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A multivariate dynamic linear model for early warnings of diarrhea and pen fouling in slaughter pigs

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ABSTRACT

We present a method for providing early, but indiscriminant, predictions of diarrhea and pen fouling in grower/finisher pigs. We collected data on dispensed feed amount, water flow, drinking bouts frequency, temperature at two positions per pen, and section level humidity from 12 pens (6 double pens) over three full growth periods. The separate data series were co-modeled at pen level with time steps of one hour, using a multivariate dynamic linear model. The step-wise forecast errors of the model were unified using Cholesky decomposition. An alarm was raised if the unified error exceeded a set threshold a sufficient number of times, consecutively. Using this method with a 7 day prediction window, we achieved an area under the receiver operating characteristics curve of 0.84. Shorter prediction windows yielded lower performances, but longer prediction windows did not affect the performance.

1. Introduction

Although it is not yet widely used in pig production, many different types of data could be collected in a standard pig herd and used in systems for early detection of disease or undesired behaviors.

For example, we have previously shown that continuously monitoring pen level temperature will yield information useful for early detection of diarrhea and pen fouling (Jensen and Kristensen, 2016). This makes sense, given that temperature is well known as a key factor for the onset of pen fouling (Aarnink et al., 2006), where the pigs will rest in the excretion area and excrete in the resting area. Furthermore, pigs are generally more sensitive to the surrounding temperatures than for example cattle (Young, 1981). Diurnal temperature differences in particular can cause the pigs to show symptoms of stress, as well as slower growth rate and higher feed consumption (Lopez et al., 1991).

Similarly, pigs are generally known to have stable diurnal drinking patterns, from which they don't typically deviate unless they are affected by disease outbreaks or environmental stressors. A model which accurately describes these drinking patterns has been presented (Madsen et al., 2005), and a test of this model on 12 batches of weaned pigs suggests that deviations from predicted water consumption can provide warning of diarrhea approximately 24 h before it was otherwise detected (Madsen and Kristensen, 2005).

Feed consumption is typically monitored closely in breeding stations, where selecting the most efficient growers is important. In such stations, the feed will often be dispensed *ad libitum* to individual pigs, identified by RFID tags. This type of data, combined with live weight measurements, has further been used to investigate questions such as how some environmental factors affect growth rate and efficiency (Jensen et al., 2014) and whether the rate of weight gain affects lean meat production in growing pigs (Stege et al., 2011). Automatic monitoring of feed usage has also been used to detect estrus, lameness and other health disorders in group housed sows (Cornou et al., 2008). However, so far as we can tell, feed consumption data have never been tested as a parameter in systems for early warning of disease or undesired behavior in slaughter pigs.

We have previously shown that distinct types of data collected at the pen level, such as live weight, dispensed feed amount, and water consumption could be meaningfully co-modeled, *i.e.* modeled together in a single model which took the co-variances between the various variables into account (Jensen et al., 2015). This was done by using a multivariate dynamic linear model (DLM) with time steps of one day. To our knowledge, that was the first demonstration of combining such different data series with a single DLM. A few examples exist of univariate DLM's for detecting events in animal production, *e.g.* the water consumption model by Madsen et al. (2005) and for automated estrus detection

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in sows (Ostersen et al., 2010). Here, we intend to expand on our previously described multivariate DLM with the aim of predicting undesired events in a Danish pig herd.

The multivariate DLM produces one-step-ahead forecasts of the modeled variables, which can be compared with actual observations. When drastic changes occur in the modeled system, such as in the case of a disease outbreak, the absolute values of the forecast errors will increase. The DLM is however also adaptive by design, meaning that a model starting with some general assumptions can adapt to the peculiarities of a specific system, such as a specific batch of growing pigs. Furthermore, the co-variances between several variables of interest can be taken into account, when one-step-ahead forecasts for these variables are calculated.

We hypothesize that when monitoring a group of pigs with a model which is optimized to describe the pigs under normal and healthy conditions, the model will be able to accurately predict new observations, so long as the pigs remain healthy. Therefore, when the model is unable to provide accurate forecasts, the state of the pigs will either have changed or be in the process of changing to an abnormal state. We unify the individual forecast errors produced at each observation using Cholesky decomposition. We therefore call this method the *DLM/Cholesky method*.

Here, we intend to show that the DLM/Cholesky method, including feed amount, water consumption, drinking bouts frequency, pen level temperature, and section level humidity in the DLM, can be used to accurately, but indiscriminately, predict undesired events of diarrhea and/or pen fouling at pen level. We further intend to estimate the relative information value of these observable variables with respect to such early warnings.

We consider the indiscriminant detection of any deviation from normalcy achieved with the DLM/Cholesky method to be potentially useful for the farmers in practice, as it allows the farmer to focus his attention on those pens which have the highest chance of needing his attention, without restricting his attention to be focused on finding any one specific type of problem. In this study, the undesired events, which had been recorded and were available to test the performance of the method, were diarrhea and pen fouling.

2. Materials and methods

2.1. Data source

All data used in this study were obtained from the finisher unit of a commercial Danish pig farm, housing slaughter pigs as they grow from approximately 30–110 kg. The unit consists of five sections, although data were only collected in four of these. Each section contained 14 pens, although observations were only made in four pens (two double pens) per section. Furthermore, one double pen per section in two of the four sections had to be omitted, due to problems with data registration. Thus data related to a total of 12 pens (6 double pens) were included in this study. Each pen contained 18 pigs (at insertion), sorted by sex and size. The climate within each section is controlled by a combi-diffuse ventilation system, computer-controlled sprinklers above each pen and heating pipes installed along the back walls. All pens in the section are paired into double pens, where two neighboring pens share feed and water supplies.

For 16 of the 70 pens in the finisher unit, sensors were installed or already available to automatically record data on feed usage, water flow to the drinking nipples, and pen level temperature, as illustrated in Fig. 1 A. In addition, humidity was monitored on section level.

Temperatures were measured continuously at the single pen level. Two thermometers were installed in each pen (Fig. 1B). Thus the temperatures were measured at two positions in every pen: near the back wall, *i.e.* near the designated resting area with solid floors, and near the section corridor, *i.e.* near the designated excretion area with slatted floors. The temperature near the back wall was generally a few degrees higher than near the corridor.

Humidity data were retrieved from the climate computer, produced by the company SKOV A/S. Humidity data was generally available once per day. However, during parts of one spring time growth period, continuous humidity recordings were available.

Water flow was measured continuously at the double pen level. Each pen in a double pen has a drinking nipple, but both share a single water pipe. A flow meter was installed in each of these pipes, where it measured rotations per second. A separate calibration was done for each water pipe.

Feed was dispensed per double pen by a feeding system from the company Big Dutchman. Feed was dispensed daily according to a preset feeding curve. However, the amounts would be adjusted daily (when relevant) based on the observed amount of surplus of feed not eaten on a given day.

Lastly, observations of undesired events were observed at single pen level on a daily basis, according to a specific observation protocol (Lyderik et al., 2016). This was done visually by the farm staff, who noted observations of diarrhea, pen fouling, and tail biting in a log book as part of their daily routine. No events other than these were recorded by the farm staff, and no cases of tail biting were apparently observed during the observation time. For these reasons, the term ‘‘events” shall hence forth refer specifically to diarrhea and pen fouling. Both of these events were recorded with numerical values; for diarrhea, the number of diarrhea spots on the floor was recorded, and for fouling, the portion of the floor being foul was recorded, as specified in the observation protocol (Lyderik et al., 2016). For the purposes of this study, however, both types of events were made binary, where any values above 0 constituted a positive observation.

Data were collected between November 20th 2013 and December 12th 2014, during which time three new batches of pigs were inserted in each pen. Thus the study population consisted of 36 groups of pen mates, corresponding to approximately 640 individual pigs. Pen mate groups were the observational unit. These shall hence forth be referred to as *groups*.

2.2. Data editing

All data editing, modeling, and various calculations were done using the statistical language and environment R (The R Core Team, 2013).

The collected data were scanned for outliers using simple summary statistics. Humidity and temperature were found to be plagued by values below 1 percent and centigrade, respectively. In addition, humidity was plagued with values above 100%. Such values were considered as missing observations during the modeling described below. All other variables were found to be within acceptable ranges.

The water flow and drinking bouts frequency data were particularly plagued by long periods of missing observations. From previous work (Madsen and Kristensen, 2005) we had reason to think that water flow would be particularly important for the detection of the undesired events. For this reason, we only included groups with less than 60% missing water flow observations when testing our model (N = 15 groups).

The continuously measured variables, *i.e.* water flow, temperature, and humidity when relevant, were aggregated to one-hour mean values. From the water flow data, we further calculated drinking bouts frequency, *i.e.* how many times the water nipple was activated per pig per (double) pen during any given hour. This value served as a proxy for pig activity level.