COGNITIVE COMPUTING IN BREWING TECHNOLOGY

M. Schmitz, Markus Fellner, Tomas Kurz, E. Murnleitner, T. Becker, A. Delgado
Technische Universität München - Lehrstuhl für Fluidmechanik und Prozeßautomation
Weihenstephaner Steig 23, D-85350 Freising Germany
Phone: +49-8161-713670, Fax: +49-8161-714510
email: becker@lfp.blm.tu-muenchen.de

ABSTRACT: In the present paper possibilities and reasons for the usage of cognitive approaches in brewing technology are mentioned. Most of the appearing processes in brewing technology are nonlinear or dynamic, hence mathematical approaches are not usable for modelling in an efficient way. However, for many processes technological knowledge or data is available. Several cognitive approaches developed at the Lehrstuhl für Fluidmechanik und Prozeßautomation/ TU München (LFP) are introduced and results presented, whereas modelling of biotechnological processes with fuzzy-logic or artificial neural networks is the main topic. Examples are a "Cognitive Estimator" for not online measurable biochemical values (ANN), state-detection and closed loop control of the fermentation of beer or the wastewater treatment during the brewing process (fuzzy-logic). In addition cognitive approaches (ANN) are used to evaluate data e.g. for the calibration of an ultrasonic density measurement system.

KEYWORD: Brewing technology, observability, modelling, process control, fuzzy-logic, software-sensor, artificial neural networks

COGNITIVE APPROACHES IN BREWING TECHNOLOGY

The brewing process is traditionally divided in several subprocesses. The mashing includes the enzymatic degradation of certain biopolymers as starch and proteins of the malt. The solid-liquid separation in a lauter-tun or a mash-filter is the next step. The product of these processes - the so called sweet-wort – is boiled with hops to increase concentration up to the desired original gravity, to transform the bitter hops resins into soluble constituents, to decrease the protein concentration and to sterilize the wort before fermentation. After separation of the so called trub (agglomerated proteins and spent hops) the wort is pitched with yeast. The following fermentation, maturation and cold storage transforms the sweet tasting wort into beer. Depending on the beer-type the yeast is removed in a filtration step and finally the beer gets bottled or filled in kegs.

Several cognitive approaches show a great potential to control or optimize the described steps of beer production. Especially the biotechnological processes represent a working field for cognitive methods, however the evaluation of e.g. data of optical systems for the control of cleaning or to detect broken bottles or trays is also be done in this way. The reason for the usage of cognitive methods in brewing technology lies in the complexity of the matrix wort or beer and in the characteristics of the interessing processes, which are mostly dynamic and non-linear. Therefore, most of the processes and the matrix are not describable with mathematical methods in an effective way. However a lot of technological knowledge or large quantities of data are existing which can be used for cognitive approaches e.g. based on fuzzy-logic or artificial neural networks.

EXAMPLES FOR COGNITIVE APPROACHES

In the field of brewing technology different applications using cognitive methods were developed at the Lehrstuhl für Fluidmechanik und Prozeßautomation.

Examples for the usage of these algorithms in brewing technology developed by the Lehrstuhl für Fluidmechanik und Prozeßautomation (LFP) are a speed control of the lautering process, a pressure control integrated in a wort-boiling system, a "Cognitive Estimator" for the estimation of difficultly measurable values, a fermentation control with fuzzy-logic, a fermentation state / -failure detection with fuzzy-logic, a control of anaerobic wastewater treatment with fuzzy logic and a data evaluation in an ultrasonic density-measurement system. Some of the developed systems are described in more detail below.

THE COGNITIVE ESTIMATOR FOR DIACETYL

Diacetyl, an indirect byproduct of yeast metabolism, is a key component in beer. It causes an off-flavor when its concentration is above a threshold of about 0.1 mg/l. Diacetyl and its precursors are present in beer during fermentation and maturation. The concentration of diacetyl is considered to be the most important criterion in the shortening of the maturation process, making its online determination of special economic interest. The current state of the art in diacetyl measurement technology is the off-line laboratory analysis using specially adopted headspace gas chromatography. The major disadvantages of this method are the high cost of the laboratory equipment, the required manual sample handling and pretreatment and the delay of several hours before results are available. These disadvantages make this method unsuited for on-line fermentation control. To date there are no alternative methods available.

There are, however, readily measurable process parameters which provide indirect information about the diacetyl concentration in the fermenting beer. The main physical and chemical process parameters used in our studies are temperature, specific gravity, pressure, turbidity and pH. In order to facilitate estimation of the diacetyl concentration the cognitive estimator needs a model of the dynamic properties of the process and how they relate to the changes in diacetyl. Dynamic artificial neural networks were used in this project to deduce these properties from the available measurements. Since it was not sufficient to only use the current set of measurements, a series of measurements taken over time up to the present point was used in order to internally reconstruct parts of the unknown process dynamics.

In the present problem a multilayer feedforward network was applied. A special neuron with a FIR filter was inserted at each connection (tapped delay line). A supervised method using the sum of the squared errors as the cost function was used to train the neural network. Gradient information was obtained using the IC-1 algorithm (instantaneous cost, instantaneous gradient), weight updates were calculated with different learning algorithms such as Rprop, SuperSAB and Quickprop. Reliable results, in terms of training time and convergence stability have been obtained in the prediction phase using these configurations.

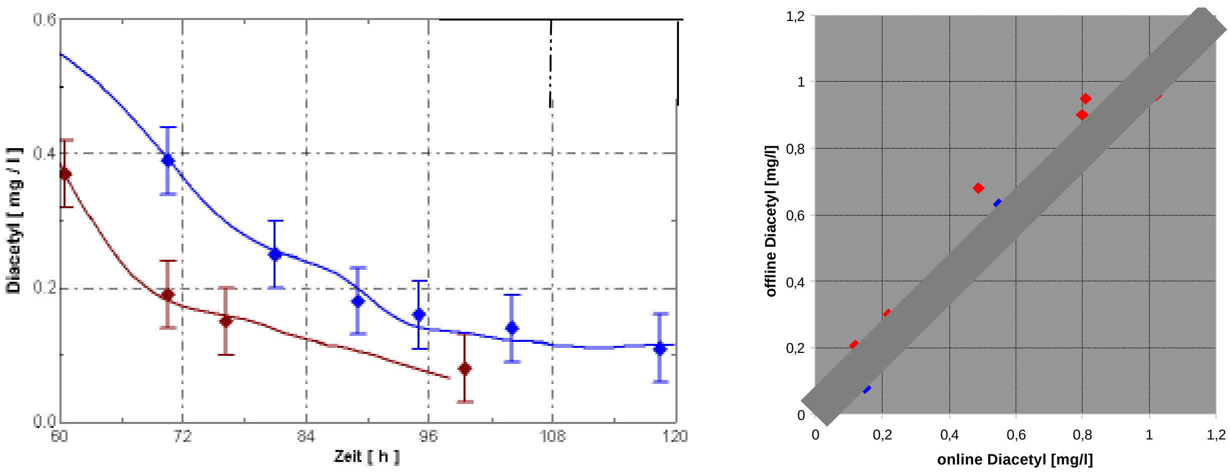


Figure 1: Results of the “Cognitive Estimator”. The left image shows the online estimation of diacetyl during the maturation at the example of two fermentations (line). As points reference analysis are given. It is obvious, that the ANN represents the reference values very well. The right image shows a parity plot of online and offline diacetyl determination. The “Cognitive Estimator” works not only during the maturation phase, but, as can be seen, over the whole range of possible diacetyl contents. Marked is a tolerance of about 0.05ppm within the online estimation to be used as input for a closed loop control.

The system was adapted to online determination of diacetyl for an industrial beer fermentation. Based on the results obtained, it can be said that the accuracy and reliability of the software sensor is sufficient for practical applications. Figure 1 shows, that especially during the maturation phase the estimation works very well. In the parity plot however it is clarified, that the estimation is possible over the whole range of appearing values in a sufficient way. Work towards improvement in the accuracy and robustness with respect to real-world problems (i.e. missing data, unexpected disturbances, confidence measures for the estimates) is being currently carried out.

THE FUZZY-LOGIC FERMENTATION CONTROL

The main topic of interest was to realize an active process control for the fermentation of beer. As in this area a lot of technological knowlegde was already existing the use of fuzzy-logic for a process control suggested itself. The realized system combined a process state (fermentation phase) detection module and a process-control module based on fuzzy logic. An active control presupposes the observability of the process. Observability means, that the process-state must be describable through the information obtained from the process in every time. Therefore, in addition to the online measurement of physical or chemical values it was necessary to record information about biochemical values by integrating the described “Cognitive Estimator” to reach a sufficient observability.
The gained values of online measurement and estimation is used as input for the fuzzy-logic fermentation phase detection. The result is the actual fermentation phase like “main-fermentation” or “maturation”. The well known coherences between input data and the fermentation phase are described as rules. Figure 2 shows an example for a rulebase used during the development of the fermentation-phase detection.

BEGIN RULEBASE Phase	
Rule 1 for Start:	IF ESK = big THEN PHA = Start
Rule 2 for Start:	IF PHW = big THEN PHA = Start
Rule 3 for Mainfermentation:	IF PHW = middle AND ESK = middle THEN PHA = Mainfermentation
Rule 4 for Mainfermentation:	IF ESK = middle AND PHW = small THEN PHA = Mainfermentation
Rule 1 for Mainfermentation:	IF ESK = middle AND DIA = middle THEN PHA = Mainfermentation
Rule 2 for Mainfermentation:	IF ESK = middle AND DIA = big THEN PHA = Mainfermentation
Rule 1 for Maturation:	IF ESK = small AND DIA = big THEN PHA = Maturation
Rule 2 for Maturation:	IF ESK = small AND DIA = middle THEN PHA = Maturation
Rule 3 for Maturation:	IF ESK = small AND PHW = middle THEN PHA = Maturation
Rule 1 for Lagern:	IF ESK = small AND DIA = small THEN PHA = Storage
END RULEBASE	

Figure 2: Rulebase for the fuzzy-logic fermentation phase detection. The rulebase represents the technological knowledge about the coherences between the measurement data and the actual process state.

A second fuzzy-logic system for the control of the fermentation uses the absolute deviation of the measured data from given setcurves of defined partial processes as input. Dependent on the input data and the detected fermentation phase the manipulated valuables (temperature, pressure) can be varied.

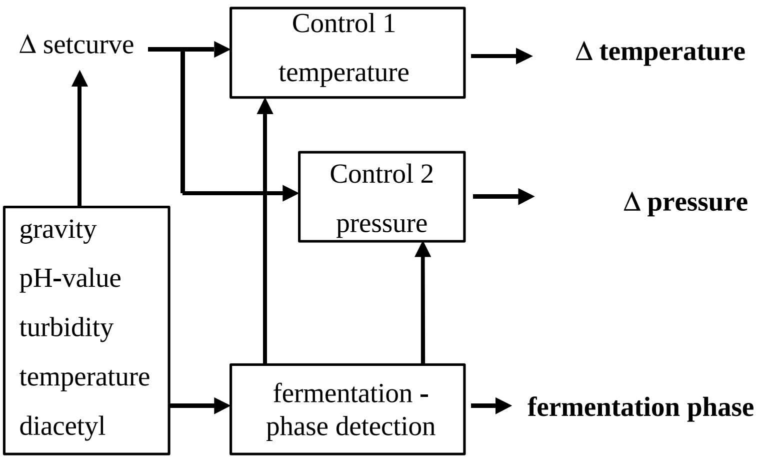


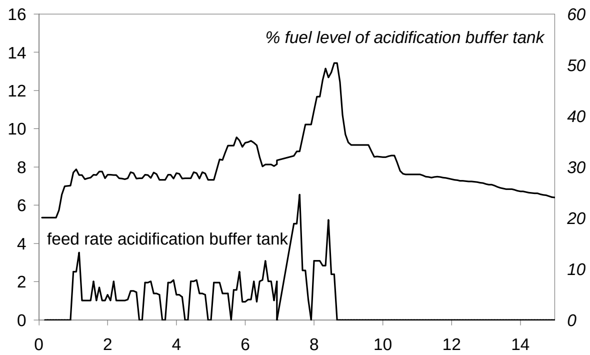
Figure 3: Scheme of the fuzzy system. Data from online measurement is used to determine the fermentation phase. A superimposed control system uses the detected phase and the deviation of the online values from given setcurves. The systems tries to lead the process on the setcurves by manipulating temperature and/or pressure.

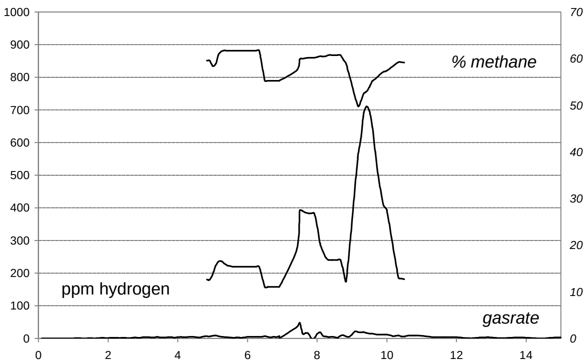
The fuzzy-logic fermentation phase detection worked very robust and reliable. Even trials with simulated failures of measurement values produced sufficient results. By using only this fuzzy-system it was possible to reduce the complete fermentation time up to 25%, by an automatic change between the fermentation phases in the sequential control. The superimposed closed loop control had an increase in process homogeneity as result. By variating the manipulated variables based on the fuzzy-logic rules the process spread concerning a set curve of gravity could be reduced to 50%.

ANAEROBIC WASTEWATER TREATMENT WITH FUZZY LOGIC

For an efficient anaerobic wastewater treatment, supervision by high qualified staff or a proper process control is required, particularly if the volumetric loading or the substrate composition is variable or if toxic inhibition can occur.

However, anaerobic treatment is difficult to control, because a system overload can halt the process, whereby a system restart can take up to weeks. Fuzzy logic was used for modelling and control of the process, because qualitative or semi-quantitative expert knowledge is available. Moreover, states like “hydrogen is normal” and “hydrogen is high”, which cannot be distinguished sharply because the transition from “high” to “normal” is not well known (it is fuzzy), is handled with the Fuzzy logic’s concept of partial truth. Hydrogen was chosen as the key parameter for the detection of an overload, as it’s concentration increases sharply after an overload. Not only the hydrogen concentration, but also pH, the first derivative of pH, the concentration of methane, the gas production rate, and – if necessary - also the concentration of organic compounds (TOC, COD, or BOD) are used as input variables.
With these variables, the state of the reactors, like “shortage”, “normal”, “overload”,” toxic” is estimated. Using these biological states together with the current reactor conditions (e. g. acidification buffer tank is full), the conditions are altered or the feed rate is changed. The conditions are influenced by changing temperature, pH, velocity of circulation and the recirculation rate.





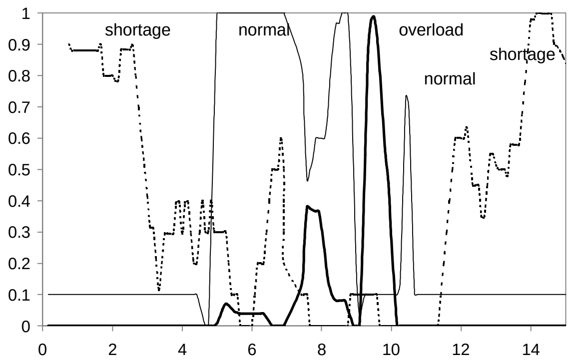


Figure 4: First graph shows the feed rate into the acidification buffer tank (divided by the methane reactor volume) and the fuel level. Second graph shows the gas measurement of the methane reactor (% methane, ppm hydrogen, and the gas flow normalised by the volume of the methane reactor). Third graph shows truth values (membership value) of the sets from the state of the methane reactor (-- shortage, — normal, ━ overload).

Figure 4 shows data from a two stage anaerobic treatment of potato processing waste water are shown. The first graph presents the feed rate and the fuel level of the acidification buffer tank. The latter is the result of the feed and the control action. Gas concentrations are depicted in the second graph. As shown in the third graph, the states could be predicted well, so proper control actions could be taken, too.

ULTRASONIC DENSITY MEASUREMENT

Together with an industrial partner the LFP is developing a system for non-invasive monitoring of the fermentation progress. The determination of apparent gravity – equivalent to the density of the fermented beer-wort – is based on temperatur and an ultrasonic wave’s time of flight. The temperature signal may be obtained with temperature-sensors, which are installed in all modern fermentation vessels. A piezo-electric ultrasonic probe provides a very convenient way to determine the time of flight since it acts as both, the sender and the receiver of the preassure wave. To approve the accuracy of measurement system the implementation of an adaptive control software to adjust the signal processing depending on the process-state was necessary. The software is not yet making use of cognitive techniques while a second target for optimization will surely benefit from this algorithms. The mapping of temperature and of the apparent gravity is done by cubic-polynominal regression. The regression degree is a compromise between accuracy and stability of the calibration since higher degrees tended to oscillate and lower degrees did not reach the needed accuracy of <0.5ww%. The integration of an artificial neural network into the system promises both, a higher stability and a higher accuracy. The considerations about the feasability were very promising but one problem could be pinpointed which is not yet solved: The ultrasonic measurement systems calibration has to be adopted to every single brand of beer. An ANN usually needs a lot of training data sets. The production of this quantity of data causes high personal costs as the data must be obtained by manual sampling. Therefore a way has to be found to improve the trained ANN’s scalability.

OUTLOOK

The paper shows that cognitive approaches can be used in many fields of brewing technology. As far as the further developments at the LFP are concerned main topics will be in the development of hybrid approaches. Especially the integration of mathematical or technological knowledge in the learning process of ANN is suggested. This allows to improve the accuracy of process predictions. One the other hand fuzzy-logic systems should be developed or adapted which use self generating methods for rules or sets. With these methods it would be possible to obtain technological knowledge about processes, which was not accessible so far, since most of the considered processes could only be modelled by black-box approaches. Hence, it can be stated that there is still a high potential of implementing cognitive algorithms in various problems of the brewing process.