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The effect of microclimate on pig weight gain evaluated with multisensor

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Abstract. In this study, a multisensory system was built to evaluate the effect of the temperature, humidity, the concentration of carbon dioxide and ammonia on pig weight gain. During the experiment, RGB-based image analysis provided body weight information of 22 pigs over a three-month period. In the experiment, two cameras were set to obtain pictures, and the resulting data showed high correlation. Pearson's and Spearman's correlation was calculated between the body weight and the monitored environmental parameters. Results showed that temperature negatively correlates with the body weight, while CO_2 and NH_3 have a positive correlation. In this study, humidity, random effect, and changes in temperature had slightly negative but not significant correlation with body weight gain. Multiple linear regression showed that temperature and humidity had a significant effect on the body weight gain of the pigs, while the effect of the NH_3 was also noticeable. Our results proved that image-analysis-based weight evaluation is a powerful tool in precision livestock farming and that environmental conditions have a significant effect on pigs' production.

Keywords and phrases: environmental data, remote sensing, RGB image analysis

1. Introduction

The daily weight gain of pigs is a multifaceted phenomenon influenced by a complex interplay of various factors. Among these determinants, genetics and feeding technology have seen remarkable advancements and innovations over the past few decades, playing pivotal roles in shaping the overall weight gain trends among pigs. However, there exists a multitude of less conspicuous variables that may exert substantial influence on pigs' weight gain trajectory (*Patience et al.*, 2015; *Wu et al.*, 2017).

Two such pivotal factors that have traditionally received less attention are the quality of the air within the pigpen and the temperature maintained inside the facility. While genetics and feeding technology are undoubtedly influential, the significance of environmental conditions in the pig farming industry cannot be either overstated or underestimated. The air quality within the pen, including variables such as carbon dioxide and ammonia levels, also humidity, is intrinsically linked to the health and well-being of the pigs. Likewise, the ambient temperature plays a pivotal role in regulating their metabolism and overall comfort (*Costa et al.*, 2013; *Hoha et al.*, 2013). These environmental parameters have often been overlooked in the broader context of weight gain, primarily due to a scarcity of comprehensive data.

Recognizing the dearth of information in this critical aspect, our research endeavours led us to develop a sophisticated multisensor system. This innovative technology was meticulously engineered to capture a wealth of environmental data, thus providing us with invaluable insights into the hitherto unexplored relationship between these environmental factors and the weight gain of pigs. In addition to the fundamental measurements of carbon dioxide, ammonia, and humidity levels in the air, our multisensor also recorded temperature variations. To ensure the credibility of our findings, we included wind strength as a control variable, given its obviously negligible influence on weight gain.

An appropriate ventilation and heating system within the pigpen is pivotal in maintaining these environmental variables within an optimal range. The optimization of air quality and temperature is a cornerstone of efficient pig farming practices, and our multisensor empowers us to monitor, analyse, and ultimately enhance these crucial parameters. Through the amalgamation of cutting-edge technology and the invaluable experiences of pig farming, this study seeks to shed light on the intricate and often overlooked connections between environmental conditions and the weight gain of pigs. The knowledge garnered from this research promises to revolutionize the pig farming industry, contributing to healthier and more sustainable practices for farmers and pigs alike.

2. Materials and methods

Experimental design

The experimental setup was conducted at a private farm situated in Németkér, Tolna County in the Transdanubian region of Hungary. The study involved pigs of DanBred genetics and focused on a single pig-fattening cycle. This cycle encompassed the care and monitoring of 22 pigs confined within a single pen, commencing when the pigs were approximately three months old, with an initial weight of approximately 30 kilograms. The study spanned a three-month duration, concluding when the pigs' weights reached an average of cc. 115 kilograms. To measure the pigs' daily weight gain, we employed a non-invasive method using RGB-based image analysis according to two cameras (cam1 and cam2) (*Kárpinszky & Dobsinszki*, 2023).

Applied sensors

After conducting an exhaustive survey of the available products in the market, we meticulously handpicked a set of sensors best suited for gauging various environmental parameters in our study. The cornerstone of our selection criteria revolved around the need for sensors with a sufficiently broad and well-quantified measurement range, coupled with a moderate degree of accuracy and affordability. We firmly believed that precision was vital; nevertheless, we recognized the importance of practicality in sensor capabilities. For instance, while the ability to measure temperature with a resolution of a hundredth of a Kelvin is undoubtedly impressive, it proved excessive for our specific research objectives, whereas room temperature operation was essential.

Our temperature and humidity sensors, which serve as integral components of our multisensor system, led us to the SHT-30 device. What makes it an excellent and convenient choice is its dual functionality, allowing us to simultaneously measure both relative humidity with a 2 per cent precision and temperature with an accuracy of 0.5 Kelvin. The device also comes equipped with a protective cover, not only ensuring the sensor's safety but also streamlining the integration process with other components. To facilitate seamless communication with the outside world, the SHT-30 uses the I2C interface, and an Adafruit Library is readily available to enhance its compatibility.

Ammonia levels were measured with the MQ-137 sensor, an outstanding choice given its expansive measurement range spanning from 5 to 500 ppm. Operating on a 5V supply, this sensor provides an analogue output linearly correlated with the concentration of ammonia that it detects. Although it necessitates a 48-hour warm-up period, this feature is typical among ammonia sensors.

Carbon dioxide levels, on the other hand, were effectively monitored using the MH-Z16 sensor. With the capability to precisely gauge concentrations from 0 to 5,000 ppm, this sensor's 1 ppm quantization and a 5 per cent accuracy further enhanced its suitability for our purposes. Moreover, its short warm-up time of just three minutes and a 5V operation with a maximum current consumption of 150 mA added to its practicality. Communication with the external systems was facilitated through a serial UART line.

For measuring wind speed, we employed the ADA-1733 anemometer, which boasts a measurement range spanning from 0.5 m/s to 50 m/s. The sensor provides data with a 0.1 m/s quantization and a worst-case error of 1 m/s. Similar to the ammonia sensor, it also offers an analogue output that is proportionate to the detected wind speed value. These sensors, collectively chosen after careful consideration, are integral to our multisensor setup (*Figure 1*), ensuring that we capture comprehensive and precise data to shed light on the intricate relationship between environmental factors and pig weight gain.

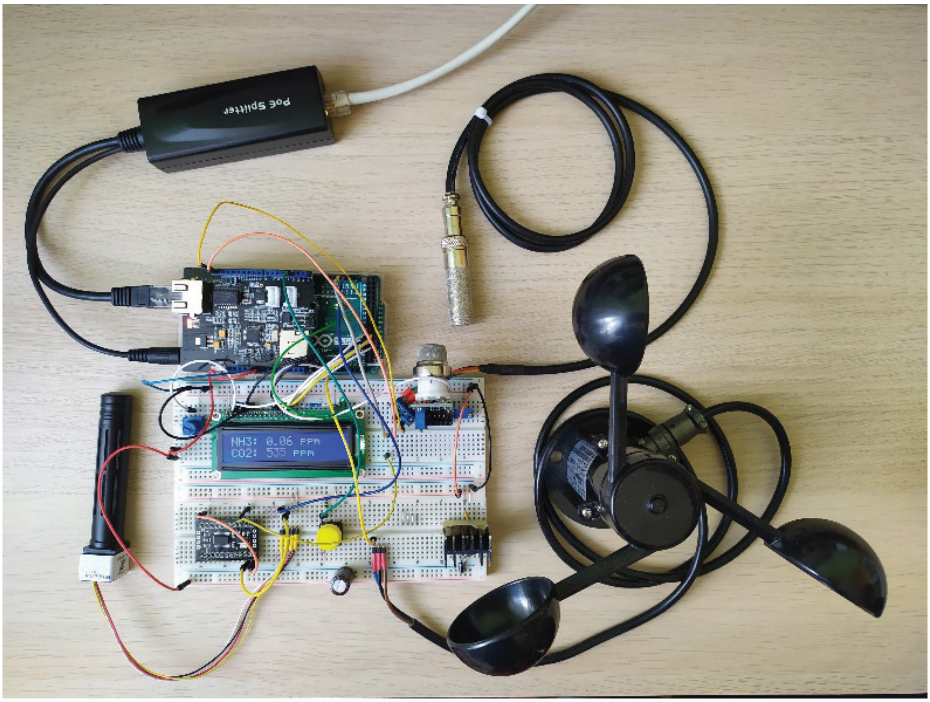

Figure 1. Multisensor test panel applied in this study

Data capturing and management

Regarding the physical infrastructure of our data management system, we selected the Arduino Mega as the central processing unit responsible for direct communication with the sensors (*Figure 2*). The Arduino was configured to transmit all measurement data via Power over Ethernet (PoE). To facilitate this communication, an A2971 Ethernet Shield was seamlessly integrated into the Arduino setup. The PoE connection was then extended to a Raspberry Pi, which served as the intermediary responsible for uploading the collected measurements to our designated web server. To ensure efficient communication and power supply separation, a PoE switch was incorporated. Furthermore, a two-line LCD screen was linked to the Arduino to facilitate easy operational monitoring, allowing us to verify the system's functionality. This screen – although limited in its display capacity – offered the flexibility to toggle between different measurement types, using a dedicated button.

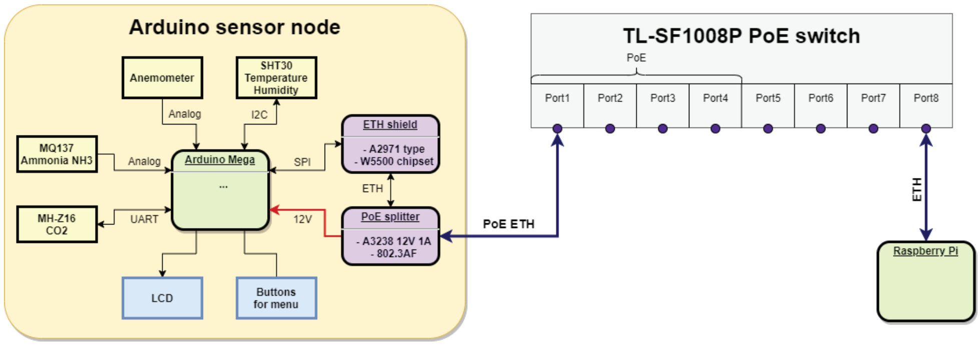

Figure 2. Physical setup of the system

In terms of software, we implemented sensor-specific readout interfaces within the Arduino framework, ensuring that data from various sensors could be harmoniously forwarded in a uniform and standardized format. Raspberry Pi played a pivotal role in the data transmission process, employing RabbitMQ and Masstransit to upload the data to our designated web server. The server, in turn, effectively stored the incoming data within a well-organized database structure and provided accessible endpoints for querying this information. Importantly, our data structures were designed to maintain flexibility, allowing for the seamless introduction of new measurement types. Each piece of data was tagged with its originating site identification, ensuring a comprehensive and organized record.

In terms of the quantitative aspects, our data collection system encompassed five sensors, with measurements taken at regular intervals (every five minutes). This extensive data collection initiative spanned from 22 November 2020 to 29 September 2021, resulting in the accumulation of a substantial 568,915 measurement values, equating to 113,783 measurements per sensor. Notably, the inclusion of pig weight data commenced on 29 June 2021, within which we recorded 132,415 measurements, thus 26,483 measurements per sensor. Given that pig weight data was computed on a daily basis, we consistently averaged the sensor measurements by day. As a result, we obtained a comprehensive 93-day dataset, in which pig weight and the corresponding averaged sensor values were meaningfully integrated and harmonized.

Assembling the sensors

The assembly of the sensors and computing devices underwent a meticulous and iterative process to ensure robustness and functionality. Initially, we established a proof-of-concept setup, illustrated in *Figure 1* (multisensor test panel), which successfully integrated all vital components. However, it became apparent that this initial setup lacked the required portability, stability, and resilience necessary to withstand the demanding conditions of our experiment.

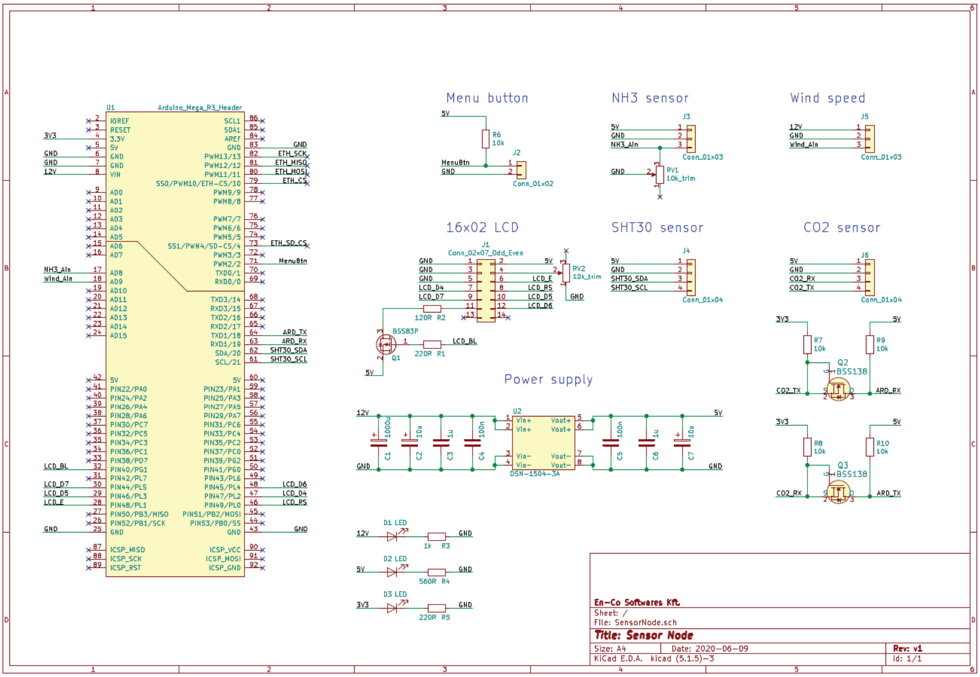

Figure 3. Wiring diagram

In our pursuit of a more durable configuration, we adopted a series of enhancements. First, we designed, fabricated, and seamlessly integrated a printed circuit board (*Figure 3*) using the KiCAD software and secured the electrical connections through soldering. Subsequently, we calculated the minimum dimensions required for an enclosure capable of accommodating all components, excluding the Raspberry Pi, which remained external to the enclosure. Our choice was the Hammond 1598BK box. To ensure optimal functionality and longevity, we employed FreeCAD to model the enclosed multisensor assembly. This process minimized mechanical and cable stress and ensured that heat-producing components did not affect each other adversely. With the design finalized, we 3D printed custom sockets and cut openings in the enclosure, ultimately resulting in the configuration (*Figure 4*).

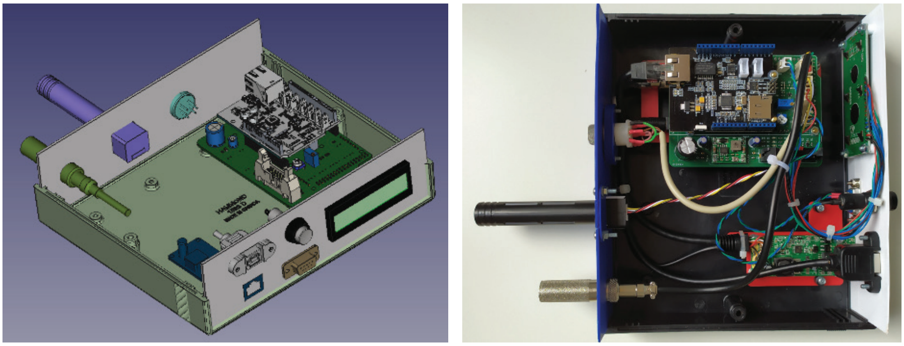

Figure 4. Boxed multisensor with FreeCAD model (left) and the physical realization (right)

At this juncture, we reached a stage where the multisensor setup was both portable and fully operational for testing. However, local testing revealed issues related to voltage stabilization, leading to overheating and occasional system shutdowns. To address this concern, we transitioned from our linear stabilizer to a switching voltage stabilizer, which significantly improved efficiency and so reduced heat generation due to power losses. This transition allowed the system to operate reliably for days without any sign of overheating.

Nonetheless, some heating persisted within the enclosure, decreasing the credibility of the temperature sensor. Consequently, we repositioned the temperature sensor outside the enclosure to ensure its proper functionality. Following these local tests and subsequent adjustments, the multisensor was deemed ready for an on-site trial.

Figure 5. Boxed multisensor on site: fresh (left), later (right)

The on-site evaluation highlighted the necessity for the enhanced protection of the sensors (*Figure 5*). Additionally, it became evident that the sensors needed to be positioned in closer proximity to the pigs to accurately measure the environmental parameters that directly influenced them. Achieving this proximity and the required protection posed new challenges.

To address these issues, we undertook the design and integration of a robust metal cover box of excellent air permeability. This new enclosure design not only facilitated valid measurements but also offered protection against the pigs, high-pressure washings, and other harsh environmental factors. Moreover, it ensured the safety of the pigs by preventing them from inadvertently causing harm to themselves. Consequently, this shielded multisensor configuration was placed inside the pigpen at the level of the pigs, as shown in *Figure 6*.

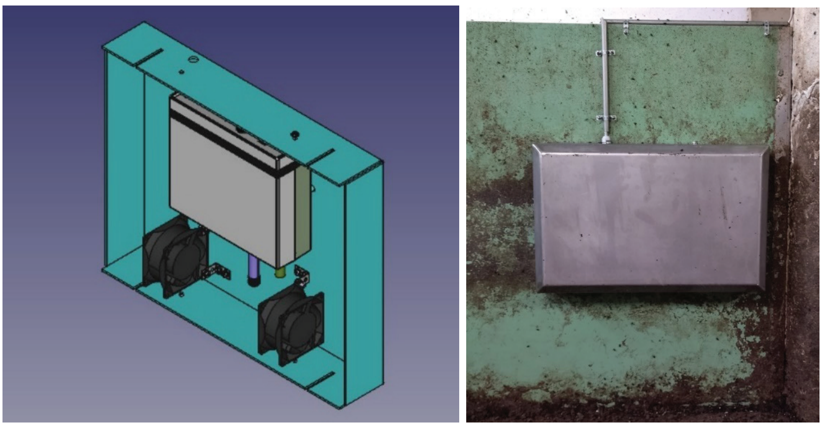

Figure 6. Shielded multisensor according to the FreeCAD model (left) and physical realization (right)

Statistical methods

We had two cameras above the pen; therefore, we obtained two weight series ("cam1" and "cam2") for the same pig population. We treated these two series independently. To improve the accuracy of average weight measurements, we applied a moving average filter on the raw average daily weight series. We computed the average daily weight gain by differentiating this smoothed weight series, so the average daily (smoothed) weight gain was as follows:

$$dw_{smooth}\left(k\right)=w_{smooth}\left(k\right)-w_{smooth}\left(k-1\right), \tag{1}$$

where: $w_{smooth}(k)$ is the smoothed average weight at day *k*.

Substituting the moving average formulas:

$$dw_{smooth}(k) = \frac{w\left(k-\frac{l}{2}\right)+\ldots+w\left(k+\frac{l}{2}\right)}{l} - \frac{w\left(k-\frac{l}{2}-1\right)+\ldots+w\left(k+\frac{l}{2}-1\right)}{l}, \qquad (2)$$

in which internal addends cancel out, and so it simplifies to:

$$dw_{smooth}(k) = \frac{w\left(k+\frac{l}{2}\right)-w\left(k-\frac{l}{2}-1\right)}{l}. \qquad (3)$$

Thus, the obtained average daily weight gain is equal to the difference of two days symmetrically further apart, divided by the number of days between them. For the latter calculations, we used a fifteen-day window.

Then pairwise correlation methods were applied to measure the relationship between each sensor data and the average daily weight gains of pigs. Both Pearson's and Spearman's correlation coefficients were calculated. The Pearson's method assesses the linear property of the relationship, while Spearman's correlation coefficient shows the extent of monotonic association between the variables. Both coefficients have ranges between -1 (perfectly negative correlation) and 1 (perfectly positive correlation). Multiple regression was also run to find an appropriate model for pig weight gain. To calculate them, we used Microsoft Excel's built-in functions, and the PAST software package (*Hammer & Harper*, 2001) was also applied.

3. Results and discussions

Pig production is one of the most important sectors of livestock farming in Hungary. With 2.7 million animals in 2021, Hungary ranked 11th among the EU27 countries (*KSH*, 2023a). According to the Hungarian Central Statistical Office, the per capita annual pork consumption in 2021 was 30.2 kg. This consumption was served by 3.2 million tons of national production and 1.7 million tons of import (*KSH*, 2023b). *Baráth et al.* (2021) showed that while from 2004 to 2019 pig production values and the number of specialized farms together with the number of animals decreased, whereas the average number of animals per holding increased, with many using precision farming technologies on the pig farms. *Kopler et al.* (2023) reviewed the most important pig-production-related precision-livestock-farming technologies and programs, including camera technology, microphones, animal-attached sensors, among them: environmental sensory thermometers, anemometers, and weather station. In our study, a multisensory system was developed and applied to find correlation between the environmental circumstances and the daily weight gain of the investigated pigs.

Pig weight evaluation based on image analysis

Regular evaluation of pig weight gain is essential to obtain information about the physiological and health status of the animals. However, since the traditional procedure of weight measurement would be stressful for the animals, remote sensing methods have become increasingly widespread (*Kongsro*, 2014; *Li et al.*, 2014). Our former study showed that animals' biometric parameters obtained from RGB images are appropriate to predict animal weight (*Kárpinszky & Dobsinszki*, 2023). In this study, the weight gain of 22 pigs was monitored with RGB-based image analysis over a period of approximately 3 months. Two monitors were collecting data concurrently. The average initial weight of the pigs was 33.47 kg and 34.11 kg, resp., while the final weight on 29 September (the date up to which the sensor data were collected) was 115.29 kg and 115.53 kg, resp., according to the images obtained from the two cameras. Pearson's correlation coefficient of the weight and smoothed rolling average weight collected by the two cameras was 0.9999 ($p < 0.01$) for both. The lowest average daily weight gains were 0.5883 kg (from 27 to 28 September 2021) and 0.5187 kg (from 21 to 22 September 2021), while the highest were 1.63 kg and 1.96 kg (from 5 to 6 September 2021) according to cam1 and cam2 respectively (*Table 1*).

Microclimatic data evaluation

Hu et al. (2022) reviewed the importance of air quality in modern livestock husbandry, highlighting the thermal environment as a significant factor affecting pigs' health and production rate. At the same time, providing the optimal microclimate is a multiple task because of the high energy prices and the harmfulness of the environmental sensors. *Yeo et al.* (2023) detail the optimal location of the pig house sensors, where maintenance and minimizing sensor damage were also considered among the necessary conditions. In this research, microclimatic data were obtained with a multisensor system developed in this study to obtain long-term data in the pig house in 5-minute intervals. Daily average data of temperature, humidity, CO_2, and NH_3 were collected. The mean temperature during the experiment was 24.88 °C (min.: 18.42 °C, max.: 31.08 °C), with an average of -0.08 °C temperature change between two days (min.: -7.14 °C, max.: 4.2 °C). Humidity was between 51.95% and 78.39%, with the mean value of 62.69%. CO_2 concentration ranged from 387.05 ppm to 900.77 ppm, with the mean value of 601.85 ppm. Ammonia concentration was between 0 and 0.012 ppm, with 0.002 ppm on average (*Table 1*).

Table 1. Summary statistics of pig weight, pig weight gain (n = 22) obtained from the two cameras and environmental data collected with the multisensory system

	Mean	St. dev.	Min.	Max.
Pig weight (cam1) (kg)	71.54	24.11	33.47	115.29
Pig weight (cam2) (kg)	72.62	23.72	34.11	115.53
Daily weight gain (cam1) (kg)	0.9321	0.2166	0.5883	1.6336
Daily weight gain (cam2) (kg)	0.9362	0.2303	0.5187	1.9664
Daily weight gain (cam. aver.) (kg)	0.9341	0.2147	0.5741	1.8
Temperature	24.88	2.82	18.42	31.08
Humidity	62.69	6.51	51.95	78.39
CO_2	601.85	118.47	387.05	900.77
NH_3	0.0021	0.0023	0	0.012
Random	$1.28*10^{-6}$	$4.18*10^{-6}$	0	$2.37*10^{-5}$
Change of temperature	-0.08	2.04	-7.14	4.2

Correlation of the microclimatic data with pig weight gain

Previous studies have shown that environmental conditions have significant consequence on pig weight gain. *Rauw et al.* (2020) investigated the effect of different temperature settings during the growing, fattening, and finishing stages on body weight gain, feed intake, and feed efficiency. Their results showed significant differences on the monitored growth curve parameters influenced by the environmental groups.

In our study, temperature, change of temperature, humidity, CO_2 and NH_3 concentration were monitored to find correlation with the daily weight gain of the animals (*Table 2*). In general, Spearman-type correlations were slightly elevated compared to Pearson's coefficients, implying that the connections were not linear.

Results showed that temperature had a significantly ($p < 0.01$) ("p" is the *probability value* of the statistical model) negative Pearson's and Spearman's correlation with daily body weight gain. This finding shows that pigs' food consumption is lower at higher temperatures. It must be highlighted that the experiment was conducted starting from midsummer. Results pointed to the same direction in the case of weight data obtained from both cam1 and cam2 images.

CO_2 concentration showed significantly ($p < 0.01$) positive correlation with body weight gain. This is probably because weightier pigs tend to exhale more CO_2 and gain more weight in absolute terms. On the other hand, in this interval, the amount of carbon dioxide was not enough to significantly prevent the pigs from gaining more weight. The NH_3 concentration also weakly correlated positively ($p < 0.01$) with body weight gain. Likewise, this result may be attributable to the metabolism of weightier pigs. The ventilation system was good enough to maintain a healthy concentration of NH_3.

Neither humidity nor temperature change nor random effect has a significant correlation with the collected weight data. Unsurprisingly, the random effect showed very low negative correlations (not significant). It also greatly fluctuated if we changed the moving average window size. For this calculated feature, computations resulted in no or only very week correlation. Multiple linear regression calculated by the average body weight gain values resulted from the 2 cameras showed significance, and the model showed that temperature and humidity had a significant effect ($p < 0.01$) on the body weight gain of the pigs, while the p value of the NH_3 concentration was 0.05 (*Table 3*).

The MLR model is ($n = 86$, multiple $R = 0.57$, multiple $R^2 = 0.33$):

$$Y = 3.29 - 0.04x_1 - 0.01x_2 - 0.0004x_3 + 24.83x_4 - 3407.1x_5 - 0.0032x_6 , \tag{4}$$

where x_1 refers to temperature, x_2 refers to humidity, x_3 refers to CO_2, x_4 refers to NH_3, x_5 is the random effect, and x_6 refers to the change of temperature.
The F-test value was 6.53 on df1, df2: 6, 79 ($p < 0.01$).

Table 2. Pearson's correlation of the environmental parameters with the average daily weight gain (moving average window size: 15)

Sensor data type	**Pearson's correlation coeff.**	
	cam1	cam2
Temperature	-0.4337*	-0.3985*
Humidity	-0.0615^{ns}	-0.0863^{ns}
CO_2	0.3338*	0.3130*
NH_3	0.3451*	0.3101*
Random	-0.0659^{ns}	-0.1084^{ns}

Note: * indicates significant correlation between the monitored environmental parameter and daily body weight gain at $p < 0.01$.

Table 3. Multiple linear regression model

Sensor data type	**Coeff.**	**Std. err.**	**t**	**p**	**R^2**
Temperature (x_1)	-0.04	0.01	-3.79	0.00	0.18
Humidity (x_2)	-0.01	0.00	-4.00	0.00	0.00
CO_2 (x_3)	0.00	0.00	-1.33	0.18	0.11
NH_3 (x_4)	24.83	12.75	1.94	0.05	0.11
Random (x_5)	-3407.1	5131.9	-0.66	0.50	0.00
Change of temperature (x_6)	0.00	0.01	-0.31	0.75	0.00

4. Conclusions

In this study, RGB-based remote sensing was applied to collect information about daily pig weight gain. A recently developed multisensor system was applied to collect environmental information about temperature, humidity, the concentration of carbon dioxide and ammonia. We found that temperature has a negative correlation with pig body weight gain, while the correlation was positive concerning the CO_2 and NH_3 concentration.

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