Automated calibration of a tractor transmission control unit

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Abstract

This paper presents an approach for an automated calibration process for electronic control units (ECU) of power split transmissions in agricultural tractors. Today the calibration process is done manually on a prototype tractor by experts. In order to reduce development costs the calibration process is shifted from prototype testing to software modelling. Simultaneous optimization methods are used within the software modelling to calculate new parameters. The simultaneous optimization includes objective evaluation methods to evaluate the tractor behaviour. With the combination of both methods inside the software modelling, the calibration process can be automated. The success of this approach depends on the quality of the software modelling. Therefore the identification of the initial prototype behaviour and the fitting of the tractor software model is done at the beginning. At the end of the automated calibration the validation and fine-tuning of the calculated parameters are done on the real tractor. These steps are condensed to a five step automated calibration process which includes simultaneous optimization and objective evaluation methods in several applications. After the detailed discussion of this automated calibration process one function of the ECU (one transmission component) will be calibrated through this process as example.

KEYWORDS: ECU tuning, automatic calibration, Tractor transmission control unit (TCU)

1. Introduction

By 2050 the output of food production should be doubled to compensate the growth in population [1]. In consideration of limited arable land, the inevitable growth in production cannot be achieved by expanding the cultivated land, but by increasing the yield. One approach to raise yields per hectare is seen in more precise farming methods. The accuracy of the working process is dependent on precisely controllable tractor speeds, widely being achieved by modern power split transmissions. Optimizing the vehicle speed requires the appropriate selection of the ratio by choosing both the mechanical gear and the swivel angle of the hydraulic pump. This task is processed by the transmission electronic control unit (ECU) of the tractor. To achieve optimal behaviour of the tractor, the ECU must be calibrated towards proper interaction of the mechanic, electric and hydraulic components. Today this calibration process has to be carried out for each tractor model and repeated for every significant change of the drive train (e.g. introduction of a new engine generation). New engines are being developed on a regular basis driven by stricter international regulations regarding allowable pollutant emissions.

Currently, the calibration of the ECU is done mainly manually, which means it is based on the subjective driving perception of an experienced calibration engineer on a test vehicle. The multiple parameters of the ECU will be optimized subsequently to achieve the anticipated driving behaviour.

The frequent repetitions of the calibration process of the ECU as well as the high number of possible parameter combinations qualifies the ECU calibration process for automation. This can reduce the time and the resources needed to achieve a desired driving behaviour of the tractor.

2. Analysis of resource usage on the manual process

The current calibration process of the ECU is shown in **Figure 1**. During the whole process a tractor prototype, a test driver and a control engineer is present. At the beginning the control engineer starts with the first ECU parameter by changing and evaluating this parameter repetitive. The number of iteration are represented by “a” (Figure 1). The number of iterations “a” of this parameter are dependent on the experience of the control engineer. After the tractor has reached the desired driving behaviour with the given constrains of the first parameter, the value for this parameter is saved and the process is repeated with all other ECU parameters (“b” Figure 1). The number of iteration with the prototype, the test driver and the control engineer for the first set of parameters is a*b. This set of parameters does not considere the interactions of the parameters. Additional iterations are needed to optimize the ECU parameters taking the interactions of all parameters (“c” Figure 1) into account. After all this iterations (a*b*c) a first set of parameters is identified.

Common tractors provide the driver the option to set different driving behaviours, for example a reduced dynamic behaviour for driving with a trailer. This is possible by changing between different parameter sets. Starting with the first identified set of parameters additional iterations are made to identify the parameter sets for different driving behaviours. The iterations for the different driving behaviour are less than in the initial process, because of the first set of parameter as starting point.

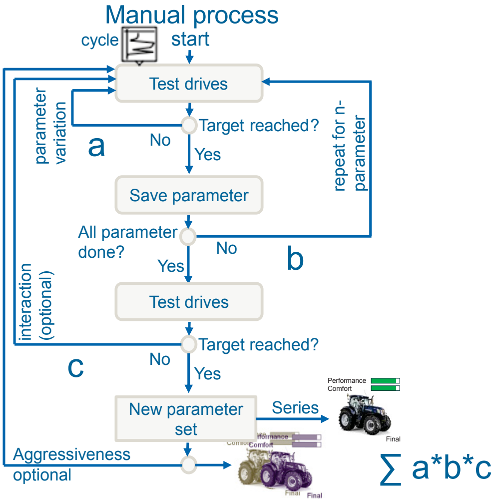

Figure 1: Current manual calibration process

Until this point of the calibration process different parameter sets for the ECU are identified and tested on the prototype tractor. Since a tractor is used in a wide field of applications all the identified parameter sets have to be tested under these various applications. These applications encompass for instance driving with a trailer, ploughing or other field work. In order to comprehensively test all these conditions of use a lead time has to be considered based on the assembly of the trailer or field attachments and the transport to the fields. The parameters have to be tested under comparable conditions which are mainly dry conditions. In addition to this, the weather can cause additional rest time for the tractor testing.

The driving with a trailer for example changes the inertia of the tractor and likewise the driving behaviour respectively. It is expected that the identified parameters on the tractor (without trailer) in general are not reaching the desired driving behaviour when driving a tractor with a trailer. Additional iterations of the tractor and the tractor with trailer/implements have to be performed in order to identify a final set of ECU parameters featuring satisfactory driving behaviour in the fields and on the street. Within every iteration the lead time to rebuild the trailer/implement and the rides to the test track/field has to be considered.

In summary of this manual process the resources (tractor, test driver, control engineer) are used during the whole process and weather conditions can cause additional rest times. The number of iterations inside this process depend on the experience of the control engineer and the knowledge of the prototype.

3. Automatic calibration process

The targets for the automatic calibration process are the reduction of the resource usage and the exclusion of the weather influence.

The reduction of resource usage is reached by transferring large parts of the process inside a simulation environment. The exclusion of the weather influence is achieved by the usage of a test rig. Therefore the following automatic calibration process has been developed.

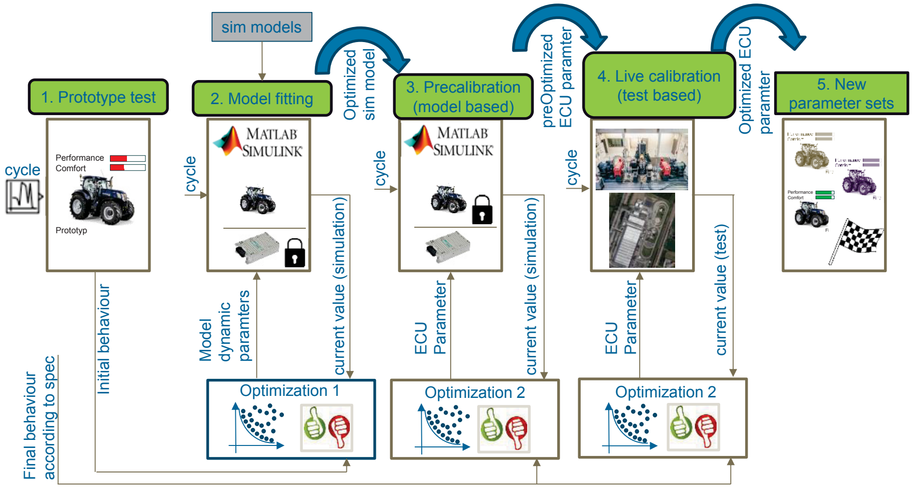

Figure 2: Automatic calibration process

Figure 2 shows the automatic calibration process in detail. The first step (1. Prototype testing) of the automatic process is the identification of the initial behaviour of the prototype tractor. Therefore the ECU parameters are set to reasonable values. The initial behaviour of the prototype tractor is identified by drive cycles. These drive cycles are performed with the prototype tractor and a test driver. A control engineer is not needed for this process step. The output of the first process step are the initial behaviour of prototype tractor, which is used as optimization target in the second process step.

The second process step is the model fitting (2.). Here the developed tractor simulation models are fitted with the identified initial behaviour of the prototype tractor. Therefore the ECU parameters of the ECU simulation model are set to the same initial values which are used in the prototype test (1./Figure 2). This eliminates the influence of the ECU parameters on the driving behaviour of the Tractor simulation model. During the model fitting a first optimization algorithm (optimization 1/Figure 2) compares the current values of the simulation with the initial behaviour of the prototype. Based on this comparison new model dynamic parameters are calculated by the algorithm and tested inside the simulation model. The evaluation of the simulation performance is based on defined drive cycles. These are the same drive cycles which are performed on the prototype in the first process step. The output of this second step is a fitted tractor simulation model.

In the third process step the ECU parameters are calibrated inside the software. The fitted tractor simulation model from the second process step is used for the ECU parameter calibration. The “final behaviour according to specification”, which the serial production tractor should have, is used as target for the optimization. This target is the input for the second optimization algorithm (optimization 2/Figure 2). The second input is the current behaviour out of the optimized tractor simulation model. New ECU parameters are calculated and evaluated by the optimization algorithm by comparing both inputs (initial behaviour according to specification / current tractor simulation behaviour). The target of the third process step is reached when the “current behaviour (simulation)” is within the range of the “final behaviour according to specification”. The output of the third process step are the pre-calibrated ECU parameters as well as the last optimization step of the optimization algorithm. The simulation is used to reduce the numbers of iterations on the test rig and on the prototype. In order to achieve the reduction the last optimization iteration of the third process step is the starting point for the optimization in the fourth process step.

In the fourth process step the ECU parameters are calibrated on the real tractor. Therefore the defined drive cycles are performed on a tractor, which is assembled to a test rig. The measured behaviour of the tractor is the input for the optimization algorithm (optimization 2/Figure 2). The second input is the “final behaviour according to specification”. The optimization algorithm compares both inputs and calculates new ECU parameter sets, which are tested on the tractor again. The target and the optimization algorithm of the fourth process step are the same as in the third process step. The difference between the fourth and the third process step is the use of a real tractor instead of the tractor simulation. The output of the fourth process step are different ECU parameter sets which are fine-tuned on the real tractor.

In the fifth step a control engineer chooses and implements (for example three) different parameter sets out of the optimized parameter sets of the fourth process step. These optimized parameter sets are sorted by the expression different target values and all are meeting the “final behaviour according to specification”.

A comparison of this automatic process and the current manual process is shown in **Figure 3**. The main advantage of the automatic process is the reduction of prototype, test driver and control engineering time. The prototype and the test engineer is used in the new process in step “1. Prototype test” once and for validation tests in “4. Calibration test”. This reduces the resource usage of them according to the manual process. The test engineer is need in the automatic process to decide which set of parameter out of the final optimized parameter sets are used in the series tractor. This reduces the time for the test engineer to a minimum. The optimization algorithm with an objective performance evaluation reduces the influence of experience on the calibration results as well as the control engineer time. With the simultaneous optimization of the ECU parameters the resource usage are reduced, but also the quality of the calibration process can be improved [2,3]. With the simulation approach of the simultaneous optimization a higher number of iterations can be evaluated parallel, which concludes in a better fitting of the driving behaviour to the specification.

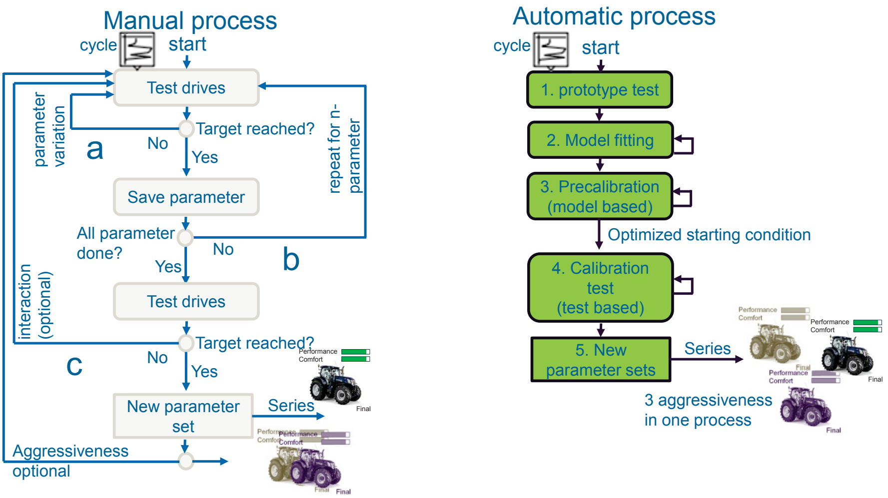

Figure 3: Comparison between automatic and manual calibration process

The automatic process reduces the manual iterations and provides different parameter sets for different driving behaviour in one process run. Therefore the requirements on the automatic calibration process is reached. The proof of this automatic process on the tractor has not finished yet, but it has shown promising results on the calibration of a transmission part. The example of this process on this transmission part is discussed in the next chapter.

4. Example of the automatic process

The automatic calibration process can be used on parts of the transmission, like clutches, synchronizer, hydraulic transmission, etc. and not only on the total tractor. The calibration of a part of the ECU, which controls one of these transmission parts, with the discussed automatic calibration process is the topic of this chapter.

The first step of the automatic process (Figure 2) is the “1. Prototype tests” in which the current behaviour is identified. In this example a step from 0 to 1 is chosen as drive cycle. The results of the prototype test on the step request and the measured response are shown in Figure 5 (measurement (before ECU Parameter calibration)).

The “2. Model fitting” is the next process step. Therefore a basic simulation model of the ECU part and dynamic model (**Figure 4**) is developed. A schema of this simulation model is shown in figure 4. The step request is the input (request/Figure 4) to the ECU model. The ECU model controls the dynamic model and the output of the model is the response (Figure 4) on the step request.

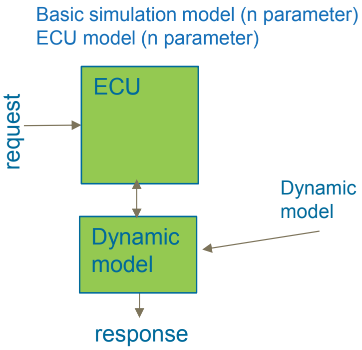

Figure 4: Schema of the basic simulation model

The response of the simulation model on the step request is shown in **Figure 5** (simulation (before fitting). The results show that with the initial dynamic parameters of the simulation model the behaviour of the prototype are not matched, considering that the ECU parameters of the simulation model and the ECU inside the prototype are set to the same values..

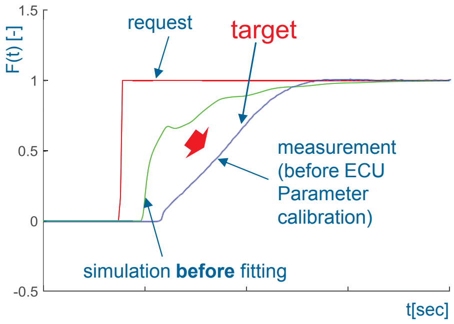

Figure 5: Prototype and simulation behaviour at the beginning of the process

The target of this step is the fitting of the simulation (before fitting) to the measurement (before ECU Parameter calibration). The optimization algorithm (1. Optimization algorithm/Figure 2) changes the dynamic parameters based on the comparison of the simulation (before fitting) and measurement (before ECU Parameter calibration). The result of this optimization is shown in **Figure 6**.

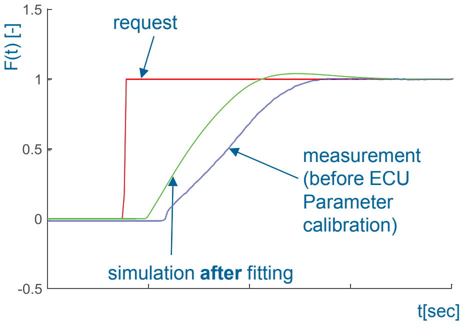

Figure 6: Prototype and simulation behaviour after the model fitting

The simulation response (simulation after fitting) is fitting better to the measurement (before ECU Parameter calibration). Considering the basic simulation model a perfect fitting couldn't be reached. The shown result is the best compromise which could be reached with this model.

The fitted simulation model is used in the next process step (3. Pre-calibration (model based)) to optimize the ECU parameter. The optimization target is shown in **Figure 7**.

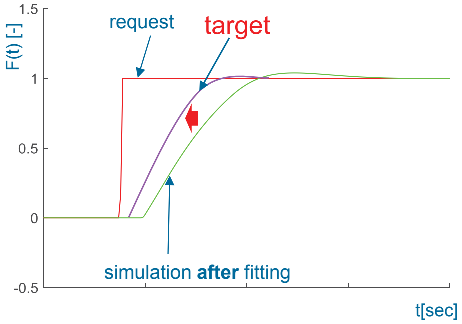

Figure 7: Optimization target for the ECU calibration

The target for the ECU calibration is a faster response without instable oscillations. Therefore the optimized simulation model from the second step is used. The ECU parameters are optimized by comparing the current simulation model behaviour with the target.

The last iteration step of this ECU parameter optimization is shown in **Figure 8**. Each point represents one set of parameters. On the x axis the performance of the simulation behaviour is plotted. On the y axis the stability is plotted. This represents the lack of oscillations of the response. The shape of the curve represents the best compromises between the stability and performance of the system.

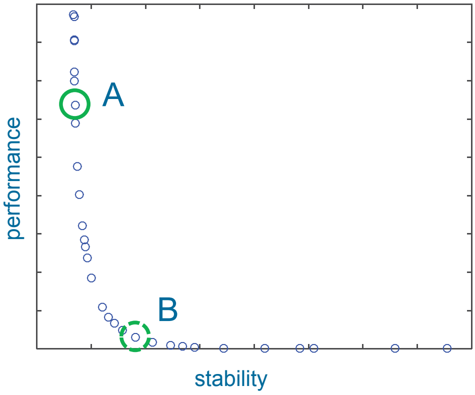

Figure 8: Optimization results of the last optimization iteration step

The results of the optimization are a number of parameter sets which are sorted by the behaviour of the sets. All these results are near the target curve and vary in expression of stability and performance. The control engineer has to choose the expression of stability and performance he prefers.

The first parameter set chosen is a fast parameter set (A /Figure 8). The response of the system with this fast parameter set is shown in **Figure 9**.

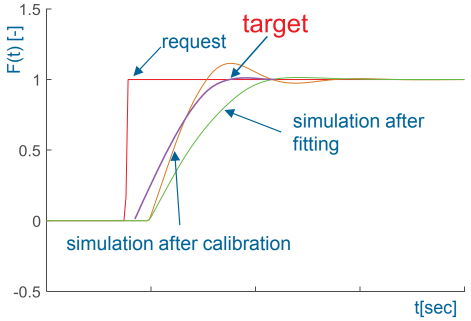

Figure 9: System response of the fast parameter set (A)

The response is compared to the simulation after the fitting. As expected the response of the optimized ECU parameter are faster than the initial system and has a slide overshoot. The optimization target (faster response) is reached with this value. To validate the optimization results the chosen fast ECU parameters “A” are tested on the prototype. The results of this test are shown in **Figure 10**.

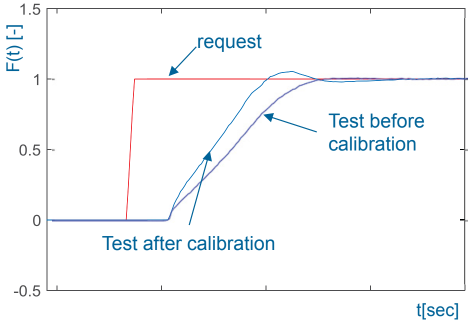

Figure 10: Measurements of the system response of the fast parameter set (A)

The validation measurement shows that the parameter set “A” are faster than the initial ECU parameter set in the simulation as well as in the real system. The overshoot and undershoot of the test after calibration (Figure 10) are comparable to the simulation (Figure 9). Considering the basic simulation model the measured response is slower than the simulation, which is consistent with the results of the second step (2. Model fitting).

The second chosen set of parameters are a slower system (B / Figure 8). The response simulation of the parameter set “B” are shown in **Figure 11**.

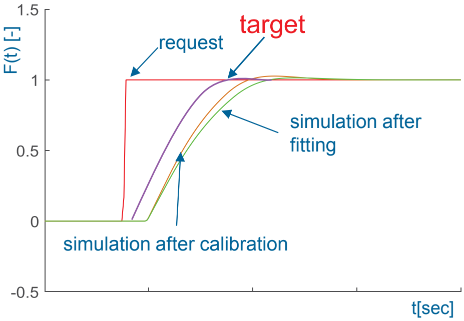

Figure 11: System response of the slow parameter set (B)

The response of the system with parameter set “B” are slower than the parameter set “A” but still faster than the initial system. The overshoot of the system response with the parameter set “B” are almost absent. The system is more stable than the system with the parameter set “A”. The optimization target (faster/stable system) is reached with this parameters as well. The decision between the slow or fast system is the task of the control engineer.

Figure 12 shows the validation results of the system with the parameter set “B”. The shape of the response is comparable to the simulation (Figure 11) results considering the slower response of the real system compared to the simulation model. The validation of the system response with the fast and the slow parameters show that the optimization algorithm has found parameter sets which reach the requirements and have a difference in expression of aggressiveness and stability. The parameter sets in between the two chosen parameter sets allow the control engineer an even more precise system response setting.

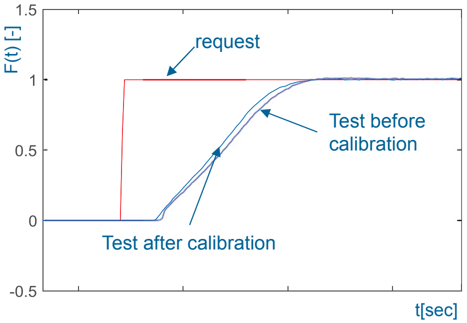

Figure 12: Measurements of the system response of the slow parameter set (B)

This example shows, that the automatic calibration process can be used to calibrate ECU parameters for the control parts of the transmission. The optimization algorithm has found solutions for the model fitting as well as for the ECU parameter optimization. The chosen ECU parameters has shown a comparable dynamic behaviour inside the simulation and in the real system. The spread of solutions has shown that parameter sets with difference in dynamic behaviour are found which are within the specification. Even with a basic simulation model the results are promising.

5. Conclusion

This paper shows an approach to an automatic calibration of a transmission control unit using methods of optimization theory. The target of this process is the reduction of development costs as well as the quality improvements of the calibration by eliminating subjective experts rate. Methods of simultaneous optimization and objective evaluation replace the subjective experts rate in this process. Software modelling decreases the necessity of tractor prototype and test driver capacity. The simultaneous optimization within the software modelling allows an optimization of the ECU parameters considering the interactions of the parameters. In addition to this, parallelization within the software modelling leads to a higher number of evaluated parameter sets. The combination of both approaches can lead to better calibration results compared to the current manual process.

The quality of the calibration results are based on the software modelling quality. Thus a proper identification and fitting of the initial prototype tractor behaviour to the tractor software model is done at the beginning of the process. Whereas the validation and the fine-tuning of the calculated parameters is done on the real tractor as last step. The simultaneous optimization and objective evaluation methods are used in this process for the ECU calibration but also for the tractor simulation model fitting.

So far the validation of this process is conducted on a specific transmission component ECU. In this example the process has shown promising results. The last optimization step of the ECU parameters has generated a wide range of parameter sets which meet the specification and show differences in expression of aggressiveness and stability, which all fulfil the specification.

6. References

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