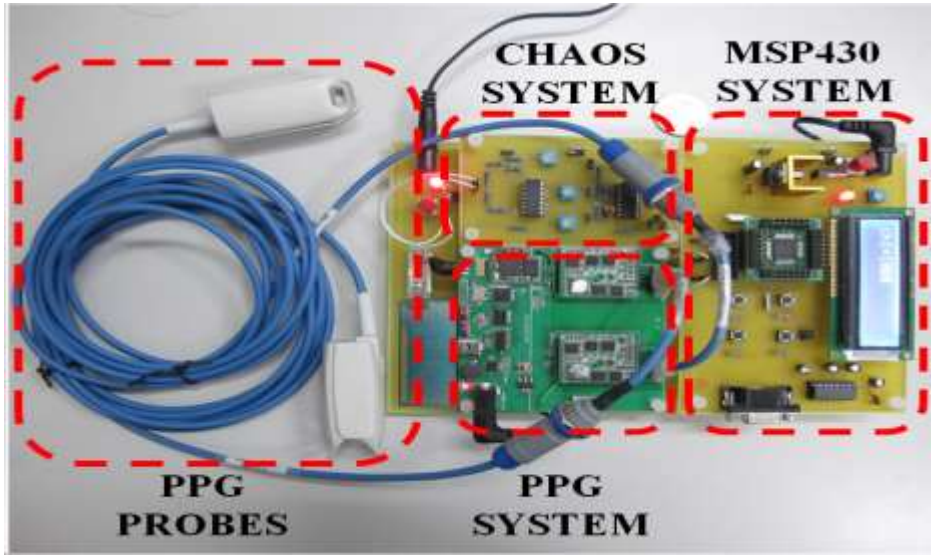


Value of estimation



$$E_{total} \cong \sqrt{p_{max}^{\ 2} + p_{min}^{\ 2}}$$

Subjects measurements in the Chi-Mei medical center



Subjects had rested for 10 min in the supine position

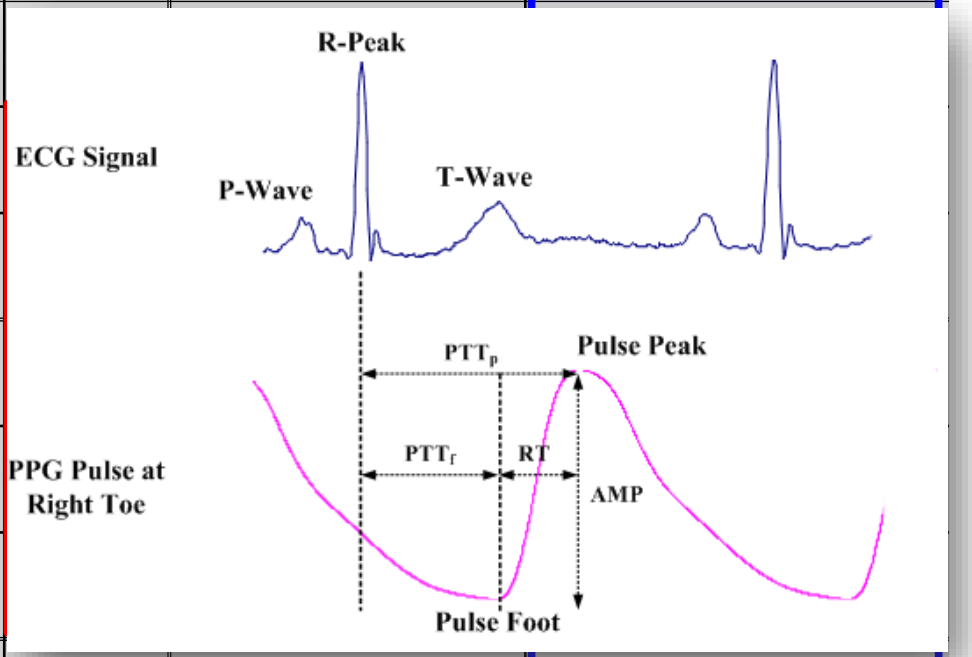
The PPG signals were collected for 5 min

Subjects had rested for 5 min in the supine position

ABPI measurement for 10 min

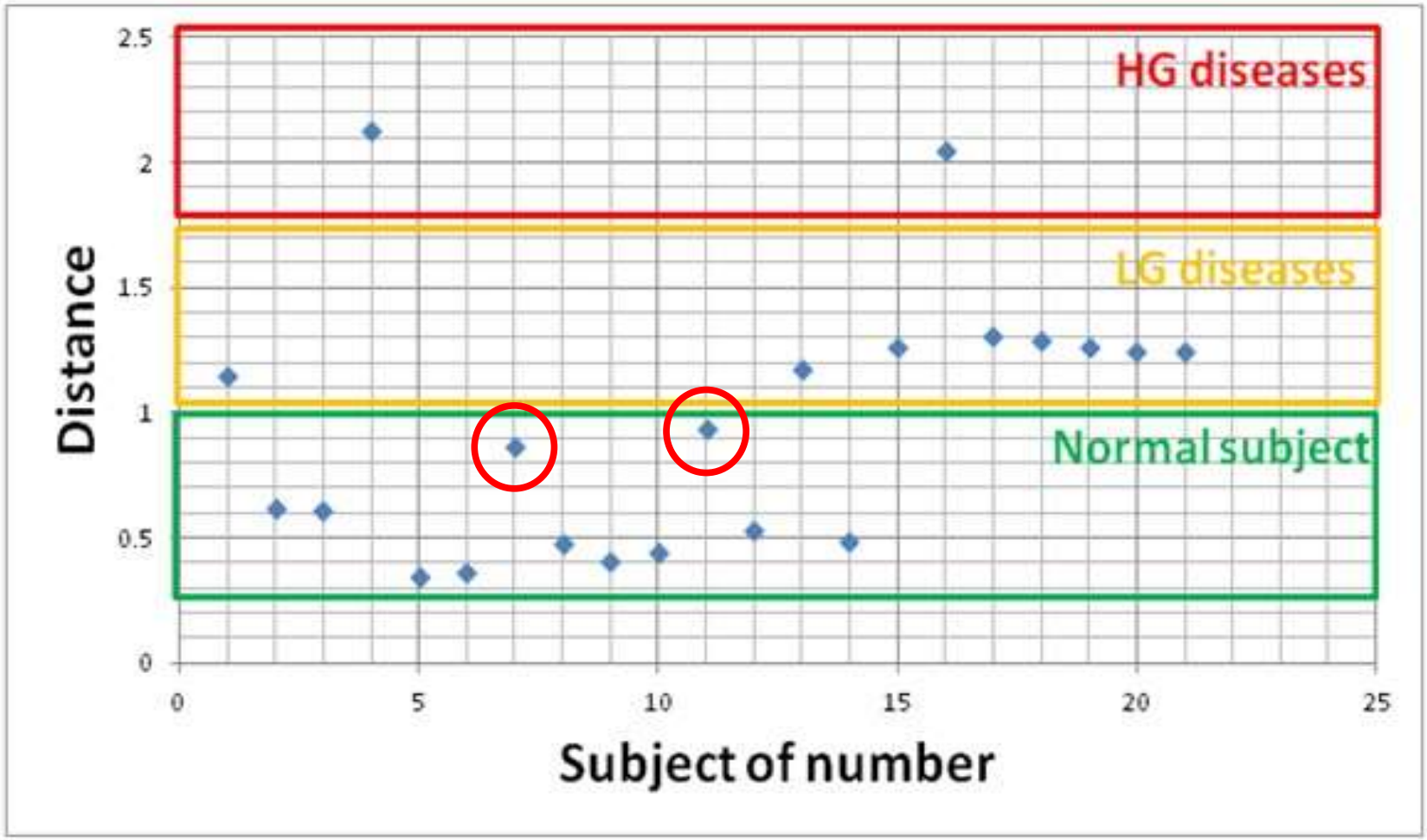
Results of PVD estimation

Subject No.	Mean Values of Bilateral Differences			ABPI R-Leg	ABPI L-Leg	Professional Physicians Decision	Proposed Method Decision
	ΔPTT_f (ms)	ΔPTT_p (ms)	ΔRT (ms)				
1	2.7330	1.9970	3.1330	1.0650			
2	1.1730	5.8700	4.6950	1.1404			
3	2.3330	3.6660	1.3330	1.1440			
4	15.321	17.286	1.9640	1.1788			
5	6.3850	16.923	17.556	1.2735			
6	23.667	33.333	32.833	1.0714			
7	33.072	48.500	15.428	1.0817	0.8941	HG Diabetic	HG Diabetic [0 0 1]
8	23.606	57.700	35.000	1.0442	0.8945	HG Diabetic	HG Diabetic [0 0 1]



The statistical result

- The dynamic error distance for 21 subjects.



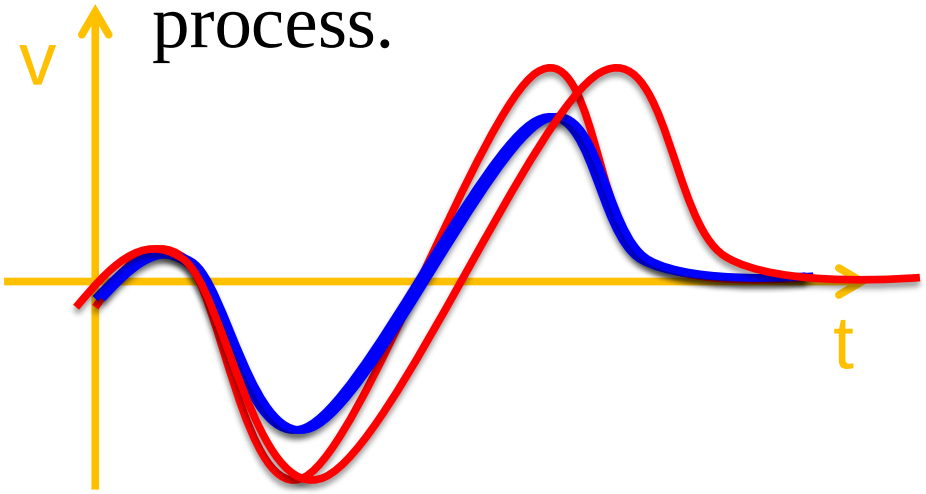
Conclusions

- The PVD measurement system provides high performances and stability for measure the physiological parameters.
- It has the advantages of portability and low-cost for medical diagnosis or healthy home-care system.
- The results indicate that the parameters of e_3 and e_2 are good indexes especially for PVD diagnosis.

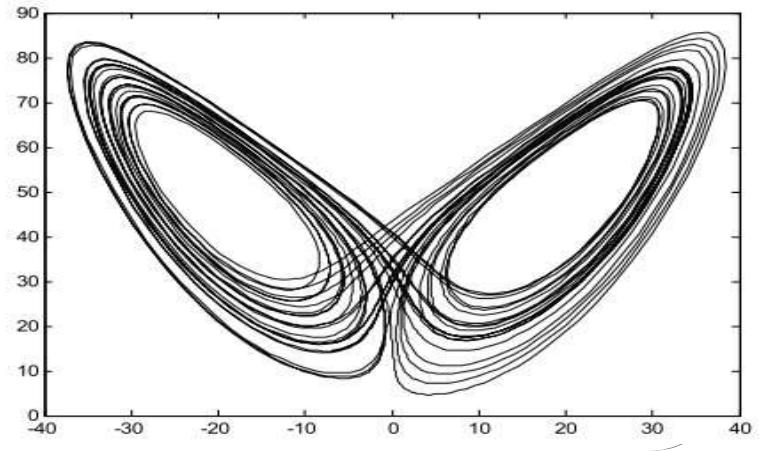
Thank you for your attention!

Chaos synchronization system

- Synchronization of chaos is a phenomenon that may occur when two, or more, dissipative chaotic systems are coupled.
  - **it must be sensitive to initial conditions**
  - **it must be topologically mixing**
  - **its periodic orbits must be dense**
- Communication, adaptive control system, information process.



Lorenz et. al., 1963.

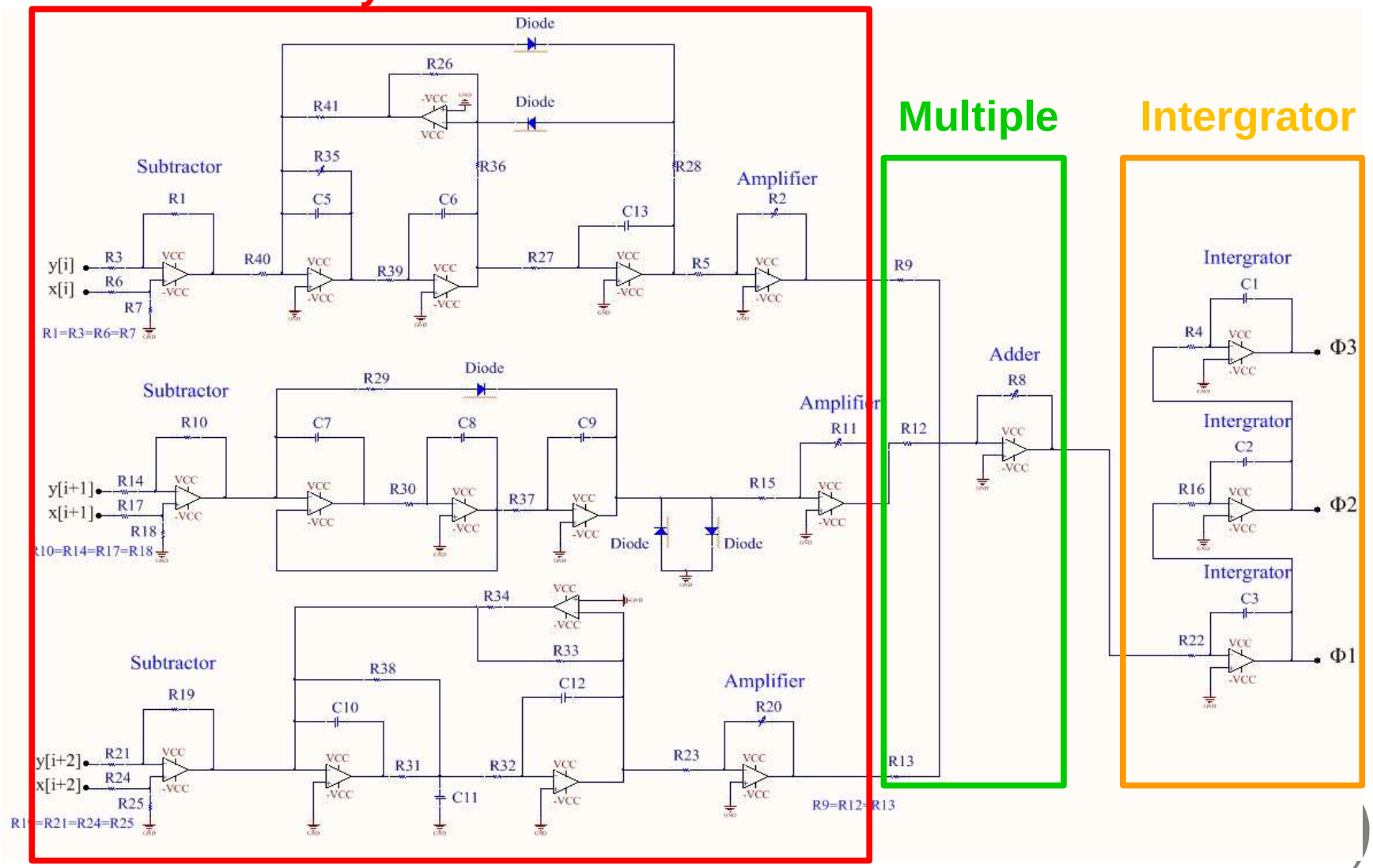


Hardware Implementation

- The idea of synchronizing two identical chaotic systems was first introduced by Carroll and Pecora (1990).

	Advantage	Shortcoming
Operational amplifier (OPA)	● Easy to manufacture ● Flexibility to set ● Low cost	● Discreteness
Field-programmable gate array (FPGA)	● Versatility	● Need an A/DC system ● Complex of structure ● High cost

The Sprott chaos circuit



Acknowledgments

- We would like to thank clinician Dr Chian-Ming Li for providing valuable suggestions and helping with experiments.

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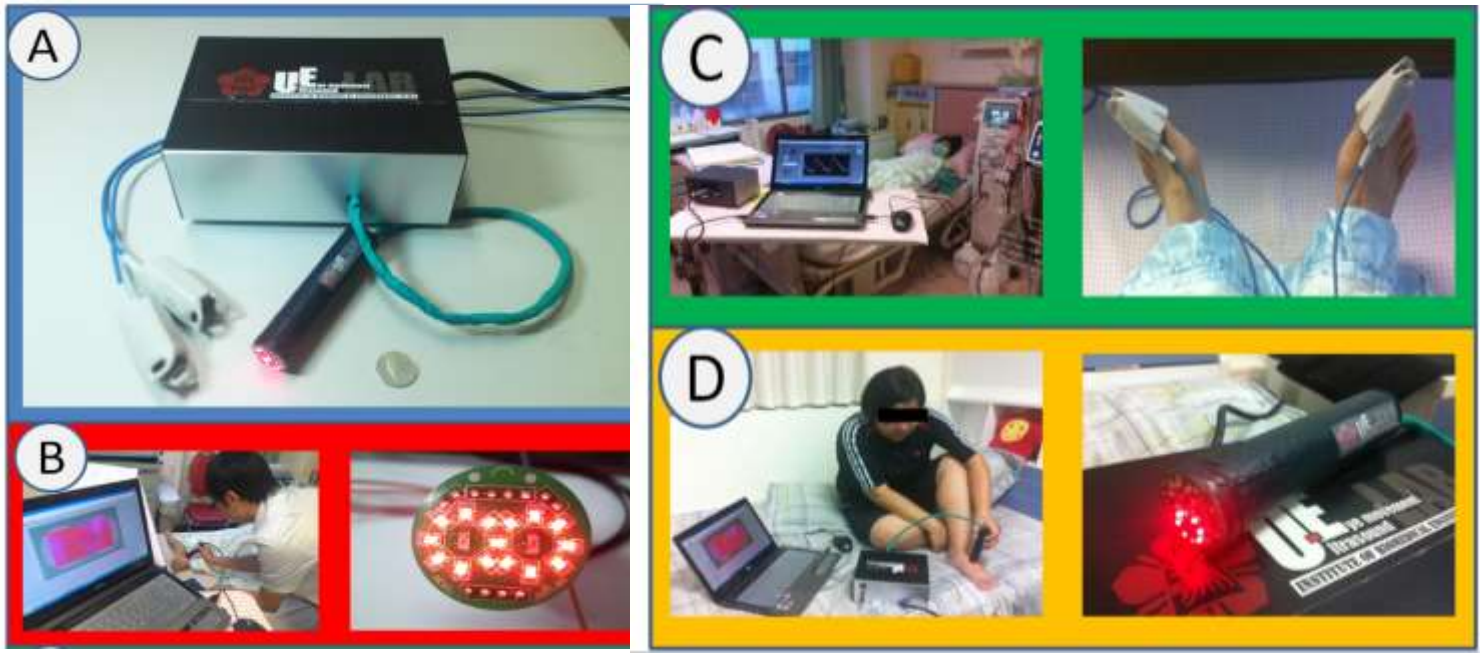
Chi Mei Medical Center



Acknowledgments

- *Software & system development:* (Matlab, FPGA(Verilog) , LabVIEW2015), *DXP*

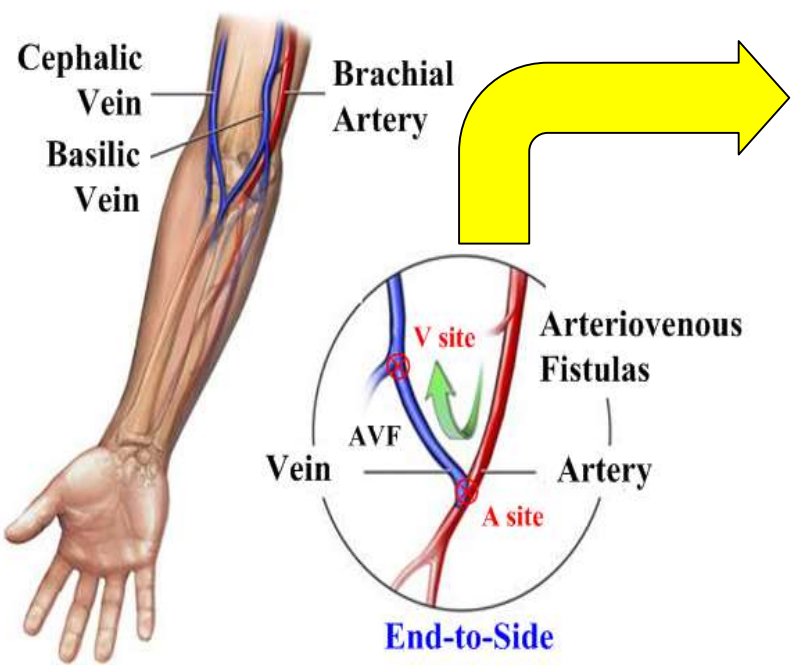
The Institutional Review Board (IRB) of the Kaohsiung Veterans General Hospital, Tainan Branch, under contract number: **VGHKS13-CT12-11**.

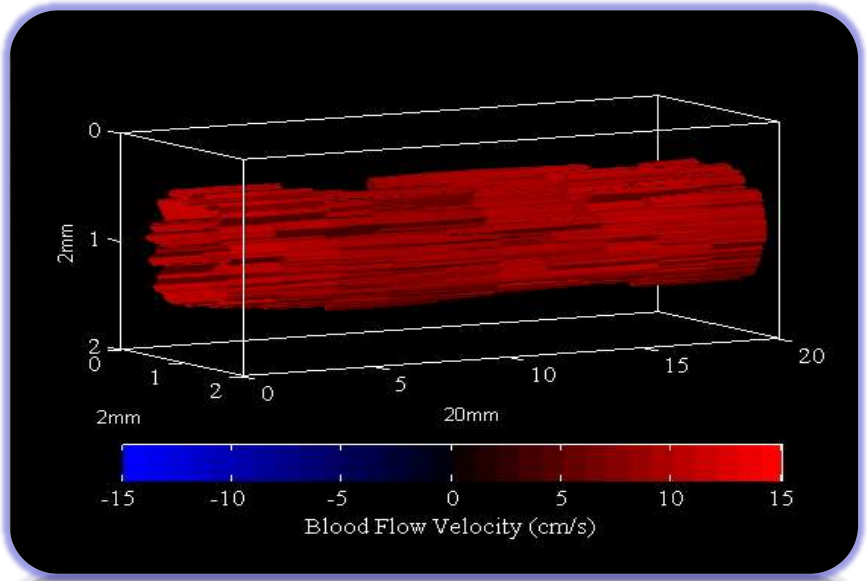
Previous researches(3)

Future works

3D Ultrasonic Imaging System

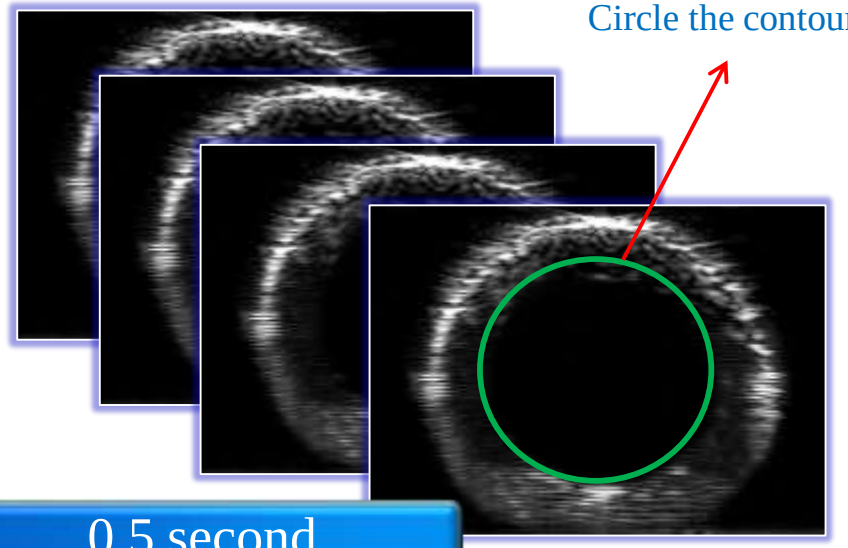
- This study proposes the 3D ultrasound imaging and acoustic Doppler analysis for PVD in arteriovenous fistula based on FPGA.





3D blood flow image

3D Reconstruction(1)



0.5 second

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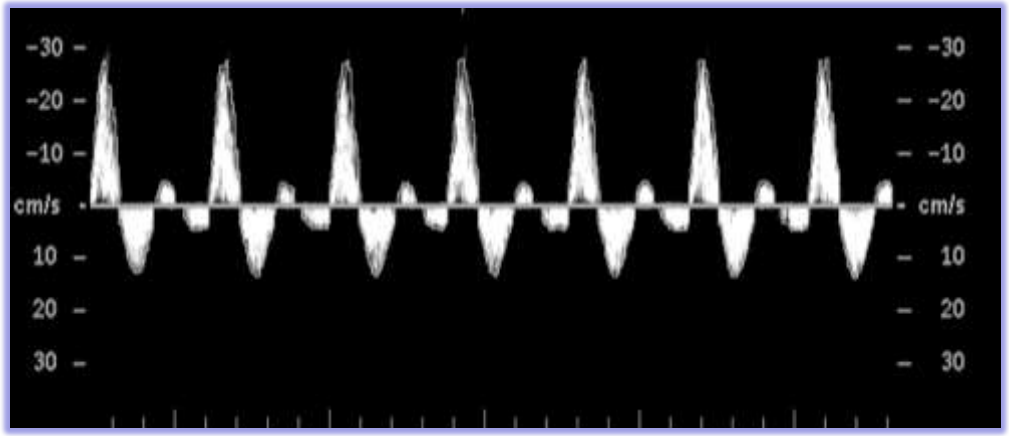

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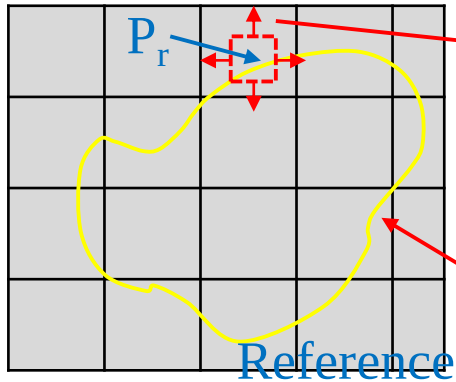
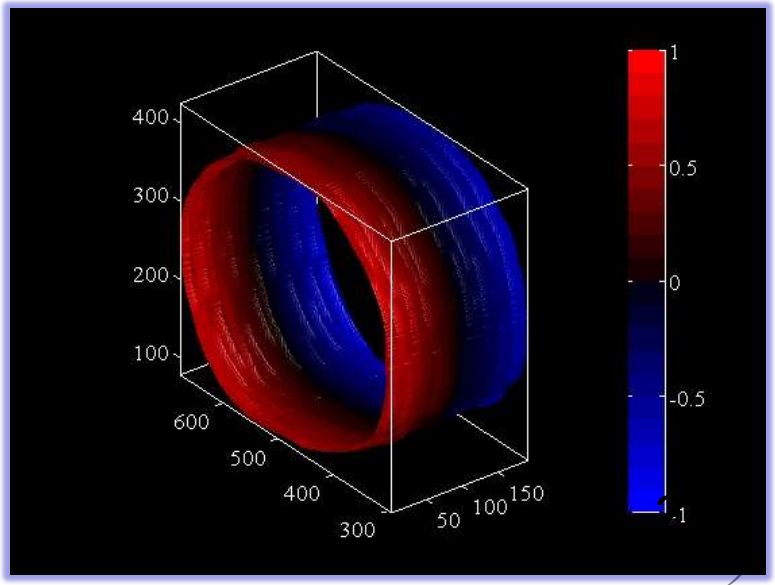


P_1	P_2	P_3
P_4	P_5	P_6
P_7	P_8	P_9

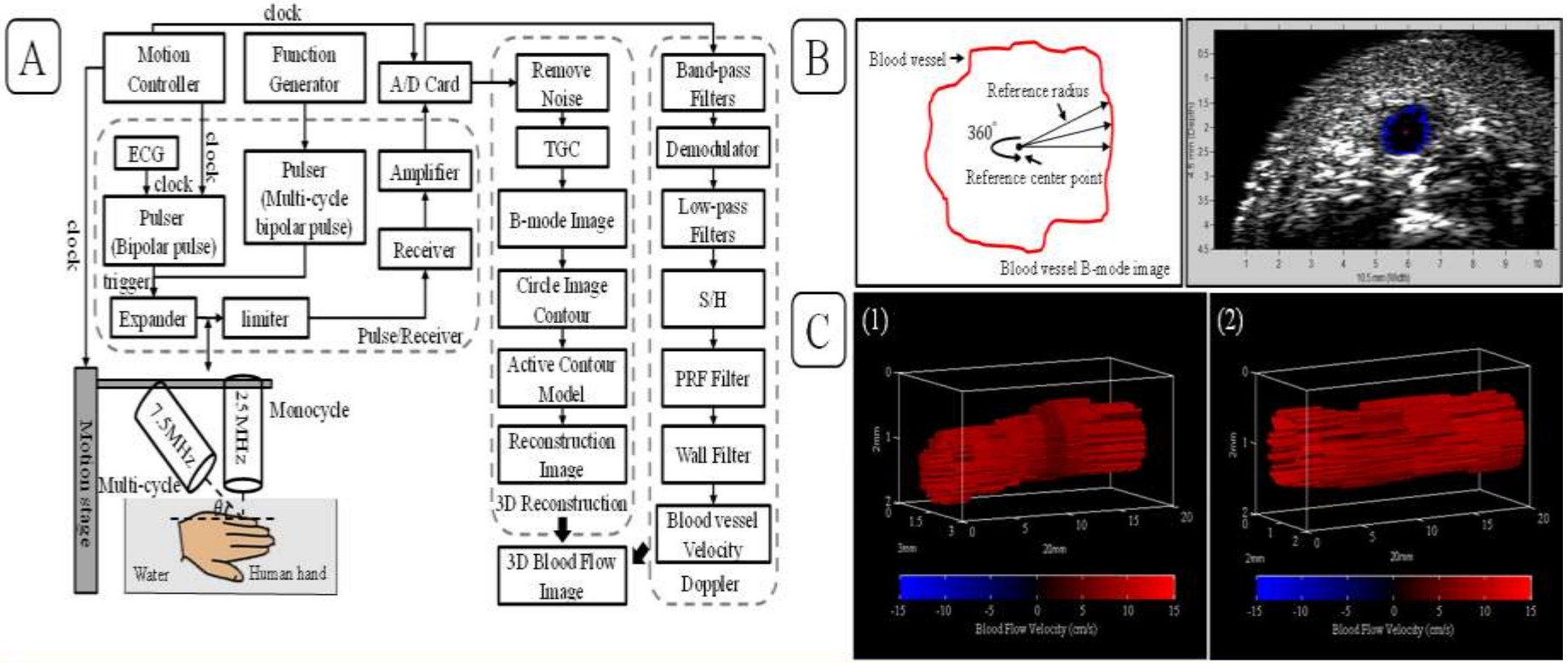
i = 1 ~ 9

Reference Contour

3D Reconstruction



3D Reconstruction(2)



(A)The imaging system block diagram. (B) The method of the circling blood vessel contour and it result. (C) The 3D blood flow image: (1) PAOD patients (2) Normal person.