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A GIS framework for spatio-temporal analysis and visualization of laboratory mice tracking data

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Abstract

Knowing the locations and spatio-temporal paths of individual mice is an essential prerequisite for behavioral analysis of large groups of laboratory mice. Traditional observations have been carried out by trained humans who are able to distinguish more than fifty behavioral patterns. This is a tedious labor limited with respect to observation length. In this paper we propose a tracking solution based on the integration of GIS and RFID (Radio Frequency Identification) technology to automatically collect 24h/7days of movement data. Appropriate cage design and antenna placement are discussed. A software solution is presented to facilitate the recording (JerryTS), visualization and analysis (TOM) of mice movements.

1. Introduction

The motivation behind this work is to observe the behavior and movement of laboratory mice in a large indoor semi-natural environment (SNE) measuring 1.75 by 1.75 by 2.1 m (L x W x H) (Figure 1). In this case biologists want to detect differences between mice carrying a genetic disposition to develop Alzheimer-like pathology and their wildtype conspecifics under semi-natural conditions. The SNE contains several floors connected by small bridges and ropes that allow the mice to establish a complex social system comprising different territories.

Figure 1 SNE without antennas

Previously, data has been collected manually by observers sitting in front of this complex cage. The observers are thoroughly trained in behavioral biology and can differentiate up to 55 unique behavioral and movement patterns. The population is allowed to grow up to a size of 40 adult mice (plus their offspring), who are individually marked using a color coding scheme on their tails and ears. The resulting data gets analyzed statistically to investigate mice behavior.

There are, however, disadvantages regarding the manual recording of animal behavior: The performance of a single human observer varies to some degree constrained by fatigue or mood, and different observers may introduce a specific bias to the recording process (Lewejohann et al. 2006). Furthermore, some information (e.g., accurate metric measures) can not be gained by analogue observation of an animal. Human observation is also limited with respect to observation length, making it difficult to gain long-term data (e.g., 24 hour observations). Moreover, data collection during the night-phase is challenging due to the difficulties of identifying color-marked mice in the dark (it is important to consider that mice are nocturnal animals).

The motivation behind the introduction of an automatic RFID-based tracking system and GIS framework for laboratory mice is to improve and extend human observations. The aim of this research is therefore to establish a system, which automatically tracks, visualizes and analyses spatio-temporal data of a large number of individual subjects over a long period of time.
The integration of RFID technology in the SNE requires some modifications to the original cage design. The enclosure is equipped with ring antennas placed at strategically chosen spots. The challenge is finding a hardware setup and cage design which allow collecting consistent data and retain the semi-natural character of the cage. Furthermore a new software solution must be developed in order to show the positions of the mice at certain times in the cage and to allow several analyses of mice behavior.

Section 2 presents the base technology and the methods used in this work. In Section 3 we introduce the test environment and application scenario – laboratory mice in a semi-natural environment. Section 4 describes and specifies the two main software solutions developed for automatic animal tracking, and the analysis and visualization of the resulting data. Section 5 discusses the results of applying the software prototype to the test environment. The paper finishes with conclusions and directions for further work.

2. Technology and Methods

Before specifying and implementing the automatic tracking, visualization, and analysis system for laboratory mice it is necessary to give some background information about the used RFID technology and concepts from time geography.

2.1 Technology

As mentioned before the collecting of data has previously been done by visual observation. Different technologies are in use to automate data collection in the fauna. For example, the movement behavior of Antarctic fur seals is observed by satellite transmitters. Three satellites were used providing a positional accuracy of 150 m to determine the tracks of the animals (Bonadonna et al. 2000). Cows are tracked in their barn using radar technology. Transmitters are fixed at the neckband of the cows, allowing a 2D localization with an accuracy of 25 cm (Neisen 2005). These tracking techniques do not fit the requirements for indoor mice tracking. GPS (Global Positioning System) is inappropriate for indoor tracking because of lacking visibility of satellites (Leick 1995). The radar technique is not useful because mice cannot wear large transponders. Both technologies also fail with regard to the accuracy requirements for the presented work.

The RFID technology for the tracking of the mice is chosen because the passive transponders are very small and therefore easy to inject into the mice. The installation of the antennas in the SNE is possible and accurate positional data can be achieved. RFID technology has been successfully applied in various domains. For example, RFID chips were used during the soccer World Cup 2006 in Germany for entrance controls. Such technology makes it also possible to track visitors and support them in their wayfinding tasks, e.g., from the parking lot to theirs seats in the stadium (Tomberge and Raubal 2006). RFID was also used to improve the position of mobile robots and persons in their environment: With RFID tags it is possible to create maps using mobile platforms that are equipped with RFID antennas which assist localization (Hähnel et al. 2004). RFID technology can be used to collect environmental data and build up a Bayesian network for positioning (Brandherm and Schwartz 2005).

2.2 Methods

Data collected with RFID have a spatial and a temporal dimension. The visualization and the analysis of the data must reflect the time-variant position in space. In *time geography* human activities have been the focus within an effort to define the space-time mechanics. Thereby human activity patterns and movement in space and time are analyzed. Individual activities and movements are continuous sequences in geographical space. The number and places of activities of one person during a day are limited by time-geographic constraints (Kwan 2004). Presence of other people and rules in a community restrict a person's potential actions. The constraints can be divided into (Hägerstrand 1970):

- *Capability constraints*: activity and movement radius are limited because of biological conditions such as eating or sleeping;
- *coupling constraints*: refer to the requirement for a person to be at a specific location at a certain time or for a fixed time duration;
- *authority constraints*: things or events are controlled by certain individuals or groups.

An individual describes a path in a space-time framework, which reaches from the point of birth to the point of death. The concept of a life path can be graphically visualized: the three-dimensional space is shown in a two dimensional plane und the perpendicular describes the time (Hägerstrand 1970). *Space-time paths* and *space-time prisms* demonstrate two central concepts for visualization and analysis of movement patterns in time geography (Miller 2005).

- Space-time path:

  Space-time paths depict the movement of individuals in space over time. Such paths are available at various spatial (e.g., house, city, country) and temporal granularities (e.g., decade, year, day) and can be represented through different dimensions. Figure 2 shows a person's space-time path during a day, representing her movements and activity participation at three different locations. The slope of the path represents the travel velocity. If the path is vertical then the person is engaged in a stationary activity.

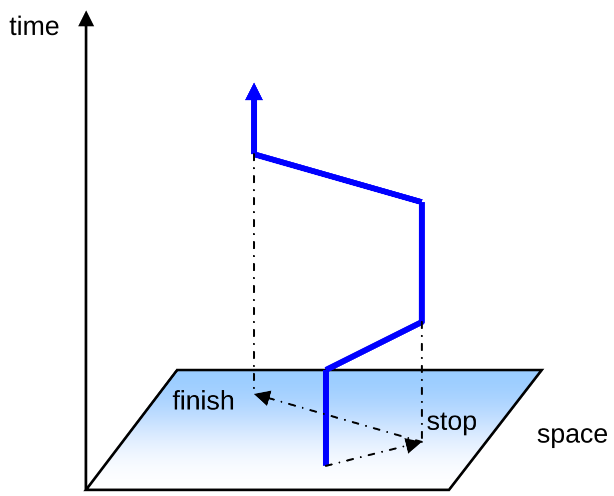

Figure 2 Space-time path

- Space-time prism:

  All space-time paths must lie within space-time prisms. These are geometrical constructs of two intersecting cones (Lenntorp 1976). Their boundaries limit the possible locations a path can take based on people's abilities to trade time for space. In order for a person or activity to be accessible, its space-time station must intersect the space-time prism for a minimal temporal duration. Figure 3 depicts a space-time prism for a scenario where origin and destination have the same location. The time budget is defined by $\Delta t = t2 - t1$ in which a person can move away from the origin, limited only by the maximum travel velocity.

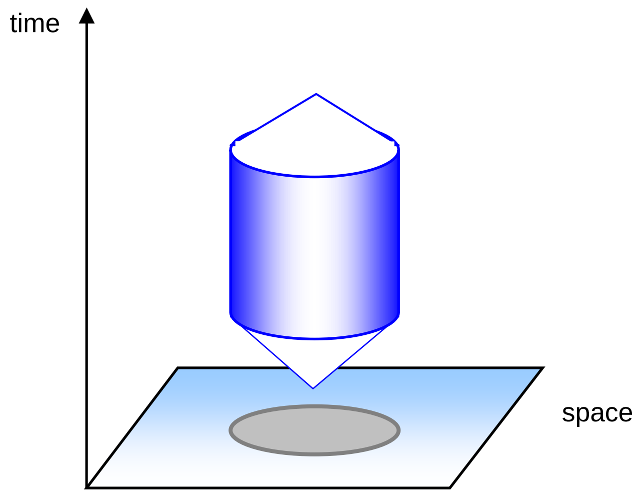

Figure 3 Space-time prism

Time geography has been applied in the area of GIS regarding transportation networks to model and measure space-time accessibility (Miller 1999, Miller and Wu 2000; Wu and Miller 2001). It has also been advocated to integrate time geography with both GIS and Location-Based Services to achieve more user-centered systems (Raubal et al. 2004; Miller 2005). Further applications in the geo-domain concern the structuring of dynamic wayfinding environments (Hendricks et al. 2003) and the modeling of geospatial lifelines (Hariharan and Hornsby 2000). Analytical formulations of basic entities and relationships from time geography can be found in (Miller 2005a). A space-time web model—a display of life paths which underlie the time-geographic constraints—can be applied to all aspects of biology to vary from flora over fauna to humans (Hägerstrand 1970).

3. Test environment and application

To get the data for movement and behavior of the mice an RFID system (Trovan Electronic Identification Systems) consisting of reader (LID 665 Miniature OEM Board), ring antennas (air-core coil antenna for LID 665) and animal glass transponders (ID 100) are used. The mice are individually marked with these small (12 mm length, 2 mm diameter) passive integrated transponders (PIT) that are injected subcutaneously between the scapulas. The IDs of individual animals can be read while traversing the electromagnetic field, which is established by the ring antennas, e.g. when passing through tubes or visiting drinking places.

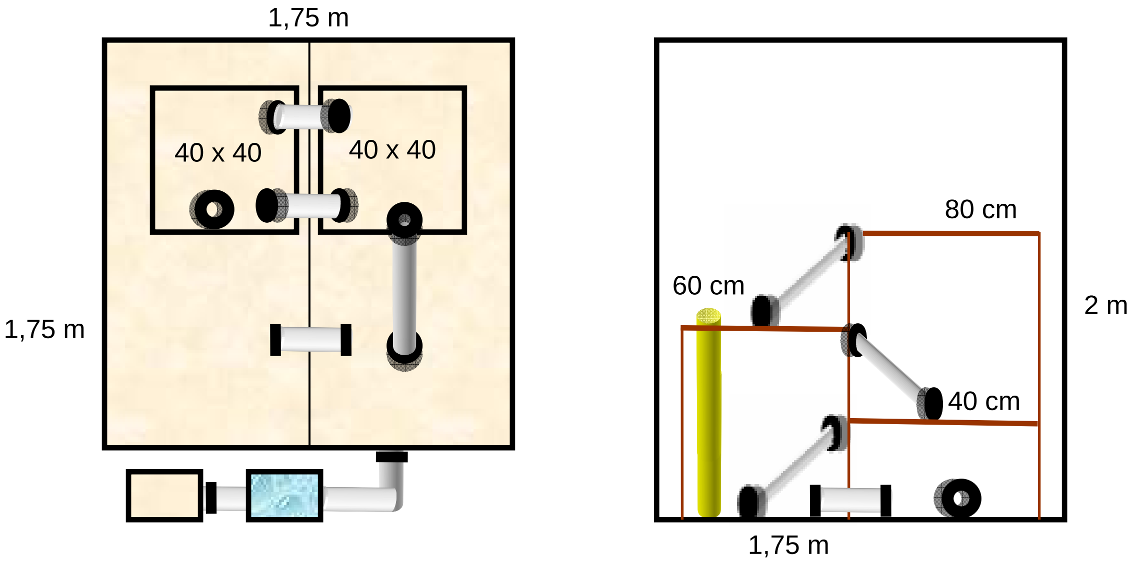

Figure 4 Schematic view of the SNE (top and front)

In the setup the minimum distance between two antennas is 20 cm (Figure 4). Transponders are read within a 0.5 cm distance, therefore mice do not necessarily have to move over antennas. The readers are able to read several transponders at the same time at a maximum rate of 26 Hertz.

In order to receive meaningful data describing the movement of mice, some structural changes must be considered and realized in the SNE, constraining the mice to pre-defined pathways. The cage is restructured to get information about the mice regarding changes of floors, movement across floors, directions of movement, home ranges of individuals, drinking and emigration behavior. To gather those data the cage is realized as follows: The SNE is divided into five areas (Figure 5). The ground is divided by a wall into two sections and there are 3 floors on different levels which are connected by sloping tubes and a rope. Outside the SNE an emigration cage is provided, which can be accessed from the ground floor (i.e., to give shelter to low-ranking animals within the group hierarchy) via a tube and crossing a water basin. To get reasonable data the antennas are placed at strategically chosen spots, i.e., where the mice must cross. Every Plexiglas tube has two antennas at the beginning and end, therefore it can be detected when a mouse changes the floor, in which direction mice cross the tubes and also the velocity of mice.

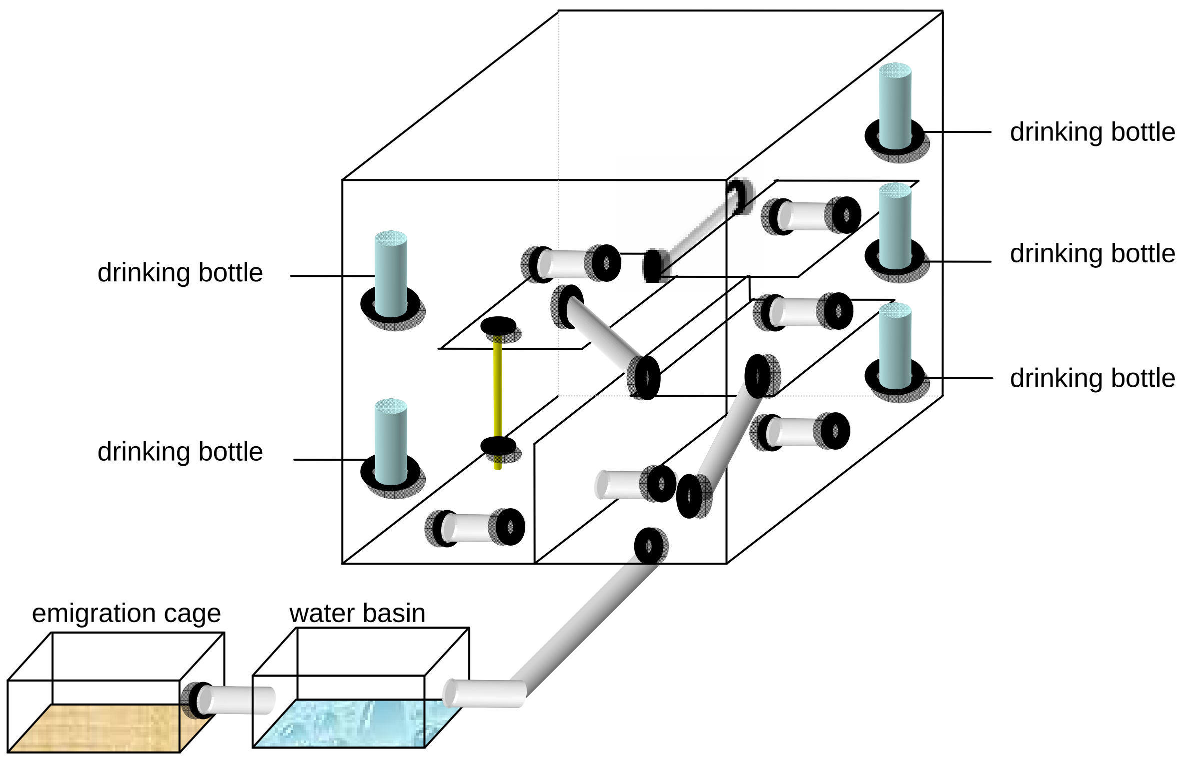

Figure 5 Schematic view of SNE with antennas

In every area there is an antenna beneath the drinking bottle to get data about the drinking behavior and to establish a warning system when a mouse does not drink. Additionally, every area contains a tube supplied with two antennas, enabling the collection of data about the movement on the floors and possible dominance relationships. In total there are 27 antennas integrated in the SNE (see Figure 6). With this design it is possible to collect the necessary data about movement and behavior.

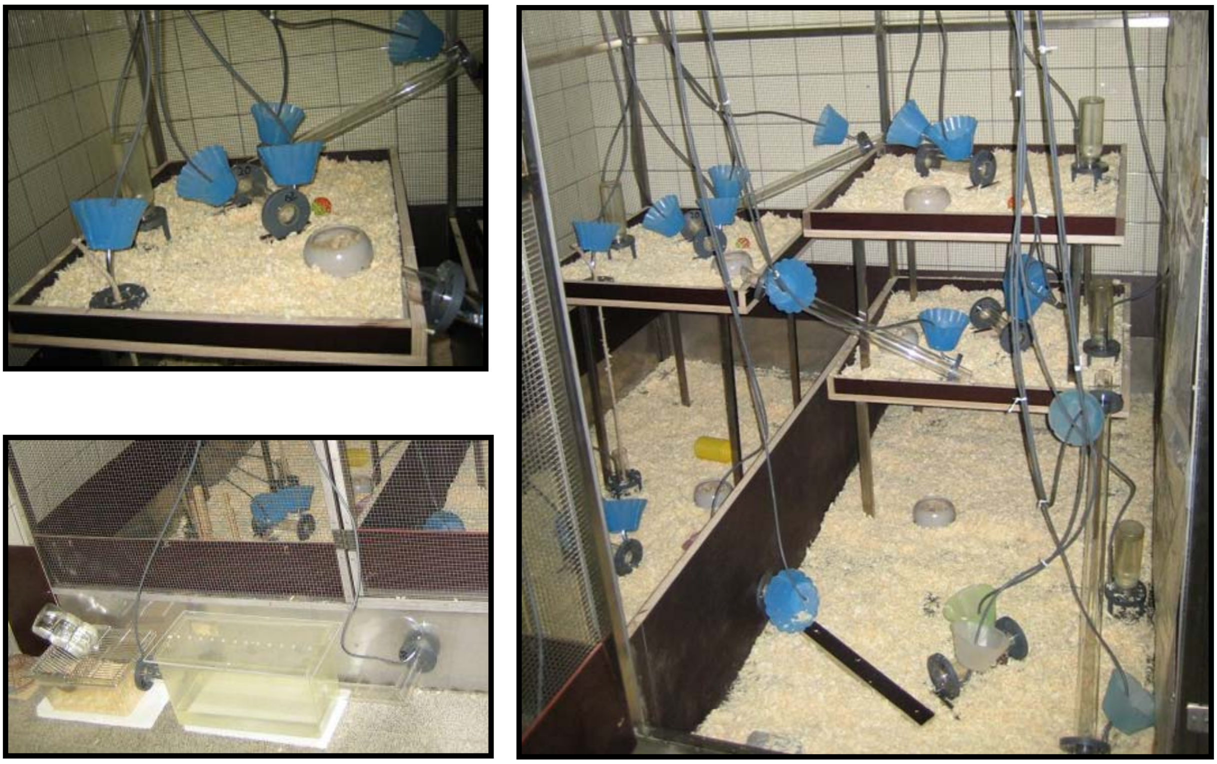

Figure 6 SNE with antennas

4. Software Solutions: JerryTS and TOM

To establish an automatic tracking, visualization and analysis system for laboratory mice it is necessary to develop a software solution, which collects, stores, manages, and supplies the data and visualizes the derived information.

4.1 JerryTS (Database management for RFID-based events)

To configure the RFID readers and to handle the reading of transponder codes a software called *JerryTS* has been developed using the programming language Java. If a mouse enters the electromagnetic field of the antenna the transponder code is read by the RFID reader, JerryTS picks it up and sends it to a personal computer. The code gets a time stamp by the PC with a millisecond resolution and is stored online in a relational database (Figure 7). The table contains data about when (date, time, milliseconds), where (the antenna), and who (transponder code) appears at an antenna.

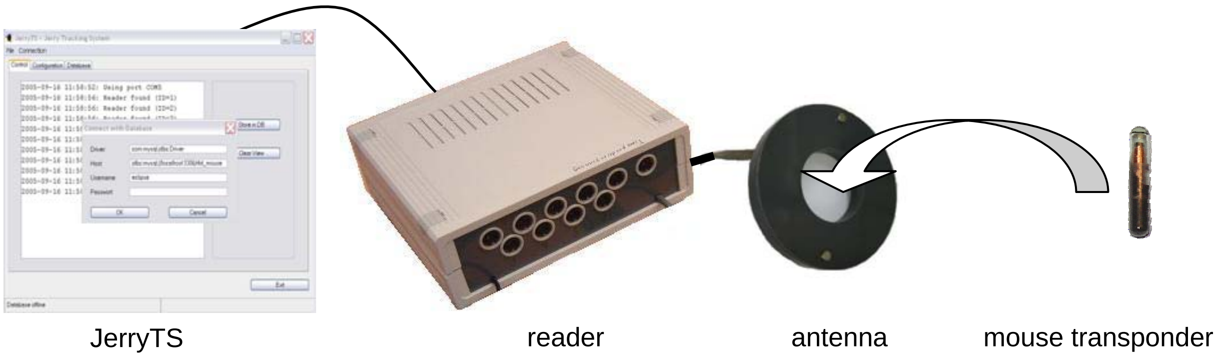

Figure 7 RFID system – when a mouse enters the antenna

4.2 TOM

For the visualization and analysis of the collected data the Geographic Information System ArcGIS[1] is used. ArcScene, an additional ArcGIS component, which is useful for the visualization of 3D data is enhanced by developing an extension called TOM (Tracking Objects - Moving). TOM enables to visualize and analyze the tracking data. The position of each mouse at a certain point (antenna) in time can be visualized and the movement of the mice in time can be shown. Furthermore, attribute data such as the date of birth of the mice can be queried.

4.2.1 Requirements

The context in which this application is used requires the following tasks:

- Allocation of movement and attribute data:

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[1] http://www.esri.com/software/arcgis/

The database filled with attribute and movement data collected by JerryTS must be connected to the new software. The data must be prepared for further processing so that redundant data can be aggregated and illegal transponder codes found.

- Digitizing of the data sources:

  The data for the visualization and analysis must be created. The SNE with the different floors, the antennas and the dynamically moving mice must be digitized to scale. Such graphical data are required for the visualization.

- Visualization of movement and behavior data:

  The created digital data must be visualized in three dimensions. Visualization of the SNE and the antennas should not change, the position of the mice must be adapted to the movement in time. The mice in the SNE have to be listed so that specific subjects can be chosen for visualization and analysis. They should be displayed for a certain time interval with different temporal resolutions and colored depending on gender. The presentation must point out whether a position of a mouse is approximated or based on a database entry. Analyses and statistics must be clearly represented.

- Analysis of movement and behavior data:

  An automated analysis function should query the attribute data (e.g. gender or day of birth) of selected mice and statistics about behavior, i.e., analysis per day and per level.

- The data export must be in a generally accepted format to be used with other software solutions.

4.2.2 Modeling

Before the software extension can be implemented, the data base must be created with the existing software solutions ArcCatalog (to manage and create the necessary files and data structures) and ArcMap (to digitize the cage). To store the data a PGDB (Personal

Geodatabase) in ArcCatalog is built. For this purpose a *feature dataset* is created. Therefore a coordinate system (local Cartesian projection) is developed that fits to the large scale. In the *feature dataset* the model of the SNE is created. Every level is represented by *feature class* with the corresponding attributes, so the layers can be handled separately. The RFID antennas and tubes are realized as a geometric network with nodes and edges containing different weights for the analysis. To visualize and analyze the mice a further feature class stores mouse objects with the necessary attributes.

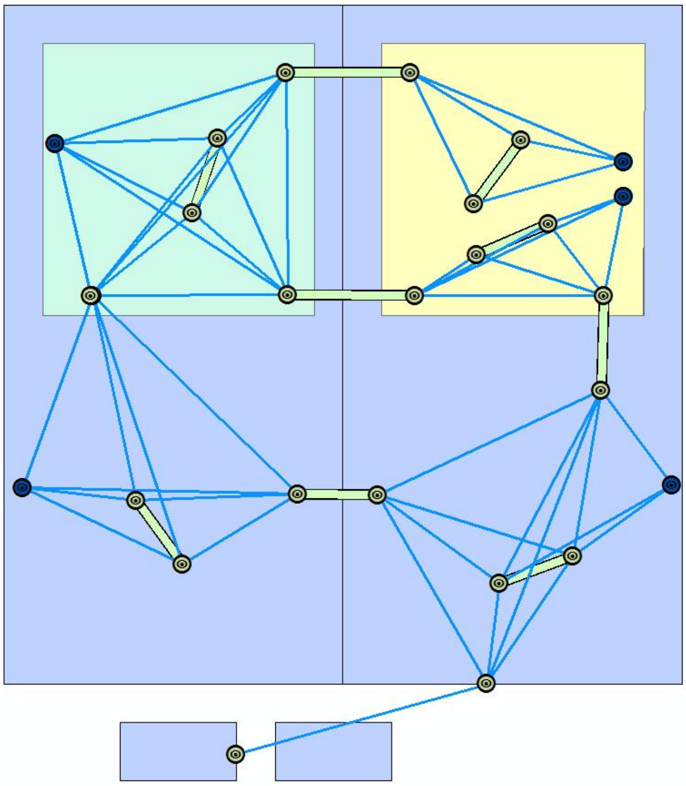
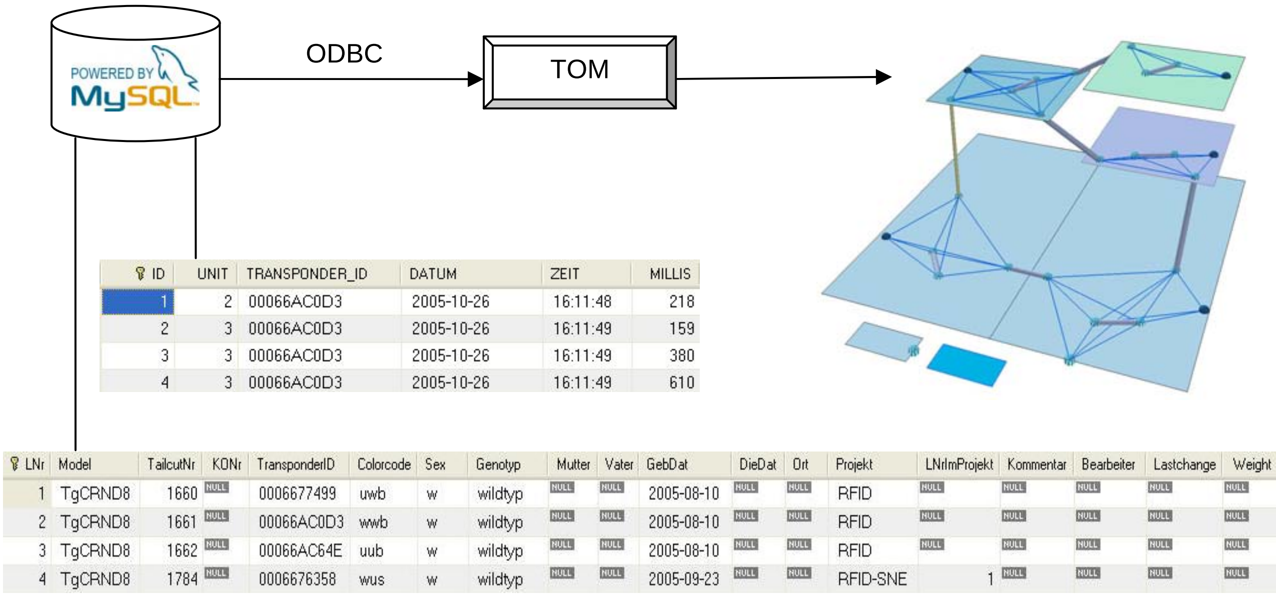


Figure 8 Data base created in ArcMap

All time invariant components of the setting are digitized in ArcMap (Figure 8). Those are the levels, the positions of the antennas and the ways between the antennas. The dot features representing the mice are created in the program dynamically because they do not have a fixed position. The spatial resolution is in centimeters.

4.2.3 Implementation

The prototypical implementation of the ArcScene extension is done with ArcObjects and the programming language C#. First the database connection to the extension is realized.



ID	UNIT	TRANSPONDER_ID	DATUM	ZEIT	MILLIS
1	2	00066AC0D3	2005-10-26	16:11:48	218
2	3	00066AC0D3	2005-10-26	16:11:49	159
3	3	00066AC0D3	2005-10-26	16:11:49	380
4	3	00066AC0D3	2005-10-26	16:11:49	610

LNr	Model	TailcutNr	KONr	TransponderID	Colorcode	Sex	Genotyp	Mutter	Vater	GebDat	DieDat	Ort	Projekt	LNrImProjekt	Kommentar	Bearbeiter	Lastchange	Weight
1	TgCRND8	1660	NULL	0006677499	uwb	w	wildtyp	NULL	NULL	2005-08-10	NULL	NULL	RFID	NULL	NULL	NULL	NULL	NULL
2	TgCRND8	1661	NULL	00066AC0D3	wwb	w	wildtyp	NULL	NULL	2005-08-10	NULL	NULL	RFID	NULL	NULL	NULL	NULL	NULL
3	TgCRND8	1662	NULL	00066AC64E	uub	w	wildtyp	NULL	NULL	2005-08-10	NULL	NULL	RFID	NULL	NULL	NULL	NULL	NULL
4	TgCRND8	1784	NULL	0006676358	wus	w	wildtyp	NULL	NULL	2005-09-23	NULL	NULL	RFID-SNE	1	NULL	NULL	NULL	NULL

Figure 9 Program flow of TOM

The data base consists of two tables: one with the time and movement data (collected by JerryTS) and the second with the mice attribute data (Figure 9). TOM is implemented by the MVC (Model View Controller) pattern (Krasner and Pope 1988) with three packages (Figure 10):

- *Model*: Data base
- *Controller*: Distribution and algorithms
- *View*: GUI-elements

Beyond this package structure there exists the superior class “TOM” which represents the whole extension.

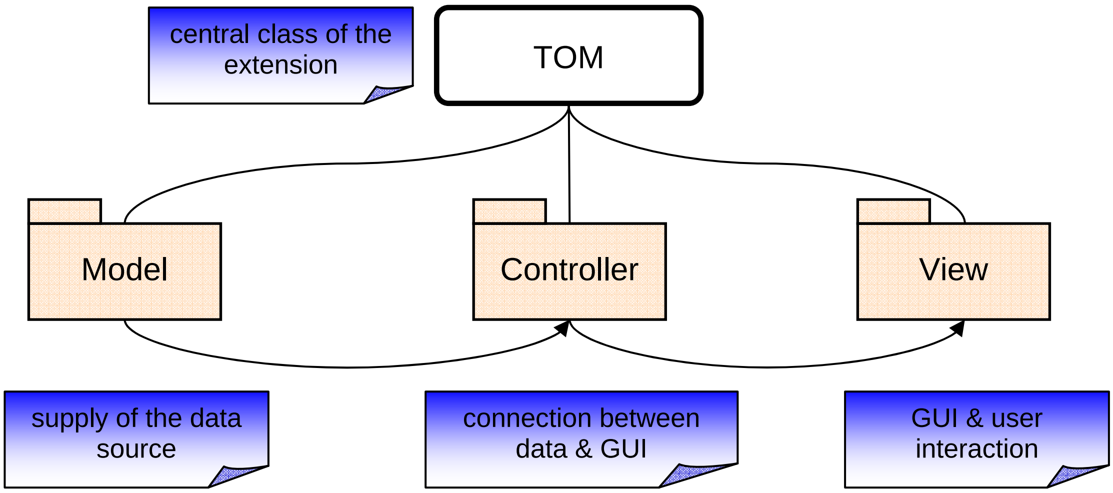


Figure 10 Architecture of TOM

Model

The *model* consists of all classes that belong to the data base. In these classes the connection to the database over an ODBC interface is made, the SQL statements which are the foundation of the visualization and analysis are held and constructed by user input. All necessary methods which provide data in the needed formats are given.

To find out which mice are actually in the cage a join over the tables with attribute and movement data is made. The result shows a list with transponder codes, which exist in both tables (Listing 1).

```
SELECT DISTINCT t.transponder_Id FROM testdaten t, mice m WHERE
 m.transponderId = t.transponder_Id
```

Listing 1 SQL-Statement which filters the transponder codes

With the use of SQL the database entries are clustered because both display and analysis should occur in a resolution of seconds. Therefore even the positional data is available in a resolution of seconds. If a mouse was in one second at two different antennas the second is dissolved into milliseconds. Both positions are stored in the database and no positional information in lost (Listing 2).

```
SELECT unit, datum, zeit, millis FROM testdaten t WHERE
 transponder_Id = '00066AC0D3' AND datum = '2005-10-27' AND
 zeit >= '16:36:27' GROUP BY zeit, unit, ORDER BY zeit, millis
```

Listing 2 Statement for clustering of positional data

To manage the mice a separate future class is needed, which represents the mice with their attribute data (Figure 11). A mouse object is created when a mouse should be displayed but does not exist. Whenever the program is started, all mouse features of a previous session get deleted.

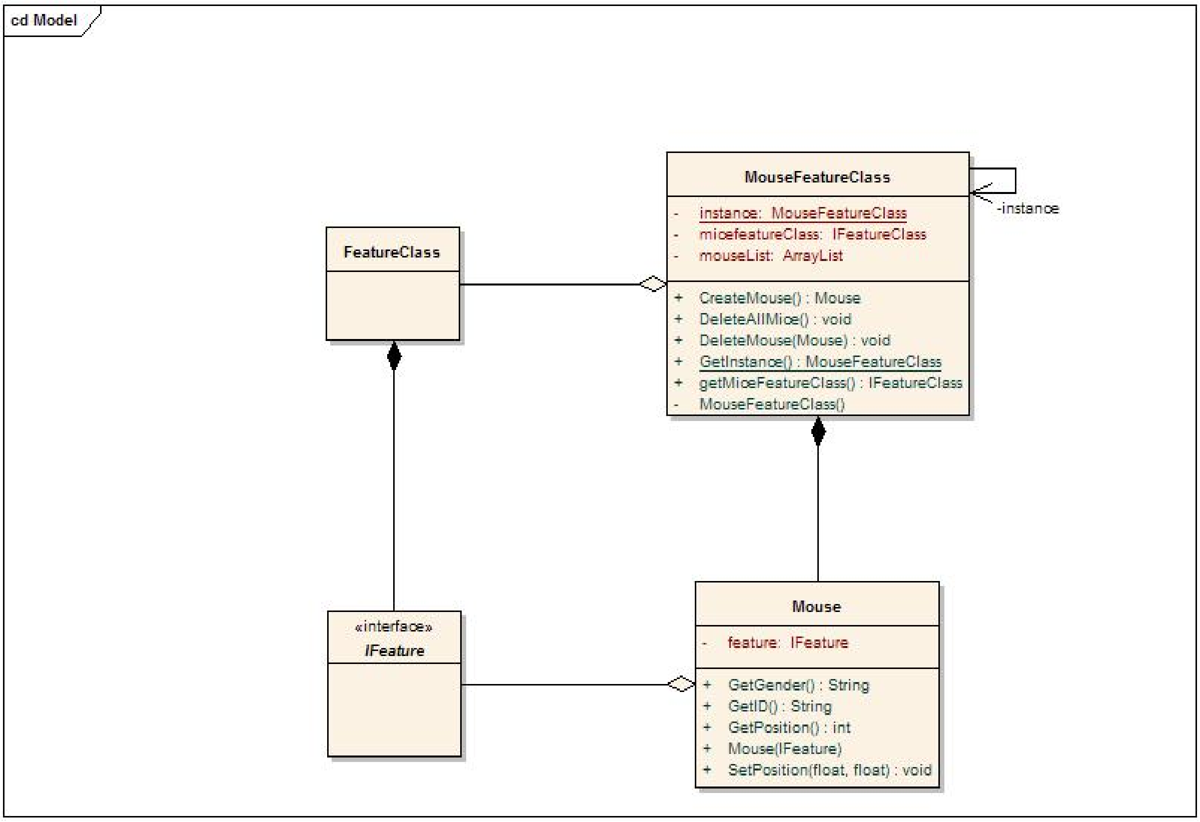


Figure 11 Data model for the mice

Controller

Classes in the controller provide methods, which allow communication between *model* and the graphical user interface (GUI), realize the time component in the extension and enable analysis. The management of time is realized with a timer. Through the start of the timer it is verified whether the selected mice exist. If a mouse object does not exist, a new one is created and depending on the gender colored in blue or red. At every tick of the timer a data structure—filled by the database—is queried with regard to whether positional data for every displayed mouse is available. When an entry is found the position of the corresponding antenna is read and assigned to the mouse object. The mouse then "jumps" from antenna to antenna. If there are there two positional entries for one second the mouse moves from the first to the second position. If there is no entry in the data structure the color of the mouse at its last position changes to indicate that data are not "live" but only approximated.

TOM provides statistical functions for analysis of the collected data. The analysis is divided into statistics per day and per level (Table 1). Analysis per day shows the last time stamp of drinking and weighting, the number of antenna contacts and the number of used levels. The two last variables are indications for the agility of mice. Analysis per level provides information about the duration of stay per level, the count of antenna contacts and whether a mouse stays alone on the level or if other mice have been present.

Table 1 Analysis functions

Analysis per day	**Analysis per level**
Time of last drinking	Number of antenna contacts
Time of last weighting	Duration of stay
Number of antenna contacts	Stay with other mice
Number of used levels	

As an example for the analysis, we describe the functionality of the algorithm calculating whether a mouse stays at a certain date alone on a level or not (Listing 3).

```
// returns an array with Boolean which show whether a mouse had contact
to other mice per level

1  contactToOtherMiceOnLevel bool[] (String mice, String currentDate){
2  bool[] levelsMeet ={false,false,false,false,false,false};
3  String[]miceWithoutSelected;     //array with all unselected mice
4  String antennaStart;             //number of start antenna
5  Date timeStart                   //time of contact with antennaStart
6     for(i = 1; i < antennaTimeArray; i++){
7           String antenna = antennaTimeArray[i][0];
8           if(antennaStart and antenna not on the same level){
9              findLevelWhereMouseIs();
10             DateTime time = antennaTimeArray[i-1][1]; //last time on
11                                                                   level
12                if(two mice on one level){
13                     getTimeFromDB&AntennasForUnselectedMice;
14                     if(unselectedMiceOnLevelWithMice){
15                        set levelsMeet corresponding of true;
16                        timeStart = time;
17                        antennaStart = antenna;
18                      }
19                }
20          }
21          return levelsMeet;
22    }
23 }
```

Listing 3 Pseudo code of the method “contactToOtherMiceOnLevel”

The method “`contactToOtherMiceOnLevel`” which returns an array with Boolean values has two parameters: the selected mouse and the date for which the information is queried (line 1). In line 2 to 5 necessary attributes are declared and initialized: the array which will be returned as result is initialized with the Boolean value ‘false’ for each level (line 2). The clustered data for one day (contacted antennas und timestamps) of the other unselected mice are stored in an array “`miceWithoutSelected`” (line 3). The number of the antenna where the selected mouse has the first contact at this date and the time of this contact are recognized (line 4 and 5).

First the changes of levels for the selected mouse must be detected (lines 6-9). Therefore the antennas were associated with the corresponding levels before. Now the list “`antennaTimeArray`” (antenna and time data) of the selected mouse is scanned until an antenna is found which is not derived from the same level like “`antennaStart`“ (line 8). If a change of level is found, we know the current level (line 9) and the time interval when the mouse was on this level (line 10). In line 13 it is verified whether an antenna entry of an unselected mouse for this time interval exists:

- If an antenna entry of an unselected mouse exists, all entries in the list “`miceWithoutSelected`” are checked if the antennas are from the same level like antenna start (line 14):
    - If the antennas are from the same level, the corresponding Boolean attribute for the level becomes true (line 15). That means the selected mouse has contact to another mouse at this date on this level.
    - If the antennas are not from the same level, nothing happens and the loop starts again: antenna start gets the first antenna of the next level as new value and the next change of level will be detected (go to line 6).
- If no antenna entry of an unselected mouse in the time interval exists in line 13, the loop starts again, the start antenna gets first antenna of the next level as new value and the next change of level will be detected (go to line 6).

The algorithm ends when the list “`antennaTimeArray`” is completely traversed and all possible level changes are detected.

It is possible to export the data for statistical analyses with other software. The data is derived from two underlying database relations: one table with the tracking data filled by JerryTS and a second table where attribute data of the mice are stored. In addition, a warning system is established, to detect when a mouse has not been drinking for a longer time period or using the emigration cage.

View

The *view* package contains all classes which belong to the GUI. The list of mice and the user input are connected to one GUI element. Furthermore there are classes for the toolbar, menu and dialogs.

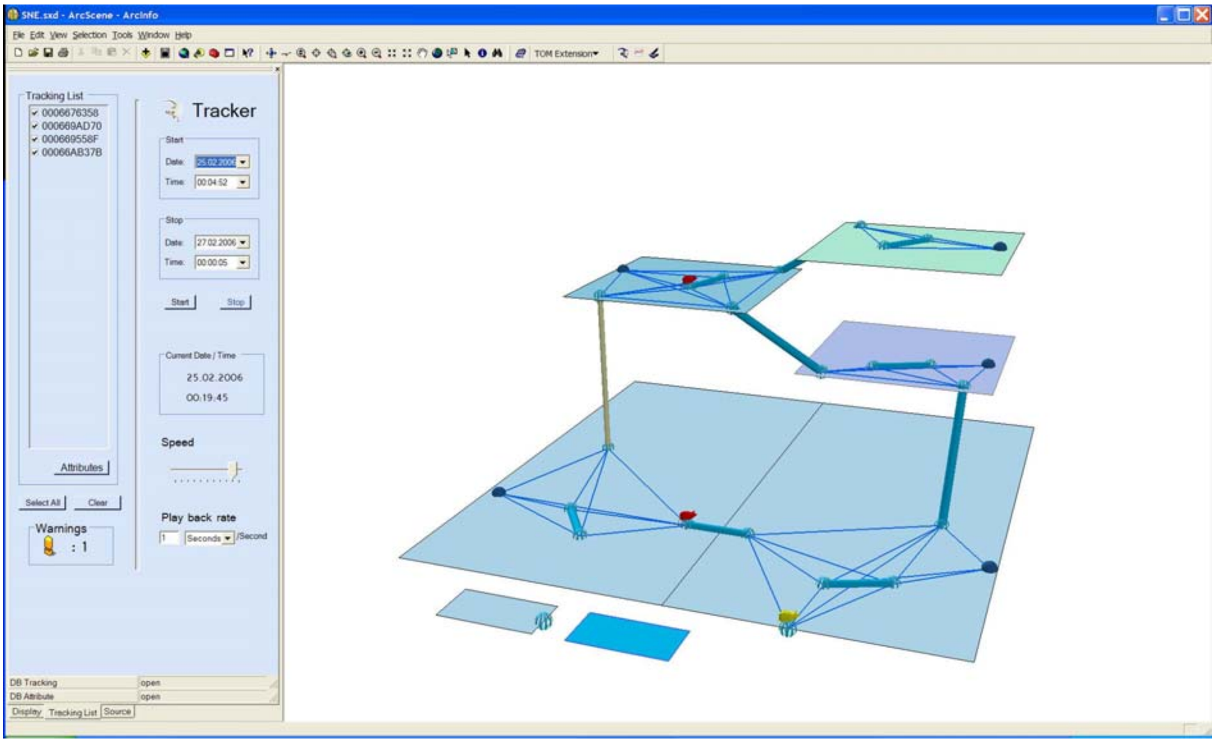
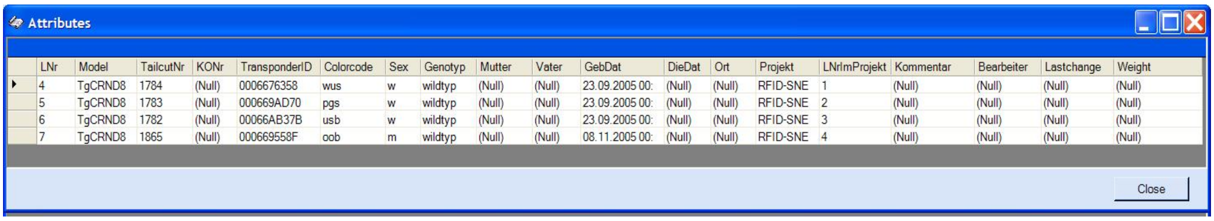


Figure 12 Screenshot TOM

To start the extension the toolbar is used. After the start the database connection must be established and the data base of the SNE must be chosen. The list of the mice is automatically loaded (Figure 12). If mice are selected, the visualization of the attribute data as well as the display of mice is possible.

5. Results and discussion

The software JerryTS configures the RFID readers and stores the read transponder codes in an RDBMS. One table of the database stores the transponder codes with the number of the reader with date, time and milliseconds. The system provides an ID so the dataset can be identified. Every dataset is unique, for every timestamp there exists only one database entry.


Attributes

LNr	Model	TailcutNr	KONr	TransponderID	Colorcode	Sex	Genotyp	Mutter	Vater	GebDat	DieDat	Ort	Projekt	LNrImProjekt	Kommentar	Bearbeiter	Lastchange	Weight
4	TgCRND8	1784	(Null)	0006676358	wus	w	wildtyp	(Null)	(Null)	23.09.2005 00:	(Null)	(Null)	RFID-SNE	1	(Null)	(Null)	(Null)	(Null)
5	TgCRND8	1783	(Null)	000669AD70	pgs	w	wildtyp	(Null)	(Null)	23.09.2005 00:	(Null)	(Null)	RFID-SNE	2	(Null)	(Null)	(Null)	(Null)
6	TgCRND8	1782	(Null)	00066AB37B	usb	w	wildtyp	(Null)	(Null)	23.09.2005 00:	(Null)	(Null)	RFID-SNE	3	(Null)	(Null)	(Null)	(Null)
7	TgCRND8	1865	(Null)	000669558F	oob	m	wildtyp	(Null)	(Null)	08.11.2005 00:	(Null)	(Null)	RFID-SNE	4	(Null)	(Null)	(Null)	(Null)

Close

Figure 13 Attribute dialog of attribute data stored in the database

The software TOM allows to visualize attribute data und motion sequences and to perform statistical analyses of the collected data. It is possible to query attribute data of selected mice from the centrally managed attribute table and to view them in a table (Figure 13).

The position of selected mice inside the SNE can be displayed. For the visualization a time interval must be chosen. During this interval the mice move in different display speeds and in different play back rates. The time-variant position can be tracked through the visualization sequence (Figure 14). A chosen mouse describes a space-time path and by means of this the activity and movement patterns can be derived. The spatial component is displayed in three dimensions, the temporal component is realized through the clock in the GUI. Through the proposed solution in milliseconds an accurate representation of the data is possible: if during one second, a signal of the same mouse is registered at two antennas—when antennas are directly connected through a tube—a linear movement is displayed.

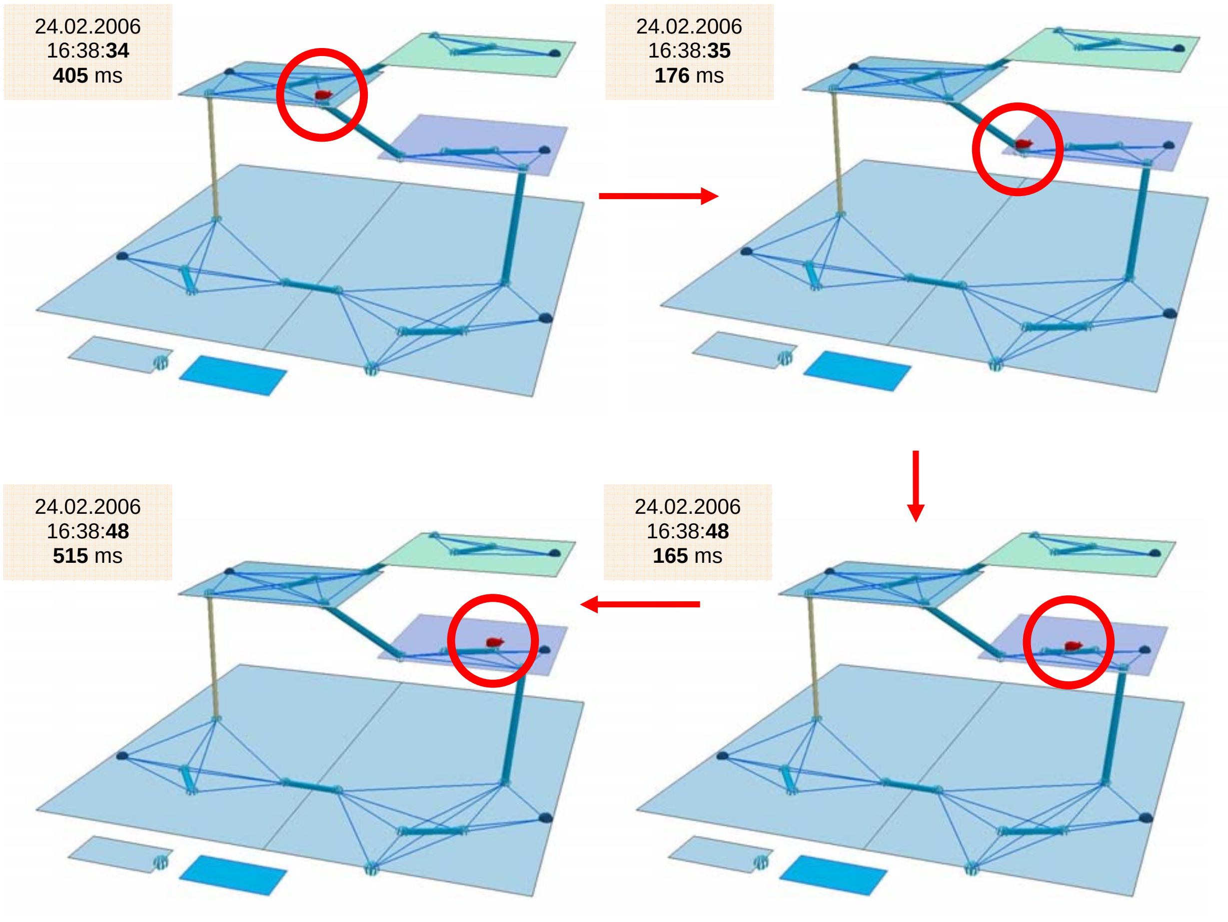


Figure 14 Sequence of mouse movement in time

The results of the prototypically implemented analysis are displayed in the shown statistics dialog (Figure 15). It gives a list of all mice in the SNE. By selecting one mouse all necessary data are queried and handled by the described algorithms. Figure 15 illustrates mouse 00066AB37B at 22.2.2006 with its statistics. It is shown that this mouse used all five areas but no meeting with other mice occurred. The tables in this dialog can be exported and serve as the data base for both visualization and analysis. The upper table contains the clustered data, the lower table contains the antenna contacts per minute.

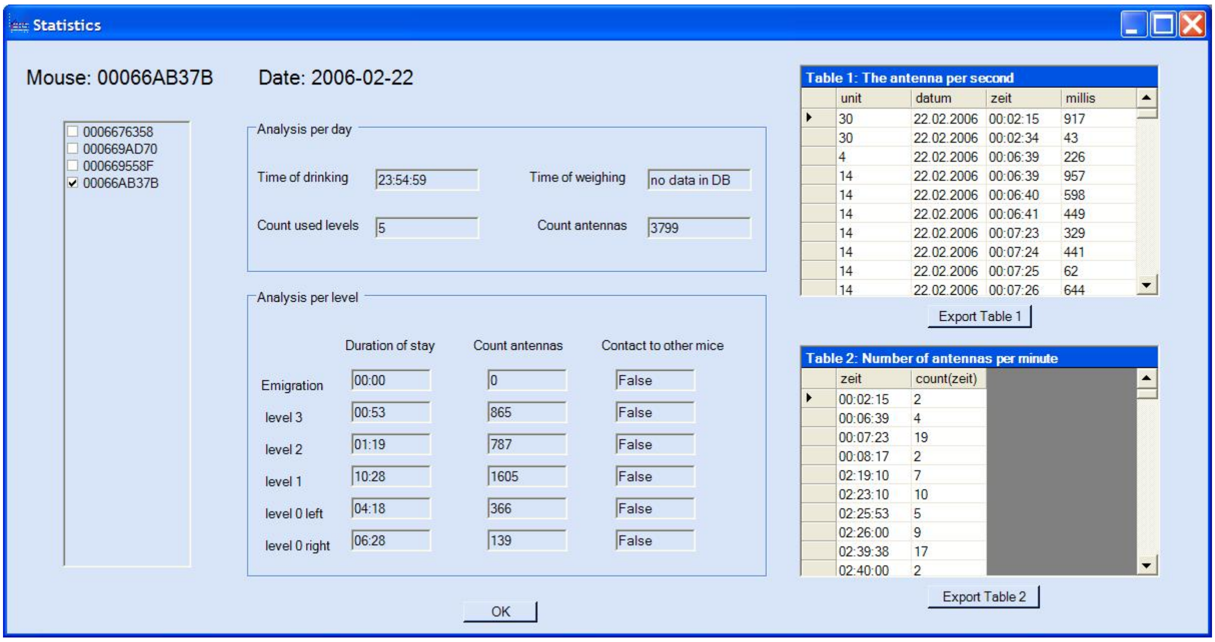


Figure 15 Statistics dialog

The warning system shows in the GUI whether and how many warnings exist. A dialog displays the warning messages which have a timestamp and the transponder code. A warning appears if there is no antenna contact at a drinking bottle within a day or the emigration cage is used.

6. Conclusions and future work

In this paper we presented an indoor-tracking solution for laboratory mice. The use of RFID technology facilitates the collection of time continuous movement data in a complex biological scenario. Twenty-four hour observation is possible without disturbing the animals. Social interaction and the outward appearance are not influenced by this technology and only a few modifications must be made to integrate the RFID antennas in the SNE. The software JerryTS collects the data and provides the data base for further analysis. The novel approach was integrated within a GIS framework by extending the software component ArcScene. This extension (TOM) was used to handle the spatio-temporal data. On the one hand the movement of the mice is visualized and on the other hand there are analysis functions, which offer information about the behavior and movement of the mice.

The described setting can be extended by using additional sensors, e.g., a scale to measure data about weight and more continuous positional data, not only point data at the antennas. Optical camera tracking is considered for tracking single mice to get additional behavior patterns. Furthermore it is possible to integrate an automated learning test for the mice. The analysis can be extended to filter behavior and movement patterns to be used in various biological behavior studies. We also consider to create a framework which allows to get tracking data of different kinds of animals in different temporal and spatial resolutions.

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