Process-Optimized System Functionality of Mobile Work Machines

PROSYMA

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Executive summary

Since the emergence of the hydraulic excavator, it has developed from a purely earth-moving machine mostly equipped with a general purpose bucket to a multifunctional mobile work machine, a so-called tool carrier. The constant expansion of work functions and corresponding increase in number of attachment tools, as well as the hydraulic quick coupler has led to efforts to improve production performance in almost of all the different types of jobsites. Due to the fast development of the full hydraulic quick coupler in the last few years, the operator is now also able to change hydraulically-driven tools in 10-15 seconds, very comfortably without leaving the cab.

However, with the use of quick couplers together with the large number of work tools there are a few drawbacks - for machines, tools and as well for the operators. Due to the high tool change rate, these operators need to quickly change many different tools. However, properly operating some of the tools has not yet been mastered to the required extent, nor the specific limitations of each tool. This fact has led to tool damage and has had an impact on work safety. Problems also arise due to the fact that the tool size does not match to the excavator, because constructors have excavators in different sizes and not every tool corresponds to each machine size. Therefore, hydraulic excavator systems of or hydraulically-driven tools can be overloaded during application or will achieve a weak performance. For these reasons, customers have requested the development of a system with which it is possible to measure loads and forces at the tool and provide operational assistance to the excavator operator.

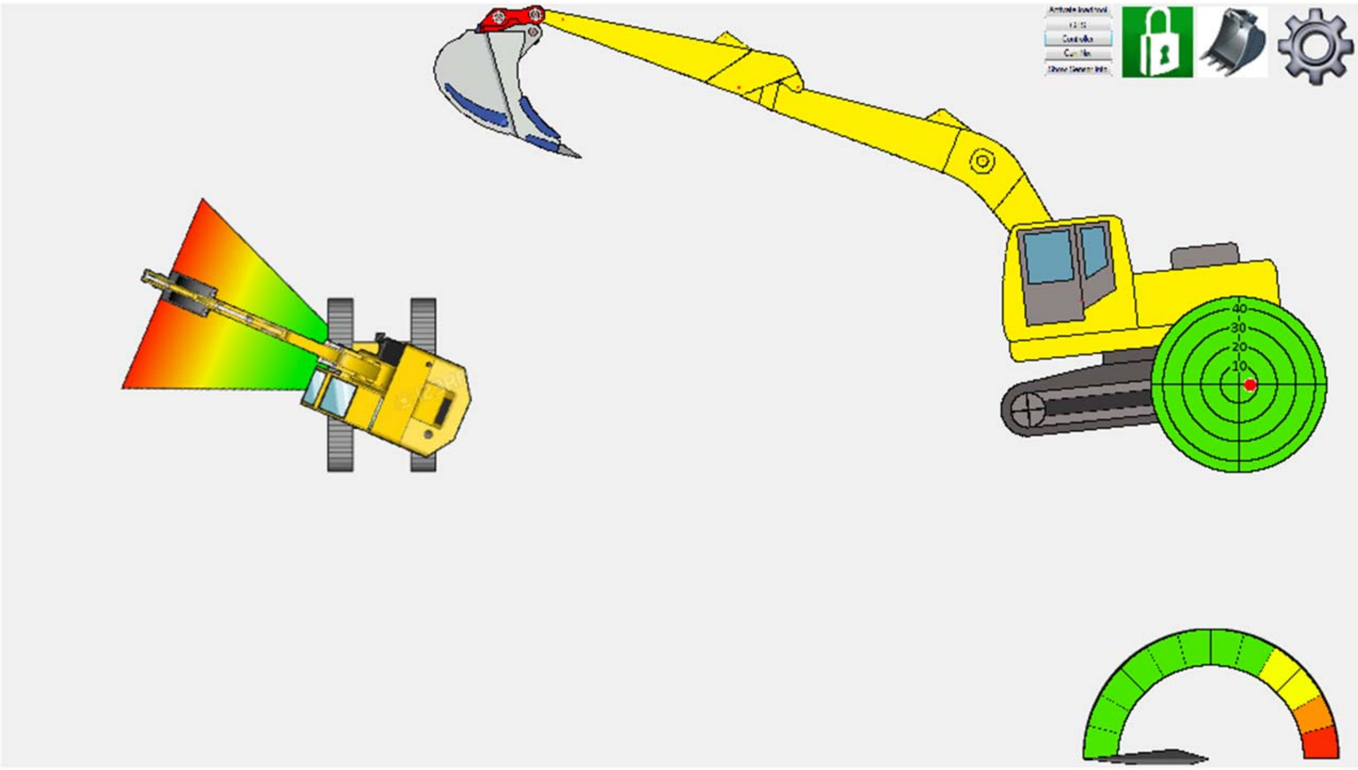
The goal of this project was to create a modular guidance and measurement system that can be retroactively fitted to any excavator.

A measurement system was adapted for the quick coupler (force-torque sensor) of the mobile excavator. The developed force-torque sensor is a completely innovative solution, not present on the market up to date. It allows measurement of all six force and torque components of load acting on the tool. Another, positioning system was developed as an independent sub-system. It allows positioning of the tool tip relative to the excavator's undercarriage. Thanks to a new mathematical model of excavator's kinematics, the positioning sub-system can be applied to **any structure** of excavator's manipulator, including joints rotating in any direction and translational joints.

One of the most innovative features of the system is the ability to determine excavator's **static and dynamic** tip-over stability. It calculates instantaneous substitute Center of Gravity of the machine based on:

- geometrical and mass parameters of each excavator link
- precise position of each link
- excavator body rotational speed
- ground slope in two planes
- mass of the material in the bucket.

The substitute Center of Gravity is then assessed with respect to excavator's tipping lines. Based on this data, the operator is informed about actual stability of the excavator and warned if the system detects possibility of tipping over.



In addition, an integrated tool recognition system provides all relevant parameters of the tool in use, such as the kind of tool, style, hydraulic parameters (if applicable) and operating life, to the processing unit of the measurement system.

Another feature of the system is a sensor integrated in the quick-coupler, which checks and informs the operator if the tool has been properly attached (locked hydraulically in the quick-coupler). This feature meets the demand of excavator users who have reported accidents happening as a result of not complete locking of the tool-locking mechanism.

The system has been calibrated and tested in real operating conditions at a few test sites. These tests have led to further improvements of mechanical parts of the system as well as the software. At present stage, the system is a first prototype which has proved appropriate, however need further developments in order to become introduced on the market.

The system concept has been presented during a few scientific and technical conferences as well as during the biggest construction and earth-moving machinery trade fair in the world – bauma 2016.

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1 Summary description of project context and objectives

The goal of this project was to create a modular guidance system that can be retroactively fitted to any excavator. It would combine existing functions with innovations in the field of guidance.

The innovative core of the project lies in the development of means of increasing operator's work efficiency, machine stability and tool wear monitoring, using data provided by a force-torque sensor installed in the quick-coupler and other sensors capturing excavator kinematics. This was accomplished through theoretical l analysis of tools such as sorting grabber, bucket (including bucket variations such as rotating, tilt and screening), ripper and experimental analysis of a bucket, as the most extensively used tool.

Another innovation lies in the development of a force measurement system with minimal crosstalk of the force components, Fx,,Fz, and moments, Mx, My, Mz suitable for excavator applications. In conjunction with a inclination sensor system to determine excavator kinematics, all relevant parameters are determined. These parameters are sent to the processing unit of the measurement system for use in the user interface algorithm, such as displaying tool load, monitoring the excavator's tip-over stability, weight of tool contents, etc.

A measurement system was adapted for the quick coupler and for each link of the mobile excavator. In addition, an integrated tool recognition system provides all relevant parameters of the tool in use, such as the kind of tool, style, hydraulic parameters (if applicable) and operating life, to the processing unit of the measurement system. A tilt sensor attached to the chassis of the machine contributes data for stability control.

Following are lists of scientific and technological objectives, divided into hardware and software objectives for the proposed project.

1.1 Scientific and Technological Objectives - Hardware

- Development of a 6-component force-torque sensor system for the quick coupler, capable of withstanding and measuring the high loads imposed by excavator work and the dirty conditions of the excavator working environment
- Design of a modular measurement system that can be retroactively installed in any excavator to make relevant measurements (boom positioning, tool load and recognition, chassis tilt)
- Verification of system functionality under laboratory conditions through calibration and test (both through simulations and experiments) of each system separately and as a whole
- Creation of a demonstrator to illustrate functionality and ensure user friendliness of the guidance system through testing at real construction sites.

1.2 Scientific and Technological Objectives – Software

- Development of a mathematical model, supported by experimental data, of excavator work processes performed by tools to be used within the software database
- Improvement of existing safety algorithms to include dynamic overturning safety (due to positioning and motion of the tool, load and boom)
- Recording of operating times in combination with tool recognition in order to suggest optimal maintenance intervals
- Programming of a user interface that incorporates performance reliability and safety algorithms as well as data bases (which can be periodically updated online) holding a mathematical model and important parameter ranges attained.

Within the course of the project, from January 2014 to March 2016, in 8 scientific work packages**,** supported by two management and dissemination work packages, the consortium managed to address most of the extensive project spectrum. The most important objectives obtained are:

- Technical and economic feasibility study: based on it, general requirements to the hardware used for the system were defined. A cost-benefit analysis has shown the project is economically sound (Work Package 1).
- Formulation of a mathematical model of excavator kinematics: based on an extensive research of available excavator kinematic structure, a universal model allowing precise determination of tool's tip position of any excavator based on a set of inputs was formulated. The inputs include geometrical constants and variable from position/inclination sensors located at each link. Another completely new feature of the model was the possibility to predict the possible loss of tip-over stability in both static and dynamic states.
- Experimental determination of work parameters: the system created requires knowledge of the center of gravity (CoG) of the excavator independent of the position of the manipulator and the body. An experimental method of determination of CoG of each link in three planes was devised. Based on these preliminary measurements it was possible to estimate other important parameters, such as dynamic forces during turning of the body acting on the undercarriage (Work Package 3)
- Design for optimal system performance: a complete working model of the excavator, work-tool and every sub-system and component of the guidance system was generated using a CAD program. Simulations done in a multi-body dynamics program allowed definition of maximum loads which may occur during the work process in different positions. Based on the results, loads for proper dimensioning of the force-torque sensor were defined (Work Package 4).
- Development of the user interface: the software structure was created. The software implements the mathematical model which calculates the tip-over stability. The user interface provides

information such as stability status, connected tool, weight of tool content and warns the operator when the system gets unstable (Work Package 5).

- Development, calibration and tests of the force-torque sensor: a solution to the force-sensing problem was integral to the success of the system. It was assessed it should:
  - be integrated into the quick coupler in order to allow measurement at various tools;
  - be able to measure both dynamic and static loads;
  - be possible to retrofit and not overly complicated to install;
  - work in dirty working environment.

  The goal was achieved by designing and manufacturing a strain-gauge transducer, which was fitted into re-designed hydraulic-quick coupler. The special flat design of the transducer allowed minor interferences in the original design of the quick-coupler and minor changes of its geometry. Two calibration methods for the transducer were proposed. The sensor has been calibrated in laboratory and in real working conditions (Work Packages 6 and 7)

- Tests under real operating conditions: a demonstrator was built to test the system mechanically and electrically and to check it’s precision in real operating conditions on a full scale machine. Field experimental tests were conducted in order to verify results of earlier laboratory tests, with use of excavator’s work tool as a source of external loads. Verification of the force-torque transducer characteristics was done by applying different components of external independent loads acting on the work tool and has shown its utility in foreseen range and type of loadings. The demonstrator was also used to verify correctness of the mathematical model of excavator’s kinematics and the user interface (Work Package 8).
- Dissemination and exploitation activities: activities were carried out simultaneously with other Work Packages. RTD performers have presented the scientific output of the project on three conferences held in Germany. Most of the consortium members have participated in the biggest construction and earth-moving machinery trade fair in the world - bauma 2016 in Munich, which gave the best opportunities for dissemination of the project. A project website has been developed (Work Package 9)

2 Description of main S&T results/foregrounds

2.1 Project definition and related research (WP 1)

Results of technical feasibility study

The feasibility study was carried out to determine the practicability of the Project. The main goal of this project was to provide machine users with an information system. This information system will monitor the position of the boom, stick and tool as well as the working process. Under consideration of the ongoing forces, e.g., loading onto the bucket, the user needs to be informed about the load acting on the tool or the mass of carried material.

After analyzing the project and contemplating the relative opportunities for hardware as well as completing a cost and risk analysis, it was possible to make the following statements:

- All necessary hardware (except of load cell) is obtainable on the market to reasonable prices.
- A technical feasibility of the information system was unrestricted possible as part of the project, as long as the load cells were fully functional as suggested.

Overall the project consortium concluded that the technical feasibility of the project with the desired functionality was possible.

Customer-benefit of the new system

The proposed system plans to not only expand upon the tools available, but also to ensure tool performance reliability by measuring and displaying tool loads to the operator, as well as offering guidance to optimize using the tools.

Due to the perceived complexity and dangers already mentioned above, this project will not directly focus on offering a fully-automatic or semi-automatic control system for the excavator (depending on time for development), but rather will develop a guidance system to help the operator ensure performance reliability.

Through this development, the operator will be given the capability to receive direct feedback from the work process. As a result, the end product and the performance reliability of diverse construction operations will be improved. Additionally, the efficiency and work safety of operation will be enhanced.

The intention of the new functions mainly focuses on safety, ergonomics and user assistance, listed as follows:

- higher work safety

  identification of load limits for stability against overturning during operation

- better performance reliability

  tool identification – adjustment of required operating parameters, e.g. flow, pressure
  determination of sensible and economic tool operation
  weighing of loads present at the quick coupler

- reduced wear or damage of tools

  tool identification – adjustment of required operating parameters
  tool identification – record and display operating time, maintenance intervals

Cost-benefit analysis

To determine the current purchasing and operating costs of corresponding excavators and implements, inquiries were made to known companies. Some of the smaller companies (20-50 employees) did not have complete cost statements that could be evaluated. However, three companies with 150-300 employees were able to furnish particulars.

One of these three companies had purchased a fully hydraulic quick coupler and implements in 2012-2013, which fit in well with the project, and a cost-benefit analysis was carried out.
The analysis resulted in the following conclusions:

- Under the new project conditions, a cost reduction on an average of 20% is predicted, so that there is a return of investment after a minimum of 18 months. This is estimated for applications under medium working conditions.
- Under heavy working conditions such as hard excavating, recycling or demolition jobsites, a cost reduction between 20-30% is assumed.

Important is the fact that the performance level can reach up to 50% and more, depending on jobsite and application.

2.2 System modelling and analysis (WP 2)

Definition of influencing variables

Single bucket excavator can realize the work cycle in different ways and in different work conditions. The most typical work tasks are:

a) Digging (mining of the material in horizontal layers)
b) Slope grading/profiling (mining of the material in inclined layers)
c) Digging using long manipulator (mining of the material in horizontal layers)
d) Deep excavation with very steep walls (digging a ‘well’)

Based on analysis of work cycles of different types of excavator working in different conditions, the following conclusions were drawn:

A. The work process is realized by manipulator and the swing mechanism. Undercarriage is used for transportation of the machine and guarantees tip-over stability;
B. Operator has limited visibility of the work area – a positioning system is needed, especially if a certain profile of the slope is required;
C. Tip-over stability of the excavator requires monitoring of the following factors:
    a) Machine position: ground inclination, vehicle orientation during swinging and relative position of body to undercarriage,
    b) Digging using long manipulator,
    c) Dynamical loads resulting from unsteady body rotation (swinging and swinging back) and manipulator movement (during digging),
    d) Ground and slope stability at which excavator stands (important especially during work at slopes and digging close to machine’s undercarriage)
D. Digging resistance, from the tool durability point of view, cannot exceed permissible values;
E. Assessment of excavator’s efficiency requires possibility of weighing of winning (material), desirably at any moment between digging and dumping phase;

F. Due to the general efficiency of the work process, dumping of the material should be performed at as short distance as possible (body rotation around 90°), what leads to shorter load transport phase.

Based on the points listed above, important input parameters of for the mathematical model of the excavator were defined. These include: six components of forces and torques acting on the tool, tool type, precise dimensions of the manipulator links, coordinates of the Centers of Gravity of each link, acceleration and angular velocity of the tool, inclination of the slope on which the machine stands.

Creation of the mathematical model of the kinematic chain

Excavator market is dominated by a few kinematic structures of the manipulator. They are depicted at fig. 1.

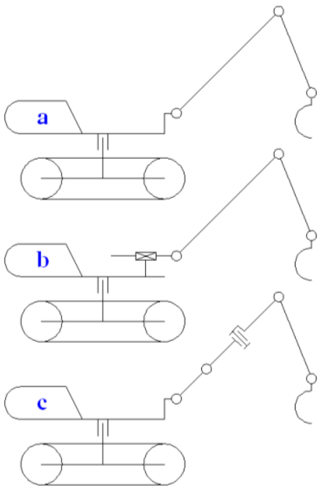


Fig. 1. Typical manipulator structures.

That is why most of the positioning systems available on the market, offer functions only for 2 or 3 types of kinematics. In the scope of this project was development of a universal model that will allow positioning of any available manipulator kinematics. After analysis of various manipulator structures, a mathematical model was formulated. The so called ‘alpha’ structure developed within this project (fig. 2.) allows positioning of the tool tip of any type of single bucket excavator’s manipulator, based on rotational and translational displacements of each link of the kinematic chain. The model is based on mathematical relationships that enable calculation of relative rotation angles of mating links $\varphi_{i+1 \rightarrow i}$ in case when:

a) inclinometers are mounted at mating links,

b) the travel of hydraulic actuator rod that forces relative link rotation is measured and

c) inclinometer is mounted on the four-bar link connecting the tool to the last but one link.

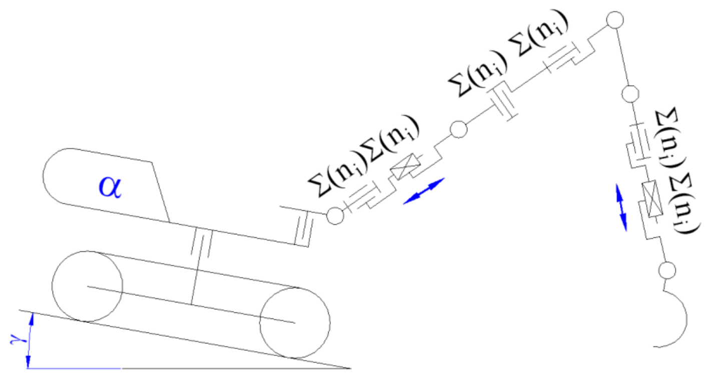


Fig. 2. Hypothetical excavator with so called α structure

The ‘alpha’ model is a completely new output of the project that was not available in any commercial solutions on the market.

Mathematical model of tracked excavator’s tip-over stability

Regulations for the stability of hydraulic excavators are standardized in the EU by ISO 10567:2007. The field of application encompasses the excavator as well as any attached tool. Nevertheless, the calculation method described in this norm is inadequate, since the effects of the surface and dynamic forces generated by the work procedure (turning, driving, lifting), are not addressed. Especially in the field of demolition, where long sticks and heavy hydraulic tools can lead to suddenly occurring large moments, there is a danger of overturning if dynamic forces are not taken into consideration.

In order to address these, formulated model takes into account the following factors that have influence on excavator’s tip-over stability:

- ground inclination angles
- location of centers of gravity of all influential excavator links, i.e.: undercarriage, body, boom, stick and the tool with the quick-coupler and possible load in the tool (winning)
- dynamic forces generated during body rotation relative to undercarriage
- dynamic forces generated by loaded tool acting on the manipulator.

During formulation of the model, it was assumed that the excavator has four fixed tip-over axes which location can be determined with satisfying degree of accuracy. It can be adopted that these tip-over axes correspond to those defined by the current standards. The difference between stabilizing and overturning moment was assumed as a measure of stability reserve relative to each tip axis. It was assumed, that the system will determine this stability reserve relative to each tip-over axis in real time.

Conceptual designs for the guidance system

Positioning systems available on the market, rarely use the slew angle. The body is oriented either using GPS receivers or sometimes magnetometers or it is not oriented at all, thus the tool is not oriented in three dimensions. The designed subsystem uses data from slew angle sensor in the positioning process as it has to be fixed either way for the stability subsystem.

In the project, it was presumed that the system after determination of the tool position will visualize current location of the tool relative to the pre-set excavation's boundaries. Diagram of conceived positioning system concept is shown at figure 3. Before the first use of the system on an excavator basic kinematic parameters of the excavator will have to be entered) and it will have to be calibrated. For some excavators and tools, necessary parameters can be available in the system's database.

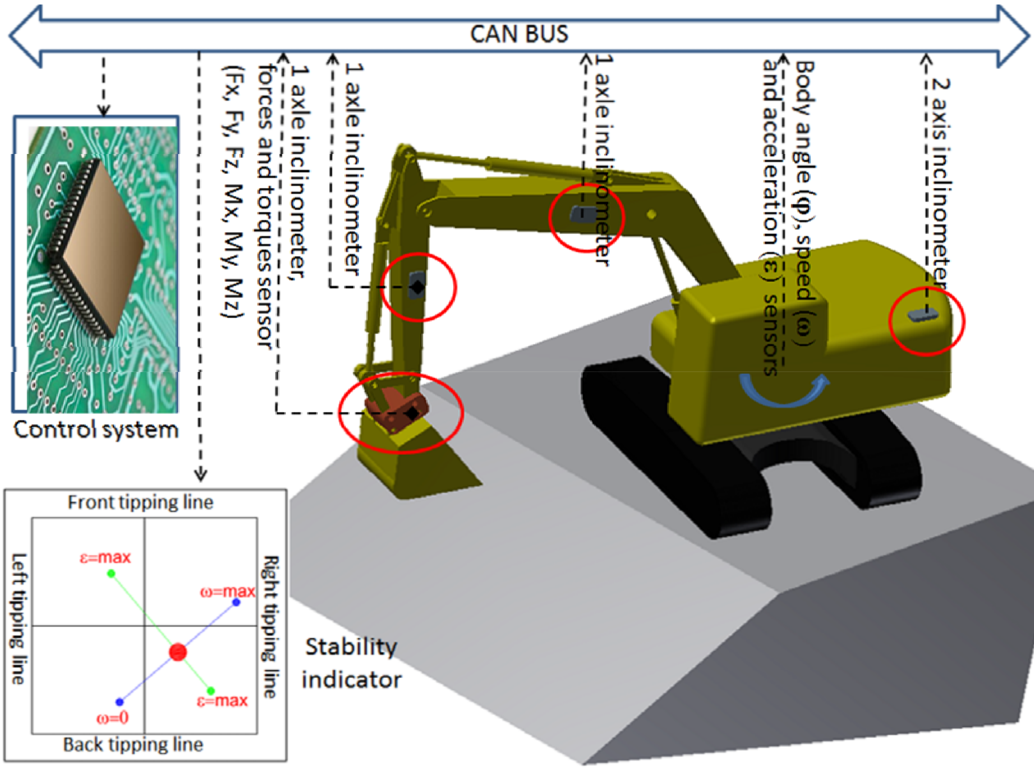


Fig. 3. Concept of the system for positioning of tool of a single bucket pull excavator

2.3 Experimental determination of work tool parameters (WP 3)

The system created requires knowledge of the center of gravity (CoG) of the excavator independent of the position of the manipulator and the body. In previous stages of the project, the CoG was estimated based on the geometrical data of the excavator links. Before conducting further work on the system, it was necessary to determine more precisely the mass of demonstrator excavator links, with which future tests of the prototype system were to be completed. The measurements to gather data enabling calculation of the essential mass parameters of the excavator were divided into two series. In the first series of measurements, the excavator stood on flat ground, while during the second series of measurements, the undercarriage was inclined at 16 degrees. Thanks to the new developed method, determination of CoG of each link was possible. This method can be applied to any type of single bucket excavator, irrespective of its manipulator kinematic structure. The outline of the method is presented below:

- The excavator is located on four simple supports as shown at fig. 4 and fig. 5.
- Two front or two back supports are placed always on two measuring scales (fig. 4 and fig. 5)
- The undercarriage is located horizontally or inclined
- In order to determine vertical position of the CoG, the excavator has to lift it's front rollers, supporting the manipulator on a measuring scale (fig. 6)
- Different positions of the manipulator and the body are set (fig. 7)
- Registered are: indications of measuring scales located under supports, angular positions of manipulator links relative to the horizontal plane, angle of body rotation relative to the undercarriage
- Precise position of supports relative to the undercarriage is defined
- Real ground, at which the measurements are conducted should be flat.

Fig. 4. Excavator setup on supports during the first series of measurements

Fig. 5. View of one of the supports located at a measuring scale during measurements

Fig. 6. Excavator setup on supports during determination of the vertical CoG coordinates

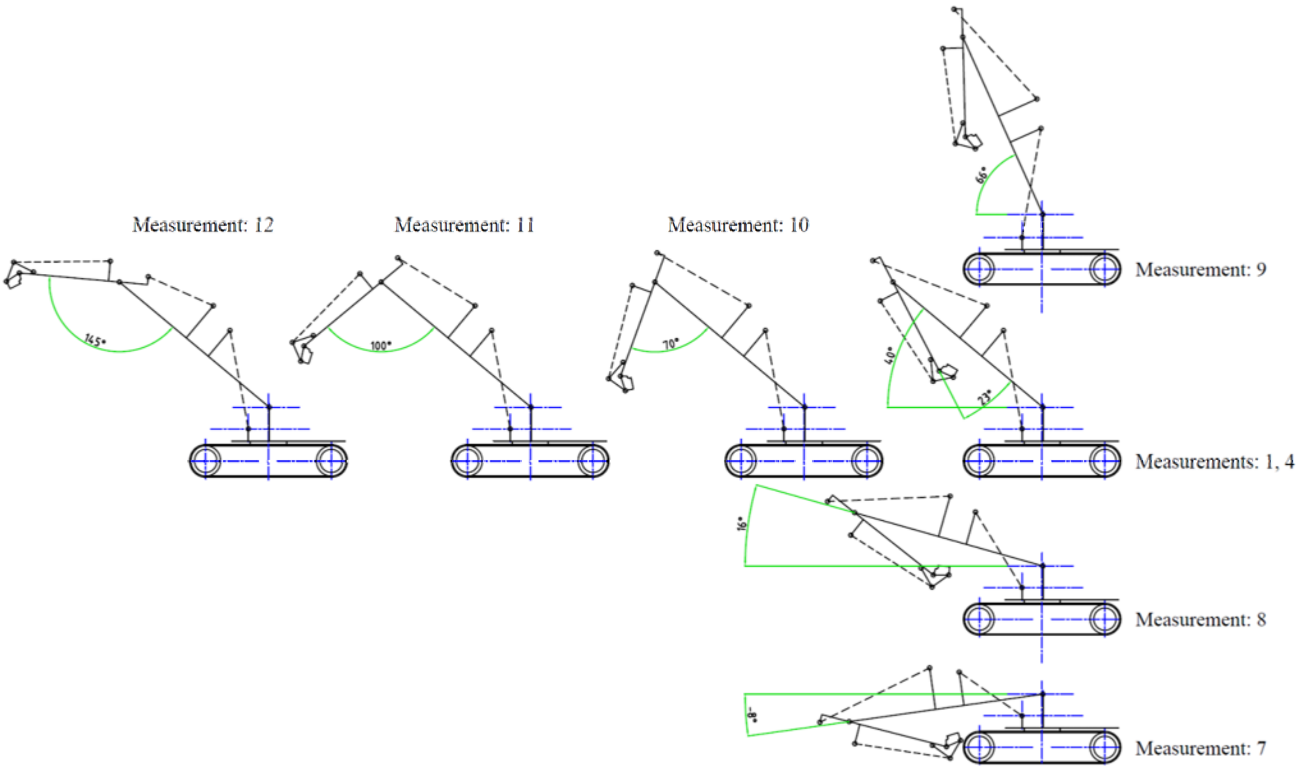


Fig. 7 . Manipulator positions set during the test procedure.

Based on the test procedure, CoG of each link in three dimensions were determined. Also the following important conclusions were drawn from the test results:

- The maximum difference between the sum of rear support reactions and analogical dynamical reaction was around 5200 kg. This value constituted to around 41% of static reaction (fig. 8).
- The high value of dynamic surplus during fast movements of the excavator showed how important it is to control the dynamics of the machine and foresee probable loss of stability.

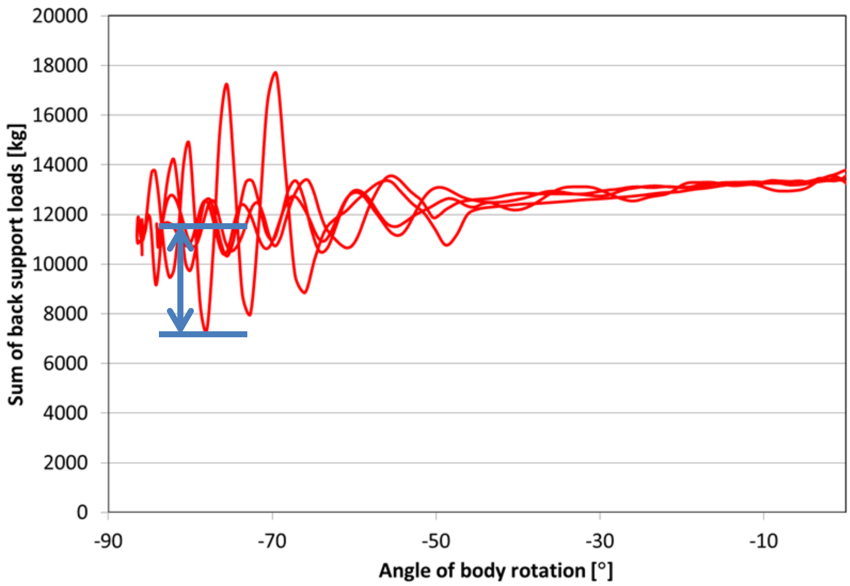


Fig. 8. Sum of back support loads measured during experimental tests on the excavator. The graph shows that due to dynamic phenomena occurring during rotation of the excavator's body, the reaction under one of tipping lines is reduced even by over 40%. That is for a case when the excavator stands on a flat ground. Tests on slopes weren't conducted due to safety reasons.

2.4 Design for optimal system performance (WP 4)

A complete working model of the excavator, work-tool and every sub-system and component of the guidance system was generated using a CAD program. Simulations done in a multi-body dynamics program allowed definition of maximum loads which may occur during the work process in different positions. Based on the results, loads for proper dimensioning of the force-torque sensor were defined.

To reach the earlier described concepts it was necessary to choose hardware that can resist the environmental influences that they are exposed. Therefore it had to be considered that the chosen hardware, which is exposed to environmental influences, had to be at least protected with IP 65. To allow easy communication of all components to the calculating unit, every part of the whole system needs to implement the CAN-bus-protocol. For those Sensors and parts that are analog driven, it was necessary to support them with a microcontroller to ensure that a communication with the system is possible. Within this work package appropriate components of the positioning and control system were selected. Simultaneously with this task, work package 6 with development of the force-torque sensor has started.

2.5 Development of the user interface (WP 5)

The software was developed for calculating the tip-over stability. It gets the sensor data from CAN-Bus and uses the mathematical model for the calculation. The user interface was designed to provide the user with important information such as stability status, connected tool, weight of tool content and warns the operator when the system gets unstable. During work the system saves the sensor values so that they can be analyzed.

2.6 Force-torque measurement (WP 6 and WP 7)

The force-sensing problem presented by the demands of the proposed guidance system is complex and a solution is integral to the success of the system. It should be integrated into the quick coupler in order to allow measurement at various tools; it must be able to measure both dynamic and static loads, be possible to retrofit and not overly complicated to install. In addition, the sensor solution must be adapted to the dirty working environment of the excavator and suited to the load magnitude expected. It is impossible to simplify the force/torque-sensing problem by changing the work tools addressed, since the bare minimum for any excavation operator is a solution for the bucket, which already requires measurement of forces/torques in all three axes. Therefore the tests carried out within the project were focused on a bucket as a work tool, which requires measurement of all load components under most demanding (dynamical) conditions.

Basically, there are two physically different technologies for multi-component measuring that define the state-of-the art:

• Piezoelectric Sensors - broad frequency range; difficult to measure static impulses; high cost

• Strain Gauge Sensors - low cost and highly rigid; possible to measure static and dynamic amplitudes; small frequency range.

A solution using strain gauge technology was implemented in the design of the force-torque transducers developed. In order to fit the transducers, the geometry of the original quick-coupler had to be changed. However, significant changes would affect its performance, therefore it was optimized, so that it was fitted between the upper and lower part of the quick-coupler, hardly affecting its height, and not affecting it’s functionality (fig. 9).

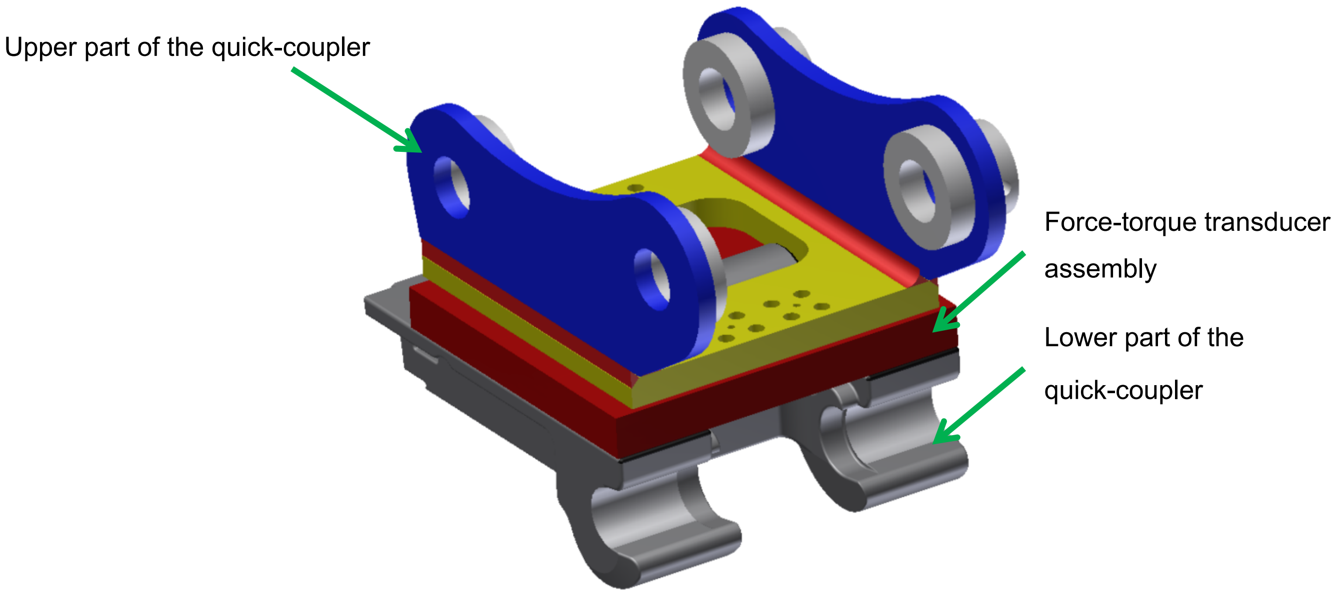


Fig. 9. Type of solution for the quick-coupler force and torque measurement applied in the project

Within the work package two methods of calibration of the force-torque transducer was proposed. First allows pre-calibration before the assembly of the quick-coupler on the excavator, which is useful for the manufacturer of the transducers/quick-coupler. The second allows calibration on an excavator, which might be useful for the user/service to recalibrate the device after certain number of work-hours.

In order to verify the correctness of the introduced structural changes to the original quick-coupler design, numerical simulations using the Finite Element Method (FEM) were conducted. The goal was to:

1) Determine maximum stresses in measuring beams/segments and in the upper plate;
2) Determine potential of the measurement elements by determination of their strain;
3) Choose materials for the modified elements of the upper plate and transducer.

Based on the simulations, structure of the force-torque transducer, its precise shape and dimensions were defined. Also optimum places for the strain-gauge application were defined.

2.7 Tests under real operating conditions (WP 8)

Force-torque transducer

The system designed within the scope of this project consists of two main sub-systems: force-torque transducer and positioning system. A demonstrator was built to test the system mechanically and electrically and to check it’s precision in real operating conditions on a full scale machine.

Field experimental tests were conducted in order to verify results of earlier laboratory tests, with use of excavator’s work tool as a source of external loads. Verification of the force-torque transducer characteristics (designed as a part of the work package 6) required tests with different components of external independent loads acting on the work tool (i.e. appropriate combination of forces and torques).

Fig. 10. Demonstrator during experimental tests.

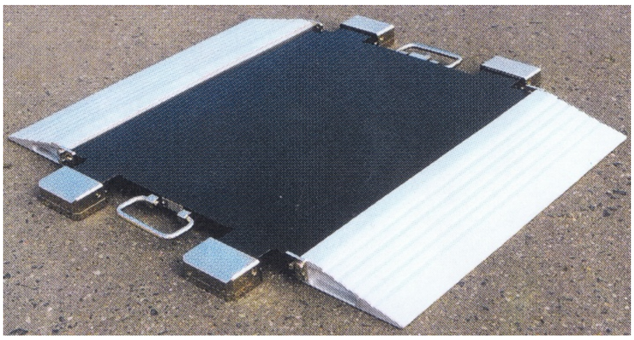
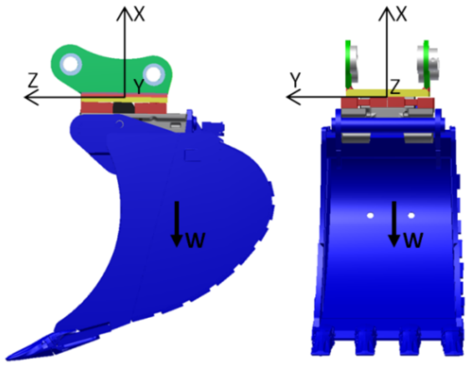
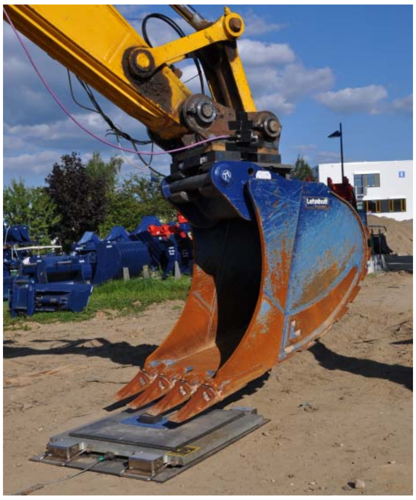
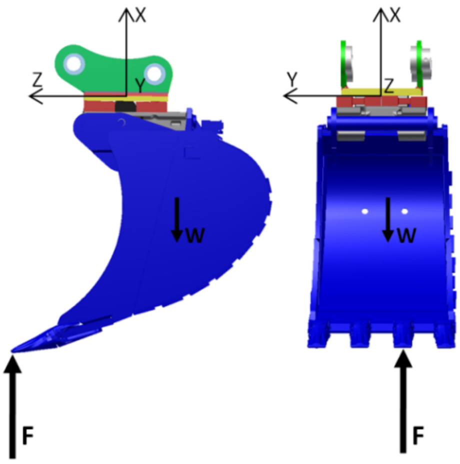
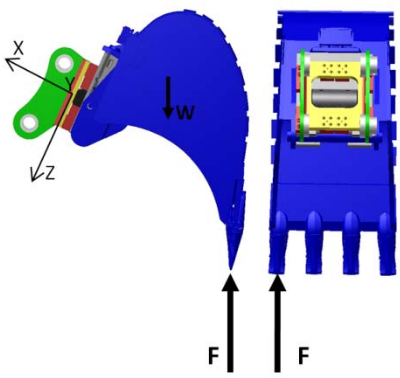
a)  b) 

Fig. 11. Measuring scale (a) and force sensor (b) used for experimental identification of real values of forces acting on the bucket.

In the table 1, 3 exemplary load cases applied in the tests are shown.

Tab. 1. Selected cases of loads applied to the quick-coupler during experimental tests

Load case no. 1 – gravitational load
 
Load case no. 2 – x force component, z and y torque components acting
 
Load case no. 3 – x and z force components, x,y, z torque components acting
 

The system was calibrated and tested in a few different operating conditions. Based on the test the following conclusion were drawn:

1) Conducted experiments proved that selected design is sound – by slight modification of standard quick-coupler VL210, a system allowing identification of loads acting on standard excavator work was made.
2) Designed force-torque transducer allows measurement of all load components acting on the tool in real time with satisfactory precision, which allows identification of dynamic loads that are dangerous for the tool or the excavator.
3) Measurement signals from the force-torque transducer allow, after proper processing, visualization of selected loads acting on the tool, e.g. winning weight.
4) For proper identification of loads acting on the work tool, information about mass parameters of the work tools (mass, location of the center of gravity, moments of inertia) have to be stored in the database of the controller.
5) Designed modified quick-coupler can be used as a source of inputs for the system for prediction of machine's tip-over stability.

Positioning system

Demonstrator of the positioning system was built in order to check the system integrity and to prove the correctness mathematical model developed in Work Package 2.

According to the plan, positioning system demonstrator consisted of a set of one-axis inclination sensors (one per each manipulator main link), one two-axis inclination sensor for determination of undercarriage inclination in two planes, rotary encoder for determination of angular position of the body relative to the undercarriage and a three component acceleration sensor for compensation of dynamic effects during weighing of the material in the tool (fitted in the quick-coupler). The whole demonstrator is depicted at fig. 12.

Fig. 12. Demonstrator installed on a Komatsu PC 210 excavator.

2.8 Dissemination and exploitation activities (WP 9)

Participation at conferences:

2015	VDBUM Großseminar, February 2015, Braunlage, Germany
	Baumaschinenfachtagung, September 2015, Dresden, Germany
2016	FVB Beiratssitzung, March 2016, Karlsruhe, Germany

Exhibitors at trade fairs:

2016	bauma 2016, April 2016, Munich, Germany

Mid-September 2015 a presentation was given by CUAS and WRUT at the Baumaschinenfachtagung in Dresden, Germany, organized by the VDMA, FVB (advisory board member) and the Technical University of Dresden. Additionally in march 2016 a presentation was given by CUAS to the VDMA / FVB advisory board during the semi-annual meeting in Karlsruhe, Germany.

From April 11th to 17th 2016, Lehnhoff, G&L, CUAS and WRUT have participated in the biggest construction and earth moving machinery fair in the world: bauma 2016 held in Munich, Germany. It was a great opportunity to inform potential customers about the project and developed system functionalities.

2.9 Management and coordination (WP 10)

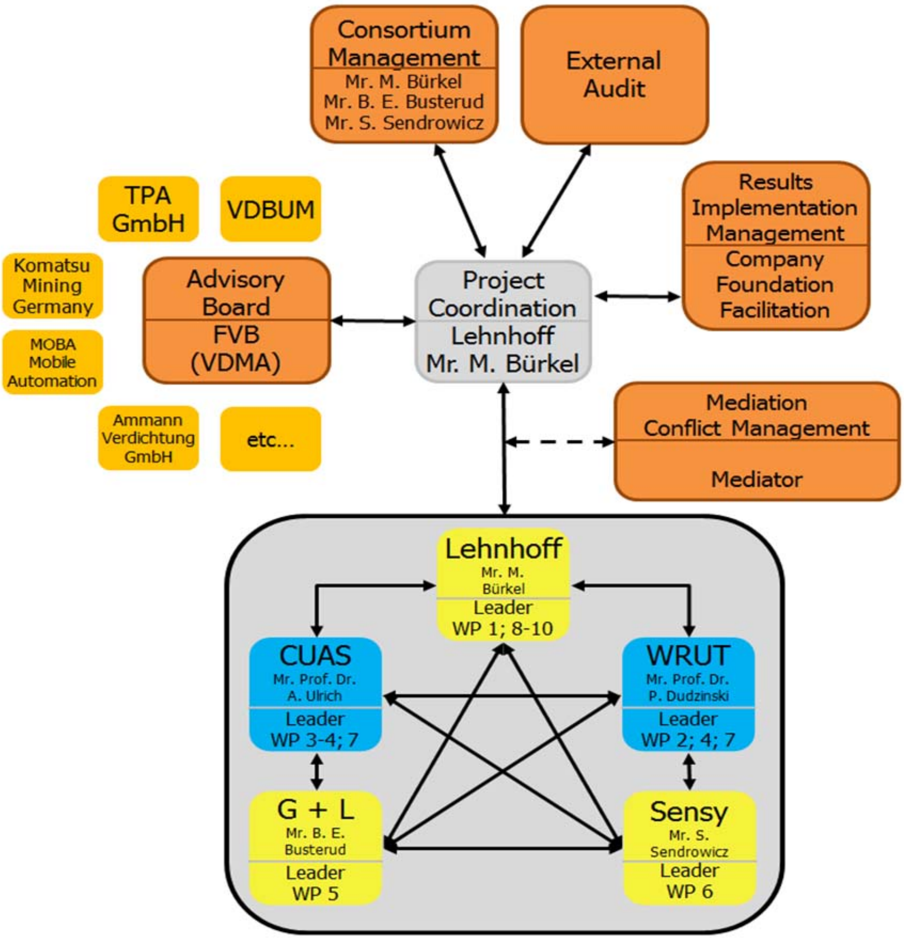


Fig. 13. Management structure

The development of the 6-components force-torque-sensor was delayed. During the work on WP 6 the originally planned solution, to measure all forces and torques through load pins, was developed and investigated. After measurements with the demonstration excavator it became clear that the suggested method cannot be applied to this task.

Discussions with Lehnhoff, as the quick coupler manufacturer, resulted in the conclusion that the system could have negative influences on the measurement results, e.g. the necessary accuracy, which has to be considered in manufacturing the measurement device. The tolerances in the device and the top of the bucket could make it difficult to keep the residual forces under control. Therefore, a second method for measuring the forces and the torques on the tool was considered and developed.

Due to these problems, the planned time line for WP6 could not be accomplished on time. The affected tasks (T6.1, T6.2, T6.3, T6.6 and all tasks from WP7) were delayed by 3 months. The problems with the development of the 6-components force-torque sensor had influences on the following milestones and deliverables: MS6 “Development of excavator-appropriate 6-components force-torque sensor”; MS7 “Force measurement sub-system completion”; MS9 “Total modular guidance system assembly”; D6.2 “Design of calibration device for 6-component force-torque sensor” and D6.3 “Calibrated positioning and force measurement sub-systems.

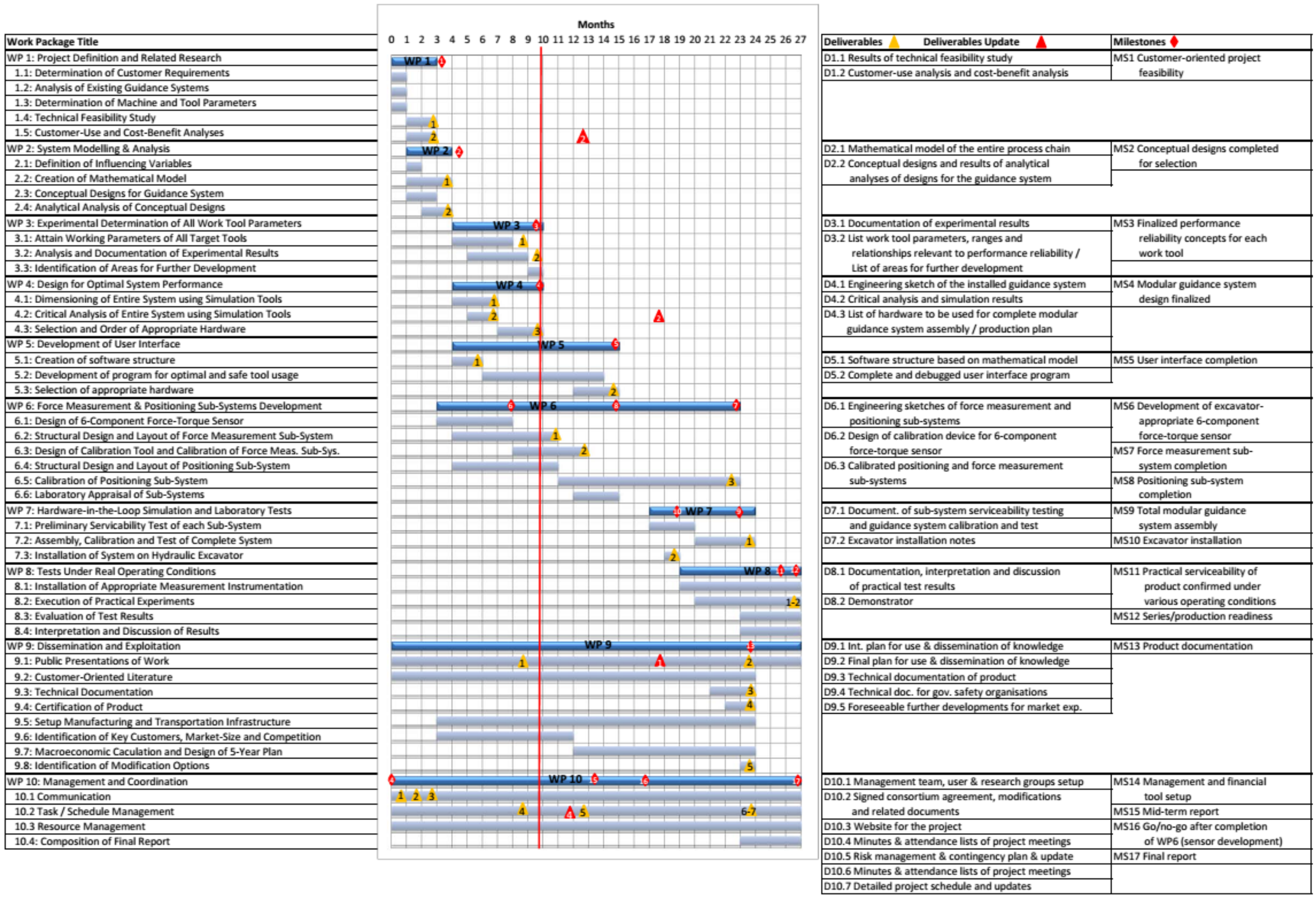


Fig. 14. Updated project schedule

3 Potential impact and main dissemination activities and exploitation results

The PROSYMA system is modular and the different marketable modules of the Excavator Guidance System are as follows:

- Tip-Over Stability (TRL 6)
- Force-Torque Measurement (TRL 6)
- Safe Tool Coupling (TRL 9)
- Work Tool Recognition (TRL 6)
- Positioning Subsystem (TRL 6)

The technical readiness level indicates also the market readiness of the modules. It is estimated that with additional work of 12 month all TRLs will rise up to TRL 9.

Potential impact

The potential impact of PROSYMA is expected on several levels. The most important is economic impact on the consortium partners. Development of a completely new system, which has no equivalent on the market is a strong asset in market competition. Its modular design makes it more versatile, thus easier to implement even for less affluent customers.

Another impact is expected in terms of safety of the workers and work environment. Developed system for monitoring excavator's stability can significantly reduce the number of accidents. The tool safe locking indicator will allow to avoid many accidents connected with tool unlocking during operation.

Scientific impact should also be mentioned, as the system is based on a new type of force-torque transducer which development might lead to further developments in measurement technology.

Dissemination

The PROSYMA dissemination is aimed mainly on promotion of the system itself. Therefore dissemination in the early stage of the project was limited to general information about its course and goals. In the latter part, project results were presented mostly on scientific and technical conferences (VDBUM Großseminar, February 2015, Braunlage, Germany; Baumaschinenfachtagung, September 2015, Dresden, Germany; FVB Beiratssitzung, March 2016, Karlsruhe, Germany).

By displaying the developed system in the stands and booths of the SMEs and the RTD performers at trade fairs, system functions and applications can be demonstrated. The first trade fair where the system concept was presented was bauma 2016 in Munich. It was a great opportunity to promote the product, even though it was in a prototype stage. Project leaflets were printed and handed over to people passing by RTD performers' booths. There were many inquiries from both private persons as well as companies about its functionality. Any possible questions and concerns were immediately explained.

Future dissemination mechanisms will include:

• Project homepage *www.prosyma.eu*

• Directly presentations with and for users; a Lehnhoff Demopark is available for this in which the product can be tested.

• Compilation of project reports, bachelor and master theses as well as dissertations with industry partners and using research results in education, such as courses in hydraulics as well as construction, forestry and municipal machines at CUAS and WRUT

Exploitation

Technical documentation for product certification in Europe was completed. Plans are for SMEs to begin production of the product after the modules have reached TRL 9.

Through a possible implementation of the product into systems of other manufacturers (e.g., Komatsu, Liebherr, Caterpillar), the system can be more widely distributed and its degree of recognition increased, thus enhancing and strengthening its market presence. The dissemination to potential partners at the BAUMA was instrumental to this end.

4 Address of project public website and relevant contact details

Website address: www.prosyma.eu

Contact details

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