Sustainable Agriculture Research; Vol. 12, No. 1; 2023
ISSN 1927-050X E-ISSN 1927-0518
Published by Canadian Center of Science and Education

An Automated Hardware-Software Module Monitoring *Acheta Domesticus* Population at Breeding Facilities

Dr. Dmitry Mikhaylov[1, 2], Mikhail S. Zeldovich[1], Rudolf Davidov[1] & Anastasiya Rybak[1]

[1] National University of Singapore, Singapore

[2] Entoverse Pte Ltd, Singapore

Correspondence: Dr. Dmitry Mikhaylov: National University of Singapore, Visiting Associate Professor; Entoverse Pte Ltd, Chief Science Officer, Bishkek, Singapore. E-mail: dr.d.mikhaylov@nus.edu.sg

Received: October 17, 2022 Accepted: February 23, 2023 Online Published: March 10, 2023

doi:10.5539/sar.v12n1p35 URL: https://doi.org/10.5539/sar.v12n1p35

Abstract

The growing population on planet Earth and the deteriorating environment are leading humanity to a swift depletion of resources. And if it is possible to reduce the use of some, it is impossible to eliminate, or even decrease the consumption of protein. Thus, an alternative solution needs to be found. For the past several decades scholars have suggested to breeding crickets as an alternative source of protein. Numerous studies have been made, which resulted in a simple description of the process and a manual of how to establish a breeding cricket farm. However, the fluctuations in breeding conditions stemming from the lack of automation in this sphere, are a hazard to the safe growth and development of the cricket breeding stock. This paper focuses on the developed prototype of a video monitoring equipment developed using machine learning technologies aiming to help identifying hazardous conditions based on the training received in the process of the experiment and numerous tests. The prototype has shown a 70% accuracy rate, yet is capable of determining when the crickets are subjected to various stressors, namely water, nutrition, thermal and methane. Via observing the cricket population, the prototype is learning to alert the breeder as to the potential danger, thereby preserving the cricket population, and increasing the chances of a future mass production of protein from crickets.

Keywords: automated machine learning technology, cricket protein, external stressors

1. Introduction

Global trends associated with epidemics, overpopulation of the planet, a growing carbon footprint, and depletion of resources contribute to the aggravation of the protein crisis. Public health concerns further drive the need to find alternative sources of protein (Pasini et al., 2022). Numerous studies have found that raw red meat significantly increases cholesterol levels, contributing to cardiovascular disease. The reproduction of protein from insects is proposed as an alternative solution to compensate for the lack of proteins. Insect farms are environmentally friendly (Halloran, Hanboonsong, Roos & Bruun, 2017). In addition, insects do not require special conditions for keeping, and the low cost and availability of feed make it possible to create such farms everywhere. However, despite the merits of establishing farms for growing cultivated insects, the abrupt climate changes on the planet create some barriers to the successful maintenance of such farms and their distribution. Temperature fluctuations are also observed in those regions where the traditional cultivation of insects as a protein ingredient in the diet was carried out without additional energy costs for maintenance (Fernandez-Cassi et al., 2019). Thus, this paper suggests a solution for an automated hardware-software module capable of video monitoring the entire process of cricket cultivation, considering their behavior and potential illnesses that may appear due to external factors.

1.1 Background

The demand for protein is growing every year. The total protein deficit on the planet is estimated at 10–25 million tons per year. Due to climate change, the production of vegetable protein is complicated by a decrease in yield, and the depletion of water resources complicates production (Garg & Sangwan, 2019). Such global trends increase the number of farms and the area of functioning insect farms. However, with increasing competition, the requirements for equipping and automating farms are growing, since only in this way can losses on the farm caused by incompetence / unprofessional employees be avoided.

The market for automated systems in this area at this stage of development is often limited to climate units that provide data on temperature and humidity and maintain them at the required level. These parameters certainly affect insects' state and vital activity, but monitoring only these indicators is not enough (Pandey, 2022). Climate systems, like any other systems, are prone to failure. In addition, an impressive proportion of the deaths of individual insects or entire colonies are not due to improper temperature or humidity (Pandey, 2022). A frequent cause of death is a disease corresponding to various types of insects.

The collection and analysis of farm indicators are done manually. Taking into account the error in manual measurements, the oversight of the farm staff, the time costs, and the reaction of insects to a person's approach, the question of the need for automation of such farms is acute (Reverberi, 2020). In a changing climate, the demand for continuous climate control is increasing. The situation is aggravated by the fact that insects become more vulnerable to diseases in the absence of the necessary conditions of detention. At the same time, if symptoms of such diseases are not detected in time, the risk of death in the entire colony increases critically. The temperature fluctuations, as in significant cooling and warming, must also bear in mind (Reverberi, 2020). These negatively affect and represent a severe problem for the cultivation of insects. Temperature fluctuations negatively affect the degree of the immune response to pathogenic invasions (Behrenes et al., 1983; Brogan, Park, Matak, & Jaczenski, 2021), as well as the emergence of new types of pathogenic biota in the region, which can pose a threat to the survival of insects that are not adapted to such changes (Reverberi, 2020). Therefore, to ensure a quick response to atypical/uncharacteristic signs of the behavior or appearance of insects, constant monitoring of the condition and notification of deviations using a hardware-software module for analyzing the situation is necessary.

1.2 Research Purpose

The purpose of this work is to test a prototype of a hardware-software module with elements of machine learning for the possibility of full-fledged monitoring of farms of cultivated insects, as well as to detect anomalies on such farms.

1.3 Research Aim

This study aims to develop and test a system for collecting video data for a prototype hardware-software module with elements of machine learning. One also strives to collect and label a set of video data, to develop and test mathematical models for constructing algorithms for detecting anomalies in the software of prototype software and hardware system.

1.4 Scientific Framework

Stress is a specific reaction of the insect organism to adverse climatic factors and/or toxic substances and/or parasitic microbiota, which manifests in the form of uncharacteristic/atypical external signs or abnormal behavior of insects (Chown, Chown, & Nicolson, 2004). In the dynamics of a hardware module of non-specific protective and adaptive reactions in response to stress, aimed at creating resistance (resistance) of the body to any factor, three stages (“Selye’s triad”) are naturally traced (Chown, Chown, & Nicolson, 2004):

1) anxiety reaction (detection of a stress factor by the sensory system);

2) the stage of resistance (at this stage, the insect organism uses all available resources and has the highest level of resistance, the stage is characterized by a response to stress: attack, defense, or flight, caused by the release of octopamine or the stress hormone - the biogenic amine of insects, which plays a crucial role in behavior insect),

3) the stage of exhaustion (the final stage of the reaction to stress, which lasts for a long time, is a state close to hibernation and suspended animation. This reaction is due to the depletion of the nervous and immune systems, metabolic reactions, and cognitive processes in the insect body)

To assess stress in *Acheta Domesticus,* behavioral, physiological, and auditory (stridulation) characteristically pronounced reactions were used.

Behavioral and sound reactions in an artificially created habitat, taken as characteristics, were the basis for typical insect reactions. In this characteristic habitat, observation and video recording were taken as control or specific, stress-free.

2. Materials and Methods

2.1 Location

Vietnam, Binh Phuoc province.

2.2 Organizational Procedure

Feeding the insects was carried out daily in the morning, by accepted internal standards of the company. The provision of water was carried out through an automatic drinking bowl, minimizing the degree of contact with the external environment, thereby avoiding contamination by pathogenic microorganisms (Adamo, 1998; Adamo, 2004).

The lighting in the room where the boxes with insects were located was natural, through window openings. In addition, artificial lighting was installed for supplementary lighting in the winter. The total amount of illumination is 16 hours per day.

The habitat created was a confined space in a plastic box containing 5 to 10 *Acheta Domesticus* crickets of different sexes (Adamo, 2004).

The environment was implemented following the objectives of the experience using mechanisms and techniques and included:

- the climatic environment, including the change in temperature regimes, in a given time;
- factors of overcrowding or a critically high degree of loading of insects per $1m^2$;
- the artificial creation of a shortage of drinking water;
- artificial restriction of air intake.

The purpose of creating an atypical or non-characteristic habitat was to create stress for insects and obtain immediate reactions, accompanied by recording such responses using video equipment and accumulating the acquired data to train the neural network.

2.3 Method

2.3.1 Overview

The prototype of the hardware-software module (further referred to as the "module," "system," or "prototype") was created based on neural networks and is designed to control the cultivation of cultivated insects. In particular, the complex makes it possible to detect atypical behavior for the related insect species, which often indicates unsuitable detention conditions: non-compliance with the temperature regime, humidity, etc. (Pandey, 2022) In addition, abnormal/atypical characteristics of the appearance of insects or their behavior may indicate the presence of diseases. In such cases, the module makes it possible to detect the condition in the initial stages and makes it possible to avoid the extinction of the entire colony.

During the tests, the ability of the module to detect anomalies in the behavior of insects was confirmed, generating alarm signals for the control center of insect farms (Halloran et al., 2017). Prototype testing was carried out on farms for the cultivation of cultivated insects.

During testing, the ability of the prototype to implement the previously declared functions required experimental confirmation:

- Collect visual data on insects through appropriate recording equipment;
- Provide storage of received visual data;
- Process visual data by classifying relevant parameters.
- Detect features not characteristic of insects in the volume of visual data.
- Create patterns of data sets corresponding to non-standard atypical behavior and state of insects.
- Notify the system user of detected events.
- Create reports on the array of processed data.

Video analysis was planned when working with farms. The possibility of identifying diseased individuals was confirmed based on the video data collected by specialized equipment. Recordings were made during the first 20 minutes of abnormal behavior to identify uncharacteristic signs of insects. In addition, by analyzing the video stream, the hardware module makes it possible to detect atypical behavior for insects if the deviation from expected behavior is 30% or more. Additionally, the hardware module demonstrated the ability to immediately see three or more types of abnormal behavior of insects, such as grouping of individuals, high motor activity, low motor activity, and lack of motor activity (Behrens et al., 1983; Adamo, 1998; Adamo, 1999; Adamo, 2004; Brogan et al., 2021).

Based on video data, the hardware module allows us to determine: an aggressive and hyperactive state, a state of lethargy, or a hypo-biotic state. Farm historical data is stored for six months.

To determine the presence of deviations, characteristic external reactions, and signs of an insect. Distinct external reactions and signs - the usual or predictable reactions of an insect, or behavioral style, caused by a response to external factors and expressed in characteristic or familiar external reactions of locomotion and stridulation in a stable environment, in response to signals from the insect's sensory system (Brogan et al., 2021).

Examples of such phenomena:

- When a male meets a female (imago), contact occurs through the antennae, then the male turns to the female and begins stridulation;
- When a male meets a male (imago), contact occurs through the antennae, in which one of the males turns around and runs away. Or a possible short, aggressive attack of one male on another takes place;
- The locomotion of adults at a temperature of 26 ℃ is, on average, 1.3–1.5 cm/s;
- Insect movements of vector type, in a straight line;
- Stridulations are frequent, with short breaks, in a characteristic range, with high volume at a typical frequency;
- According to this report, the color of the cricket's integument is dark brown.

2.3.2 Testing

To create stressful conditions for insects, under which insects would give a reaction that would be recorded by video equipment. Anomalies in the behavior of cultivated insects were studied under conditions of: - nutrient stress (under the influence of hunger, insects, as a rule, change their behavior, including cannibalism, a decrease in the number of eggs laid, as well as diapause, etc.);

- water stress (under the influence of water deficiency, insects can resort to cannibalism, eggs change color when the substrate dries out, and females begin to lay eggs in open water sources, where eggs die) (Adamo, 1999);
- heat stress (when the temperature exceeds the permissible limits, insects change their behavior, including attempts to leave the place of stress, a gradual decrease in jumping activity, and subsequent lethargy, movement is almost absent) (Angilletta, Wilson, Navas, & James, 2003; Angilletta, Huey, & Frazier, 2010; Adamo & Lovett, 2011);
- methane stress (under the influence of a poisonous substance, oxygen starvation occurs, which provokes specific reactions of the insect, expressed in atypical/uncharacteristic behavior, for example, an attempt to escape and aggression) (Halloran et al., 2017).

Description of experiments:

Nutritional stress. For this experiment, the feeding was stopped for two days. The activity of the colonies was monitored throughout the whole test period.

Water stress. For this experiment, the water supply was stopped for one day. The activity of the colonies was monitored throughout the whole test period.

Thermal stress. One placed several containers and set them to different temperature conditions. The experiment is carried out in three phases for cold (in 3 hours, the temperature was gradually reduced from +26°C to +18°C, then in 6 hours from +18°C to +10°C, in 12 hours from +10°C to + 5°C) and three phases for high temperature (in 3 hours a gradually increase from +26 ℃ to +34 ℃ was accomplished, in 8 hours from +34 ℃ to +38 ℃, in 24 hours increased from +36 ℃ up to +41°C). The activity of the colonies was monitored throughout the whole test period.

Methane stress. Containers with an average density of crickets were used, and cricket secretions were moistened to increase the toxicity of the air, with the consequential reduction of the amount of oxygen within and a subsequent increase of CO_2. The activity of the colonies was monitored throughout the whole test period.

2.4 Materials

1. *Netatmo Smart Home Weather Station* is a weather station that displays parameters such as temperature, humidity, pressure, carbon dioxide level, wind speed, and noise level. The room module of the smart weather station measures important indoor climate parameters and warns of high levels of air pollution. A smart weather station's wireless outdoor module instantly allows receiving essential weather data.

Specifications:

- Measurement frequency: every 5 minutes;
- Temperature (indoor): Range 0 ℃ to 50 ℃ / 32 ℉ to 112 ℉, Accuracy: ±0.3 ℃ / ±0.54 ℉;

- Temperature (Outdoor): Range: -40 ℃ to 65 ℃ / -40 ℉ to 150 ℉, Accuracy: ±0.3 ℃ / ±0.54 ℉;
- Humidity (indoor and outdoor): Range: 0 to 100%, Accuracy: ±3%
- Barometer: Range: 260 to 1260 mbar / 7.7 to 37.2 inHg, Accuracy: ±1 mbar / ±0.03 inHg
- CO_2 measurement (indoor): Range 0 to 5,000 ppm, Accuracy: ±50 ppm (0 to 1,000 ppm) or ±5% (1,000 to 5,000 ppm)
- Noise level: Range from 35 dB to 120 dB.

2. *Xiaomi Mijia light sensor*. Allows to track the current illumination level and has a built-in log with historical data.

Specifications:

Measurement limits: from 0 to 83000 Lux;

Operating temperature: -10℃ to 50℃ at rel. humidity 0-95%;

Protection level: IPX.

3. *Reusable pH rod meter* with unique data storage features. The flat surface electrode allows pH measurement in liquids, semi-solids, and solids and limits electrode breakage and clogged junctions. The CAL alert provides accurate readings by letting you know when you need to calibrate. The memory function records and recalls 15 sequentially labeled lessons. The LCDs' pH, temperature, and analog bar graph show acidity or alkalinity and indicate when readings are stable.

Specifications:

- PH: from 0.00 to 14.00;
- Temperature: -5℃ to 90℃;
- Maximum resolution: 0.01pN, 0.1 °;
- Maximum accuracy: ±0.01rN, ±1.8 ℃.

4. *Mi Home Security Camera 360°*. The camera allows one to view different room parts according to the monitoring schedule. The camera has good quality night surveillance capability and also provides good quality remote access to the camera. It is possible to control the farm, even being at a great distance from it.

Specifications:

- Maximum memory card size: up to 64 GB;
- Memory card slot: Separate;
- Resolution: 1080p.

Depending on the customer's needs, the basic module can be expanded with additional sensors.

Computer hardware for the complex has the following technical characteristics:

- Processor: AMD A9 9420E;
- Processor frequency: 1.8 GHz (2.7 GHz, in Turbo mode);
- RAM: DDR4 4096 MB 2666 MHz;
- Video card: AMD Radeon R5;
- SSD ROM: 128GB

The block diagram of the software package is shown in Figure 1 and is an array of models, one for each type of anomaly/deviation.

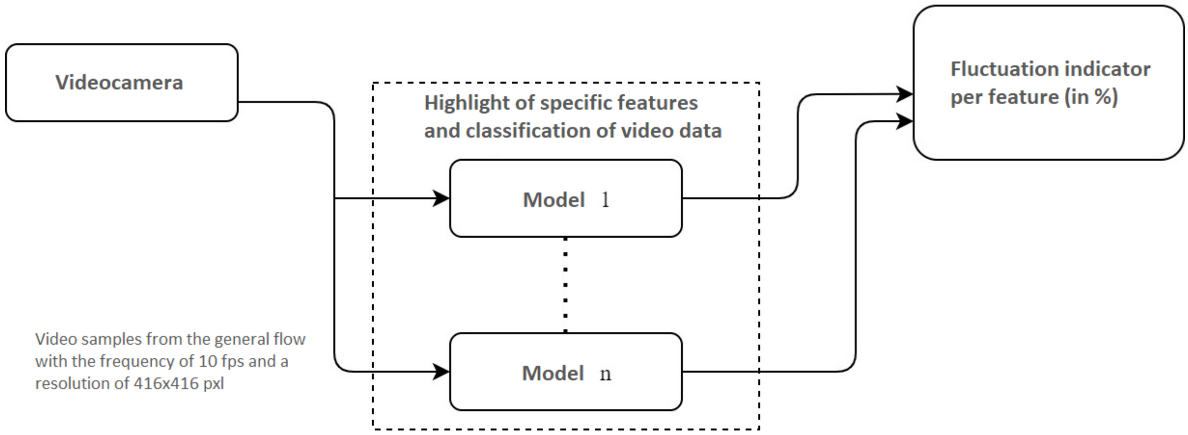

Figure 1. Block diagram of the software package

3. Results and Discussion

3.1 Nutritional Stress

The following are screenshots from video recordings of cricket behavior on the final day of the experiment. During the 5-minute recording, most crickets in a chaotic sequence demonstrated attempts to leave the container, which was a place of stress for them.

Figure 2. Cricket behavior during the nutritional stress test

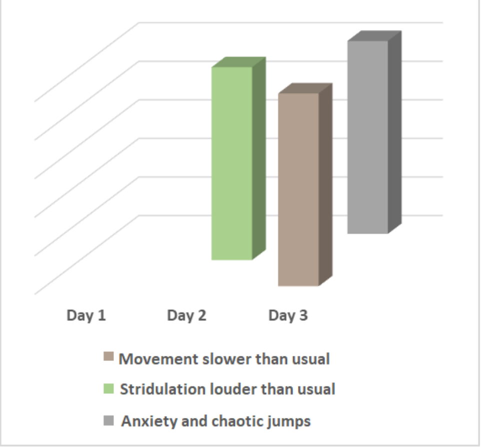

Figure 3. Anomaly in cricket behavior during the nutritional stress test

Figure 3 shows that no irregularities in the conduct of crickets were detected on the first day; however, on the second day, a noticeable reaction appears in the form of stridulation, which subsides by the third day due to the weakening of the body and loss of strength. The slow movement of insects confirms this.

3.2 Water Stress

The experiment was conducted for one day, and a video recording was made in the morning and evening. In the experience with water stress, atypical behavior patterns are also highlighted. During the 5-minute recording, most crickets in a chaotic sequence demonstrated attempts to leave the box - a place of stress. However, the insects move more actively than in the nutrient stress experiment, and some of the individuals make jumps.

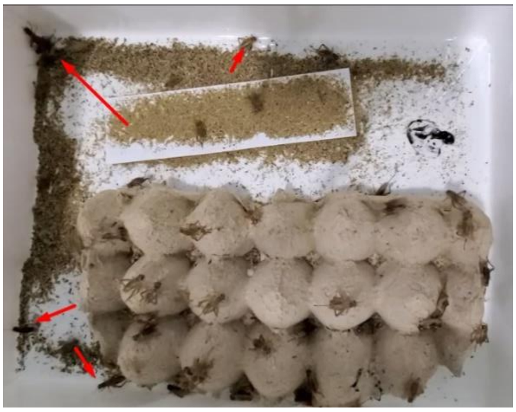

Figure 4. Cricket behavior during water stress test

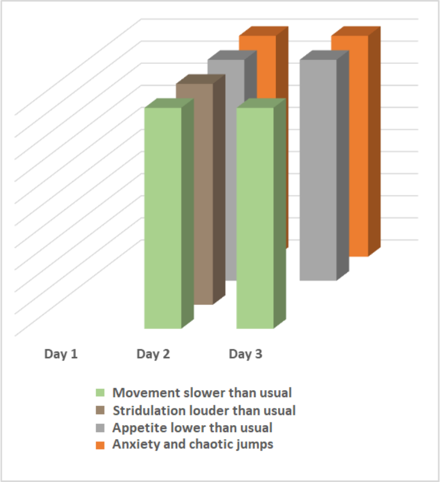

Figure 5. Anomaly in cricket behavior during the water stress test

It can be seen from Figure 5 that no irregularities in the behavior of crickets were detected on the first day; however, on the second day, a noticeable reaction appears in the form of loud stridulations, which subsides by the third day due to the weakening of the body and loss of strength. In addition, there is a decrease in appetite and chaotic movement.

3.3 Thermal Stress

3.3.1 Hypothermia, Cold

Phase 1. The gradual temperature decrease from the study's beginning in 3 hours, from +26 ℃ to +18 ℃. An analysis of the video recordings showed the atypical behavior of insects, expressed in uncharacteristic amplitude locomotion, namely, in the movement of insects in short, with stops and short dashes (presumably in search of shelter). A decrease in feed intake and interest in it was recorded. The movement speed decreased from 1.5 cm/s to 1.1 cm/s as the temperature dropped.

Phase 2. The gradual temperature decrease from the study's beginning in 3 hours, from +18 ℃ to +10 ℃. Insects showed the following reactions to a temperature decrease: the state of inhibition of communicative responses, expressed in immobility, a decline in reactions; the refusal of food; lack of mating; no stridulation. The movement speed decreased from 1.1 cm/s to 0.3 cm/s as the temperature dropped. Locomotion is uncharacteristic and slow. The movements of the antennae (antennae) are passive, almost stopped.

Phase 3. The temperature from the beginning of the study was reduced from +10°C to +5°C within 12 hours. Reactions: hypo-biotic state; insects are practically immobile for more than 5 hours; there is almost no movement of the antennae (antennae); complete denial of nutrition; movements (locomotion) uncharacteristic, absent; movement speed decreased to 0.0 cm/s as the temperature decreased

3.3.2 Hyperthermia, Heat

Phase 1. The temperature from the beginning of the study for 3 hours was gradually increased from +26℃ to +34℃. Reactions: some insects (30%) make jumps and try to climb the walls of the box with an interval of 5-10 seconds; another part of the insects (70%) moves in jumps, making short and sharp dashes; the movement of insects occurs along the perimeter of the box, unidirectional; a sharp decrease in the number, intensity, and volume of stridulation as the temperature increases; a sharp reduction in food intake; lack of mating; the speed of movement increased from 1.5 cm/s to 1.8 cm/s as the temperature rose; paw movements (locomotion) are not characteristic, sharp, corresponding to a hyperactive state; activities of the antennae (antennae) are fast.

Phase 2. The temperature from the beginning of the study for 8 hours increased from +34°C to +38°C. Reactions: most of the insects (80%) make jumps and try to climb the walls of the box with an interval of 10-15 seconds; some insects (20%) move in leaps, making short and sharp dashes; the movement of insects occurs along the perimeter of the box, unidirectional; the refusal of food; lack of mating; no stridulation.

The movement speed decreased from 1.8 cm/s to 1.3 cm/s as the temperature increased. The locomotion is not characteristic or sharp, corresponding to a hyperactive state. Insects are hyperactive. The movements of the antennae (antennae) are swift and mobile.

Phase 3. The temperature from the start of the study for 24 hours increased from +36°C to +41°C. Reactions: hypo-biotic state; insects (90%) are inactive; insects (10%) show little activity and try to climb the box's walls. Occurs with an interval of 15-30 seconds; movements of antennae (antennae) hardly noticeable; lack of stridulation; complete denial of nutrition; movements (locomotion) uncharacteristic, insignificant; movement speed decreased to 0.3-0.5 cm/s

The following is a screenshot from video recordings of cricket behavior on the final day of the experiment. During the 5-minute recording, crickets move very quickly compared to other types of stress; the movement is chaotic, and often, individuals try to leave the place of stress by climbing the walls of the box.

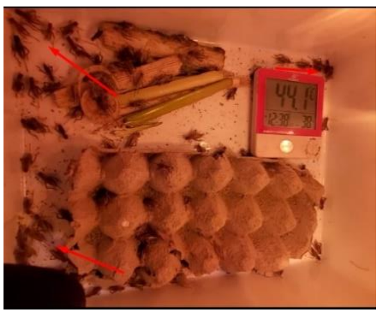

Figure 6. Cricket behavior during the thermal stress test

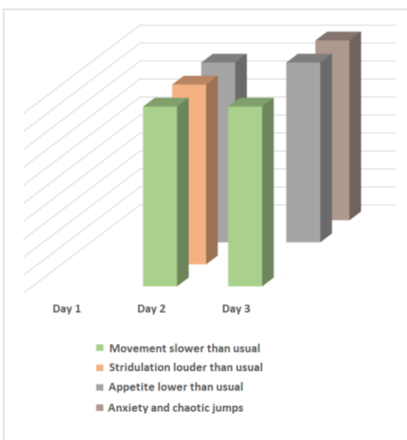

Figure 7. Anomaly in cricket behavior during the thermal stress test

In contrast to previous tests, thermal stress is characterized by increased motor activity, as seen in Figure 7. In addition, stridulation on the second day becomes louder; the movement is chaotic and restless. The general state of individuals is characterized as panic. However, it is sufficient to control the accumulation of insects near the walls of the container with the speed of their movement and intensity of stridulation.

3.4 Methane Stress

Phase 1. 8 hours after the lack of oxygen in the box. Reactions: part of the insects (80%) move abruptly and quickly; when meeting with another insect, aggression occurs, and the insect quickly attacks; some insects (80%) make jumps and try to climb the walls of the box with an interval of 10-15 seconds; another part of insects (20%) is in a shelter; short and rare stridulations of low volume in an uncharacteristic frequency range. Characteristic movement speed: 1.7 cm/s

Phase 2. 12 hours after the lack of oxygen in the box. Reaction: aggression, expressed in short attacks on individuals. Some insects (40%) make jumps and try climbing the box's walls. Occurs with an interval of 15-20 seconds; another part of the insects (60%) is in the shelter; movement speed is unstable from 1.7 cm/s to 0.0 cm/s; lack of mating; the complete absence of stridulation; the absolute refusal of food.

Phase 3. 24 hours after the absence of oxygen in the box. Reaction: no movement of insects. A state close to anabiosis, lack of stridulation, lack of mating initiative, and a complete rejection of food.

Phase 4. 36 hours after the absence of oxygen in the box. Reaction: insects are without signs of life (100%).

Crickets tried to escape the stressed area by climbing the box's walls or trying to jump out of it (Figure 8).

Figure 8. Cricket behavior during methane stress test

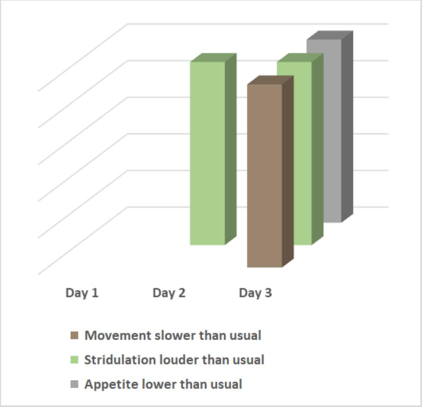

Figure 9. Anomaly in cricket behavior during the methane stress test

Figure 9 shows no irregularity in the behavior of crickets on the first day identified. In the second, a noticeable reaction appears in loud stridulations. On the last day of the experiment, the slow movement of insects is added to the symptoms, while a decrease in appetite is observed due to intoxication of the body.

Based on the results of the studies, patterns were identified and recorded between the characteristics of the individual's behavior and external influencing factors.

Based on the results of the experiments, processing the results, and comparing the performed functions with those specified in terms of reference, the developed prototype was confirmed to fully comply with the prototype, in particular, its specialized equipment, with the requirements that were set for the goals and objectives of this R&D paper.

3.5 Models Functioning

3.5.1 Overview

YOLO (You Only Look Once), the currently popular CNN architecture, was chosen to analyze the video stream. The main feature of this architecture is that, unlike most systems that apply CNN several times to different regions of the image, YOLO CNN is used once to the entire image at once. The network divided the image into a kind of grid and predicted the bounding boxes and the probability that there is the desired object for each area. We used the YOLOv3, an advanced version of the YOLO architecture (Figure 10).

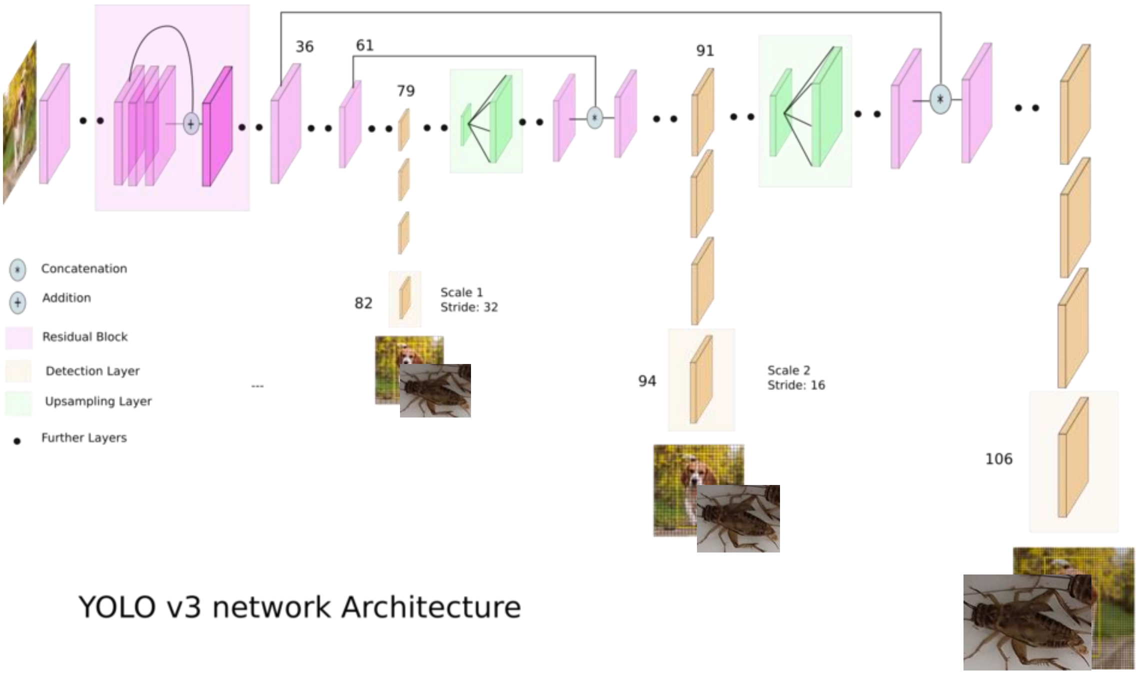

Figure 10. YOLOv3 structural model

The YOLOv3 model uses three layers as an output to divide the image into a different grid. The cell sizes of these grids have the following values: 8, 16, and 32. A picture of 416x416 pixels is fed to the input in the developed complex, then the output matrices (grids) will have a size of 52x52, 26x26, and 13x13 (416/8 = 52, 416/16 = 26, and 416/32 = 13).

As a result, the output is three class objects for each type of mesh. To get the coordinates and dimensions of the bounding box-a, one used these formulas:

$$x = \sigma(\dot{x}) + C_x \quad (1)$$

$$y = \sigma(\dot{y}) + C_y \quad (2)$$

$$w = p_w + e^{\dot{w}} \quad (3)$$

$$h = p_h e^{\dot{h}} \quad (4)$$

where $\dot{x}$, $\dot{y}$, $\dot{w}$, $\dot{h}$ — predicted x, y coordinates, width, and height, respectively, σ(x) is a sigmoid function, and p_w, p_h — anchor values for the three boxes (Figure 11). These values are determined during training.

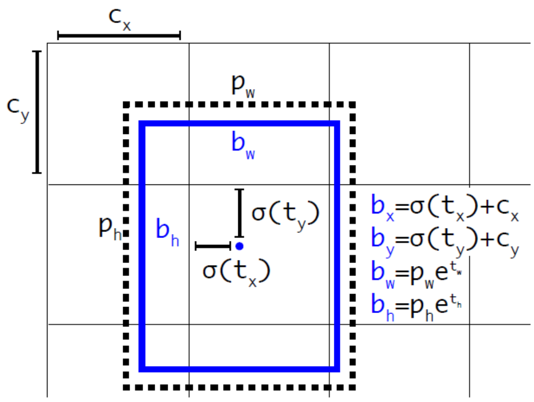

Figure 11. Schematic representation of the calculation of the position of the bounding box

Based on this data, it was possible to memorize the position of each cricket and its color and, at the next iteration, quantify the movement and activity of the colony.

3.5.2 Model Training

To train the model, ready-made modules from the TensorFlow library were used. The training time for each model on the GPU for 300 epochs was 3 hours. Adam was used as an optimization algorithm, and every 100 epochs, the classifier learning rate decreased by γ=0.1. The quality metric was accuracy, i.e., the ratio of correctly predicted classes to the total number of records. The loss function was the binary cross-entropy,

$$l_n = -w_n \begin{cases} \log x_n & , \quad y_n = 1 \\ \log(1 - x_n) & , \quad y_n = 0 \end{cases}, \tag{5}$$

Where y_n is the label of the true class, x_n is the label of the predicted one.

The batch size for training the model was seven records. The training sample contained 1000 records of each class; this amount of data was achieved by applying augmentations to the original 300 records. Among the augmentations used are adding white noise to the recording and obtaining a new spectrogram by averaging two others with the same frequency range.

3.5.3 Model Testing

Model testing was performed using the following quality metrics:

$$A = Accuracy = \frac{TP+FP}{TP+FP+TN+FN}, \tag{6}$$

$$P = Precision = \frac{TP}{TP+FP}, \tag{7}$$

$$R = Recall = \frac{TP}{TP+FN}, \tag{8}$$

$$F_1 = 2 \cdot \frac{P \cdot R}{P+R}, \tag{9}$$

where TP, FP, TN, FN are responsible for the number of correctly and falsely predicted anomalies and the number of correctly and falsely predicted absence of anomalies.

The software architecture of the complex includes the following modules:

- Data acquisition software module. Provides receiving data and transferring them in a normalized form to the system core;
- Analytical module. Includes processing of received data and selection of critical features from the stream;
- Classification module. Classifies the data depending on the features found.
- Reporting module. To build and display reports based on specified templates.
- Database (DB). Provides storage of initial data and selected features of each fragment with flags of each element. For the considered module, a database with a hierarchical data representation model was used;

The software architecture of the complex was finally approved in the course of work and is being built based on the following neural networks:

- Neural networks using supervised learning;
- Networks with dynamic links;
- Recurrent neural networks;
- Neural networks of direct distribution;
- Hopfield neural network;
- Convolutional Neural.

The following programming languages were used to develop the prototype: C++, Python, and Java.

Libraries:

- Librosa 7.2 is a library used to process sound and decompose it into a spectrum.
- Matplotlib 3.3.0 is a library used to visualize a spectrogram in .png format.
- Numpy 18.5 is a library used to work with multidimensional data structures.
- PyTorch 1.6.0 is a framework used to build and train neural network models.

3.5.4 System Architecture

The prototype ecosystem provides neural networks for detecting anomalies in the behavior of insects. The system has a client-server architecture. Data from different customers are stored on other partner servers per the legislation protecting personal data in the users' countries of residence. At the same time, the neural network accessed by client systems for analysis is deployed on the central server (Figure 12). The main server also stores a dataset containing the data provided by the farms and necessary for training the neural network. Customers request the server via the API to collect and markup data for the dataset, send data from local servers to the main one and receive anomaly detection results.

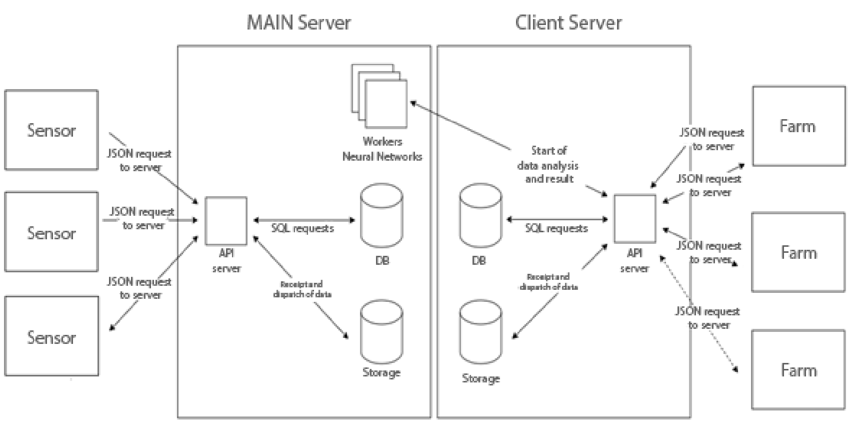

Figure 12. Server functioning scheme

The server part of the prototype consists of the central server designed to collect data for the dataset and unify the operation of neural networks. The server includes the following components:

1. S3 File Storage is a cloud service needed for fast file access and cryptographic data protection.
2. A database is a systematization tool.
3. The API server is required to coordinate the operation of the server part of the system and the data collection and markup tools.

The client part of the server performs the functions of collecting data for the dataset. Collection of video recordings of the behavior of individuals to expand the existing dataset and more correctly train the neural network.

3.5.5 System Functioning

Depending on the functional load, three subsystems can be distinguished: a subsystem for collecting and labeling data, a subsystem for learning neural networks, and a product subsystem.

1. The internal subsystem for collecting and labeling data necessary for training neural networks has two stages of operation:

- (1) The input to the system is data with anomalous characteristics of behavior and behavior characteristics of individuals collected by various sensors.
- (2) The data is subjected to a labeling procedure to identify essential characteristics of anomalies.

2. Internal subsystem for learning neural networks. Further training of neural networks occurs regularly as data accumulates in the dataset. All collected data are divided into training and validation sets used for training (3) and validation (4) of the model.

3. The subsystem for using the finished product functions as follows:

- (5) Farms provide sensor data to the system.
- (6) An analytical system based on neural networks analyzes data, resulting in which the user receives notifications about incidents, negative impact on individuals, the state of individuals, and recommendations for stabilizing the situation.

Further training of neural networks occurs as new data arrives from client farms. All data is stored in the database and file storage and goes through a markup procedure to identify representative videos with pronounced deviations from the norm of 30% or more. Only representative records are divided into training and validation samples. Further training of neural networks occurs regularly using a temporary snapshot of the current state of the database. For this, the following steps are required:

Figure 13. Functioning of the neural network training subsystem

3.5.6 System Interface

In addition, an interface for the complex was developed (Figure 14). The interface shown in the figure is a layout, which will subsequently be adjusted individually depending on the wishes and needs of a particular customer.

Figure 14. Prototype interface for the customer

Figure 20 shows the dashboard tab. Dashboards are editable. The user can take out the information that is fundamentally paramount for him. The displayed parameters include data from all sensors:

-pressure;

-air temperature;

-humidity;

- the intensity of lighting;

- etc.

The data varies depending on the set of sensors used by the customer. The data can be displayed not only in the form of accurate data but also in the form of dynamics compared to the previous day.

It is also possible to track the farm's output, including the amount of waste, protein, and fat.

In addition, the menu displayed on the right has several tabs:

- Reports. In reports, the user has the opportunity to build an account and independently select the parameters and indicators that he wants to see in the news, as well as build dependency graphs and download the report/graph.

- Vault. Storage is a tab that stores historical data from all sensors and video information.

- Containers. The tab allows you to view data separately for each container and indicator in the mating rooms.

- Add container. The tab allows you to add a manually created container or mating room.

- Settings. The settings tab allows you to change general system settings and configure notifications.

There is a notification area on the right side of the screen. In this area, notifications of adverse events appear in pop-up windows, depending on the degree of negative consequences for individuals and the magnitude of the deviation from the norm: red, orange, and yellow. Also, container numbers are indicated if variations were found only in particular containers.

To avoid accidental closing of the notification and loss of information, which can lead to the death and illness of individuals, the function of closing the message is disabled in the default settings. If necessary, this function can be enabled in the tab: Settings.

4. Conclusion

As a result of R&D, the following works were performed:

- Relevant experiments were carried out;
- A dataset for training neural networks was compiled;
- Based on the dataset, neural networks were trained, which will be further trained in the process of data collection;
- Approved the architecture of the software package;
- A basic set of sensors was approved with an indication of recommended manufacturers;
- The prototype was tested on a real object.

The following experiments were carried out:

• nutritional stress;

• water stress;

• thermal stress;

• methane stress.

With the obtained video data, a heuristic analysis was performed, and the data was marked up for further use in training the neural systems of the complex at a later stage.

The following set of neural networks has been selected for implementation in the complex:

• Neural networks using supervised learning;

• Networks with dynamic links;

• Recurrent neural networks;

• Neural networks of direct propagation;

• Hopfield neural network;

• Convolutional neural networks.

The obtained results of R&D have an accuracy of 70%. Work on finalizing the prototype continues. The accuracy of determining anomalies in the behavior of individual test subjects planned to be achieved is 95%.

During the development and testing process, the most significant functions were identified that are necessary for such a prototype, according to the customer.

Based on the results of the R&D carried out, the developed prototype satisfies all the points of the technical assignment and performs all the necessary functions to determine anomalies in the behavior of individuals.

The prototype proved successful on a test farm in Vietnam, where data collection and training of neural networks continues to this day.

The prototype is planned to be finalized, starting from the technical component, and ending with the data displayed in the system individually for each customer, depending on the client's wishes and requirements.

References

Adamo, S. A. (1998). The specificity of behavioral fever in the cricket Acheta domesticus. *The Journal of parasitology*, 529-533. https://doi.org/10.2307/3284717

Adamo, S. A. (1999). Evidence for adaptive changes in egg laying in crickets exposed to bacteria and parasites. *Animal Behaviour, 57*(1), 117-124. https://doi.org/10.1006/anbe.1998.0999

Adamo, S. A. (2004). Estimating disease resistance in insects: phenoloxidase and lysozyme-like activity and disease resistance in the cricket Gryllus texensis. *Journal of insect physiology, 50*(2-3), 209-216. https://doi.org/10.1016/j.jinsphys.2003.11.011

Adamo, S. A., & Lovett, M. M. (2011). Some like it hot: the effects of climate change on reproduction, immune function and disease resistance in the cricket Gryllus texensis. *Journal of Experimental Biology, 214*(12), 1997-2004. https://doi.org/10.1242/jeb.056531

Angilletta Jr, M. J., Huey, R. B., & Frazier, M. R. (2010). Thermodynamic effects on organismal performance: is hotter better?. *Physiological and Biochemical Zoology, 83*(2), 197-206. https://doi.org/10.1086/648567

Angilletta Jr, M. J., Wilson, R. S., Navas, C. A., & James, R. S. (2003). Tradeoffs and the evolution of thermal reaction norms. *Trends in Ecology & Evolution, 18*(5), 234-240. https://doi.org/10.1016/S0169-5347(03)00087-9

Behrens, W., Hoffmann, K. H., Kempa, S., Gäßler, S., & Merkel-Wallner, G. (1983). Effects of diurnal thermoperiods and quickly oscillating temperatures on the development and reproduction of crickets, Gryllus bimaculatus. *Oecologia, 5*9(2), 279-287. https://doi.org/10.1007/BF00378849

Brogan, E. N., Park, Y. L., Matak, K. E., & Jaczynski, J. (2021). Characterization of protein in cricket (Acheta domesticus), locust (Locusta migratoria), and silk worm pupae (Bombyx mori) insect powders. *LWT, 152*, 112314. https://doi.org/10.1016/j.lwt.2021.112314

Chown, S. L., Chown, S., & Nicolson, S. (2004). *Insect physiological ecology: mechanisms and patterns*. Oxford University Press. https://doi.org/10.1093/acprof:oso/9780198515494.001.0001

Fernandez-Cassi, X., Supeanu, A., Vaga, M., Jansson, A., Boqvist, S., & Vagsholm, I. (2019). The house cricket (Acheta domesticus) as a novel food: a risk profile. *Journal of Insects as Food and Feed, 5*(2), 137-157. https://doi.org/10.3920/JIFF2018.0021

Garg, S., & Sangwan, A. (2019). Dietary protein deficit and deregulated autophagy: a new clinico-diagnostic perspective in pathogenesis of early aging, skin, and hair disorders. *Indian Dermatology Online Journal, 10*(2), 115. https://doi.org/10.4103/idoj.IDOJ_123_18

Halloran, A., Hanboonsong, Y., Roos, N., & Bruun, S. (2017). Life cycle assessment of cricket farming in north-eastern Thailand. *Journal of Cleaner Production, 156*, 83-94. https://doi.org/10.1016/j.jclepro.2017.04.017

Pandey, P. (2022). *Optimization of cricket farming business model through customer experiences: case of next-generation cricket farming technology*. Retrieved from https://urn.fi/URN:NBN:fi:amk-2022060917231

Pasini, G., Cullere, M., Vegro, M., Simonato, B., & Dalle Zotte, A. (2022). Potentiality of protein fractions from the house cricket (Acheta domesticus) and yellow mealworm (Tenebrio molitor) for pasta formulation. *LWT*, 113638. https://doi.org/10.1016/j.lwt.2022.113638

Reverberi, M. (2020). Edible insects: Cricket farming and processing as an emerging market. *Journal of Insects as Food and Feed*, *6*(2), 211-220. https://doi.org/10.3920/JIFF2019.0052