CowBhave Localization Instructions

1. Data content

The data is available at https://zenodo.org/deposit/3900340. The data folder includes:

1. Raw data from the Entire barn experiment in the archive *Data_Exp08_11_2019.zip.001-016* divided into 16 parts.
2. Files related to the Entire barn experiment in the archive *AuxiliaryExp08_11_2019.zip*.
3. Raw data from the Waiting yard experiment in the archive *DataExp_30_01_2020.zip.001-003* divided into 3 parts.
4. Files related to the Waiting yard experiment in the archive *AuxiliaryExp30_01_2020.zip*.
5. Raw data from the RSS features experiments (propagation model and tag orientation) in the archive *TagStationExperiments.zip*.
6. Example of the reference video for the Entire barn experiment in *2019_11_08_14-15.wmv*.

The reference video can be viewed by *SpotterPlayer.exe* at https://www.mirasysusa.com/support.

2. Data structure

    2.1. Raw data files

The Ruuvi tag messages with the tag accelerations were received by the receiving stations (Raspberry Pi) and transferred to a computer. The collecting program running on the computer separated the messages related to different tags and stored in the files *RuuviData_TagTT_YYYY-MM-DD-HH.csv*, where TT is the tag number (1-25), YYYY, MM, DD and HH are the year, month, day and hour. The files include the following fields:

1. Receiving station number (1-10),
2. Receiving moment of the receiving station in format “2019-11-28T17:00:05.751”,
3. Number of tag (1-25),
4. RSSI measured by the receiving station,
5. Number of message sent by the RuuviTag,
6. Five triplets of the accelerations (X, Y, Z) measured by the RuuviTag,
7. Receiving moment of computer collecting data consisting of year, month, day, hour, minute, second, millisecond.

The files can be read by the function *ReadRuuviDataCSV*.

When the Ruuvi tag messages were not transferred to the collecting computer, they were stored on the receiving stations in files *RuuviData_TagTT_StST_YYYY-MM-DD.csv*, where TT is the tag number (1-25), ST is the receiving station number (1-10), YYYY, MM and DD are the year, month and day. The files can be read by the function *ReadRuuviDataRaspPiCSV*.

    2.2. RSS data files

The RSS received by all the receiving stations at all available moment for a single tag for a single day is stored in files *RSSData_TagTT_YYYY-MM-DD.csv*, where TT is the tag number (1-25), YYYY, MM and DD are the year, month and day. The files were generated from the raw data files by the file *Main_RawDataMerging*. The files include the tag number, the

Ruuvi tag message number, the sampling moment and the RSS values from all the receiving stations. The files can be read by the function *ReadRSSData*.

2.3. Accelerations data files

The accelerations measured by the tag at all available moment for a single tag for a single day are stored in files AccData_TagTT_YYYY-MM-DD.csv, where TT is the tag number (1-25), YYYY, MM and DD are the year, month and day. The data files were generated from the raw data files by the file *Main_RawDataMerging*. The data files include the sampling moment and the X, Y and Z components of the tag acceleration. The files can be read by the function *ReadAccData*.

2.4. Auxiliary files

2.4.1. Tag attaching table

During the experiment, the tags were attached to different cows for specific period. The information about the cow number and the periods is written in the file *TagCowNoFittingRef.csv* only for the periods when the reference was available, and in the file *TagCowNoFitting.csv* for the entire experiment. The file can be read by the function *ReadTagCowNoFitting*.

In the table the rows correspond to the tag number, and the columns correspond to the experiment day. During the days with empty cells the tags were not attached or fallen.

2.4.2. Barn and localization system structure (Figure 3)

The information about the location of the receiving stations, barn mapping points and obstacles for the cow motion is written in the file *BarnSystemStructure.csv*. The information is used for calculating the RSS depending on the distance between the mapping points and the receiving stations locations, calculating the emission and transition matrices for the Viterbi algorithm and drawing the barn map. The file can be read by the function *ReadBarnSystemStructure*.

The barn map with details can be drawn by the function *DrawBarnMap*. The location probabilities for the mapping points can be illustrated by the function *DrawHeatMap*.

2.4.3. Feeding and drinking reference

The feeding and drinking reference for the experiment period was generated by the Hokofarm system measuring the feed and water intake and was stored in the *FeedingData.csv* and *DrinkingData.csv* files. The files include the cow number, number of the feeding or drinking station and feeding or drinking periods. The files can be read by the function *ReadReferenceFeedingData*.

2.4.4. Milking reference

The milking reference for the experiment period was generated by the Lely Astronaut robot and was stored in the file *MilkingData.csv*. The file includes the cow number, milking periods. The file can be read by the function *ReadReferenceMilkingData*.

2.4.5. Body position reference

The cow body position (standing, lying and walking) and the cow location at the mapping points achieved from the video decoding was stored in the files *Reference_BodyPosition_YYYY-MM-DD.csv*, where YYYY, MM and DD are the year, month and day. Each file contains reference for all cows at the corresponding day. The files include the cow number, number of the mapping point where the cow was located, body position and location or body position time intervals. The files can be read by the function *ReadReferenceBodyPositionData*.

2.4.6. Feeding behavior reference

The cow feeding behavior (feeding, ruminating, nothing and drinking) achieved from the video decoding was stored in the files *Reference_FeedingBehavior_YYYY-MM-DD.csv*, where YYYY, MM and DD are the year, month and day. Each file contains reference for all cows at the corresponding day. The files include the cow number, feeding action and the time intervals. The files can be read by the function *ReadReferenceFeedingBehaviorData*.

3. Tag features experiment

3.1. RSS deviation illustrations (Figure 5 a, b, Figure 7)

Examples illustrating the RSS deviation are taken from the RSS propagation experiment and barn data and are presented in the file *Main_RSSDeviationPresentingForPaper*. The presenting includes the following stages:

1. Reading data from the RSS propagation experiment.
2. Choosing distances for examples.
3. Drawing the RSS for each distance and averaged lines (Figure 5 a).
4. Drawing histograms of the RSS distributions (Figure 5 a).
5. Choosing reference interval when cow is sleeping for examples.
6. Reading data from the barn experiment.
7. Drawing the RSS and filtered RSS line (Figure 5 b).
8. Drawing the RSS propagation line (Figure 7).
9. Reading data from the barn experiment.
10. Choosing reference with two cow walking intervals for examples.
11. Drawing the RSS for each interval and filtered RSS lines (Figure 7).

3.2. RSS propagation experiment (Figure 6, equation 1)

The data from the RSS propagation experiment is located in the folder TagStationExperiments\DistOrient_22-04-2020 an is processed in the file *Main_RSSPropagationExperiment*. The processing includes the following stages:

1. Reading the data from the data files and collecting into arrays.
2. Setting the measurement time recorded in the file *MeasurementTimeRecords.jpg*.
3. Drawing an example of RSS with average values for each distance and a line for the RSS propagation model (Figure 6 a, equation 1).
4. Extracting data for each tag-receiving station combination.
5. Drawing the RSS for each tag-receiving station combination and total averaged line (Figure 6 b, equation 1).
6. Calculating averaged RSS propagation model and drawing its line (Figure 6 b).

7. Drawing the averaged RSS achieved from all 10 tags (Figure 6 c).
8. Drawing the averaged RSS achieved from all 10 receiving stations (Figure 6 d).

3.3. RSS orientation experiment (Figure 8)

The data from the RSS propagation experiment in open space is located in the folder TagStationExperiments\Orient_28-04-2020 and from the RSS propagation experiment in open space is located in the folder TagStationExperiments\BarnOrient_16_06_2020. The data is processed in the file *Main_RSSOrientationExperiment*. The processing includes the following stages:

1. Reading the data from the data files and collecting into arrays.
2. Setting the measurement time recorded in the file *MeasurementTimeRecords.jpg*.
3. Extracting data for each tag-receiving station combination.
4. Drawing the RSS for each tag-receiving station combination and total averaged line (Figure 8 a and b).

3.4. Illustration of RSS filter development (Figure 10)

The application of the RSS filters is illustrated by the file *Main_RSSFilterDevelopment*.

The illustration includes the following stages:

1. Choosing date, time, tag and receiving station for example.
2. Reading the data from the barn experiment.
3. Definition of the windows size and Q parameter as in Table 1.
4. Application of different filters with different parameters and drawing the filtered RSS (Figure 10).

4. Localization

4.1. Localization algorithm (equations 1, 3, 4)

The localization algorithm is implemented in the function *RSSLocation_XYMap*. The calculation includes the following stages:

1. Reading data about the system and the barn structure (function *ReadBarnSystemStructure*).
2. Creating the RSS look up table for all mapping points and all receiving stations and calculating the average RSS for all the mapping points (function *DistToRSSI*, equation 1).
3. Searching for the best fit in the look up table for normalized RSS (equation 3) for all RSS samplings.
4. Calculating a probability of locating in all mapping points (equation 4) for all RSS samplings.
5. Applying the Viterbi algorithm finding locations maximizing the total probability for entire time interval (function *ViterbiCorrection*).

4.2. Example of localization for one tag for one day

An example of tag localization for one tag for specific hours of a day can be presented by the file *Main_LocalizationOneDayWithReference*. The calculation includes the following stages:

1. Definition of the tag number, date and time interval.
2. Reading the RSS data from the RSSData_TagTT_YYYY_MM_DD.csv file.
3. Filtering the RSS (function *MovingAverage0*).
4. Decreasing the RSS sampling frequency to 1 sampling in 5 seconds (function *DecreaseSignalFrequency*).
5. Applying the localization algorithm (function *RSSLocation_XYMap*).
6. Comparison of the calculated locations with the reference and evaluation of the localization accuracy (function *ComparisonWithLocationReference*).

4.3. Illustration of localization for one tag for one day (Figure 11)

An example of tag localization with illustration for one tag for specific hours of a day is presented by the file *Main_LocalizationPresentationForPaper*. The calculation includes the following stages:

1. Definition of the tag number 1 and date 2019-11-09.
2. Applying the localization algorithm (function *RSSLocation_XYMap*).
3. Drawing of the comparison between the calculated locations and the reference (function *ComparisonWithLocationReference*) (Figure 11 a).
4. Definition and adding the presented moments (Figure 11 a).
5. Drawing heating maps for all the presented moments (Figure 11 b).

4.4. Estimation of the localization accuracy (Figure 12)

The localization accuracy is estimated in the file *Main_LocalizationAccuracyEstimation*. The calculation includes the following stages:

1. Reading the data about the system and barn structure (function *ReadBarnSystemStructure*).
2. Reading the numbers of tags participating in the experiment and the dates on the experiment (function *ReadTagCowNoFitting*). The experiment dates with the available reference are recorded in the file *TagCowNoFittingRef.csv*. To achieve the tags attached to the cow collars, the function gets value 1.
3. Reading the RSS data from all available files with RSS data from the experiment by tag and day.
4. Filtering the RSS (function *MovingAverage0*).
5. Decreasing the RSS sampling frequency to 1 sampling in 5 seconds (function *DecreaseSignalFrequency*).
6. Applying the localization algorithm (function *RSSLocation_XYMap*).
7. Fitting the time intervals between the calculated locations and the reference (function *ComparisonWithLocationReference*).

8. Collection the calculated and reference data for each cow.
9. Collection the calculated and reference data for each tag.
10. Calculation of the average localization error and box plot parameters.
11. Calculating the average localization accuracy.
12. Drawing the box plots for each cow (Figure 12 a, b).
13. Drawing the total cumulative error (Figure 12 c, d).

4.5. Application of the localization algorithm (Figure 13)

The localization accuracy is estimated in the file *Main_LocalizationApplication*. The calculation includes the following stages:

1. Reading the data about the system and barn structure (function *ReadBarnSystemStructure*).
2. Reading the numbers of tags participating in the experiment and the dates on the experiment (function *ReadTagCowNoFitting*). The experiment dates with the available reference are recorded in the file *TagCowNoFitting.csv*. To achieve the tags attached to the cow collars, the function gets value 1.
3. Reading the RSS data from all available files with RSS data from the experiment by tag and day.
4. Filtering the RSS (function *MovingAverage0*).
5. Decreasing the RSS sampling frequency to 1 sampling in 5 seconds (function *DecreaseSignalFrequency*).
6. Applying the localization algorithm (function *RSSLocation_XYMap*).
7. Collection the calculated data for each cow.
8. Drawing an example of a behavior histogram (Figure 13 e).
9. Drawing an example of preferable cow locations (Figure 13 a).
10. Drawing total preferable locations in the barn (Figure 13 b).