

Supplementary Material

TABLE S1
Fusion feature set (FS3) based on PPG and PCG

Feature set	Sources of Signal	Feature	Definition
FS3	PPG and PCG	PTT	Pulse transit time
		PWV	Pulse wave velocity
		$T1/(SI+SYS)$	The ratio between $T1$ and $(SI+SYS)$
		$T2/(S2+DIA)$	The ratio between $T2$ and $(S2+DIA)$
		$Area_{(SI+SYS)}$	The PPG's area between SI and SYS
		$Area_{(S2+DIA)}$	The PPG's area between $S2$ and DIA
		$Area_{(SI+SYS)/(S2+DIA)}$	The ratio between $Area_{(SI+SYS)}$ and $Area_{(S2+DIA)}$
		$slpoe_{vl}$	The slope between v and l in PPG
		$slope_{vm}$	The slope between v and m in PPG
		$(T1+T2)/(SI+SYS)$	The ratio between $(T1+T2)$ and $(SI+SYS)$
		$(T1+T2) - (SI+SYS)$	The difference between $(T1+T2)$ and $(SI+SYS)$
		$T3/(S2+DIA)$	The ratio between $T3$ and $(S2+DIA)$
		$T3 - (S2+DIA)$	The difference between $T3$ and $(S2+DIA)$

TABLE S2
PPG VPG and APG feature set (FS1)

Feature set	Sources of Signal	Feature	Definition
FS1	PPG	PPG_SK	The skewness of PPG.
		PPG_KU	The kurtosis of PPG.
		PW_{100}	The pulse width of PPG
		PW_{95}	$0.95 * PW_{100}$
		PW_{95_Area}	The PPG's area of PW_{95}
		PW_{95_SK}	The PPG's skewness of PW_{95}
		PW_{95_KU}	The PPG's kurtosis of PW_{95}
		PW_{90}	$0.90 * PW_{100}$
		PW_{90_Area}	The PPG's area of PW_{90}
		PW_{90_SK}	The PPG's skewness of PW_{90}
		PW_{90_KU}	The PPG's kurtosis of PW_{90}
		PW_{85}	$0.85 * PW_{100}$
		PW_{85_Area}	The PPG's area of PW_{85}
		PW_{85_SK}	The PPG's skewness of PW_{85}
		PW_{85_KU}	The PPG's kurtosis of PW_{85}
		PW_{80}	$0.80 * PW_{100}$
		PW_{80_Area}	The PPG's area of PW_{80}
		PW_{80_SK}	The PPG's skewness of PW_{80}
		PW_{80_KU}	The PPG's kurtosis of PW_{80}
		PW_{75}	$0.75 * PW_{100}$
		PW_{75_Area}	The PPG's area of PW_{75}
		PW_{75_SK}	The PPG's skewness of PW_{75}
		PW_{75_KU}	The PPG's kurtosis of PW_{75}
		PW_{70}	$0.70 * PW_{100}$
		PW_{70_Area}	The PPG's area of PW_{70}
		PW_{70_SK}	The PPG's skewness of PW_{70}
		PW_{70_KU}	The PPG's kurtosis of PW_{70}
		PW_{65}	$0.65 * PW_{100}$
		PW_{65_Area}	The PPG's area of PW_{65}
		PW_{65_SK}	The PPG's skewness of PW_{65}
		PW_{65_KU}	The PPG's kurtosis of PW_{65}
		PW_{60}	$0.60 * PW_{100}$
		PW_{60_Area}	The PPG's area of PW_{60}

PW_{60_SK}	The PPG's skewness of PW_{60}
PW_{60_KU}	The PPG's kurtosis of PW_{60}
PW_{55}	$0.55 * PW_{100}$
PW_{55_Area}	The PPG's area of PW_{55}
PW_{55_SK}	The PPG's skewness of PW_{55}
PW_{55_KU}	The PPG's kurtosis of PW_{55}
PW_{50}	$0.50 * PW_{100}$
PW_{50_Area}	The PPG's area of PW_{50}
PW_{50_SK}	The PPG's skewness of PW_{50}
PW_{50_KU}	The PPG's kurtosis of PW_{50}
PW_{45}	$0.45 * PW_{100}$
PW_{45_Area}	The PPG's area of PW_{45}
PW_{45_SK}	The PPG's skewness of PW_{45}
PW_{45_KU}	The PPG's kurtosis of PW_{45}
PW_{40}	$0.40 * PW_{100}$
PW_{40_Area}	The PPG's area of PW_{40}
PW_{40_SK}	The PPG's skewness of PW_{40}
PW_{40_KU}	The PPG's kurtosis of PW_{40}
PW_{35}	$0.35 * PW_{100}$
PW_{35_Area}	The PPG's area of PW_{35}
PW_{35_SK}	The PPG's skewness of PW_{35}
PW_{35_KU}	The PPG's kurtosis of PW_{35}
PW_{30}	$0.30 * PW_{100}$
PW_{30_Area}	The PPG's area of PW_{30}
PW_{30_SK}	The PPG's skewness of PW_{30}
PW_{30_KU}	The PPG's kurtosis of PW_{30}
PW_{25}	$0.25 * PW_{100}$
PW_{25_Area}	The PPG's area of PW_{25}
PW_{25_SK}	The PPG's skewness of PW_{25}
PW_{25_KU}	The PPG's kurtosis of PW_{25}
H_1	The amplitude between v and g
H_2	The amplitude of PPG.
$H_{1/2}$	The ratio between H_1 and H_2
A_v	The minimum amplitude of PPG
$T1+T2$	The time delay between v and h
$T1$	The time delay between v and g
$T3$	The time delay between h and v'
$(T1+T2) / T3$	The ratio between $(T1+T2)$ and $T3$
$T1 / T3$	The ratio between $T1$ and $T3$
$T1 / (T1+T2+T3)$	The ratio between $T1$ and $(T1+T2+T3)$
$T3 / (T1+T2+T3)$	The ratio between $T3$ and $(T1+T2+T3)$
PIR	Photoplethysmogram intensity ratio
A_i	The amplitude between v and i
$Area$	The area of PPG
$Area_{vh}$	The area between v and h
$Area_{hv'}$	The area between h and v'
$Area_{vh/hv'}$	The ratio between $Area_{vh}$ and $Area_{hv'}$
$Area_{vg}$	The area between v and g
$Area_{vg/vv'}$	The ratio between $Area_{vg}$ and $Area_{vv'}$
$Area_{gv'}$	The PPG's area between g and v'
$Area_{vg/gv'}$	The ratio between $Area_{vg}$ and $Area_{gv'}$
$slope_{vg}$	The slope between v and g
$slope_{vh}$	The slope between v and h
$slope_{hv'}$	The slope between h and v'
$slope_{vg/vh}$	The ratio between $slope_{vg}$ and $slope_{vh}$
$slope_{vg/hv'}$	The ratio between $slope_{vg}$ and $slope_{hv'}$
$slope_{vh/hv'}$	The ratio between $slope_{vh}$ and $slope_{hv'}$
$F1_{PPG}$	The first constituent frequency of PPG

	$F2_{PPG}$	The second constituent frequency of PPG
	$F3_{PPG}$	The third constituent frequency of PPG
	A_F1_{PPG}	The first constituent frequency amplitude of PPG
	A_F2_{PPG}	The second constituent frequency amplitude of PPG
	A_F3_{PPG}	The third constituent frequency amplitude of PPG
	$Area_F1_{PPG}$	The first constituent frequency area of PPG
	$Area_F2_{PPG}$	The second constituent frequency area of PPG
	$Area_F3_{PPG}$	The third constituent frequency area of PPG
VPG	VPG_SK	The skewness of VPG.
	VPG_SK_{hi}	The VPG's skewness between h and i
	VPG_SK_{gh}	The VPG's skewness between g and h
	VPG_SK_{fg}	The VPG's skewness between f and g
	VPG_KU	The kurtosis of VPG
	VPG_KU_{hi}	The VPG's kurtosis between h and i .
	VPG_KU_{gh}	The VPG's kurtosis between g and h .
	VPG_KU_{fg}	The VPG's kurtosis between f and g .
	VPG_A_{gh}	The amplitude of VPG
	VPG_{min}	The minimum amplitude of VPG
	VPG_{min_index}	The index of VPG_{min}
	$VPG_A_{f'}$	The VPG's amplitude in f'
	VPG_A_i	The VPG's amplitude in i
	$VPG_A_{gh/f'}$	The ratio between VPG_A_{gh} and $VPG_A_{f'}$
	A_{hi}	The amplitude between h and i
	T_i	The time delay between f and i
	T_i / PW_{100}	The ratio between T_i and PW_{100}
	$T2$	The time delay between g and h
	$T2 / PW_{100}$	The ratio between $T2$ and PW_{100}
	$T4$	The time delay between h and i
	$T2+T4$	The sum between $T2$ and $T4$
	$T3-T4$	The difference between $T3$ and $T4$
	$T4 / PW_{100}$	The ratio between $T4$ and PW_{100}
	VPG_Area	The area of VPG.
	$VPG_absArea$	The absolute area of VPG
	$VPG_absArea / PW_{100}$	The ratio between $VPG_absArea$ and PW_{100}
	VPG_Area_{fg}	The VPG's area between f and g
	$VPG_Area_{gf'}$	The VPG's area between g and f'
	$VPG_absArea_{gf'}$	The VPG's absolute area between g and f'
	$VPG_Area_{fg/gf'}$	The ratio between VPG_Area_{fg} and $VPG_Area_{gf'}$
	$VPG_Area_{fg} / Area_{vh}$	The ratio between VPG_Area_{fg} and $Area_{vh}$
	$VPG_Area_{fg} / Area_{vg}$	The ratio between VPG_Area_{fg} and $Area_{vg}$
	$VPG_Area_{fg}/VPG_absArea$	The ratio between VPG_Area_{fg} and $VPG_absArea$
	VPG_Area_{fh}	The VPG's area between f and h
	VPG_Area_{gh} / VPG_Area	The ratio between VPG_Area_{gh} and VPG_Area
	$VPG_Area_{fg/gh}$	The ratio between VPG_Area_{fg} and VPG_Area_{gh}
	$VPG_absArea_{gf'} / VPG_Area_{fg}$	The ratio between $VPG_absArea_{gf'}$ and VPG_Area_{fg}
	VPG_Area_{hi}	The VPG's area between h and i
	VPG_Area_{gi}	The VPG's area between g and i
	$VPG_Area_{hi/gh}$	The ratio between VPG_Area_{hi} and VPG_Area_{gh}
	$VPG_Area_{if'}$	The VPG's area between i and f'
	$VPG_Area_{fh/if'}$	The ratio between VPG_Area_{fh} and $VPG_Area_{if'}$
	$VPG_Area_{gf' / if'}$	The ratio between $VPG_Area_{gf'}$ and $VPG_Area_{if'}$
	$VPG_Area_{fg/if'}$	The ratio between VPG_Area_{fg} and $VPG_Area_{if'}$
	$VPG_Area_{gh/if'}$	The ratio between VPG_Area_{gh} and $VPG_Area_{if'}$
	$VPG_Area / VPG_Area_{if'}$	The ratio between VPG_Area and $VPG_Area_{if'}$
	VPG_slope_{gi}	The VPG's slope between g and i

	<i>VPG_slpoe_{gh}</i>	The VPG's slope between <i>g</i> and <i>h</i>
	<i>VPG_slpoe_{gi}</i>	The VPG's slope between <i>g</i> and <i>i</i>
	<i>F1_{VPG}</i>	The first constituent frequency of VPG
	<i>F2_{VPG}</i>	The second constituent frequency of VPG
	<i>F3_{VPG}</i>	The third constituent frequency of VPG
	<i>A_F1_{VPG}</i>	The first constituent frequency amplitude of VPG
	<i>A_F2_{VPG}</i>	The second constituent frequency amplitude of VPG
	<i>A_F3_{VPG}</i>	The third constituent frequency amplitude of VPG
	<i>Area_F1_{VPG}</i>	The first constituent frequency area of VPG
	<i>Area_F2_{VPG}</i>	The second constituent frequency area of VPG
	<i>Area_F3_{VPG}</i>	The third constituent frequency area of VPG
	<i>APG_SK</i>	The skewness of APG.
	<i>APG_SK_{ab}</i>	The APG's skewness between <i>a</i> and <i>b</i>
	<i>APG_SK_{ag}</i>	The APG's skewness between <i>a</i> and <i>g</i>
	<i>APG_SK_{aj}</i>	The APG's skewness between <i>a</i> and <i>j</i>
	<i>APG_SK_{gj}</i>	The APG's skewness between <i>g</i> and <i>j</i>
	<i>APG_SK_{gk'}</i>	The APG's skewness between <i>g</i> and <i>k'</i>
	<i>APG_KU</i>	The kurtosis of APG.
	<i>APG_KU_{ab}</i>	The APG's kurtosis between <i>a</i> and <i>b</i>
	<i>APG_KU_{ag}</i>	The APG's kurtosis between <i>a</i> and <i>g</i>
	<i>APG_KU_{aj}</i>	The APG's kurtosis between <i>a</i> and <i>j</i>
	<i>APG_KU_{gj}</i>	The APG's kurtosis between <i>g</i> and <i>j</i>
	<i>APG_KU_{gk'}</i>	The APG's kurtosis between <i>g</i> and <i>k'</i>
	<i>APG_A_a</i>	The amplitude of APG
	<i>APG_A_b</i>	The amplitude of <i>b</i>
	<i>APG_A_{ab}</i>	The ratio between <i>APG_A_a</i> and <i>APG_A_b</i>
	<i>APG_A_j</i>	The amplitude of <i>j</i>
	<i>APG_A_{k'}</i>	The amplitude of <i>k'</i>
	<i>APG_T_a</i>	The time delay of <i>a</i>
	<i>APG_T_a / PW₁₀₀</i>	The ratio between <i>APG_T_a</i> and <i>PW₁₀₀</i>
	<i>APG_T_b</i>	The time delay of <i>b</i>
	<i>APG_T_b / PW₁₀₀</i>	The ratio between <i>APG_T_b</i> and <i>PW₁₀₀</i>
	<i>APG_T_{ab}</i>	The time delay between <i>a</i> and <i>b</i>
	<i>APG_T_{ab} / PW₁₀₀</i>	The ratio between <i>APG_T_{ab}</i> and <i>PW₁₀₀</i>
	<i>APG_Area</i>	The area of APG.
	<i>APG_absArea</i>	The absolute area of APG.
	<i>APG_absArea / PW₁₀₀</i>	The ratio between <i>APG_absArea</i> and <i>PW₁₀₀</i>
	<i>APG_Area_{ag}</i>	The APG's area between <i>a</i> and <i>g</i>
	<i>APG_Area_{ag} / APG_Area</i>	The ratio between <i>APG_Area_{ag}</i> and <i>APG_Area</i>
	<i>APG_Area_{ag} / APG_absArea</i>	The ratio between <i>APG_Area_{ag}</i> and <i>APG_absArea</i>
	<i>APG_Area_{gj}</i>	The APG's area between <i>g</i> and <i>j</i>
	<i>APG_absArea_{gj}</i>	The APG's absolute area between <i>g</i> and <i>j</i>
	<i>APG_Area_{ag/gj}</i>	The ratio between <i>APG_Area_{ag}</i> and <i>APG_Area_{gj}</i>
	<i>Area_APG_ag / APG_absArea_{gj}</i>	The ratio between <i>Area_APG_ag</i> and <i>APG_absArea_{gj}</i>
	<i>F1_{APG}</i>	The first constituent frequency of APG
	<i>F2_{APG}</i>	The second constituent frequency of APG
	<i>F3_{APG}</i>	The third constituent frequency of APG
	<i>A_F1_{APG}</i>	The first constituent frequency amplitude of APG
	<i>A_F2_{APG}</i>	The second constituent frequency amplitude of APG
	<i>A_F3_{APG}</i>	The third constituent frequency amplitude of APG
	<i>Area_F1_{APG}</i>	The first constituent frequency area of APG
	<i>Area_F2_{APG}</i>	The second constituent frequency area of APG
	<i>Area_F3_{APG}</i>	The third constituent frequency area of APG

TABLE S3
PCG feature set (FS2)

Feature set	Sources of Signal	Feature	Definition
FS2	PCG	<i>m_S1</i>	The mean value of the first heart sound.
		<i>sd_S1</i>	The standard deviation of the first heart sound.
		<i>m_S1_SK</i>	The mean value of the first heart sound skewness.
		<i>sd_S1_SK</i>	The standard deviation of the first heart sound skewness.
		<i>m_S1_KU</i>	The mean value of the first heart sound kurtosis.
		<i>sd_S1_KU</i>	The standard deviation of the first heart sound kurtosis.
		<i>m_SYS</i>	The mean systolic period of the heart sound.
		<i>sd_SYS</i>	The standard deviation systolic period of the heart sound.
		<i>m_SYS_SK</i>	The mean systolic period skewness of heart sound.
		<i>sd_SYS_SK</i>	The standard deviation systolic period skewness of heart sound.
		<i>m_SYS_KU</i>	The mean systolic period kurtosis of the heart sound.
		<i>sd_SYS_KU</i>	The standard deviation systolic period kurtosis of the heart sound.
		<i>m_S2</i>	The mean value of the second heart sound.
		<i>sd_S2</i>	The standard deviation of the second heart sound.
		<i>m_S2_SK</i>	The mean value of the second heart sound skewness.
		<i>sd_S2_SK</i>	The standard deviation of the second heart sound skewness.
		<i>m_S2_KU</i>	The mean value of the second heart sound kurtosis.
		<i>sd_S2_KU</i>	The standard deviation of the second heart sound kurtosis.
		<i>m_DIA</i>	The mean diastolic period of the heart sound.
		<i>sd_DIA</i>	The standard deviation diastolic period of the heart sound.
		<i>m_DIA_SK</i>	The mean diastolic period skewness of heart sound.
		<i>sd_DIA_SK</i>	The standard deviation diastolic period skewness of heart sound.
		<i>m_DIA_KU</i>	The mean diastolic period kurtosis of heart sound.
		<i>sd_DIA_KU</i>	The standard deviation diastolic period kurtosis of heart sound.
		<i>M_{SYS/DIA}</i>	The mean value of <i>SYS/DIA</i> .
		<i>SD_{SYS/DIA}</i>	The standard deviation of <i>SYS/DIA</i>
		<i>m_RR</i>	<i>m_S1+m_SYS+m_S2+m_DIA</i>
		<i>sd_RR</i>	The standard deviation of <i>S1+SYS+S2+DIA</i>
		<i>M_{SYS/RR}</i>	The mean value of <i>SYS/RR</i> .
		<i>SD_{SYS/RR}</i>	The standard deviation of <i>SYS/RR</i>
		<i>M_{DIA/RR}</i>	The mean value of <i>DIA/RR</i>
		<i>SD_{DIA/RR}</i>	The standard deviation of <i>DIA/RR</i>
		<i>M_{AMP_SYS+AMP_S1}</i>	The mean amplitude value of <i>S1</i> and <i>SYS</i>
		<i>SD_{AMP_SYS+AMP_S1}</i>	The standard deviation amplitude value of <i>S1</i> and <i>SYS</i>
		<i>M_{AMP_DIA+AMP_S2}</i>	The mean amplitude value of <i>S2</i> and <i>DIA</i>
		<i>SD_{AMP_DIA+AMP_S2}</i>	The standard deviation amplitude value of <i>S2</i> and <i>DIA</i>
		<i>MFCC</i>	The Mel-scale Frequency Cepstral Coefficients of the heart sound
		<i>LPC</i>	The linear predictive coding of the heart sound
		<i>Shannon Entropy</i>	The Shannon entropy of the heart sound
		<i>wavedec</i>	The discrete wavelet transforms coefficients of the heart sound
		<i>SC</i>	The spectral centroid of the heart sound

TABLE S4
Statistical information (FS4) of subjects

Feature set	Sources of Signal	Feature	Definition
FS4	Statistical information	<i>Age</i>	The age of the subjects
		<i>Gender</i>	The gender of the subjects
		<i>Height</i>	The height of the subjects
		<i>Weight</i>	The weight of the subjects
		<i>BMI</i>	The BMI of the subjects

TABLE S5
BP estimation results in different feature sets

Feature Classes	Blood Pressure	BP Estimation Results (Mean \pm SD)	Evaluation of BHS			
			Grade	C.P.5	C.P.10	C.P.15
FS3+FS4	SBP (mmHg)	1.03 \pm 10.74	C	52%	70%	81%
	DBP (mmHg)	1.03 \pm 6.68	B	55%	79%	100%
FS1+FS4	SBP (mmHg)	1.42 \pm 9.01	B	53%	79%	91%
	DBP (mmHg)	0.58 \pm 6.98	B	53%	85%	98%
FS1+FS3+FS4	SBP (mmHg)	1.25 \pm 7.75	B	57%	81%	95%
	DBP (mmHg)	0.47 \pm 5.88	B	58%	92%	100%
FS2+FS4	SBP (mmHg)	0.97 \pm 10.74	C	48%	66%	84%
	DBP (mmHg)	1.21 \pm 8.01	C	48%	75%	93%
FS2+FS3+FS4	SBP (mmHg)	1.34 \pm 10.06	C	47%	75%	84%
	DBP (mmHg)	0.49 \pm 5.91	B	57%	93%	100%
FS1+FS2+FS4	SBP (mmHg)	0.78 \pm 8.46	B	51%	77%	93%
	DBP (mmHg)	0.98 \pm 6.33	B	57%	88%	99%
FS1+FS2+FS3+FS4 (Proposed Method)	SBP (mmHg)	0.33 \pm 7.47	B	67%	85%	93%
	DBP (mmHg)	1.05 \pm 5.72	A	61%	95%	100%

Bolded black lettering represents compliance with AAMI / ISO standards.

FS1 (PPG features), FS2 (PCG features), FS3 (fusion features), and FS4 (personalized features).

TABLE S6
Comparison of different signal feature extraction times and power consumption

Test Signal	System Consume (mW)	Sensor Consume (mW)	Features Time Consume (ms)
ECG	98.952	0.561	0
PPG	107.426	7.920	0.125
ECG+PPG	108.072	8.481	0.125
PCG	99.104	0.693	0.777
ECG+PPG+PCG	108.87	9.174	0.916

TABLE S7
Hyperparameter in LightGBM

Estimation Model		LightGBM	
Blood Pressure		SBP	DBP
Hyperparameter	learning_rate	0.1	0.1
	n_estimator	100	100
	max_depth	12	10
	num_leaves	17	18
	min_child_weight	0.001	0.001
	min_child_samples	21	10
	feature_fraction(colsample_bytree)	0.8	0.8
	bagging_fraction	0.6	0.6
	reg_alpha	0.08	0.001
	reg_lambda	0.01	0.001
BP Estimation error	ME \pm SD (mmHg)	0.33 \pm 7.47	1.05 \pm 5.72