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REVIEW
Artigo de Revisão

Infrared thermal image for assessing animal health and welfare

Imagem termográfica infravermelha na avaliação do bem-estar animal

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Abstract Infrared thermal imaging is a non-destructive testing technology that can be used to determine the superficial temperature of objects. This technology has an increasing use in detecting diseases and distress in animal husbandry within the poultry, pig and dairy production. The process can identify changes in peripheral blood flow from the resulting changes in heat loss and; therefore, have been a useful tool for evaluating the presence of disease, edema, and stress in animals. This paper reviews the current literature related to the use of infrared technology and discusses their results and implications in animal welfare issues, poultry, pig and bovine industry.

Keywords emissivity, husbandry, surface temperature, thermal environment

Resumo Imagem térmica infravermelha é uma tecnologia experimental não destrutiva, que pode ser utilizado para determinar a temperatura superficial dos objetos. Esta tecnologia tem uma crescente aplicação na detecção de doenças e estresse em criação de animais: aves, suínos e produção de leite. Este processo pode detectar mudanças no fluxo de sangue periférico das alterações resultantes na perda de calor e, portanto, têm sido ferramenta útil para avaliar a presença de doença, edema e estresse nos animais. Este trabalho revisa a literatura atual em relação ao uso da tecnologia de infravermelho e discute seus resultados e implicações em questões de bem-estar animal, e na indústria de produção de aves, suínos e bovinos.

Palavras-chave emissividade, produção animal, temperatura superficial, ambiente térmico

Introduction

All substance emits radiant energy as a consequence of its absolute temperature. The portion of the electromagnetic spectrum extending from approximately 0.1 to 100mm, (the visible and the infrared spectrum) is named thermal radiation (Incropera and DeWitt 2007). Radiation is a form of heat loss through infrared rays involving the transfer of heat from one object to another without physical contact. Skin emissivity is an important factor in determining the true skin temperature, and through the assessment of surface temperature it is possible to acquired knowledge regarding physical and healthy status of humans and other living creatures (Chiu et al 2005; Cook et al 2006; Bouzida et al 2009; Alsaood et al 2014)

Infrared thermography (IRT) is a non-destructive testing technology that can be used to determine the superficial temperature of objects. Thermal cameras collect infrared radiation emitted by the surface, convert it into electrical signals and create a thermal image showing the body's superficial temperature distribution (Incropera and DeWitt 2007). In this process, each color expresses a specific temperature range, related to the defined scale. In homeothermic animals, thermoregulation is a key feature in the maintenance of homeostasis. Thermoregulatory abilities are strongly related to energy balance and animals are often seeking to limit the energy costs of normothermia (Donkoh 1989; Cooper and Washburn 1998; Yahav et al 1998; Aksit et al 2006). In the case of thermal changes, physiological mechanisms are enhanced, increasing rates of energy expenditure (Shinder et al 2007; Stewart et al 2008).

IRT allows the visualization of temperature distribution, and it can detect changes in peripheral blood flow from the resulting changes in heat loss and; therefore, have been a useful tool for assessing the presence of disease, edema, and stress in animals (Nikkhah et al 2005; Bouzida et al 2009; Alsaood et al 2014). Surface temperature measurements can be made without trouble and with high precision, especially on animal coats that have low heat

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capacities (McCafferty et al 1998; Tessier et al 2003; Montanholi et al 2008).

This paper reviews the use of IRT technology in evaluating forms of disease and distress in animal production, and it presents cases reports related to the use of this technology in experimental procedures for assessing thermal stress in pigs and poultry.

Animal welfare assessment

The definition of animal welfare is generally accepted as the balance between the animal and its surrounding environment. In practice, this means to provide them with sufficient health and comfort, as well as avoiding stress of any order. This means that health, welfare, and productivity are intimately connected (Moura et al 2006). Dawkins (1990) support the idea that welfare is mainly dependent on what the animal feels more than its response; however, other authors identified welfare determinants as related to the degree of distress and suffering (Zhou and Yamamoto 1997; Yahav et al 2004; Nääs et al 2010). At the same time, the lack of effective assessments of animal welfare represents a great difficulty for the establishment of welfare regulations and the evolution of animal welfare information.

IRT has been used to evaluate the welfare of livestock under usual managing procedures or health status control in calves (Schaefer et al 2004; Stewart et al 2008), in poultry research (Yahav et al 2001; Yahav et al 2004; Cangar et al 2008), and also in pig production (Warriss et al 2006). It has also been useful for assessing welfare in wild animals (McCafferty et al 1998; Dawson et al 1999; Ward et al 1999). Based on the association between muscle temperature rise and early postmortem pH fall rate (Nicol and Scott 1990) IRT has also been applied to identify the temperature increase in pigs, in response to pre-slaughter handling with the objective of predicting meat quality variation (Weschenfelder et al 2013).

The phenomenon of stress-induced hyperthermia or psychogenic fever occurs in numerous species and is characterized by an increase in body temperature within 10 to 15 min of the onset of an emotional stressor. Studying the handling stress in broiler chickens, Edgar et al (2013) found that the eye temperature changed significantly during handling. The authors concluded that surface temperature changes assessed using IRT are sensitive to routine management such as handling and it represent a potentially useful method for evaluating stress-induced hyperthermia in chickens.

Surface temperature assessment

Several studies have been conducted using as IRT tool for assessment of animal welfare, especially in regard to issues related to rearing thermal exchanges (Cook et al 2006; Bouzida et al 2009; Ferreira et al 2011). In previous researches, the source for assessing the heat exchange in livestock have been an animal and surroundings surface temperature recorded using IRT (Li et al 1991; Yahav et al 2004; Warriss et al 2006; Shinder et al 2007).

A key issue regarding surface temperature assessment is the material emissivity coefficient (ε). In a research related to animal husbandry, there have been various assumptions for establishing the skin temperature emissivity coefficient. For instance, the emissivity coefficient used was 0.94 for the regions with feathers and 0.95 for the featherless regions, which are within the range of emissivity values for biological material (Ferreira et al 2011). There are many suggestions for this subject in the literature. McCafferty et al (1998) indicated the emissivity value of 0.98 for feathers, when calculating the radiant heat loss of a barn owl. Dawson et al (1999) adopted the emissivity value of keratin equal to 0.8, when building a model of radiant heat transfer through the penguin coat. Ward et al (1999) and Cangar et al (2008) suggested the emissivity value of 0.95 for the whole bird. Malheiros et al (2000) used $\varepsilon = 0.94$ to define the variation of the surface temperature in post hatch pullets.

However, surface temperatures data do not always explain the amount of heat exchange due to eventual body core temperature increase during metabolization of feed. Case et al (2012) showed that surface temperature traits explained only a small proportion of variation in feed intake, in turkeys. The authors report that the recording of infrared images was efficient and required minimal contact with the caged birds; however, the low correlations indicate that the IRT presented limited advantages for increasing the accuracy of selection for feed efficiency.

Using data on surface temperature measurements from IRT have also been successfully used to recognize orthopedic injuries in horses (Eddy et al 2001),

Pig production

Warriss et al (2006) studied the variation of body temperature of groups of pigs using IRT, in order to evaluate the housing conditions, and found that IRT was an interesting and non-invasive way of assessing surface temperature for determining heat exchange. Other research in pig production is reported by Kastberger and Stachl (2003).

Sykes et al (2012) used IRT to discriminate between estrus and diestrus phases of the porcine estrous cycle. The authors found that vulva thermal images were positively correlated with ambient temperature, and vulva thermal temperatures were greater at estrus than at diestrus (36.6 ± 0.2 °C and 33.4 ± 0.3 °C vs. 35.6 ± 0.3 °C and 31.8 ± 0.6 °C, respectively), whereas they did not differ between stages of the cycle.

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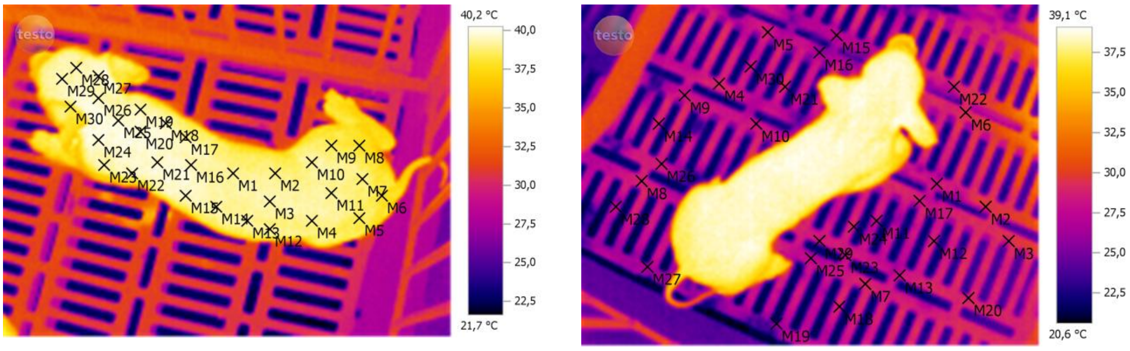
Graciano et al (2014) used IRT images to detect edema in pigs. The authors showed the efficiency of image analysis in early detection of arthritis.

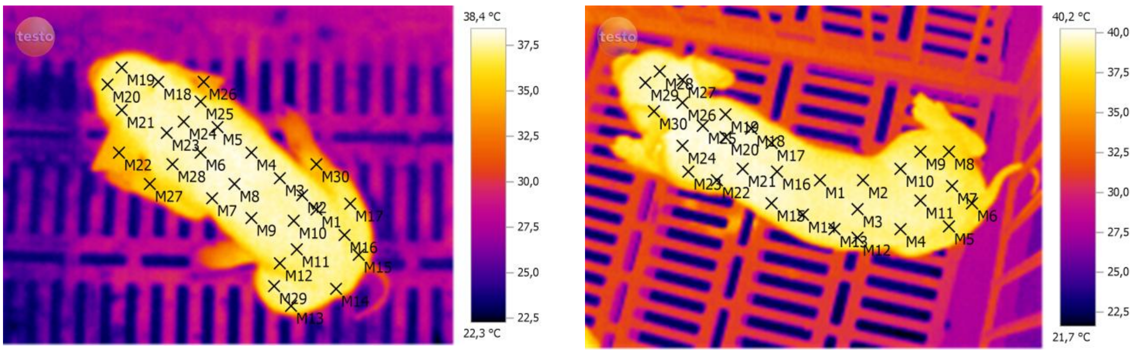
Caldara et al (2014) evaluated by means of IRT images of the rearing environment and the effect of it in the weight of piglets at birth. The authors calculated piglets heat loss in the first hours after birth and reported the value of proper temperature in the nursing rooms. Thermal exchanges by conduction between newborn piglets and the farrowing crates' floor are high, and it may affect piglets' body heat loss decreasing their performance (Figure 1). The authors also observed by recording IRT images that piglets with lower birth weight tend to have higher drop in body temperature in the first hour of life than others, a fact related to their smaller body energy, making it more disposed to hypothermia, thus suggesting particular attention to newborns of low birth weight (Figure 2).



(a) (b)

Source: Caldara et al (2014)

Figure 1 Thermography images in selected points to present the difference on the surface temperature of the piglet´s skin (a), and the floor of rear part of farrowing crates (b)



(a) (b)

Source: Caldara et al (2014)

Figure 2 Thermography images and selected points to present the difference on the surface temperature of the piglet´s skin reared in cold stress (a) and at the thermal neutral zone (b), 15 min after birth

IR images were also used successfully to verify the importance of the presence and proper functioning of cooling water sprinkler systems in piggeries rest before slaughter, on the maintenance of body temperature of the animals and consequently their thermal comfort (Caldara et al 2014).

IRT images were also used successfully to verify the quality of the presence and proper functioning of cooling water sprinkler systems in piggeries rest before slaughter, on the maintenance of body temperature of the animals and consequently their thermal comfort (Caldara et al 2014). Analyzing the IRT images obtained by comparing the use of intermittent water sprinkler systems during the management of pigs unloading and waiting for slaughter, at the slaughterhouse, the authors showed that intermittent water sprinkler systems at intervals 30 minutes during this period are effective in reducing the surface temperature (Figure 3). However, they point out that planning the proper operation of sprinklers (interval between sprays and duration of

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spraying) are conditioned to both ambient temperature and relative humidity.

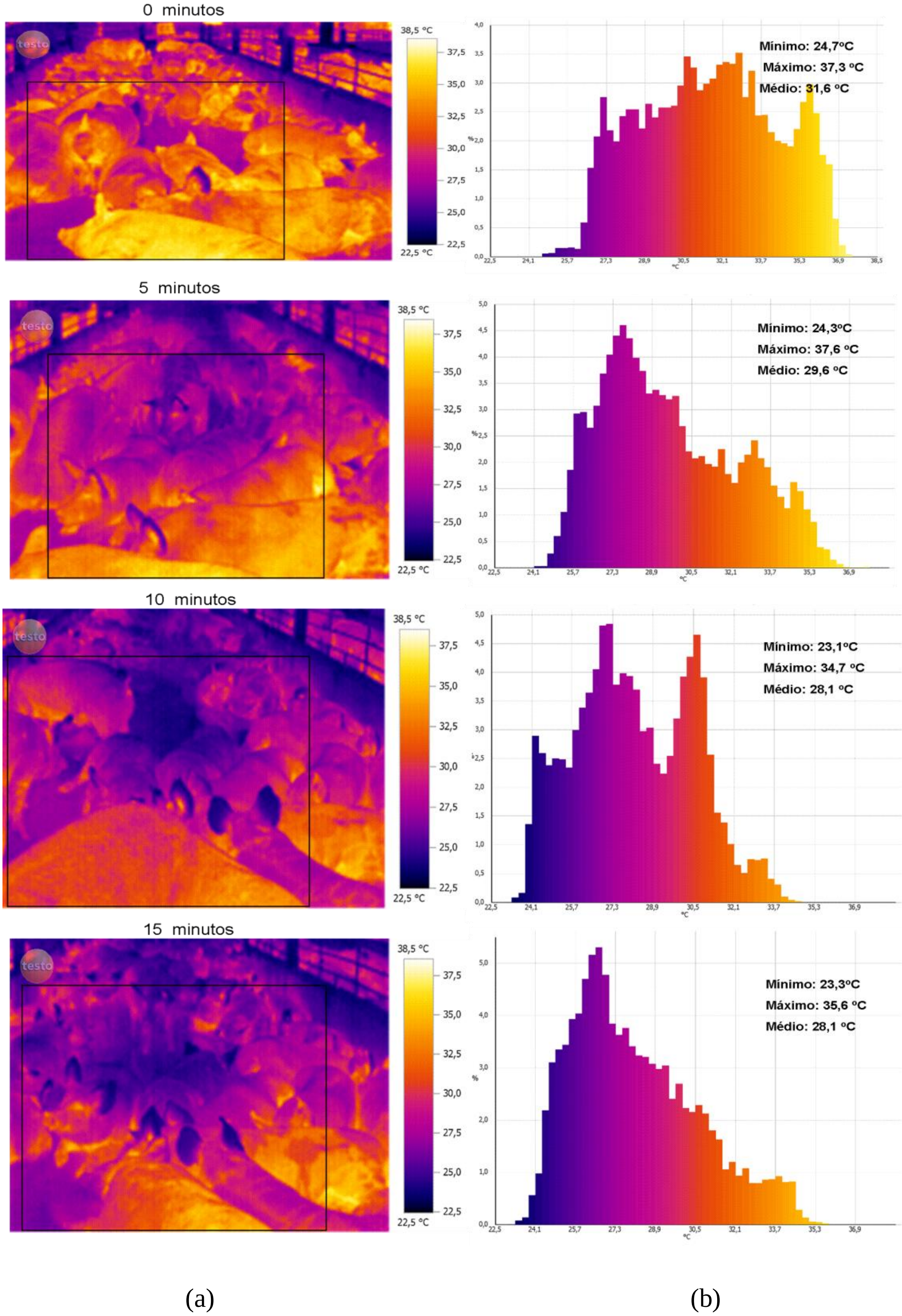

Figure 3 Thermal images of the pigs recorded in rest pens, 180 min after the animals arrive in the slaughterhouse, in time equivalent 0, 5, 10 and 15, after activation of the sprinklers (a), and histogram of the surface temperature calculated based on the area marked on the image (b).

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Poultry production

IRT images were used by Ferreira et al (2011) to estimate the effectiveness of using images of infrared thermography in assessing the loss of sensible heat in pullets fed different dietary energy levels. Results indicated that IRT was efficient to predict the excess of metabolic heat loss due to a high energy diet. Average surface temperature of the body area and the flock were calculated using the surface temperature recorded at 100 spots within the image (Figure 4). Total radiant heat loss was calculated based on the average surface temperature data, and results showed that pullets fed the high-energy diet presented higher metabolic energy loss than the baseline.

Several studies on poultry production used IRT to predict heat exchange between the bird and the environment (Malheiros et al 2000; Yahav et al 2001; Tessier et al 2003; Cook et al 2006), while others estimated feed consumption decrease during heat stress (Zhou and Yamamoto 1997; Cooper and Washburn 1998). Malheiros et al (2000) found that body weight declined in chicks reared at 20°C, and radiant heat loss was nine times higher than for the birds kept at 35°C at 7 days of age.

Using IRT images to assess the effects of exposure of commercial laying hens to cold, Alves et al (2012) found that birds under cold stress conditions spent about four times more energy trying to maintain body temperature. Due to its limited capacity to consume food they have been unable to generate enough metabolic heat to balance these losses and maintain their body temperature, thereby causing a reduction in egg production (Figure 5).

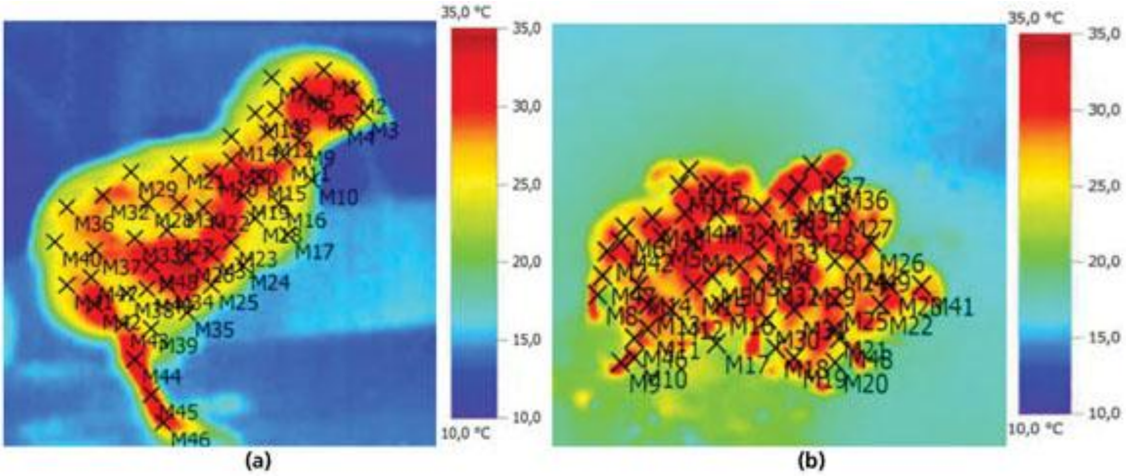
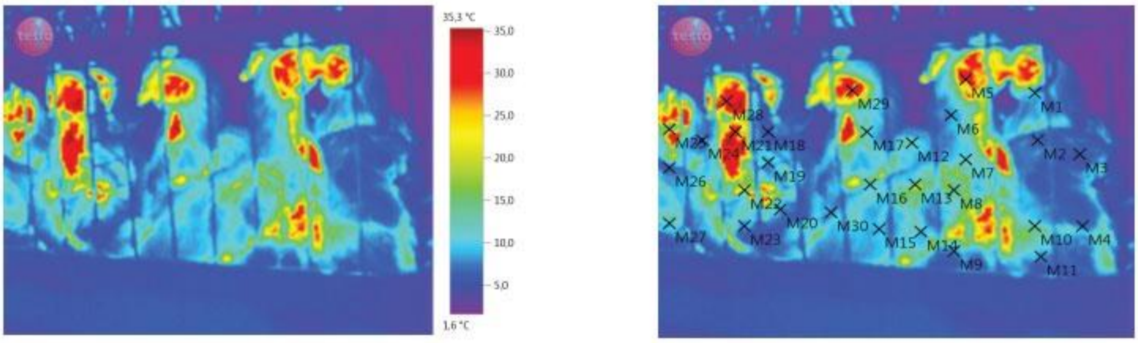


Figure 4 Infrared thermal image of a pullet (a) and the flock (b) with the spots where the surface temperature was marked and registered for calculating the total heat loss



(a) (b)

Source: Alves et al (2012)

Figure 5 Infrared thermal image of caged laying hens (a), and the spots were the surface temperature was assessed (b)

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Dairy and cattle production

In bovine medicine, IRT is used primarily for diagnostic purposes, but also for assessment of animal welfare and even feed utilization efficiency. Uses of IRT in the dairy industry include early detection of estrus, mastitis and lameness. Previous studies have focused on the use of infrared thermography to detect mastitis much earlier than previously possible (Stewart et al 2005).

Previous studies used IRT analysis as a method for early detection of animals infected with bovine viral diarrhea virus or bovine respiratory disease using facial scans (Schaefer et al 2012). IRT has been also identified as a possible detection method for laminitis in lactating dairy cattle (Nikkhah et al 2005). These studies have concluded that while IRT provides an additional perspective on disease and injury, it should complement traditional diagnostics methods (Schaeffer et al 2004; Alsaaod et al 2014).

The possibility that changes in eye temperature, measured using IRT, can detect stress in dairy cattle was examined by Schaefer et al (2012). Despite the findings using IRT, the increases in eye temperature following catheterization might need a cognitive component for assessing an appropriate animal response.

Final remarks

Surface temperature is an important indicator of animals' illnesses and for estimation of their physiological status; therefore, surface temperature estimation should be fast and accurate. In practice, different methods may be used for recording skin temperature; however, with IRT images analysis for estimating animals' body temperature and forecasting its implication is becoming more popular.

The surface temperature distribution is shown by the regions of different colors, and the image might be analyzed by scanning the surface by points, or focusing the thermal radiation of the surface with a number of pixels sufficient for getting precise images.

Nowadays most affordable cameras with adequate measurement accuracy are developed to have the thermal accuracy up to ±1°C and opportunity to save both thermal and visual images. Thermographic equipment has found increasing applicability in human and veterinary medicine, as infrared thermography is a non-invasive safe method for evaluating surface temperature and its derivative implications.

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