Patient Discrimination from In-Bottle Sensors Data

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Joint work with:

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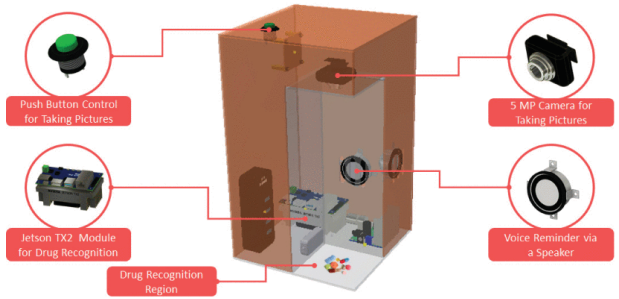
Few facts

❑ Human lifespans is continuously increasing

- People aged ≥ 60 years will grow by 250% in 2050
- Assistive Health Technology (AHT) increases
- One strategy: Correct medication

❑ Existing work

- Proximity sensing-based systems
- Vision-based systems
- Ingestible biosensors
- Wearable Sensors
- Smart pill bottles/containers

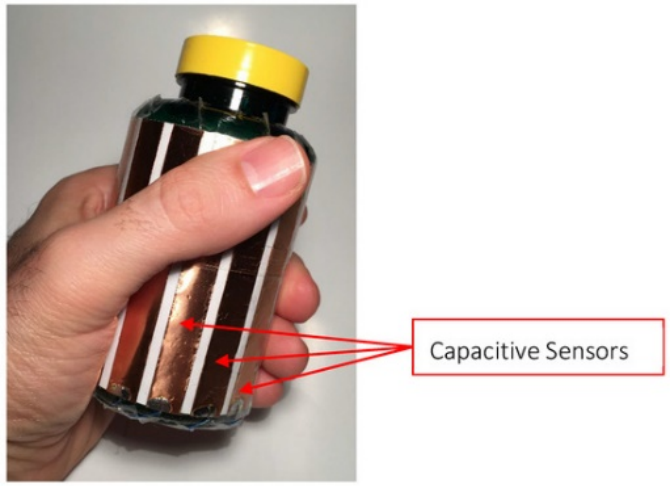


Ref: *Aldeer, Javanmard & Martin; Applied Sys Inovation, vol.2, 2018*

"A Review of Medication Adherence Monitoring Technologies"

Motivation-Smart Pill Bottles

- **Smart pill bottles can be the best among other solutions**
  - **Unobstritive,**
  - **Battery-powered,**
  - **Can be equipped with sensors to collect data about user behavior**



Application

❑ Medication Adherence Monitoring,

- Medication non-adherence is a complex problem
- Smart pill bottles can be used for monitoring medication adherence (when the medication was taken and by whom)

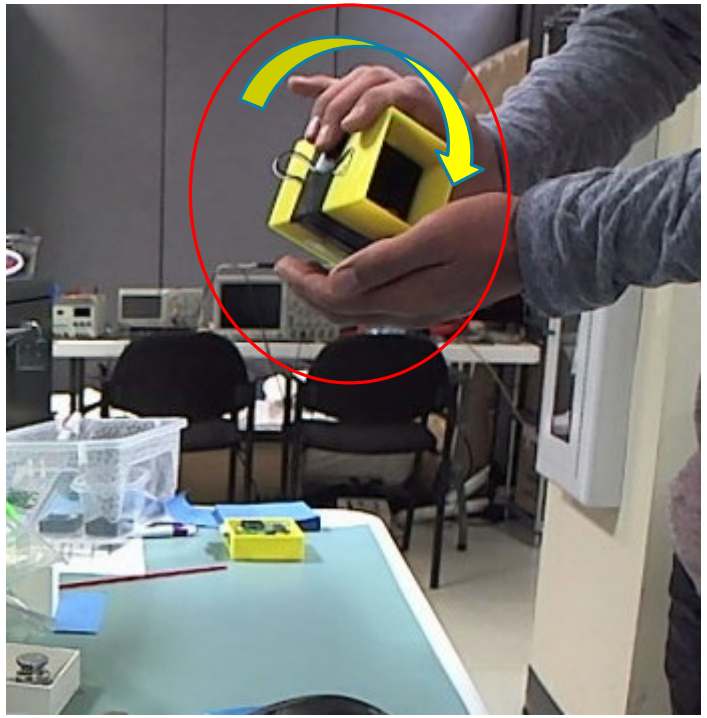
❑ Drug Abuse Monitoring,

- ER visits of children (≤5) in the US is the highest due to drug poisoning*,
- A result from unsupervised medication overdoses
- Medicine cabinets available at homes are the main sources of medication abuse
- A real-time monitoring system is required

*among emergency visits for those aged ≤ 18 years

How to differentiate users from a pill bottle?

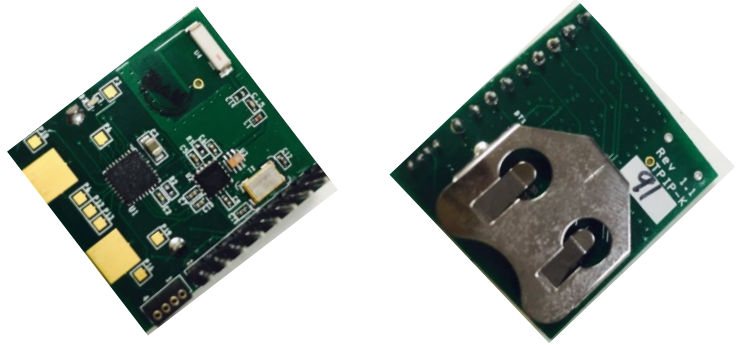
- **Different subjects interact with the pill bottle differently**

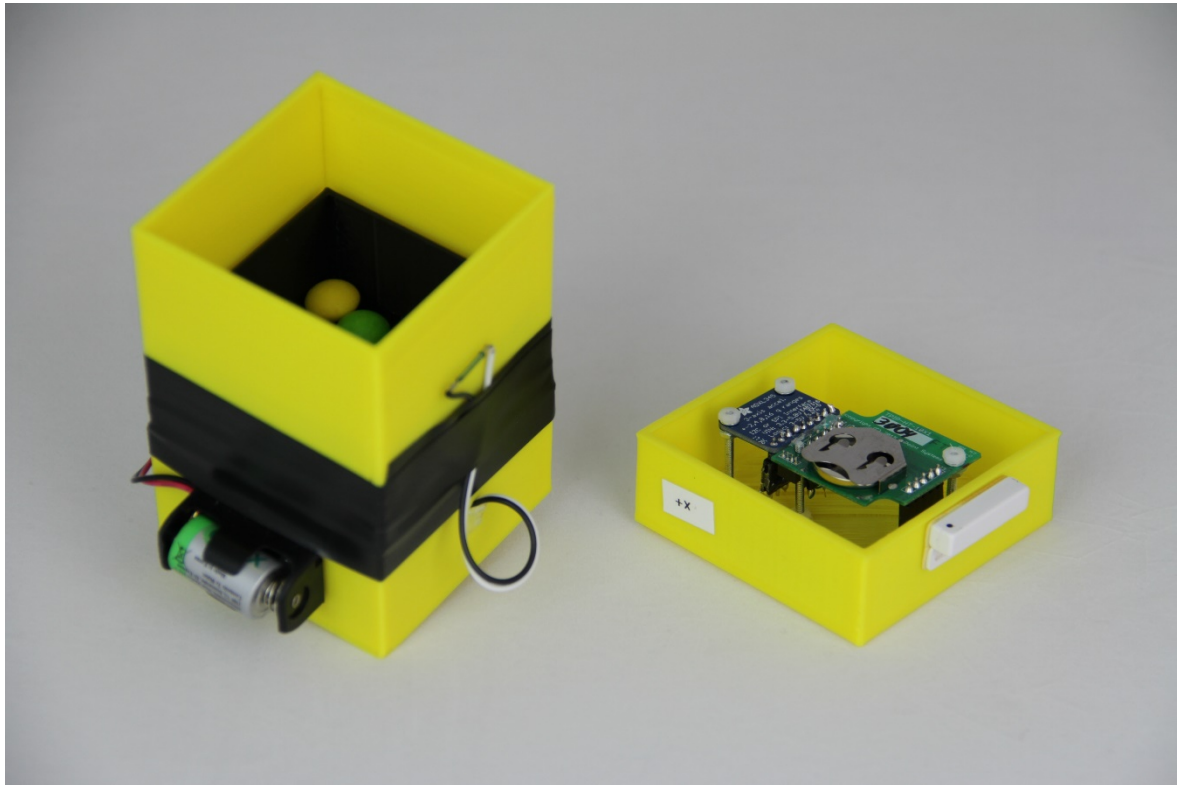


IRB number Pro2018001757

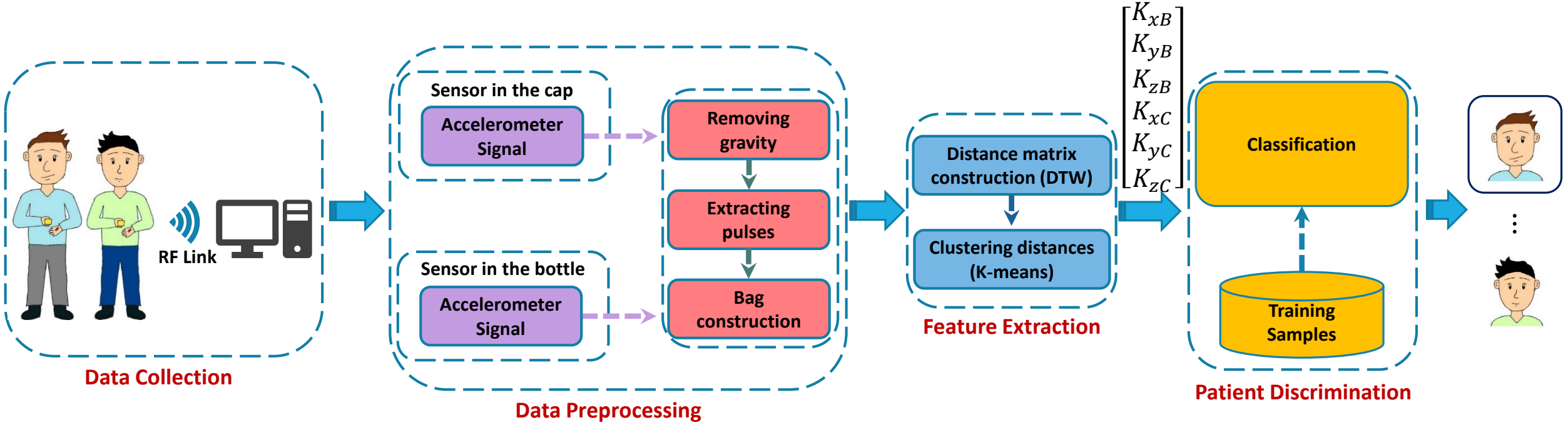
PatientSense architecture

- **Two acceleromters**
- **PIP-Tag**

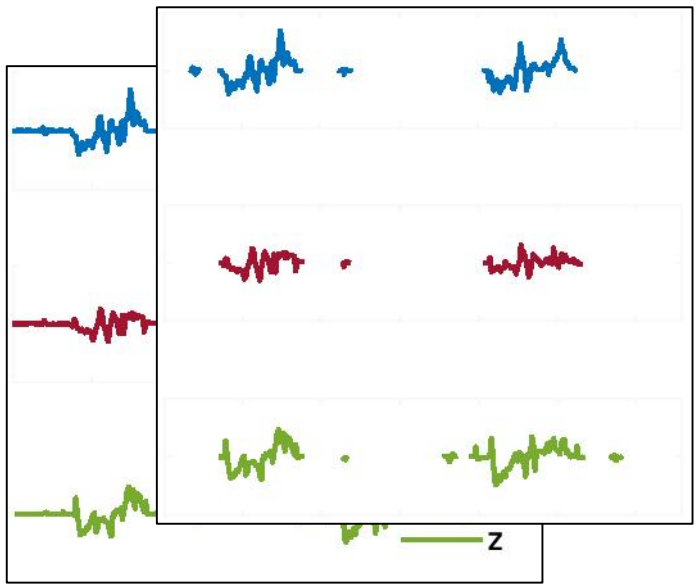




PatientSense

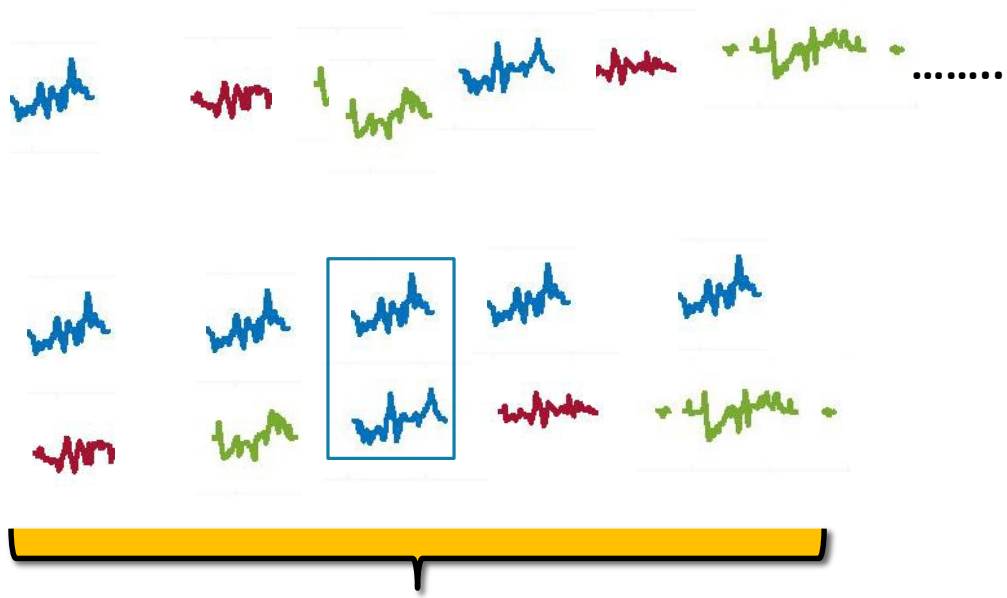


Bag of words construction, Building distance matrix



Bag of pulses

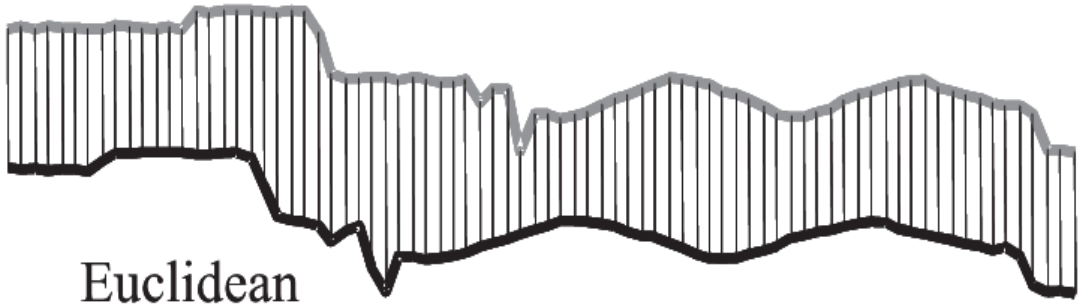
DTW

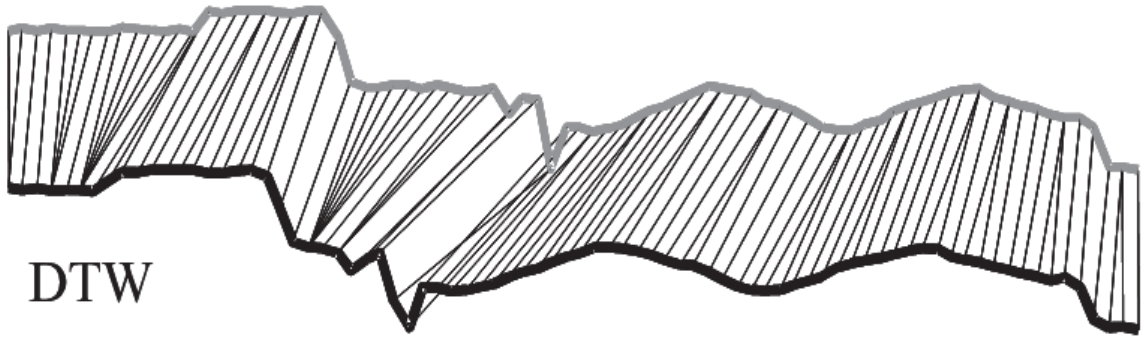


Distance matrix

0	2.2	1.5	..
2.2	0	1.8	..
1.5	1.8	0	..
:	:	:	0

Why DTW for distance measurement?





- DTW allows for some elasticity,
- Computes the differences between the points that are better aligned

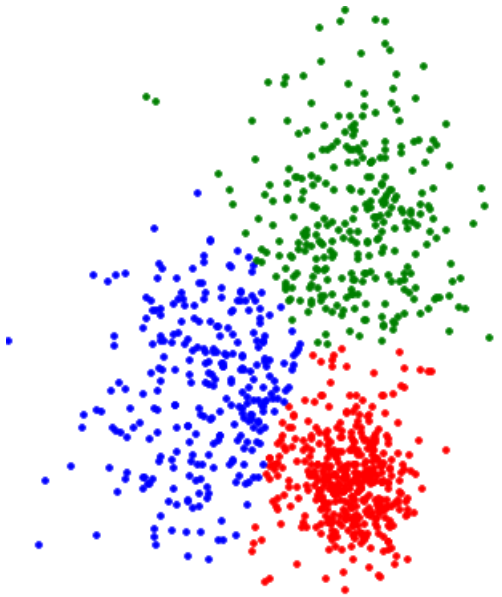
Ref: *Keogh & Ratanamahatana; Knowledge and Information Systems (2005) 7*
"Exact indexing of dynamic time warping"

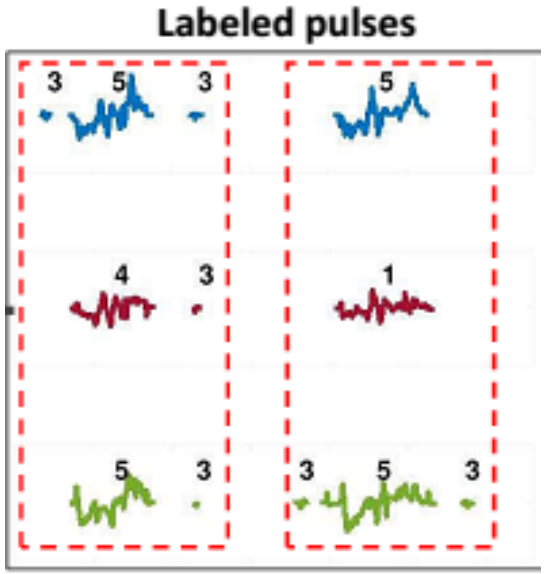
Clustering the DTW (pair wise) distances

Distance matrix

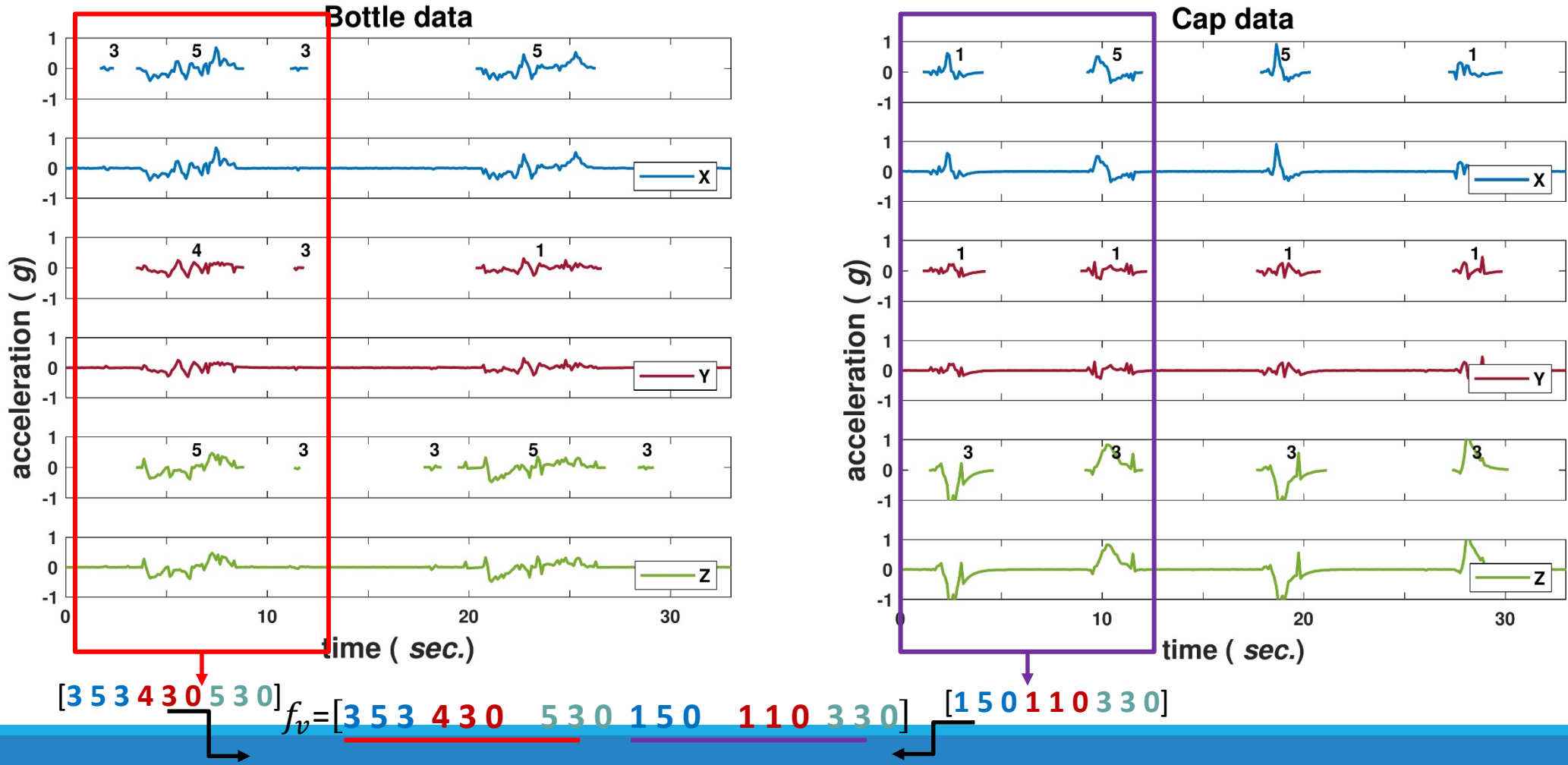
0	2.2	1.5	..
2.2	0	1.8	..
1.5	1.8	0	..
:	:	:	0

K means





Feature construction



Classification approach

- **Two class approach** → **Discriminate the patient from any other person**
  - Legitimate patient or everybody else
  - Binary SVM: simple, lightweight in computations

- **Multi-class approach** → **Identify a specific person in a set**
  - Multi-class SVM
  - Random Forest

Classification approach

Evaluation criteria

- Number of users
- Training size
- Classification algorithm
- Number of sensors

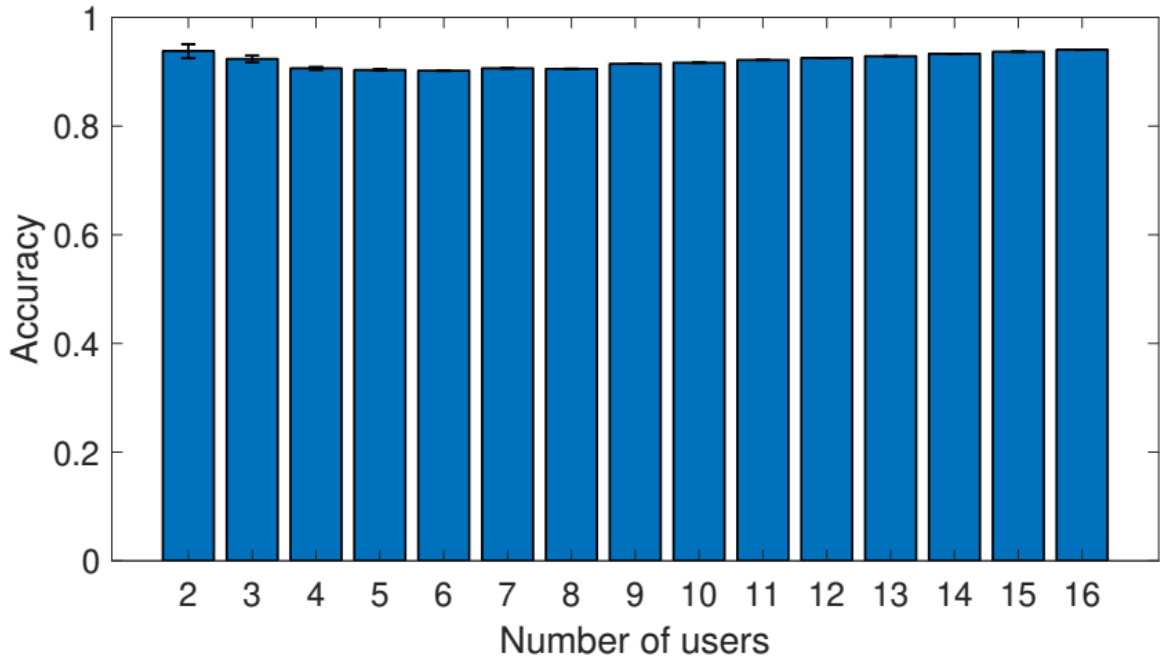
Evaluation

- **Participants**
  - 16 healthy adults
  - 14 males; 2 females
  - Ages: 18 – 64, mean 34.93, SD 11.44
  - Each participants took 10 candy pills

- **Other settings:**
  - Low sampling rate: 10Hz
  - Camera is used for ground truth

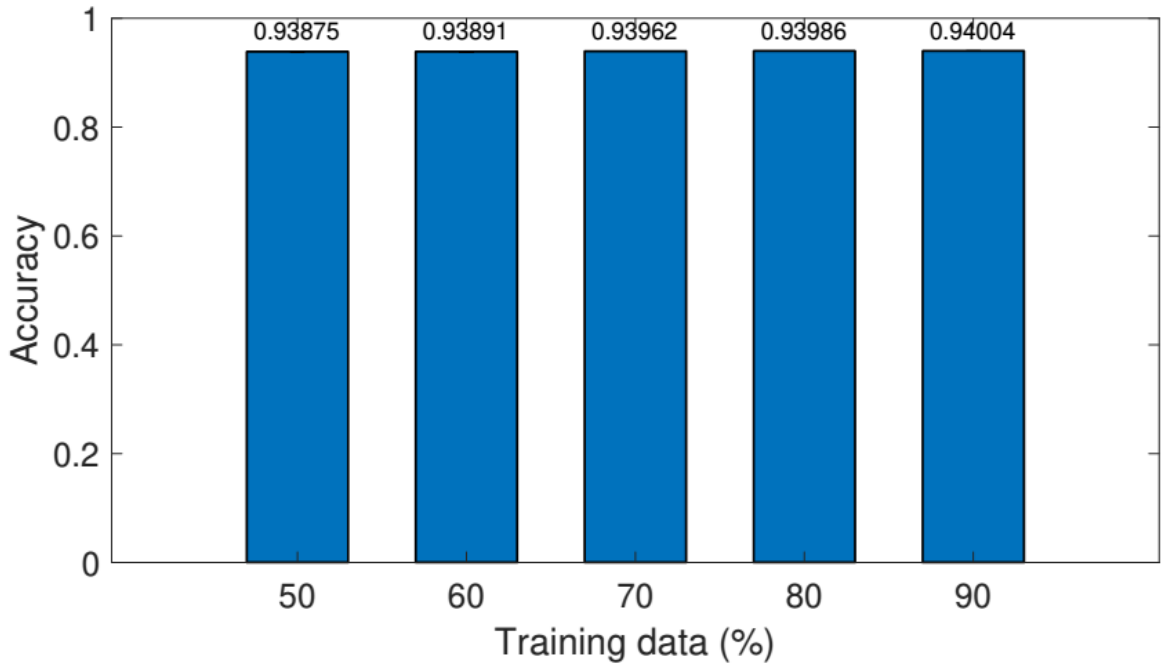
Number of users effect

- Accuracy over 90%, for different number of users
- For 16 users, accuracy = 94%



Number of users effect

- **Training data size: 50%, 60%, 70%, 80%, 90%**
- **Accuracy over 93%, for different training size**

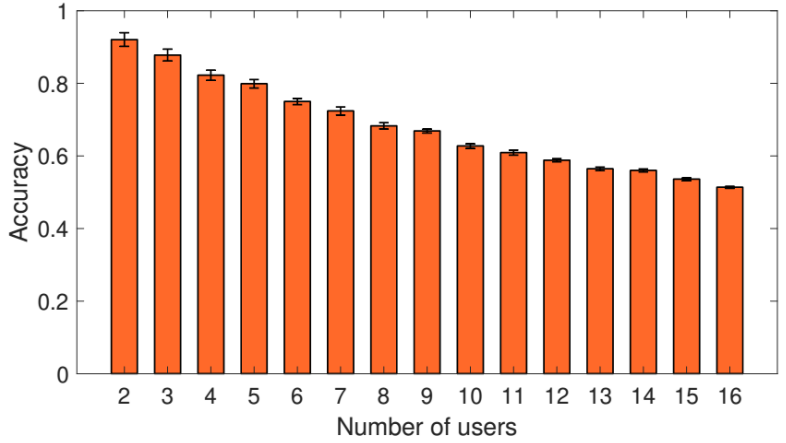


Other learners (Multi-class classification)

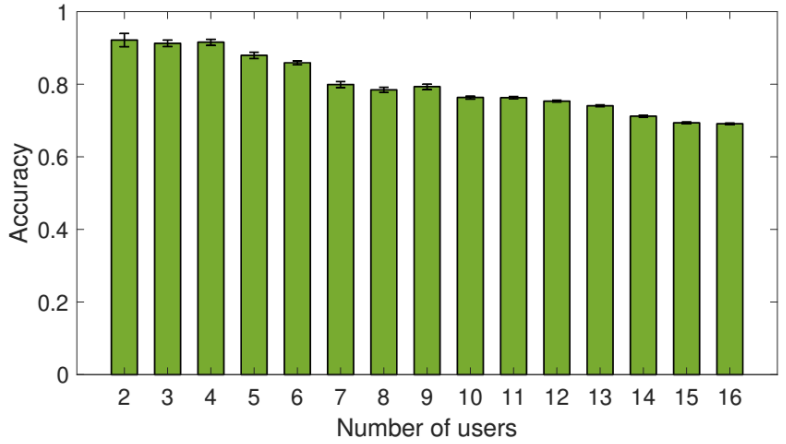
- **Multi-class SVM & Random Forest**
- **Random Forest gave better performance**
- **When focusing on a subset (3 people)*:**

➢ **Random Forest accuracy: 91%**

➢ **SVM: 87%**

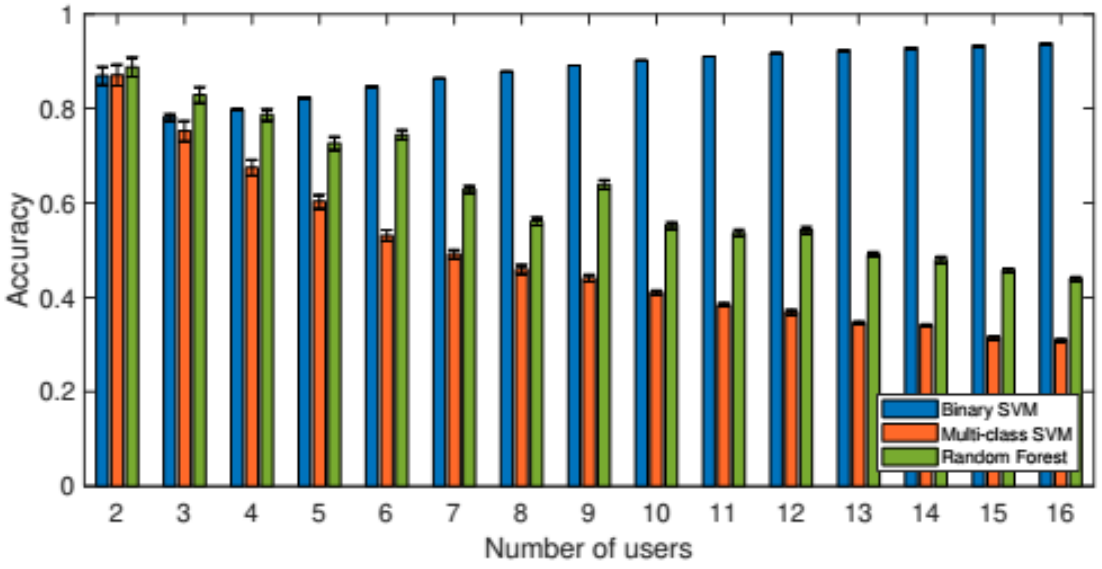


(a) Multi-class SVM

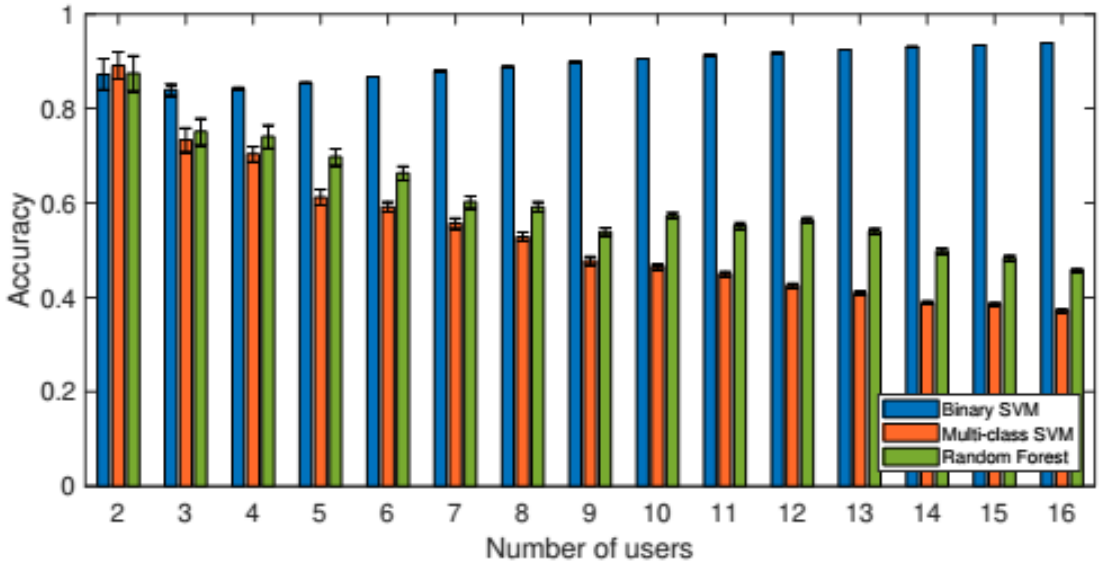


* Ref: *U.S. Census Bureau. 2019. U.S. Census Bureau QuickFacts: UNITED STATES.*

Performance with individual sensor



(a) Bottle sensor only



(b) Cap sensor only

- **Two-class SVM accuracy: higher than 93% (1 out of 16 users)**
- **Random Forest & multiclass SVM: accuracies decline**
- **Random Forest accuracy: 82% (3 people)**
- **SVM: 75% (3 people)**

Conclusion

- **PatientSense is a patient identification system from a pill bottle**
  - **uses acceleration traces**
- **PatientSense is**
  - **Accurate**
  - **Performs well with one *vs.* all situation**
  - **Off-body**

Thank you

Questions !

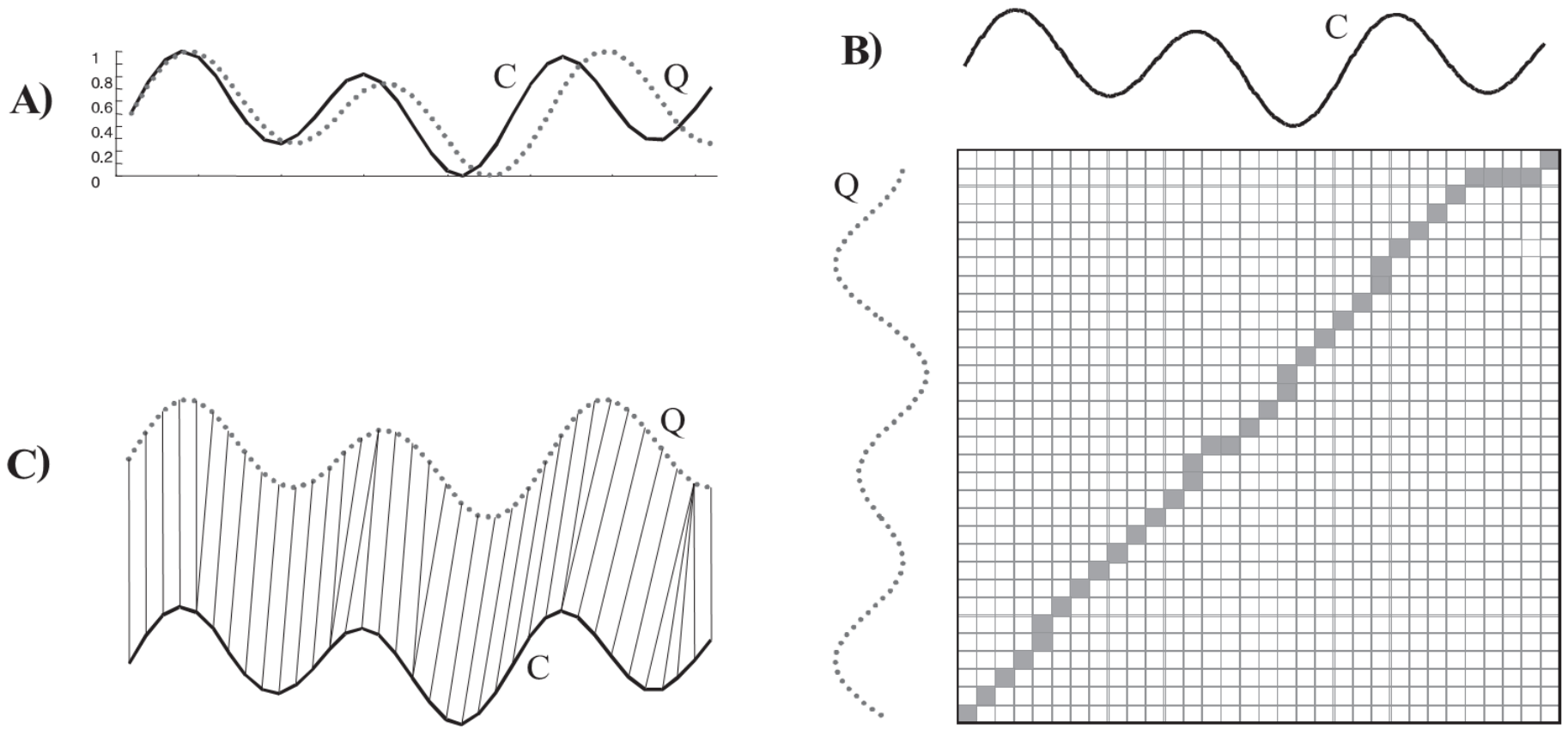


Fig. 3. **A**) Two sequences Q and C that are similar but out of phase. **B**) To align the sequences, we construct a warping matrix and search for the optimal warping path, shown with solid squares. **C**) The resulting alignment