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Oral

AN OFFLINE DEEP LEARNING-ASSISTED AUTOMATED PAPER-BASED MICROFLUIDIC PLATFORM

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This paper reports an automated microfluidic paper-based analytical device (μPAD) platform, featuring a highly integrated rotary valve with deep learning-assisted smartphone offline detection, for early screening of Alzheimer's disease (AD). Unlike existing platforms, our platform utilizes deep learning-assisted smartphones to achieve offline detection, avoiding data transfer with the assistance of large-scale equipment and privacy leakage issues for the cloud. Meanwhile, we use a simple mechanical rotary valve to achieve complex enzyme-linked immunoassay (ELISA) detection of blood biomarker, β-amyloid peptide 1-42 (Aβ 1-42). In this paper, we perform 38 clinical serum samples (healthy: 19, unhealthy: 19; N=6), and the platform provided 98.4% mean average precision (mAP).

To implement autonomous ELISA on μPAD, valve design, and result analysis are key points [1-4]. Existing valve designs include electromagnetic braking or shape changes of smart materials [1,2]. However, these designs only realize control of a single flow channel with long response times and complex assembly processes. Meanwhile, with the development of artificial intelligence, deep learning-assisted smartphone analysis for microfluidic detection has received much attention [3,4]. However, these methods required large-scale equipment or cloud for data transfer, hindering their wide use in low-resource settings. Therefore, we propose a fully automated ELISA using a rotary valve and deploy the YOLOv5 deep learning model to smartphones using the novel convolutional neural network (NCNN) framework for early screening of AD (Figure 1).

Figure 2(a) shows the design of our μPAD using a sandwich ELISA to detect Aβ 1-42. All reagents are pre-stored in storage and test zones connected/disconnected by valve rotation. Moreover, we develop a portable platform (Figure 2(b)) that utilizes a smartphone for offline control and detection of the μPAD. It consists of a smartphone, μPAD, motor (to control valve rotation), microcontroller, Bluetooth module, and a power supply unit. To perform the ELISA, the user mounts the μPAD in its holder, then adds 3 μL of a serum sample to the test zone, followed by 180 μL of PBS buffer at the inlet. The start of the ELISA is controlled by a pre-set smartphone program, and the results are displayed on the smartphone screen after the end of the ELISA (Figure 2(c)). We construct the dataset by testing 38 serum samples (healthy: 19, unhealthy: 19, N=6), thereby 228 images (38 samples × 6 tests for each sample). Then the dataset is labeled with classes (class 0: healthy, class 1: unhealthy) using the Labelimg, where 70% of the dataset is used for training, 20% for testing, and the rest for validation (Figure 3(a)). Figure 3(b) shows the YOLOv5 model structure.

The performance of the deep learning model is evaluated by precision (samples predicted as healthy are healthy), recall (healthy samples are correctly predicted), mAP, and objectless loss (small values represent high target predicted). Figure 4 shows that after 200 epochs (training rounds), four performances are stabilized with a high mAP (98%) (Table 1). In addition, we move the YOLOv5 model to the smartphone using the NCNN framework to achieve offline detection.

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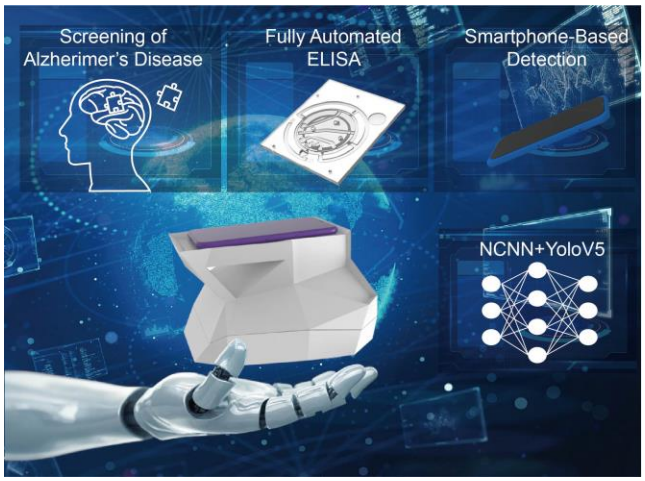

Figure 1: The schematic diagram of a deep learning-assisted offline smartphone-based automated paper-based microfluidic platform for screening of Alzheimer's disease.

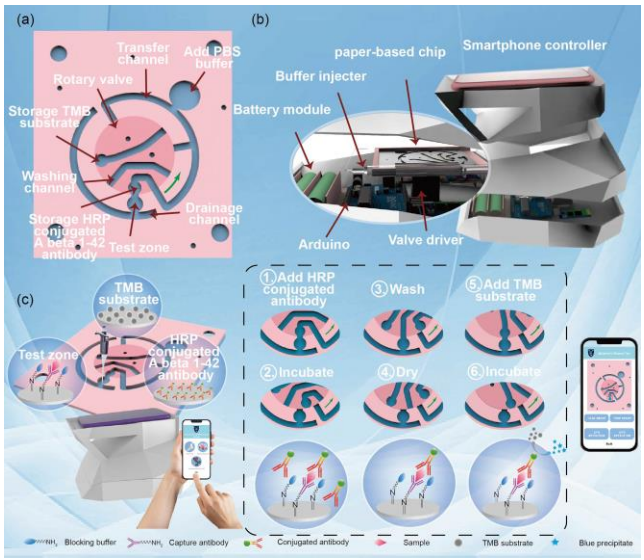

Figure 2: (a) The design of a microfluidic paper-based analytical device (μPAD). (b) Smartphone-based automated paper-based microfluidic platform. (c) The working flow of deep learning-assisted offline smartphone-based automated paper-based microfluidic platform for screening of Alzheimer's disease.

Table 1. The results of the YOLOv5 model.

AP@0.5		mAP@0.5	Precision	Recall	Objectless loss
Health	*Unhealth*				
99.0%	97.8%	98.4%	92.17%	96.43%	0.00478

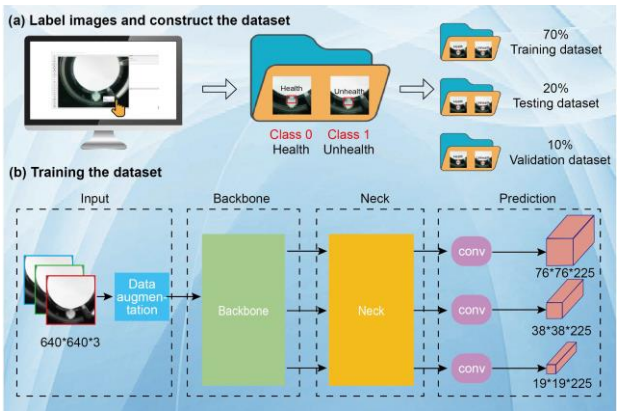

Figure 3: (a) Label images and construct the dataset. (b) YOLOv5 model structure.

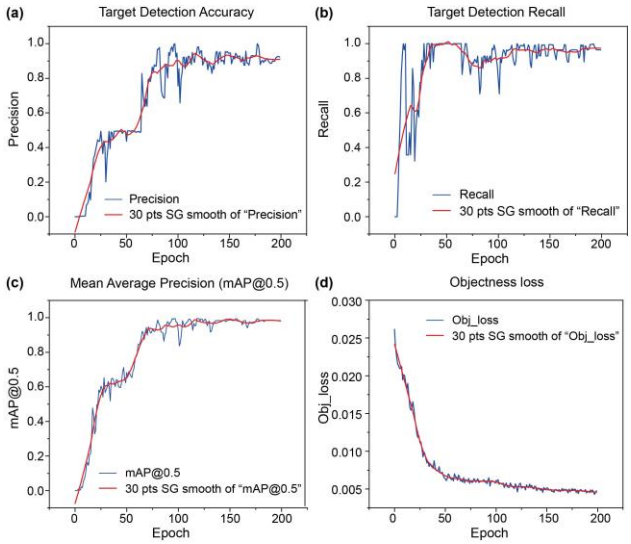

Figure 4. The results of the YOLOv5 model. (a) The target detection accuracy (Precision), and (b) Target detection recall. (c) The mean average precision at 0.5 (mAP@0.5). (d) The objectless loss.

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