Monitor digit Recognition

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1. Introduction

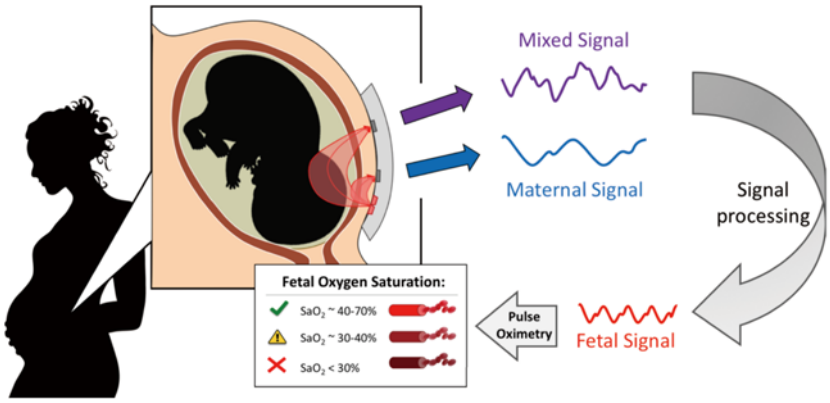
1.1 What is Transabdominal Fetal Oximetry?

Transabdominal fetal pulse oximetry (TFO) is a non-invasive technique to estimate the fetal arterial oxygen saturation (SaO2). We are developing a Non-invasive, Transabdominal Fetal Oximetry system to provide worried mothers and obstetrician's with needed information regarding fetal well-being during late-stage pregnancy/active labor.

1.2 How does it work?

This is performed by shining light into the maternal abdomen using a reflectance-based optode at the skin surface near the fetus and measuring the diffuse reflectance a few centimeters away. Slight modulation in the diffuse reflectance is caused by the expansion of vascular tissue with each ventricular contraction, and can be inspected to extrapolate and identify a photo-plethysmograph signal (PPG) belonging to the fetus and mother, which can be used to estimate arterial oxygen saturation.

Fig.1 Transabdominal Fetal Oximetry



1.3 Evaluation method

Generally, reference signals are required to evaluate the results. Therefore, during the experiment, we apply several medical monitors to record the physiology activities of the fetus and the mother, whose outputs are used reference signals.

1.4 Issues with evaluations

Unfortunately, the monitors provided by the clinic can only display the outputs on the screens and cannot store the data. To solve this issue, we set up a high-resolution camera to record a video of the monitors' screens (fig.2). Then we adopt the method of image processing and printing digit recognition to read out signals from the videos.

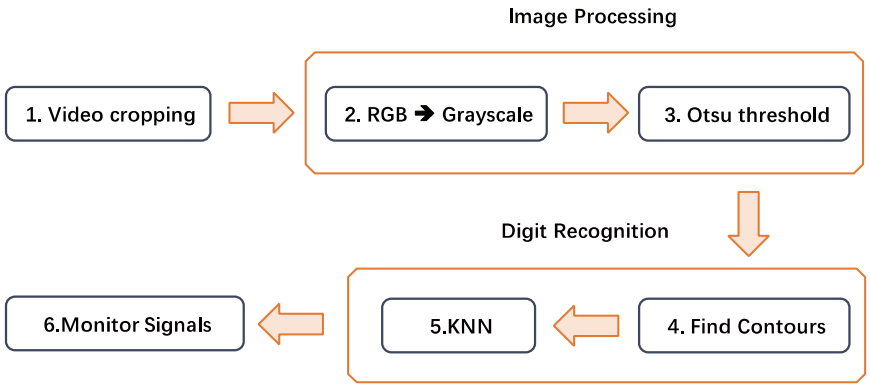
*Fig.2 A screenshot of one of the recorded videos (1920*1080)*

2. Approach

2.1 Recognition Pipeline

1. Crop the long videos down and focus the window on each number.
2. Down-sample the video from 30 frame/sec to 3 frame/sec to downsize the file.
3. Take one frame each time and convert it from RGB to Grayscale format.
4. Apply Otsu's method and convert the image into binary format.
5. Find the contours of digits by using FindContour(), a function provided by OpenCV.
6. Apply K-Nearest Neighbor (KNN) Algorithm to train the model.
7. Use the trained model to recognize digits and extract monitors' signals.

Fig.3 Pipeline



2.2 Possible improvement points:

1. resolution/quality improvement of cropped videos.
2. more robust recognition network based on pretrained models
3. more automatic method of fixing down the digits' locations.

3. Result

3.1 Evaluation method

After using the extracted contours and KNN algorithm to train the model, we test the model on images directly from the videos and the result is good enough. Then we run the model on videoes. Since the length of videos is from 25 minutes to more than 1 hour, it would be painful to label all the frames of the videos. Therefore, we have to run the model under an unsupervised manner and evaluate the results in other ways. Here are two methods.

3.1.1 Method 1: Random selection

Randomly select about 100 images over the span of the video. Then compare selected pictures with corresponding predicted digits, and obtain accuracy rates (fig.4). Then repeat this process of random selection and comparison multiple times to ensure the validity.

Fig.4 Method 1 on video 13. Note that for now the maternal indexes are not readable.

Physiological index	Accuracy rate
Temperature	100% (94/94)
Fetal SpO2 (Oxygen Saturation)	100% (91/91)
Pulse/Heartrate	100% (92/92)
ART_mean (mean arterial BP)	100% (96/96)
ABP_mean (mean arterial BP)	98.9% (93/94)
ART_low (diastolic arterial BP)	100% (93/93)
ART_high (systolic arterial BP)	100% (93/93)
ABP_low (diastolic arterial BP)	100% (97/97)
ABP_high (systolic arterial BP)	98.8% (85/86)
Maternal SpO2	-
Maternal HR (heartrate)	-

3.1.2 Method 2: Signal Figures

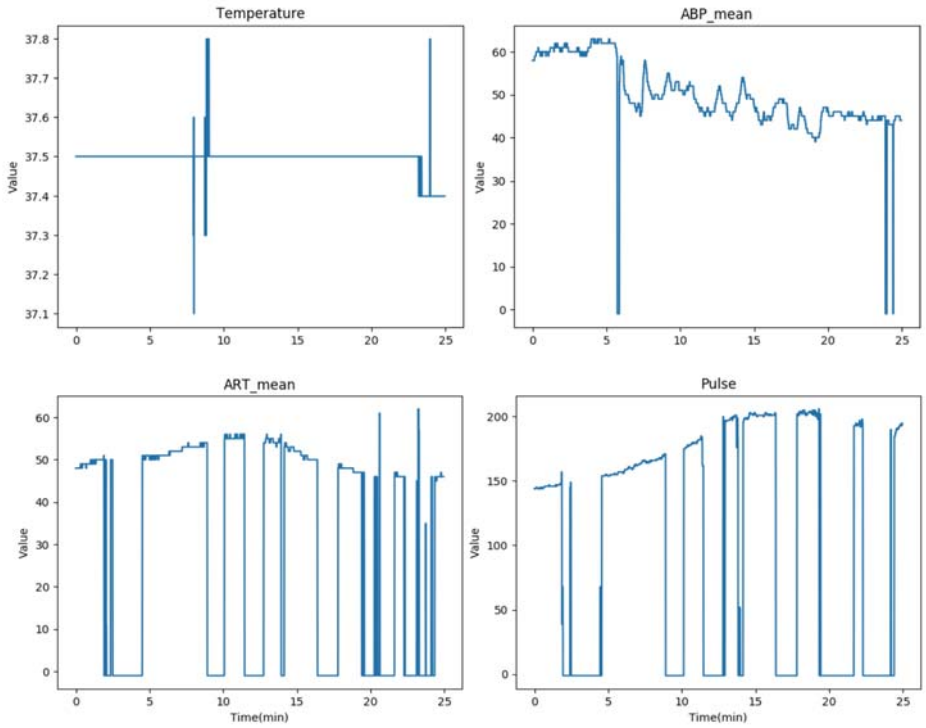
Though method 1 is relatively accurate for comparing the labels and predicted digits side by side, the number of select samples is limited and cannot fully represent overall outcomes of digit recognition. Therefore, we propose to draw out the signals (fig.5), and visually compare the figures with the video to check if there is any mistake to improve our model.

3.2 Evaluation Results

I mainly adopt method 2 to evaluate the results of sheep 3. Most of extracted fetus signals are pretty good, while maternal signals are not really readable for now.

The results are presented in **Evaluation sheet** in the next page.

Fig.5 Above are some results, including temperature, mean arterial BP and pulse. Note that abnormal jumps to -1 are invalid digits due to blank space or question marks on the monitors.



Evaluation sheet

Object: Sheep 3, 4 long videos (25min-1h)

Phase & Name:

Original video name	phase	Cropped video/folder name	timestamp
20190614_104233	1	3_10_1	00:12 - 04:34
	2	3_10_2	05:00 – 08:05
	3	3_10_3	09:00 – 40:26
	4	3_10_4	41:00 – 48:50
20190614_113747	1	3_11_1	00:00 – 06:45
	2	3_11_2	07:00 – 1:00:00
20190614_123750	1	3_12_1	00:00 – 01:40
	2	3_12_2	02:00 – 09:35
	3	3_12_3	10:00 – 10:44
	4	3_12_4	11:05 – 23:30
	5	3_12_5	24:35 – 39:05
20190614_131920	1	3_13	00:10 – 25:06

Video log

```
Long video segmentation
\ten
F1: 00:12 - 04:34 camera shake 01:30
F2: 05:00 - 08:05 camera shake 07:00
F3: 09:00 - 40:26
    camera shake  10:00/33:00
    hands block 15:00/23:00/30:00/38:30
F4: 41:00 - 48:50
    hands block 44:00 - 45:00

\eleven
F1: 00:00 - 06:45
    camera shake around 00:30
    04:20 left monitor turned

F2: 07:00 - 1h(left shift 3-4pixels)
    camera down shift around 09:30
    hands block 17:40/19:10/28:07
    25:00 left monitor turned back(different location)

\twelve
F1: 00:00 - 01:40
F2: 02:00 - 09:35
F3: 10:00 - 10:44

F4: 11:05 - 23:30

F5: 24:35 - 39:05
    camera shake 35:15/37:20/38:15

\thirteen
F1: 00:10 -
    head block 07:40/08:50/09:00-09:10
    hands block 22:20
```

Individual Evaluation

Conclusion:

1) Results of *temperature, pulse, ABP and fetal SpO2* are generally favorable.
2) Results of *ART* are usually messy and requires a lot of ***manual finetune.***
3) Results of *maternal SpO2* are bad.
4) Results of *ABS* are good enough, except for ***10_3, 11_1, 11_2. 12_5, 13.***

Note:

1) ***Bad*** results are highlighted in ***red***.
Inadequate results are highlighted in ***yellow***.
Good results are highlighted in ***green***.
Bad and inadequate results need to be improved.

2) ***Notes*** point out some ***abnormal*** signal changes in the results.

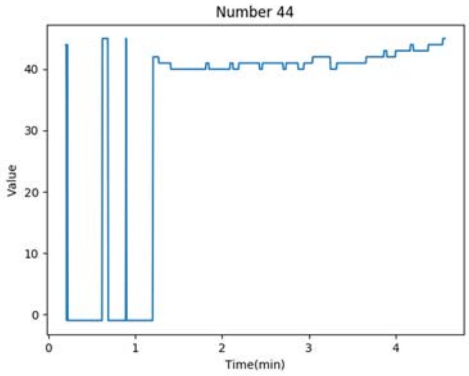
3) all ***temperature*** results need to be divided by 10, to gain the real ones.
For example, our result is 378, but the actual temperature is 37.8.

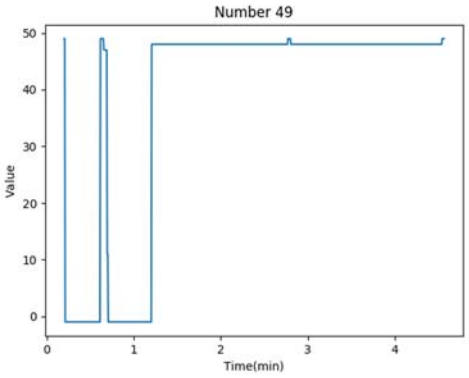
Original Video Name: 20190614_104233

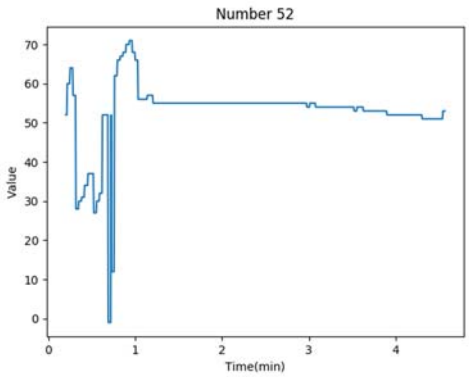
Phase: 1 || Folder name: 3_10_1 || timestamp: 00:12 - 04:34

Index	Video_tag	Notes
Temperature	380	
Pulse	104	
ART_mean	49	Wrongly recognize '1)' as '11' at 00:42
ART_high	52	Invalid: 00:01-00:25, 00:33-00:59 (timestamp is based on individual cropped videos)
ART_low	44	Abnormal signal surge around 01:00
ABP_mean	69	
ABP_high	80	
ABP_low	57	
Fetal SpO2	100	
Maternal SpO2	82	
ABS	101	

Corresponding images of notes



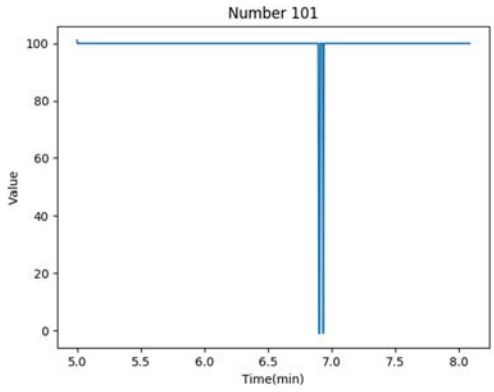




Phase: 2 || Folder name: 3_10_2 || timestamp: 05:00 – 08:05

Index	Video_tag	Evaluations
Temperature	379	
Pulse	180	
ART_mean	49	
ART_high	52	
ART_low	46	
ABP_mean	68	
ABP_high	79	
ABP_low	56	
Fetal SpO2	100	
Maternal SpO2	84	
ABS	101	Abnormal drops to -1 around 07:00

Corresponding images of notes

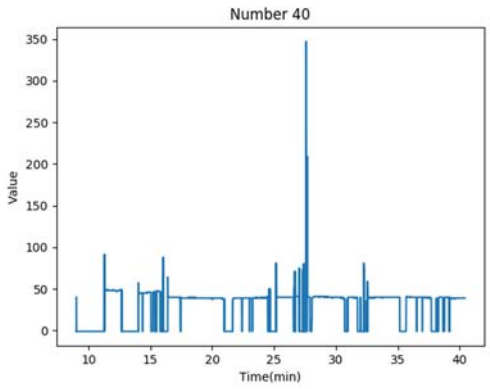


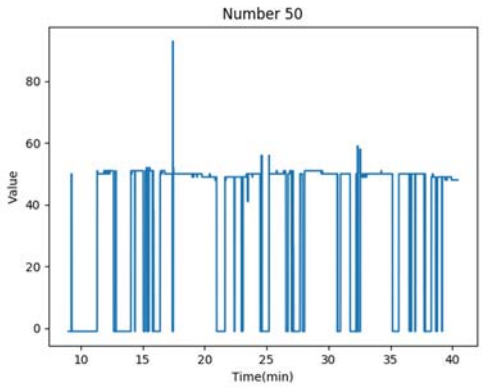
Phase: 3 || Folder name: 3_10_3 || timestamp: 09:00 – 40:26

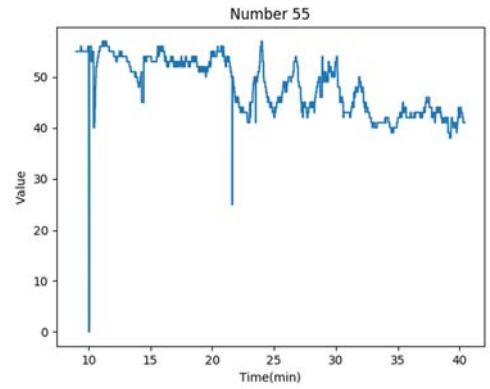
Index	Video_tag	Evaluations
Temperature	379	
Pulse	196	
ART_mean	50	Abnormal surge to 90 around 17:00
ART_high	47	
ART_low	40	Abnormal surge with signal values above 60
ABP_mean	66	
ABP_high	78	
ABP_low	55	sudden drop to 25 around 21:00
Fetal SpO2	100	

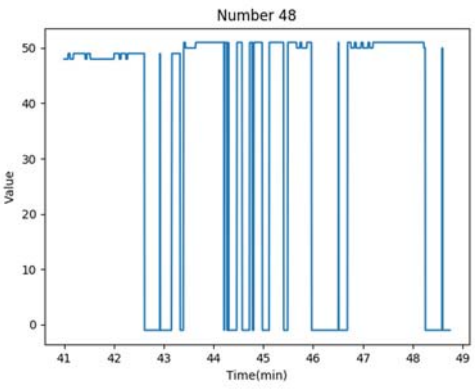
Maternal SpO2	81	
ABS	101	

Corresponding images of notes (Phase 3&4)









Phase: 4 || Folder name: 3_10_4 || timestamp: 41:00 – 48:50

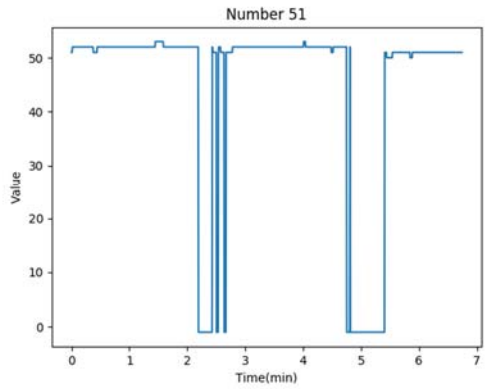
Index	Video_tag	Evaluations
Temperature	378	
Pulse	186	
ART_mean	48	Sudden surge at 42:58 and 46:30
ART_high	59	Invalid: 01:38-02:09, 02:20-02:23, 04:59-05:42, 07:16-07:45 (timestamp is based on individual cropped videos)
ART_low	39	
ABP_mean	42	
ABP_high	44	
ABP_low	40	
Fetal SpO2	100	
Maternal SpO2	79	
ABS	92	

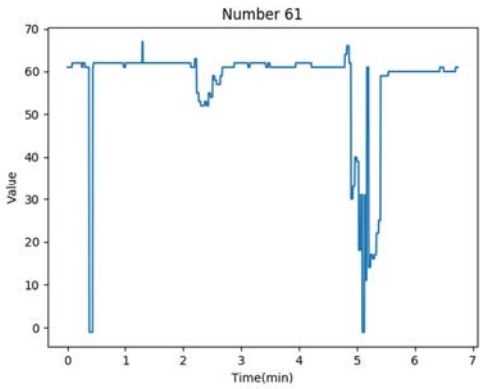
Original Video Name: 20190614_113747

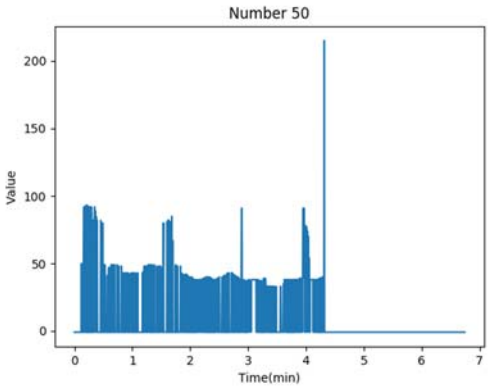
Phase: 1 || Folder name: 3_11_1 || 00:00 – 06:45

Index	Video_tag	Evaluations
Temperature	378	
Pulse	207	
ART_mean	51	Abnormal surge at 04:50
ART_high	61	Wrongly recognize '6)' as '61' at 05:10
ART_low	42	
ABP_mean	34	
ABP_high	36	
ABP_low	33	
Fetal SpO2	100	
Maternal SpO2	72	
ABS	50	A lot of digits are actually predicted correctly, but the overall the signals are messy.

Corresponding images of notes





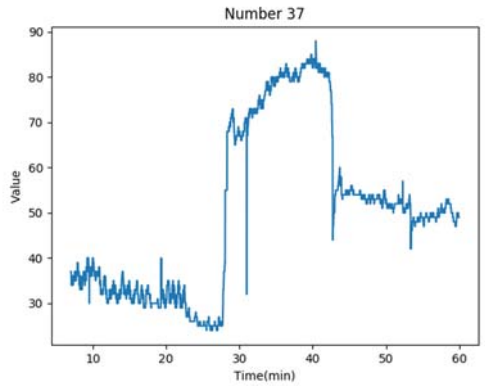


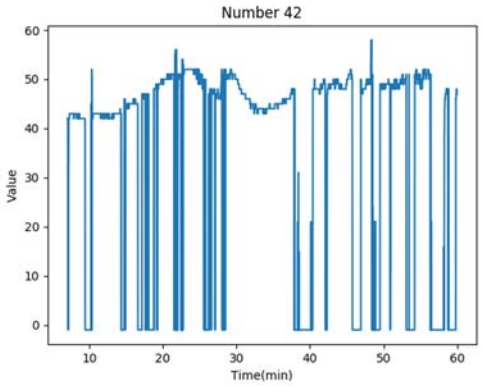
Phase: 2 || Folder name: 3_11_2 || timestamp: 07:00-1:00:00

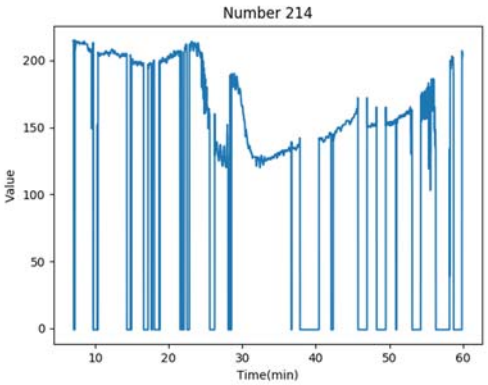
Index	Video_tag	Evaluations
Temperature	378	
Pulse	214	There are a lot of shakings in the signal, but the general values/trend are correct
ART_mean	51	
ART_high	60	
ART_low	42	
ABP_mean	35	
ABP_high	37	Sudden drop around 30:00
ABP_low	34	
Fetal SpO2	99	
Maternal SpO2	71	
ABS	1	

Note: ABS is set to 1 because the monitor was manually turned away and unreadable.

Corresponding images of notes





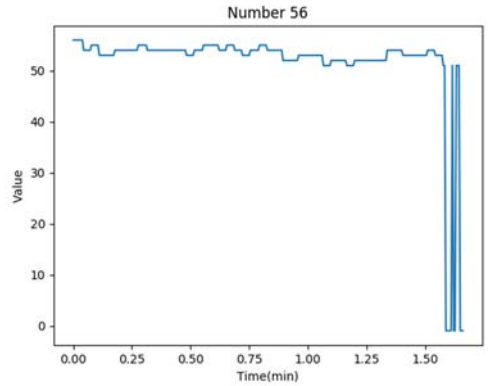


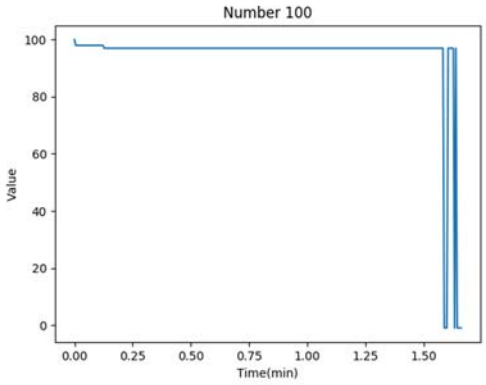
Original Video Name: 20190614_123750

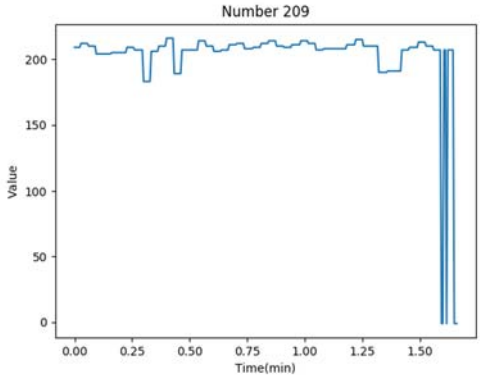
Phase: 1 || Folder name: 3_12_1 || timestamp: 00:00-01:40

Index	Video_tag	Evaluations
Temperature	376	
Pulse	209	Hands interference after 01:35
ART_mean	56	
ART_high	64	
ART_low	49	
ABP_mean	44	
ABP_high	48	
ABP_low	41	
Fetal SpO2	100	Hands interference after 01:35
Maternal SpO2	85	
ABS	102	

Corresponding images of notes



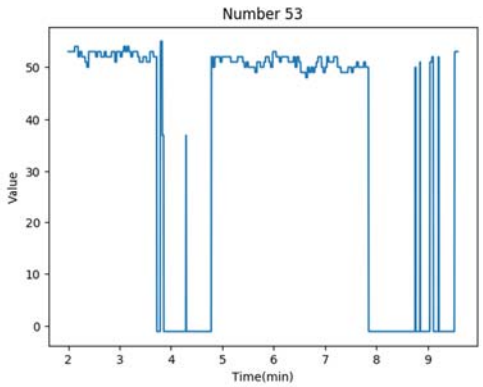


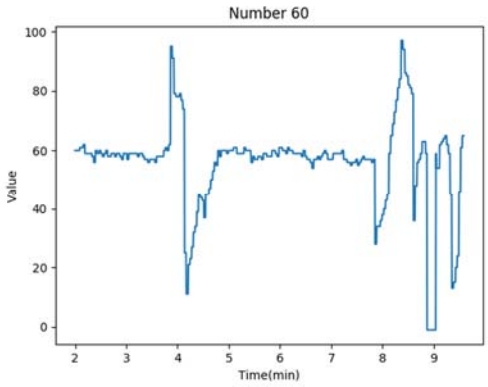


Phase: 2 || Folder name: 3_12_2 || timestamp: 02:00-09:35

Index	Video_tag	Evaluations
Temperature	376	
Pulse	209	
ART_mean	53	Abnormal surges around 04:15 and 09:00
ART_high	60	Invalid: 1:43-2:47, 05:51-07:02 (timestamp is based on individual cropped videos)
ART_low	46	
ABP_mean	47	
ABP_high	50	
ABP_low	42	
Fetal SpO2	100	
Maternal SpO2	79	
ABS	92	

Corresponding images of notes



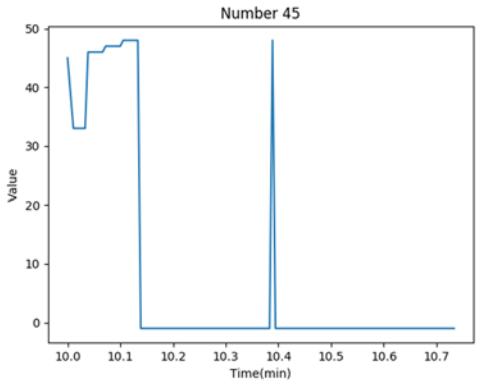


Phase: 3 || Folder name: 3_12_3 || timestamp: 10:00-10:44

Index	Video_tag	Evaluations
Temperature	376	
Pulse	220	
ART_mean	45	Sudden surge at 10:24
ART_high	53	
ART_low	13	
ABP_mean	43	
ABP_high	46	
ABP_low	39	
Fetal SpO2	100	

Maternal SpO2	74	
ABS	93	

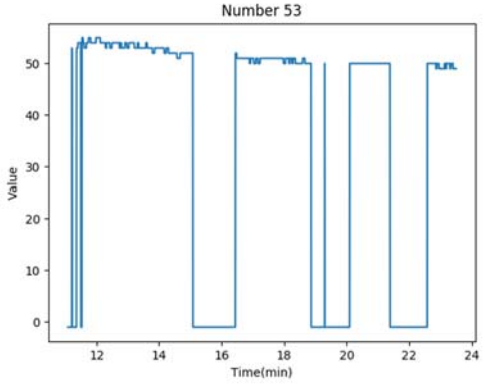
Corresponding images of notes



Phase: 4 || Folder name: 3_12_4 || timestamp: 11:05-23:30

Index	Video_tag	Evaluations
Temperature	376	
Pulse	210	
ART_mean	53	Abnormal surge around 19:10
ART_high	21	Invalid: 00:00-00:16/ 04:00-05:21/ 07:48-09:00/ 10:18-11:30 (timestamp is based on individual cropped videos)
ART_low	47	
ABP_mean	42	
ABP_high	45	
ABP_low	38	
Fetal SpO2	100	
Maternal SpO2	72	
ABS	103	

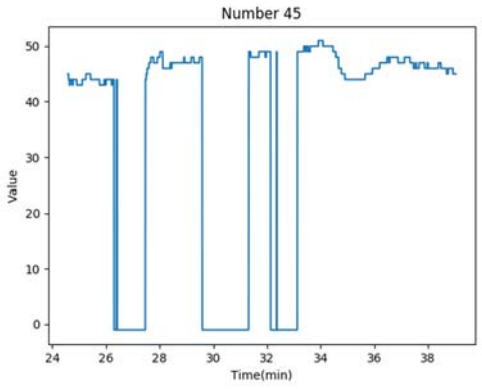
Corresponding images of notes (Phase 3&4)

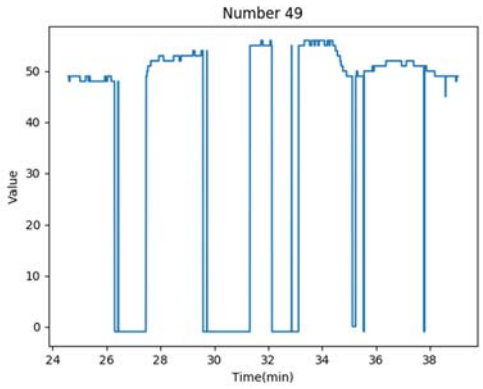


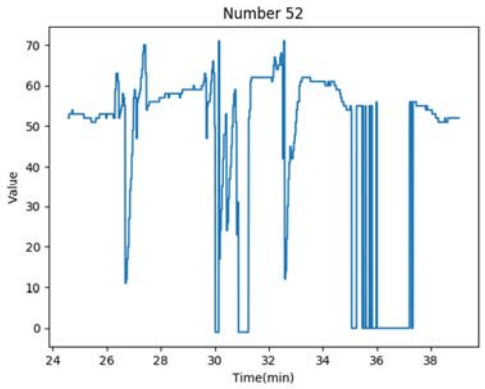
Phase: 5 || Folder name: 3_12_5 || timestamp: 24:35-39:05

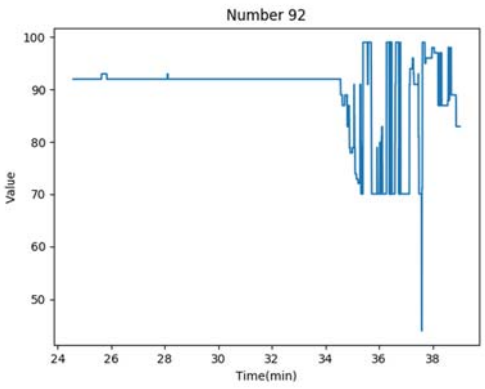
Index	Video_tag	Evaluations
Temperature	376	
Pulse	207	
ART_mean	49	Abnormal surges around 26:10, 30:00 and 32:50
ART_high	52	Invalid: 01:42-02:52/ 05:00-06:44/ 07:33-08:32 (timestamp is based on individual cropped videos)
ART_low	45	Abnormal surge around 32:10
ABP_mean	35	
ABP_high	38	
ABP_low	32	
Fetal SpO2	100	
Maternal SpO2	70	
ABS	92	Results are good before 34:00

Corresponding images of notes







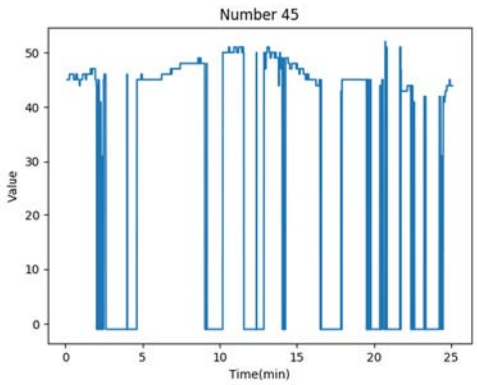


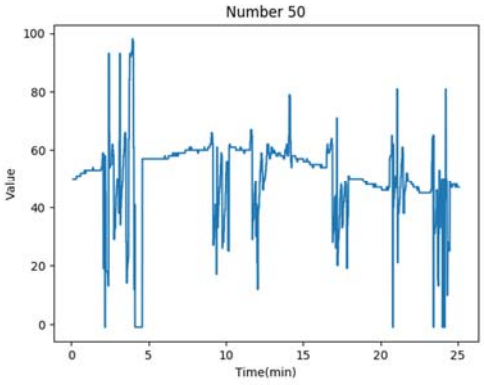
Original Video Name: 20190614_131920

Phase: 1 || Folder name: 3_13 || timestamp: 00:10-25:06

Index	Video_tag	Evaluations
Temperature	375	
Pulse	144	
ART_mean	48	
ART_high	50	Invalid: 01:54-02:00/ 02:05-02:21/ 02:28-04:28/ 08:54-10:03/ 11:26-12:42/ 13:55-14:07/ 16:22-17:46/ 19:23-21:35/ 22:19-23:05/ 23:17-24:20 (timestamp is based on individual cropped videos)
ART_low	45	Abnormal surges around 4:30, 12:30 and 24:00
ABP_mean	58	
ABP_high	69	
ABP_low	47	
Fetal SpO2	100	
Maternal SpO2	88	
ABS	55	

Corresponding images of notes





Corresponding code notation (v.py)

Note: there are some mistakes in the name distributions. Evaluation sheet has final correct names.

Phase Name	*Wrongly-named data*	*Correct Name*
3_10_3	*art_mean*	*art_high*
	art_high	*art_mean*
3_12_4	*art_mean*	*art_low*
	art_high	*art_mean*
	art_low	*art_high*

#10_1
'''temperature = [380]
pulse = [104]
spo2 = [100, 82]#[fetal, maternal]
art =[44, 49, 52]#[low, mean, high]
abp =[57, 68, 80]#[low, mean, high]
ABS =[101]'''

#10_2
'''temperature = [379]
pulse = [180]
spo2 = [100, 84]#[fetal, maternal]
abp =[56, 68, 79]#[low, mean, high] red
art =[46, 49, 52]#[low, mean, high] yellow
ABS =[101]'''

#10_3
'''temperature = [379]
pulse = [196]
spo2 = [100, 81]#[fetal, maternal]
abp =[55, 66, 78]#[low, mean, high] red
art =[40, 47, 50]#[low, mean, high] yellow
ABS =[101]'''

#10_4
'''temperature = [378]
pulse = [186]
spo2 = [100, 79]#[fetal, maternal]
abp =[40, 42, 44]#[low, mean, high] red
art =[39, 48, 59]#[low, mean, high] yellow
ABS =[92]'''

#11_1
'''temperature = [378]
pulse = [207]
spo2 = [100, 72]#[fetal, maternal]
abp =[33, 34, 36]#[low, mean, high] red
art =[42, 51, 61]#[low, mean, high] yellow
ABS =[50]'''

#11_2
'''temperature = [378]
pulse = [214]
spo2 = [99, 71]#[fetal, maternal]
abp =[34, 35, 37]#[low, mean, high] red
art =[42, 51, 60]#[low, mean, high] yellow
ABS =[1]
'''

#12_1
'''temperature = [376]
pulse = [209]
spo2 = [100, 85]#[fetal, maternal]
abp =[41, 44, 48]#[low, mean, high] red
art =[49, 56, 64]#[low, mean, high] yellow
ABS =[102]'''

#12_2
'''temperature = [376]
pulse = [209]
spo2 = [100, 79]#[fetal, maternal]
abp =[42, 47, 50]#[low, mean, high] red
art =[46, 53, 60]#[low, mean, high] yellow
ABS =[92]'''

#12_3
'''temperature = [376]
pulse = [220]
spo2 = [100, 74]#[fetal, maternal]
abp =[39, 43, 46]#[low, mean, high] red
art =[13, 45, 53]#[low, mean, high] yellow
ABS =[93]'''

#12_4
'''temperature = [376]
pulse = [210]

spo2 = [100, 72]#[fetal, maternal]
abp =[38, 42, 45]#[low, mean, high] red
art =[21, 47, 53]#[low, mean, high] yellow
ABS =[103]'''

#12_5
temperature = [376]
pulse = [207]
spo2 = [100, 70]#[fetal, maternal]
abp =[32, 35, 38]#[low, mean, high] red
art =[45, 49, 52]#[low, mean, high] yellow
ABS =[92]

#13
'''temperature = [375]
pulse = [144]
spo2 = [100, 88]#[fetal, maternal]
art =[45, 48, 50]#[low, mean, high]
abp =[47, 58, 69]#[low, mean, high]
ABS =[55]'''