Improving mobility and data processing of a non-invasive glucose sensing system using Quantum Cascade Lasers (QCL)

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Motivation

Over 420 million people in the world have diabetes.
Right now, they have to prick the finger several times a day to control their glucose concentration in the blood using a glucose meter:

By building a non-invasive glucose sensing system, the comfort of the diabetics will be increased. The system radiates mid-infrared light into the finger and predicts the glucose concentration with the backscattered light.

Data Processing

How does the Glucose Concentration Prediction work?

Collected Data → Genetic Algorithm → Glucose Prediction

Data Processing to improve the machine learning algorithm

Collected Data

- Randomly adding or subtracting an error up to 15% (commercial glucose meter has an error of 15%)
- Randomly removing data points per wavenumber and whole wavenumbers (reducing testing time)

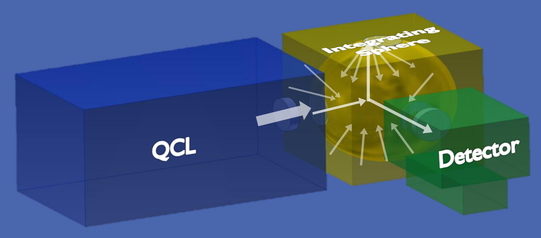
→ New Data → Genetic Algorithm → New Glucose Prediction

The processed data is plotted in the Clarke Error Grid.

Method and System Components

The System consists of:

QCL + Integrating Sphere + MCT Detector



Improving the stability and comfort of the system:

→ Custom mount
→ Decreasing the size of the system
→ Building a case by laser cutting acrylic
→ Protects the components against dust and displacement
→ Printing curved support mount for the finger
→ Reducing movement of testing finger
→ Adding foam to the mounts
→ Improving comfort for the hand
→ Adding aluminium plate on the bottom
→ Increasing stability of the whole case

Collected Data:

The system goes through 103 wavenumbers between 1020 cm^{-1} and 1224 cm^{-1} and takes 85 data points per wavenumber.
This process takes about 3 minutes.

Fundamental Physics

Quantum Cascade Laser:

- Semiconducter laser in the mid-infrared
- Intersubband transitions between multiple quantum well grown by layers of GaAs and AlGaAs

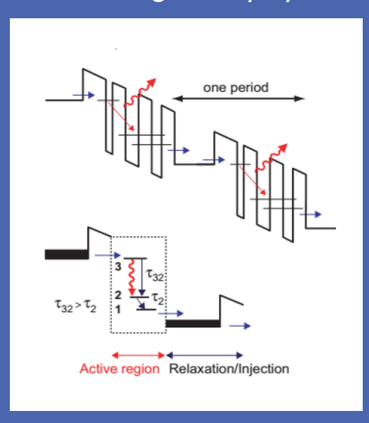


Figure 1:Transitions in the QCL
A) Electron undergoes intersubband transitions and emit a photon.The electron tunnels through the barrier and the process repeats.
B) Photon emission between energy level 3 and 2, LO phonon emission between energy level 2 and 1 and Electron tunneling after energy level 1.

Concentration detection:

- Lambert-Beer law → $A(\lambda) = \varepsilon(\lambda) * c * l$

$A(\lambda)$ ... Absorbance, $\varepsilon(\lambda)$ … attenuation coefficient, l … path lenghts
→ Parameters differ for each person → Machine learning

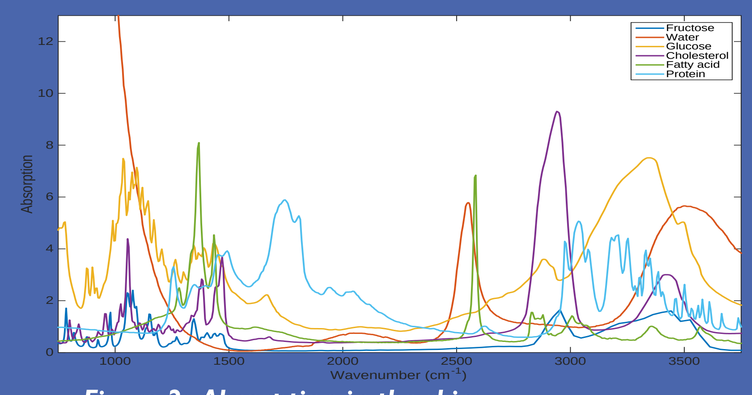


Figure 2: Absorption in the skin:
Good glucose absorption between 1000 cm^{-1} and 1200 cm^{-1} .

Results

The **Clark Error Grid** correlates the predicted glucose concentration with the reference concentration:
A… within 20% accuracy and clinically accurate
B… benign action
C… unnecessary insulin intake
D… harmful inaction
E… catastrophic insulin intake

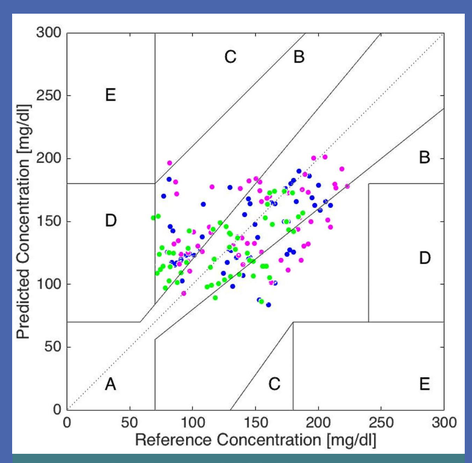


Figure 3: Up to 15% Error:
3 different runs→ No Spread

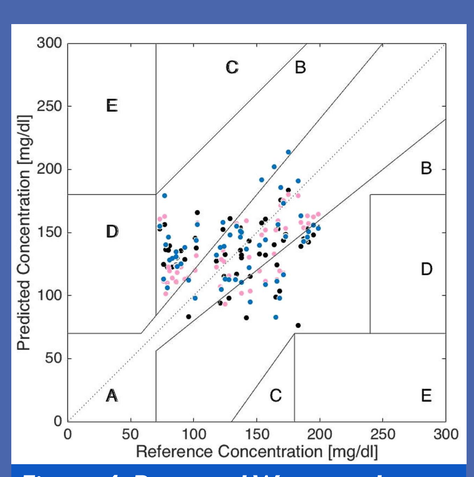


Figure 4: Removed Wavenumbers:
5 Removed (pink), 45 Removed (blue),
85 Removed (black) → Spread in Data Points

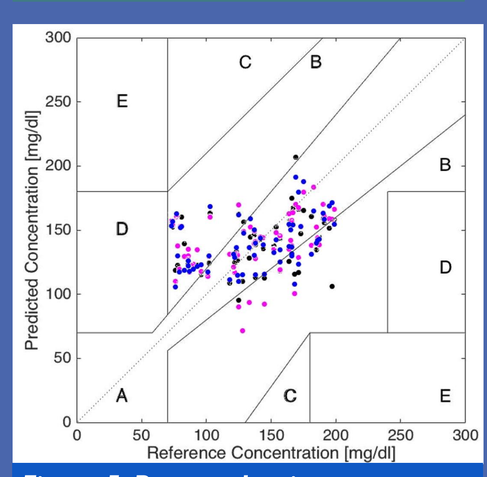


Figure 5: Removed points per Wavenumber:
20 Removed (black), 40 Removed (blue), 60 Removed (pink) → No Spread

Conclusion

Clarke Error Grid for 15% Error shows no significant difference.
→ Calibration errors **do not significantly effect** the algorithm.

Clarke Error Grid for deleted wavenumbers shows a spread of data points.
→ Reduction of recorded data leads to **inaccurate predictions.**

Clarke Error Grid for deleted data points per wavenumbers shows no spread of data points.
→ Reduction of recoded data points will not affect the outcome.The running time can then be reduced.

Future Work

1) Running the algorithm only on significant parts of the spectra by comparing it with the absorption spectra of glucose.
→ Determine which regions are important to keep

2) Test other machine learning algorithms like neural network algorithm or boosted decision to see whether the same or a better prediction is possible.

3) Taking data in San Diego with Diabetics.
→ More data, more possibilities to improve the algorithm

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