



# Smart estrus detection (SED): Transformation of internet of things-based technology as an effort to increase the success of sustainable dairy farming businesses

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## ABSTRACT

**Background:** The dairy industry plays a significant role in meeting the need for animal protein in Indonesia, one of which is milk. The demand for milk in Indonesia continues to increase along with the population growth that continues to increase every year. The population of dairy cattle in Indonesia in 2022 reached 507,075, with a fresh milk production rate of 824.3 thousand tons. This figure is still far from the national milk requirement of 4.3 million tons per year. **Methods:** The data collection method used is field observation and literature study by reviewing several previous studies and related articles. **Findings:** The problem in achieving the national milk requirement target is that dairy cattle farming in Indonesia is dominated by small and medium-scale livestock farmers. The lack of knowledge of livestock farmers in identifying estrus in livestock is still a significant problem. This has an impact on the success rate of Artificial Insemination (AI) which is influenced by the timeliness of implementation in carrying out insemination on cows in estrus. The success rate of AI in livestock has implications for the economic status of livestock farmers because it involves the cost of semen (seeds) and the operational costs of inseminator officers. Along with the advancement of technology in the Society 5.0 era, Smart Estrus Detection (SED) is here as a solution in detecting estrus in real time using an infrared thermography camera. The working system of this tool utilizes the ESP32 microcontroller to process data received by the sensor and send it to a database which will later be sent via a network so that it can be monitored directly via an application on a smartphone. **Conclusion:** The results of this study are that the implementation of SED technology can increase reproductive efficiency in the dairy cattle industry. SED can detect changes in temperature in the vulva of livestock (35.5oC to 36.8oC) and temperature in the nose (33.5oC to 34.5oC) obtained 24 hours before ovulation which indicates that the livestock is in estrus. **Novelty/Originality of this article:** SED is expected to be a breakthrough in answering the problem of relatively inaccurate estrus detection in livestock, so that it can later increase the success of sustainable dairy cattle farming.

**KEYWORDS:** dairy cows; detection; estrus; reproductive efficiency.

## 1. Introduction

Indonesia is a developing country with a population that continues to increase every year. The increase in population drives need for food which also increases, including animal food. The dairy cattle industry is one of the livestock sub-sectors that has a significant role in supporting the fulfillment of animal food needs through livestock products in the form of milk. Fresh milk is one of the dairy cattle commodity products with high nutritional content and is an important source of animal protein for the people of Indonesia. According to the

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Central Statistics Agency (2024), the population of dairy cattle in Indonesia in 2022 was 507,075, which decreased compared to 2021 which reached 582,169. This population decline has an impact on the milk production produced. Currently, the level of domestic fresh milk production is only able to produce 837,223 tons, which is still far from the national milk requirement which reaches 4.3 million tons per year (Ministry of Agriculture, 2021). The problem in achieving the national milk requirement target is that dairy farming in Indonesia is dominated by small and medium-scale farmers with livestock ownership of 5-20 heads. Maintenance management that still uses traditional methods and the lack of knowledge of farmers in identifying estrus or heat in livestock is a significant problem for the decline in livestock population and national milk production. One effort to increase the population and genetic quality of livestock is by implementing artificial insemination using semen (seed) from superior males.

Artificial insemination (AI) is a development of biotechnology in the field of livestock reproduction that allows humans to mate female livestock without a male. The use of AI in the livestock industry greatly encourages reproductive efficiency in livestock because it can improve production performance and the resulting genetic quality. The key steps in implementing AI are the skills of the AI officer (inseminator) and the accuracy of farmers in detecting estrus or heat in livestock. Estrus is an important factor in reproductive management because failure to detect estrus will result in pregnancy failure. Accurate detection of heat is an important factor in the mating program so that fertilization can be carried out at the right time. The normal estrus cycle in cows recurs regularly and is accompanied by the appearance of visual symptoms (Jurame & Womsiwor, 2018).

Ngantang District is one of the centers of dairy cattle farming with the majority of its population making a living as livestock farmers. Having a geographical location of  $7^{\circ} 51' 23.1$  East Longitude and  $112^{\circ} 22' 09.9''$  South Latitude with an altitude of 870 meters above sea level, making the district very suitable for the development of dairy cattle farming. According to the Central Statistics Agency (2021), the population of dairy cattle in Ngantang District in 2021 reached 17,864. The large population of dairy cattle can help increase milk production in Indonesia so that it can balance consumer demand for milk. However, the majority of farmers in Ngantang District still do not fully understand the signs of estrus in livestock and have an impact on the success rate of AI which is influenced by the timeliness of implementation in carrying out insemination on cows in estrus. The success rate of IB in livestock has implications for the economic status of smallholder farmers because it involves the cost of semen (seedlings) and the operational costs of inseminators.

Based on the above problems and along with technological advances in the Society 5.0 era, there needs to be a breakthrough in helping smallholder farmers detect estrus in livestock as an effort to increase the efficiency of dairy cattle reproduction, namely with "Smart Estrus Detection (SED): Artificial Intelligence-Based Technology Transformation as an Effort to Increase the Success of Sustainable Dairy Cattle Farming Businesses". This innovation integrates the Internet of Things to detect estrus in real time using an infrared thermography camera. The working system of this tool utilizes the ESP32 microcontroller to process data received by the sensor and send it to the database which will later be sent via the network so that it can be monitored directly via the application on the smartphone.

## 2. Methods

### 2.1 Research methods

The method used in this study is a literature study approach presented quantitatively. The study was conducted by collecting data on previous research and related scientific articles from reliable sources. Several stages of writing this work began with finding a problem topic that was in accordance with the competition sub-theme, then looking for the causal factors of the problems raised and continued with a literature study of related problems and various solutions that had been made. After a solution was obtained that was in accordance with the problem, development was carried out with the latest innovations.

In addition, data sources were also obtained from field observations by visiting Sumberagung Village, Ngantang District and recording relevant data related to the problems that needed to be resolved. Data from field observations aims to strengthen the case study which aims to determine the current conditions of the project location, identify the main problems in the case, conduct case analysis using theoretical concepts, and find solutions related to the resolution of the case.

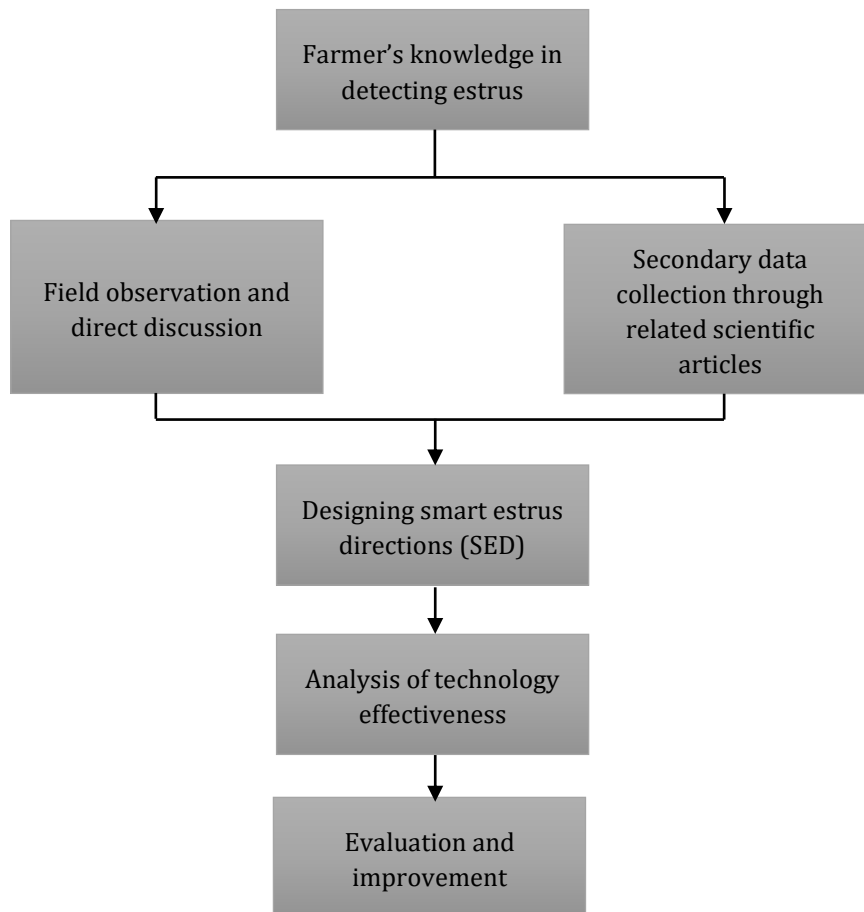


Fig 1. Framework of thinking

## 2.2 Data collection technique

The data collection method used is a descriptive exploratory research method using related journals. The process of identification and collection of information related to the implementation of integrated Internet of Things estrus detection technology in supporting reproductive efficiency in dairy cattle was carried out. In addition, a study was also conducted on the sustainability of Smart Estrus Detection (SED) in helping farmers identify estrus in livestock via smartphones so that sustainable livestock farming is created.

## 2.3 Data analysis techniques

Data analysis techniques for journals, books, articles, and observation and discussion data obtained are as follows: data obtained according to the theme that the author is researching in order to facilitate the author in grouping the data. Data obtained from a set of information is arranged according to the provisions to allow for drawing conclusions and taking action. Interpretation of data that has been obtained by the researcher and correlated with literature studies. Verification is the final stage, at this stage the researcher analyzes, deepens, and sharpens the previous analysis.

## 2.4 Drawing conclusions

Data collection is obtained from several literature studies and field observations that have been analyzed by researchers. Drawing conclusions is done by drawing several important related data points.

### **3. Result and Discussion**

#### *3.1 Dairy farming*

Dairy farming is one of the livestock businesses that has a strategic role in meeting the increasing need for animal protein food, increasing population income and increasing the national economy. Dairy cattle are one of the livestock commodities that can produce milk as their main product. Dairy cow milk productivity is influenced by several factors, namely livestock genetics, environment and the relationship between genetics and the environment. Dairy cows can produce milk as their main product, calves and meat from culled dairy cows (Susilawati et al., 2023). Good management of pen maintenance and feeding can support the productivity and reproductive cycle of livestock.

The reproductive cycle in dairy cattle is very important to pay attention to because with these livestock, pregnancy will produce calves and mothers will produce milk. Therefore, it is necessary to regulate good reproductive management so that livestock can give birth every year in a healthy condition until weaning and the milk production produced is also abundant (Susilawati, 2022). A good maintenance system (good dairy farming practices), namely providing sufficient feed in terms of quality and quantity, will support optimal livestock production performance. Dairy cattle have the best characteristics in terms of efficiency in converting feed into animal protein and calories compared to other cattle. Dairy cattle are very suitable for cultivation in cold areas to prevent stress due to heat stress so that dairy cattle production can be optimal.

#### *3.2 Estrus cycle*

Estrus is a phase or stage in the estrus cycle that is seen from the behavior of females who accept male animals for reproductive activities or are ready to be mated. Signs of estrus can be in the form of clear and thin mucus where the mucus forms a fern-like crystallization pattern and after ovulation and the final estrus phase, the mucus becomes a thick white mass that has many horny cell elements. Estrus can also be observed by looking at the color of the vulva which is red and swollen. Estrus can be influenced by external factors such as rainfall and the growth of animal feed plants (Kusumawati et al., 2018).

In addition, observations of estrus can also be seen from their behavior such as restlessness, wanting to be ridden or being more tame, and being swollen. The emergence of estrus behavior is caused by external stimuli to the senses (sight, hearing, smell, and taste) received by the hypothalamus then the anterior pituitary orders FSH so that growth and maturation of follicles in the ovaries occur so that the estrogen hormone is secreted in the ovaries by theca cells. The estrogen hormone provides feedback to the hypothalamus so that the anterior pituitary can secrete the ACTH hormone to the adrenal glands, then the adrenaline hormone and cortisol hormone are secreted. Narrowing of blood vessels and faster heart rate activity than usual occur due to the presence of the adrenaline hormone so that blood pressure increases and signals the hypothalamus which then gives an anxious response to the behavior of cows experiencing estrus (Anisa et al., 2017).

#### *3.3 Estrus detection technology*

One of the applications of the Internet of Things in the livestock sector is the existence of wireless sensor network technology that enables the implementation of low-cost sensor platforms with applications in various sectors and communities. In the livestock sector, these sensors are the basis for the creation of decision-making tools that improve the

efficiency of livestock operations. One of the early applications of sensor technology at the individual animal level was the accurate identification of cows entering estrous or estrous detectors to increase the success rate of pregnancy and thus optimize milk yield per animal (Michie et al., 2020). Detection of estrous by farmers conducted in 1994 on 4,550 cattle in the United States, found an average detection accuracy of 38% (Gröhn & Rajala-Schultz, 2000). In contrast, through the application of technology such as estrous detectors, it is reported to have a success rate of up to 80–90% (Wolfger et al., 2015).

The sensors used in low-power estrous detectors are typically Micro-Machined Electromechanical (MEMs) accelerometers combined with low-power wireless radio chipsets to provide 24/7 monitoring capabilities over long periods of time (5 to 10 years). To determine when a cow is in estrus, the animal's activity is measured. It is well known that cows in estrus become restless (Van Vliet and Van Eerdenburg, 1996) so machine learning or statistical approaches can be used to identify outlier behaviors that align with the onset of estrus (Martiskainen et al., 2009). Measuring these activity changes is easy using MEMs accelerometers (Michie et al., 2017), but it is not possible to transmit all unprocessed accelerometer data to a three-axis system with a sampling frequency of 10 Hertz or greater. This is because low-power wireless transmission channels do not have sufficient bandwidth. Therefore, data must be processed locally (i.e. on the animal) with only periodic status updates delivered along with alerts every one or two hours to save power consumption. Alternatively, the data can be preprocessed into a summary describing the dominant signal characteristics over a period of time so that this information can be processed further. In this way significant savings in radio transmission power consumption can be achieved and battery life of 5–10 years is typical. The information generated in this way can then be processed on the farm's central computer or in the cloud to represent the measurement data in a way that is useful to the herders to support daily decision making.

### 3.4 Cow pregnancy evaluation

High pregnancy success rates contribute to good reproductive efficiency in dairy cattle, which refers to the percentage of cows that successfully become pregnant after mating. The higher the pregnancy success, the better the reproductive efficiency of the cows. Reproductive efficiency as an evaluation of the success of AI can be observed from several parameters such as NRR (Non Return Rate), CR (Conception Rate) and PR (Pregnancy Rate) (Susilawati et al., 2019).

Non-return Rate (NRR) is the percentage of cattle that do not request re-mating or return to heat after the first Artificial Insemination. NRR observations are carried out by following the inseminator on duty and recording the date of the first Artificial Insemination, then observations are made again on the 21st (NRR 1) and 42nd (NRR 2) days (Setiawan, 2018). If during the NRR 1 observation the cattle experience heat again, this means that the AI that was carried out failed and must be repeated. Meanwhile, if the livestock does not show signs of estrus again, it can be assumed that it is pregnant so that NRR2 observations can be carried out after the first AI (Susilawati et al., 2022). The NRR calculation can be done using the following formula Equation 1.

$$NRR = \frac{\text{number of cows in IB} - \text{number in cows in heats}}{\text{number of cows in IB}} = 100\% \quad (\text{Eq. 1})$$

The rise and fall of the NRR value is caused by several factors such as the timeliness of IB, estrus detection, feed, and semen quality as well as the occurrence of embryo death, if the NRR value is high then it means it is better (Fernanda et al., 2014). The Conception Rate (CR) is the percentage of the number of livestock that are pregnant based on the results of rectal palpation by the inseminator on the 60-90th day after Artificial Insemination (Khan et al., 2015). The CR calculation can be done using the formula according to Ervandi et al., 2019 as follows Equation 2.

$$PR = \frac{\text{number of pregnant cows}}{\text{number of livestock in IB}} \times 100\% \quad (\text{Eq. 2})$$

A good CR value usually reaches around 60%-70%, but in Indonesian terms, seen from various aspects such as management, natural conditions, and distribution of livestock that are spread out, it is considered good if the CR value is 45%-50% (Wardhani et al., 2022). Pregnancy Rate (PR) is the percentage of pregnant cows from the total of all cows that have been inseminated. Pregnancy examination is carried out by rectal palpation where the inseminator will feel the uterus to find out if there is any enlargement of the female reproductive organs during pregnancy (Utami et al., 2023). Determination of PR can use the following formula Equation 3.

$$CR = \frac{\text{number of pregrant cattle in the first IB}}{\text{number of livestock in IB}} \times 100\% \quad (\text{Eq. 3})$$

One of the factors that can increase the PR value is the accuracy in detecting estrus. Inseminators have a very important role in identifying whether livestock are in estrus or not, so that if farmers observe estrus more often, the success of IB will be better (Susilawati et al., 2016).

### 3.5 Design and working mechanism of smart estrus detection

In the era of Society 5.0, technological developments in the livestock sector are increasingly massive in driving the performance and efficiency of livestock production towards independent and sustainable livestock farming. Technological advances in the dairy cattle industry can support the efficiency of livestock reproduction in producing calves every year and optimal milk. The development of estrus detection technology in livestock is intended to identify the estrus status of livestock on time and minimize delays in the implementation of IB. Smart Estrus Detection (SED) is the development of estrus detection technology in livestock by integrating the Internet of Things using infrared thermography sensors and digital time lapse cameras.

Infrared thermography is a non-invasive, non-destructive and safe tool for measuring the physiology of livestock reproduction in obtaining a visual picture of the thermal profile of body surface temperature. Infrared thermography is used to monitor changes in temperature, infrared radiation and frequency of movement that affect the physiological status of livestock reproduction emitted from the surface of the livestock's skin. This camera then converts the infrared intensity into an electromagnetic signal that is processed and displayed in the form of a thermal map. This map shows the temperature distribution that shows several colors to represent a specific temperature range on the skin surface and correlates with the physiological status of the livestock. This technology does not require direct contact with the observed object, thus allowing for remote temperature measurement in a wider area (Pamungkas et al., 2020).

A digital time-lapse camera is a tool for recording livestock behavior such as resting, rumination, and standing activities. The use of a digital time-lapse camera functions to take pictures of cattle every 2 minutes for 24 hours to determine the duration of livestock activity. The photos obtained will be stored on an SD-Card which is transferred to the cellphone memory for further conversion. The livestock behavior data that has been collected will be calculated for the total duration in a 24-hour (daily) observation interval automatically (Sulistya et al., 2021).

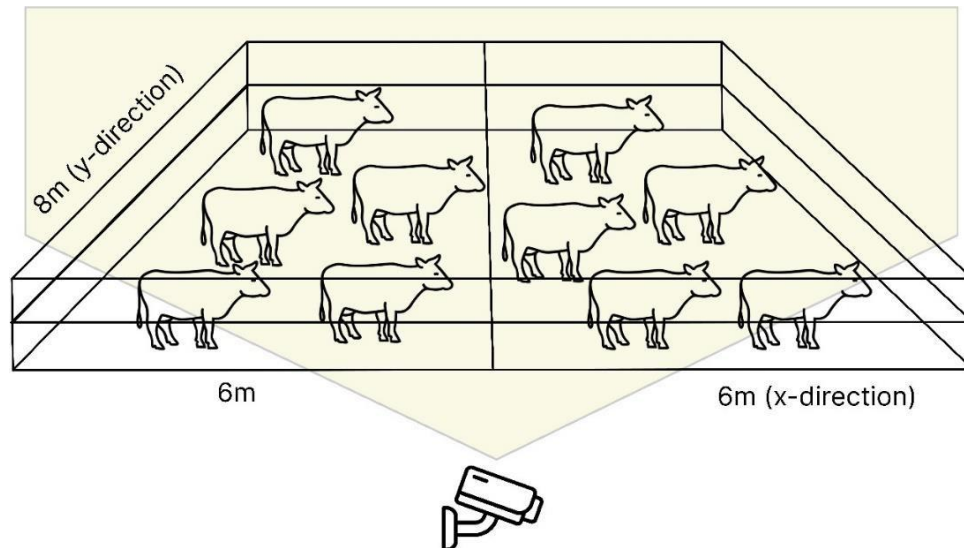


Fig 2. Smart estrus detection scanning principle

The working system of Smart Estrus Detection technology integrates the Internet of Things in optimizing real-time livestock monitoring and makes it easier for farmers to monitor and control dairy cattle experiencing estrus. The Internet of Things is generally defined as the ability to connect smart objects and allow them to interact with other objects or the environment with other smart computing equipment via the Internet network. The working system of this tool utilizes the ESP32 microcontroller to receive data and send the data to the database. This allows farmers to monitor the condition of their livestock via a mobile application on their smartphone.

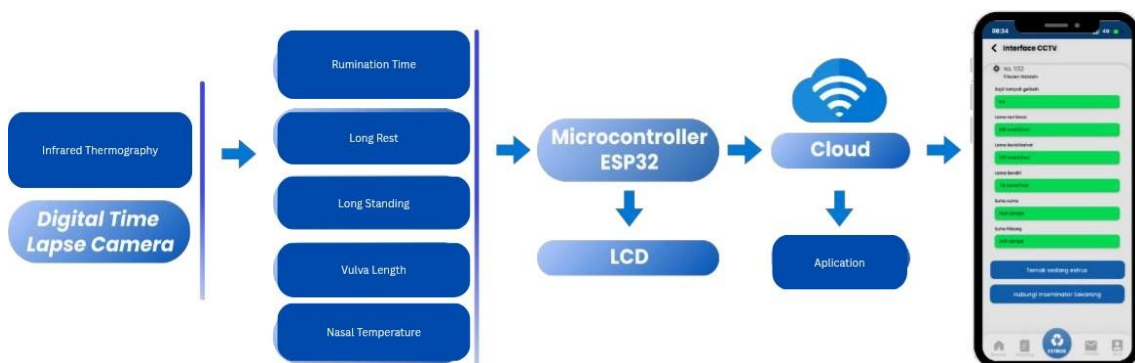


Fig 3. Flow of technology working mechanism

Application development is carried out to provide facilities for farmers in recording livestock reproduction with a mobile system to facilitate farmers in the process of recording livestock reproductive estrus cycles. This application makes it easy for farmers to remember and record livestock estrus cycles to be efficient and effective in determining livestock estrus periods. This application has 5 main superior features, including: livestock biodata: this feature will store databases related to livestock biodata such as livestock number, sex, year of birth, type of cow, body weight, height of the hump and body length. Livestock estrus calendar: this feature will display the date when the estrus period occurs and the history of the livestock estrus phase which will then display a notification to check the NRR and PKB as a reminder that on that date the livestock must be checked to avoid pregnancy failure in livestock.

Pregnancy evaluation: this feature will provide evaluation data in the form of NRR percentage and Conception Rate from all livestock data that has been entered into the application. The data is used as an evaluation of farmers in the reproductive management carried out so far. Daily livestock data: this feature will provide information on the number

of pregnant cows, the number of heifers, the number of calves, the number of cows that have been inseminated and the number of cows that have given birth. This information is to make it easier for farmers to record their livestock. Scoring: this feature will provide several questions related to signs of estrus in livestock which aim to evaluate the inseminator whether the livestock is entering the estrus cycle or not so that later the inseminator can take action according to the scoring results.



Fig 4. Design of estrus monitoring application

### 3.6 Implementation of smart estrus detection in monitoring the reproductive physiological status of cows

Smart Estrus Detection uses infrared thermography and digital time lapse camera to detect the estrus condition of livestock. This tool has several indicators used to identify dairy cattle in estrus, including an increase in vulva temperature, an increase in the temperature of the cattle's nose, restless cattle, rumination time, rest time, and standing time. Based on these parameters, there will be a notification whether the cattle are in estrus or not and will then be directed to contact the inseminator so that AI can be carried out immediately.

The use of Smart Estrus Detection can detect cattle in estrus through an increase in temperature in the vulva (35.5 °C to 36.8 °C) and nose (33.5 °C to 34.5 °C) which occurs 24 hours before ovulation which indicates that the cattle are in estrus. Meanwhile, a decrease in temperature in the vulva of livestock (36.5 to 35.5) and nose (35.3 to 33.5) occurred 48 hours before ovulation and can be correlated with the corpus luteum undergoing regression. This condition causes the progesterone hormone in livestock to decrease, which can be interpreted that the livestock has passed the estrus phase (metestrus). In this condition, livestock cannot be inseminated because the egg cells are not mature so they cannot fertilize spermatozoa cells. This is what allows farmers to lose in reproductive efficiency because it involves the cost of semen (seedlings) and the operational costs of inseminator officers. Temperature detection in the vulva and nose of livestock has a standard deviation ranging from 0.2 - 0.3 to allow the data received by the system to be valid. The increase in temperature in the vulva and nose of livestock also depends on the breed of cattle, livestock conditions, adequacy of feed nutrition and environmental conditions.

Table 1. Data on livestock behavior during livestock

Parameter	Cow Condition (Estrus)	Cow Condition (Tidak Estrus)
Rumination duration (minutes/day)	240	470
Rest time (minutes/day)	330	462
Standing time (minutes/day)	191	508

Based on their behavior, it was found that the rumination time of livestock in estrus was 240 minutes/day, while in livestock that did not experience estrus, the rumination time was 470 minutes/day. The rest time was 330 minutes/day, while in livestock that did not experience estrus, the rest time was 462 minutes/day. The standing time was 191 minutes/day, while in livestock that did not experience estrus, the standing time was 508. The duration of livestock experiencing estrus was recorded as shorter when compared to livestock that did not experience estrus. This is because changes in the behavior of livestock that are in estrus can be caused by changes in the estrogen hormone (Baliarti, et al., 2018). Several of these indicators have a standard deviation ranging from 8.79 to ensure that the data received by the system is valid. The intensity of movement in livestock is also influenced by several factors such as livestock health conditions, environmental conditions, adequacy of feed and drink, and maintenance management.

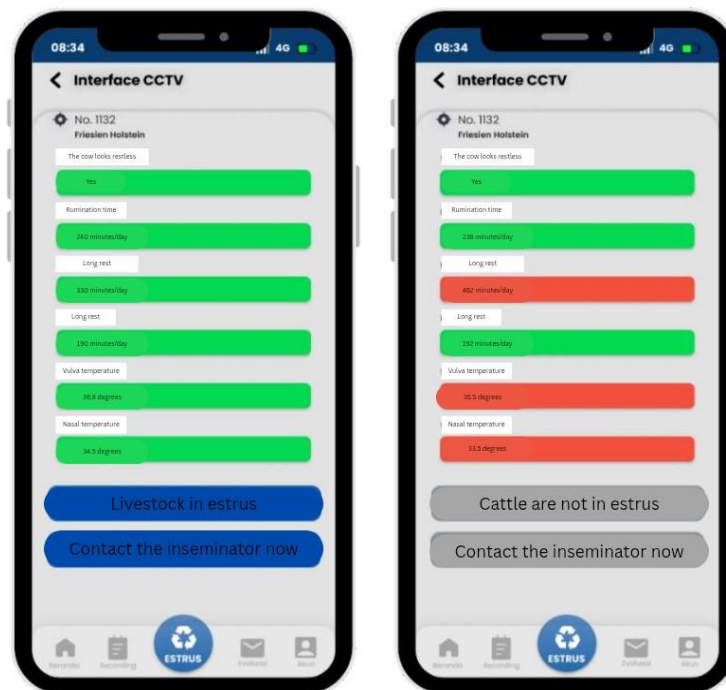


Fig 5. Scan results interface in the application

Modern estrus detection tools are still rarely used in small-scale livestock farming in Indonesia because the cost is still relatively expensive. Therefore, there needs to be a tool that is easier and more efficient to apply, such as the use of infrared thermography and digital time-lapse cameras. The application of these two tools has been widely used abroad in the field of veterinary medicine for diagnostic purposes. In addition, infrared thermography and digital time-lapse cameras are also used in the field of livestock in thermoregulation, livestock welfare, and livestock physiology and reproduction. These two tools are recommended in the field of livestock in Indonesia in creating a method that can produce important information as a replacement for manual diagnostic techniques that have been applied so far.

### 3.7 Contributing parties

Smart Estrus Detection innovation integrated with the Internet of Things can be realized through cooperation between related parties. Government: the government is a stakeholder that plays an important role as the person in charge, provider of supporting facilities for activities and counseling, and formulating policy regulations related to the dairy cattle population and national milk production. Cooperation in the Ministry of Agriculture, between the Food Security and Agriculture Service and the Animal Husbandry

Service is needed to support the implementation of the Internet of Things integrated SED. Non-Government: farmer groups have a primary role as implementers of the Internet of Things integrated SED implementation as implementers of dairy cattle businesses and milk producers. The implementation of this technology is expected to increase national milk production and improve the economic level of members of the community farmer groups.

In the implementation of the Internet of Things integrated SED, support is needed from companies that provide component tools as materials for the technology. With this cooperation, it is hoped that the implementation of this dairy cattle farming technology can be realized widely and evenly to meet the demand for milk in Indonesia. Investors act as providers of funds based on cooperation in the implementation of the Internet of Things integrated SED. The Higher Education Institution has a role as a facilitator of research on an ongoing basis and an intermediary for cooperation in government work programs with the community. The development of science in the implementation of SED integrated with the Internet of Things is expected to be a solution to problems in society. KUD can be a driving force in modernizing the livestock sector by providing training, distribution, and financing to farmers who want to adopt an innovation.

#### **4. Conclusion**

Smart Estrus Detection (SED) is a development of estrus detection technology by integrating the Internet of Things using infrared thermography and digital time lapse cameras. The working system of this tool utilizes the ESP32 microcontroller to receive data and send the data to the database. This allows farmers to monitor the condition of livestock through a mobile application on a smartphone. The application development was carried out to make it easier for farmers to record livestock reproduction with a mobile system. The use of the Smart Estrus Detection tool can detect livestock in estrus through an increase in vulva temperature (35.5 °C to 36.8 °C) and nose (33.5 °C to 34.5 °C) occurring 24 hours before ovulation. Meanwhile, a decrease in temperature in the vulva of livestock (36.5 to 35.5) and nose (35.3 to 33.5) occurring 48 hours before ovulation can be correlated with the corpus luteum undergoing regression. the duration of rumination of livestock in estrus is 240 minutes/day. In addition, several indicators such as the length of rest time of 330 minutes/day, and the length of standing time of 191 minutes/day show a shorter difference compared to livestock that do not experience estrus. Smart Estrus Detection (SED) is expected to be able to answer the problem of decreasing dairy cattle population in Indonesia and national milk production which still cannot meet national milk needs.

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Not available.

## Conflicts of Interest

The author declare no conflict of interest.

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