COMPRESSIVE MULTISPECTRAL SENSING ALGORITHM WITH TUNABLE QUANTUM DOTS-IN-A-WELL INFRARED PHOTODETECTORS

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In recent years, our group has developed and reported two multispectral sensing algorithms that aim to exploit the continuous bias-dependent spectral tunability of the quantum dots-in-a-well (DWELL) infrared photodetector and enable higher spectral resolutions without using spectral filters. The key idea is to probe an unknown target of interest sequentially with the DWELL detector at multiple biases, producing a set of bias-dependent photocurrents. Then, a post-processing algorithm performs a linear superposition of these bias-dependent photocurrents with a pre-determined set of weights, which is the optimal solution for a specific multispectral sensing task. The first algorithm, termed the spectral-tuning algorithm, is designed to perform algorithmic spectrometer, which is capable of reconstructing the spectrum of any unknown target of interest (admitted by the DWELL's spectral response) without utilizing any physical spectral filters or spectrometer. The set of weights obtained by the spectral-tuning algorithm can optimally approximate the desired shape of narrowband tuning filter with a specified bandwidth. According to this optimal set of weights, the spectrum of the unknown target at each desired tuning wavelength is reconstructed by performing a weighted linear superposition with the set of bias-dependent photocurrents. This algorithm has been experimentally demonstrated by our group [1] and other groups [2]. The second algorithm, termed, the spectral matched-filtering algorithm, is geared toward performing target classification [3]. With known multiple spectra, representing classes of targets of interest, the idea is to obtain the optimal sets of weights, which form a linear superposition with the bias-dependent DWELL's spectral bands. Each superposition band is regarded as the most informative "spectral direction" (in a vector-space sense) for a given target spectrum. Then, the classifier uses these sets of weights to perform a linear superposition with the measured set of bias-dependent photocurrents. The outcome from the classifier is the set of extracted superposition features, which is used to classify the unknown target.

Both of the algorithms described above were designed without any constraint on the number of required DWELL's bias-dependent spectral photocurrents. This implies that these two algorithms use DWELL's spectral data over a large number of applied biases (over 30 biases or more), causing large overall data acquisition times in proportion to the number of applied biases required by the algorithms. In this paper we report a novel data compressive multispectral sensing algorithm combined with the tunable DWELL photodetector that identifies and employs the minimal set of biases that need to be applied to the DWELL detector subject to a prescribed performance level. The use of minimal bias set allows the detector to sense only the most essential spectral information for specific sensing applications. Also, this minimal bias set is designed to render a uniformly accurate solution across a collection of desired spectral filters supporting specific remote-sensing applications of interest.

We have used the algorithm to approximate the collection of six specified spectral sensing filters: three disjoint hypothetical narrowband triangular sensing filters centered at 7.4 μm, 8.8 μm and 10.2 μm and three actual spectral filters in the ranges 7.5-10.5 μm, 8.0-9.0 μm and 8.5-11.5 μm. The algorithm identified the minimal set of four biases (-3, -0.8, 1.0, 2.8 V) for successful approximations of filter collection. These minimal four biases correspond to over 7X reduction in the number of required biases, from original 30 (from -3 to 3 V in 0.2 V steps) biases down to 4. We then applied the collection of six approximated spectral filters and the minimal four biases to two remote-sensing problems: spectrometry of unknown filter target and the classification of three known filter targets.

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For the spectrometry problem, we selected three disjoint narrowband filters in the collection and used their corresponding weight vectors to reconstruct samples of the transmittance of the unknown target (i.e., the spectral filter in the range 7.5-9.5 μm shown in dotted line of Fig. 1) at 7.4 μm, 8.8 μm and 10.2 μm tuning wavelengths without the use of any physical dispersive elements or optics. These three samples of the filter transmittance were reconstructed by the weighted superposition with the measured bias-dependent photocurrents by probing the unknown target by the detector using the minimal four biases only. Reconstructed samples are shown in Fig. 1; they are all within 7 % error of the actual values.

For the classification problem, we selected three actual spectral filters (i.e., 7.5-10.5 μm, 8.0-9.0 μm and 8.5-11.5 μm filters) in the collection comprising the three classes of spectra. Three optimal weight vectors were obtained. The classifier then performed the weighted superposition with the measured photocurrent vector as the detector was exposed to radiation transmitted through three actual target filters using the same minimal four biases used in the spectrometry problem. As a result, the classifier generated three synthesized features, which form a feature vector. Finally, the classifier assigned this feature vector to a class whose feature value is the highest among the three features; namely, it selects the class that gives the "best match" to the compressed data comprising the four bias-dependent photocurrents. The classification results shown in Fig. 2 demonstrate that the classifier has assigned all three different test sets of photocurrents to their respected classes with 100 % accuracy solely based upon their extracted feature vectors.

In conclusion, the new data compressive multispectral sensing algorithm has demonstrated the substantial reduction (i.e., over 7X reduction) in the number of required biases for multiple sensing applications. Such data compression can lead to at least 7X faster data acquisition times in proportion with the number of required biases since the amount of data to be sensed is minimized.

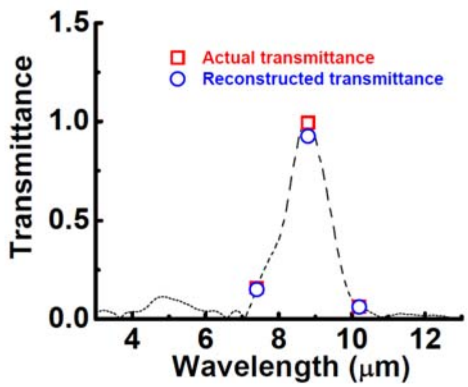

Figure 1. Experimentally reconstructed transmittances (shown in blue) at 7.4μm, 8.8 μm and 10.2 μm extracted by the new algorithm using minimum four biases. Results are compared to the actual transmittances (shown in red). Dotted line shows the entire transmittance spectrum of filter target.

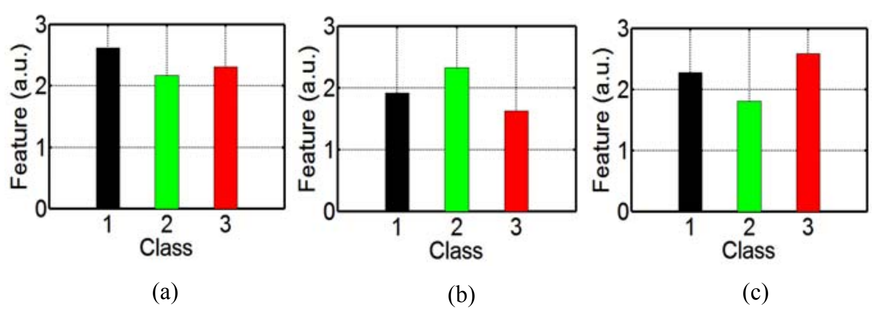

Figure 2. Classification results for identifying three experimental test data. The classifier successfully assigned the data to class 1 (see (a)), the data to class 2 (see (b)), and the data to class 3 (see (c)).

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