UbiNIRS: A Software Framework for Miniaturized NIRS-based Applications

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Abstract
We present UbiNIRS, a software framework for rapid development and deployment of applications using miniaturized near-infrared spectroscopy (NIRS). NIRS is an emerging material sensing technology that has shown a great potential in recent work from the HCI community such as in situ pill testing. However, existing methods require significant programming efforts and professional knowledge of NIRS, and hence, challenge the creation of new NIRS-based applications. Our system helps to resolve this issue by providing a generic server and a mobile app, using the best practices for NIRS applications in literature. The server creates and manages UbiNIRS instances without the need for any coding or professional knowledge of NIRS. The mobile app can register multiple UbiNIRS instances by communicating with the server for different NIRS-based applications. Furthermore, UbiNIRS enables NIRS spectrum crowdsourcing for building a knowledge-base.

Author Keywords
NIRS; software framework; mobile sensing.

CCS Concepts
+Human-centered computing → Ubiquitous and mobile computing systems and tools; Interactive systems and tools; Ubiquitous and mobile devices;
Introduction

Despite the widespread availability of advanced sensors, there is still no feasible way to obtain information on the ingredients of objects in our daily life. Conventional methods require samples to be sent to a dedicated laboratory for sophisticated analysis. However, recently emerging miniaturized near-infrared spectroscopy (NIRS) enables the analysis of an object's ingredients \textit{in situ} \cite{10, 11}. NIRS utilizes near-infrared lights in multiple wavelengths between $780\,\text{nm}$ and $2500\,\text{nm}$. This approach leverages the phenomenon that different ingredients (molecules) absorb different wavelengths of near-infrared lights. By emitting near-infrared lights to an object and measuring the intensities reflected back from the object in those wavelengths, a near-infrared spectrum can be acquired. This spectrum can be regarded as a unique chemical “fingerprint” for the object, from which ingredient information can be extracted.

However, recent studies in the HCI community suggest that it is not straightforward to use the miniaturized NIRS technology in practice \cite{4, 5, 9}. For example, Klakegg \textit{et al.} highlighted various challenges for non-experts to take advantage of miniaturized NIRS, including spectrum distortions as the result of user-induced errors \cite{8, 9}. Nevertheless, a follow-up study by Klakegg \textit{et al.} demonstrated that it was possible to assist non-experts in identifying medical pills more accurately through the use of a well-designed prototype and usable software \cite{7}. Their study can be generalized to solid objects, such as estimating the maturity of fruits, ranking beef, etc. For the identification of non-solid objects, Jiang \textit{et al.} extended the study to identify liquids such as everyday drinks and liquors using a customized 3D printed clamp and software \cite{4, 5}.

The aforementioned studies show great potential across a number of applications for the usage of miniaturized NIRS. Such applications include, but are not limited to, identifying counterfeit products (\textit{e.g.} medicines and liquors), detecting allergens, or estimating the maturity of foods \cite{10}. However, it is still time-consuming for developers to design and deploy applications using miniaturized NIRS, due to non-trivial programming tasks and lack of professional knowledge on NIRS. In fact, applications in existing studies show a major part of common components, including a mobile application and a remote server. The mobile application interacts with end-users and communicates with the miniaturized NIRS scanner and the remote server. The server processes the uploaded spectra from the client and returns interpreted information to the mobile application. The most important information is the classification results, as based on a machine learning model fed by the spectra. With these observations, we build and present UbiNIRS, a ubiquitous NIRS sensing framework that leverages rapid development and deployment of miniaturized NIRS applications. The contributions of UbiNIRS are

- A generic server and a mobile application for developing general NIRS-based applications, as shown in Figure 2 and 4. This contribution reduces the workload for development and deployment of applications using miniaturized NIRS for developers. As an implementation, we developed the framework using Python Django and the Android platform.
- Generic NIRS spectrum processing methods on a server, reducing the requirement for professional knowledge of NIRS.
- A straightforward logging-feedback method to collect NIRS spectra from the end-users to enrich the knowledge-base of miniaturized NIRS. The method can be used to crowdsource tasks for NIRS spectra collection.

UbiNIRS is open sourced in \cite{1}. 
**UbiNIRS Framework**

Figure 3 presents a system overview of UbiNIRS. There are only two steps to start a UbiNIRS instance: 1) Creating a UbiNIRS instance in the dashboard using a web browser, as shown in Figure 4, which automatically generates a URL to access the application. 2) The end-user registers the created UbiNIRS instance in the mobile application using the generated URL, as shown in Figure 5. If necessary, the developer can further customize the server for additional functions, such as updating the spectrum processing methods or the machine learning methods, without any modifications to the mobile application.

**Session procedure**

Each usage session, i.e., the end-user scans an object and acquires the result, includes the following steps:

1. **Start instance**: The end-user chooses a registered UbiNIRS instance in the mobile application to send a starting request to the server. The server replies with instructions shown to the end-user for further actions. For example, when scanning pills, the end-user should put the flattest surface without carvings on the scanning window, then select “scan”. The user can choose to either train the machine learning model in the server, or identify objects using the pre-train model.

2. **Scan object**: The end-user follows the instructions and pushes the “scan” button. The mobile application then sends a command to the NIRS scanner to perform a scan and retrieve a raw NIRS spectrum via Bluetooth. The spectrum is uploaded to the server for analysis.

3. **Receive result**: The server processes the raw spectrum and runs the machine learning model for either training the model or making an estimation using the processed spectrum. The result is sent back to the client.

4. **Give feedback**: As an option, the end-user can send feedback for this session to the server for crowdsourcing tasks, such as validating the results, etc.

**Model Training**

When a UbiNIRS instance is created, the developer can upload reference spectra to train the machine learning model. As shown in Figure 6, the end-user can also train the model with the uploaded spectra for labeled samples *in situ* as described above.

**Spectrum Crowdsourcing**

An additional challenge for the use of miniaturized NIRS is constructing a knowledge-base for various objects. According to the literature, it is recommended to have at least 12 spectra for each object in the knowledge-base [10]. Collecting these...
spectra requires increasing efforts with larger knowledge-base. Furthermore, some samples may not be directly accessible to the developer, obstructing inclusion in the knowledge-base.

Our UbiNIRS framework can be used to address the aforementioned challenge by collecting information through crowdsourcing tasks. End-users can train the model as described above, or provide feedback to the result returned by the trained model. The uploaded spectra are stored on the server and can be used for online training or validation.

Implementation
We have implemented the UbiNIRS platform using the Django 2 library [2] in Python 3. The spectrum processing methods and machine learning models are based on the ‘scipy’ and ‘sklearn’ packages [6], as adopted from existing literature [5, 7]. The mobile application is implemented for Android and uses the KS Technologies NIRScan Nano Android library [12].

Conclusion
In conclusion, we present UbiNIRS, a software framework for miniaturized NIRS-based applications. Our system greatly reduces the bar of developing NIRS-based applications, enables rapid deployment of material-level object identification application for miniaturized NIRS non-expert end-users.

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