Final Report

IMAGING-BASED OPTICAL CALIPER FOR OBJECTS IN HOT MANUFACTURING PROCESSES

A Project under Award

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Other Partners:

Michigan Seamless Tube (MST), Republic Steel, Ellwood City Forge, Charter Steel, V&M Star

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EXECUTIVE SUMMARY

OG Technologies, Inc. (OGT), in conjunction with its industrial and academic partners, proposes to develop an "Imaging-Based Optical Caliper (hereafter referred to as "OC") for Objects in Hot Manufacturing Processes". The goal is to develop and demonstrate the OC with the synergy of OGT's current technological pool and other innovations to provide a light weight, robust, safe and accurate portable dimensional measurement device for hot objects with integrated wireless communication capacity to enable real time process control. The technical areas of interest in this project are the combination of advanced imaging, Sensor Fusion, and process control. OGT believes that the synergistic interactions between its current set of technologies and other innovations could deliver products that are viable and have high impact in the hot manufacture processes, such as steel making, steel rolling, open die forging, and glass industries, resulting in a new energy efficient control paradigm in the operations through improved yield, prolonged tool life and improved quality.

In-line dimension measurement and control is of interest to the steel makers, yet current industry focus is on the final product dimension only instead of whole process due to the limit of man power, system cost and operator safety concerns. As sensor technologies advances, the industry started to see the need to enforce better dimensional control throughout the process, but lack the proper tools to do so. OGT along with its industrial partners represent the indigenous effort of technological development to serve the US steel industry.

The immediate market that can use and get benefited from the proposed OC is the Steel Industry. The deployment of the OC has the potential to provide benefits in reduction of energy waste, CO_2 emission, waste water amount, toxic waste, and so forth. The potential market after further expended function includes Hot Forging and Freight Industries.

The OC prototypes were fabricated, and were progressively tested on-site in several steel mill and hot forging facilities for evaluation. Software refinements and new calibration procedures were also carried out to overcome the discovered glitches. Progress was presented to the hot manufacture facilities worldwide. Evidence showed a great interest and practical need for this product. OGT is in the pilot commercialization mode for this new development.

The R&D team also successfully developed a 3D measurement function with no additional investment of hardware or equipment to measure low or room temperature object dimensions. Several tests were conducted in the reality environment to evaluate the measurement results. This new application will require additional development in product design.

INTRODUCTION

The goal of this program is to develop an imaging-based Optical Caliper, to be used on key dimensional measurements in hot processes such as rolling, casting and forging. Through the synergistic interactions between its current set of technologies and other innovations in sophisticated software and wireless communication, this project could deliver products that are viable and have high impact in the metal industry.

Dimension control is very important in manufacturing. The success of OGT's HotEye® RSB systems (end of line surface inspection systems) and the associated process control efforts have unveiled a key issue in the bar and rod rolling mills: more than 60% of the surface defects carried on the finished products are due to sloppy dimension and/or orientation controls in the initial rolling stages (breakdown mills). For instance, a slight underfill in the 3rd stand could result in random seams after the 15th stand. An overfill in the 4th stand has the potential to become random laps after the 30th stand. For those mills that roll shapes and rebars, dimension control along the rolling train is also important and incorrect dimensions may affect the cross-section weight distribution and final product straightness. While it is important to control the dimension and the orientation (which could be detected from a projected dimension), there exist only primitive tools for dimensional measurement after each rolling stand, even though the end-of-line sophisticated measuring systems are widely available.

This project is aim to develop a portable, self-calibrating Optical Caliper in the steel mills, melting shops and forging plants to replace the hand tools that require the operators to be at the proximity of extremely hot objects. The proposed Optical Caliper has the potential to result in a more efficient (flexible, easier to take measurements, better data management, more accurate, more frequent) and safer (farther away from hot objects) operation paradigm.

Technologies developed in this program can also benefit other applications. OGT is working with steel mills to apply the newly developed technologies to the manufacturing process of seamless steel tubes, steel rails and continuously cast slabs.

BACKGROUND

State of the Art

There are various kinds of measuring instruments and/or tools in hot processes.

A very common approach is to cool parts down, then using tools such as dial indicators and calipers. This is particularly true for discrete parts like forged crankshafts and wheel hubs. It is also true for many long product mills, in which the tail ends are from time to time cropped off the rolling train for measurement.

In steel mills, there are expensive automatic instruments installed for diameter, height, and width measurements on bars, rods, plates and slabs. Nevertheless, these instruments, such as Zumbach, LAP, Danieli, to name but a few, are fixed in locations, typically end of line and/or end of a mill block. They are too expensive to be installed mill wide at various locations, such as after each rolling stand. Therefore, the existing practices, in addition to these sophisticated instruments, are to use a hand-held caliper, if the hot object is moving slowly such as in the roughing mill. A worker may burn a wood plank against the hot bar and measure the burned profile, if the hot object is moving fast such as after the intermediate mill. As the wood plants are pushed manually from one side, it can provide only partial profile but not true measurements. Using handheld caliper gauges is also common on open-die forging for large parts such as transmission shafts and crankshafts for ships or power plants.

Area of Interest

The technical area of interest in this project is to provide the steel mill with a safer measurement tool with capacity to enable more timely and effective process control through advanced imaging, in-situ self calibration, noise reduction and process control.

With the synergistic interaction of all these innovations, the OC will represent a technological leap, in that the OC will be the first to provide a economical feasible solution for mill wide stand by stand dimension feedback and its related process control in a steel mill. Doing so shall reduce setup time and scrap, improve quality and prolong tool life, resulting in significant energy savings.

Project Objective

The goal of this project is to develop and demonstrate an OC prototype that will meet the need of the steel industry for enhancing the process control in hot rolling process for improved inter-stand dimensional control for the targeted benefits. This goal can be further delineated with the following objectives:

(a) To develop and demonstrate a handheld OC prototype that will have the ability of providing accurate measurements under “point and shoot” operations, with the following constraints:

   a. Measurement Range: Lens configurable; up to 500mm.

   b. Accuracy: 0.1% of measurement range under normal operating condition.

c. Battery life: Greater than 30 minutes.

d. Weight: Less than 2.5 Kg.

e. Size: Less than 300 x 150 x 100 mm.

(b) To develop and demonstrate a hybrid predictive control module that will have the ability to detect imminent process drift, automatically identify the source of variations and provide system level monitoring and estimation for feedback to bring the dimensions "on target" along the length of the mill.

Project Team

The project team includes the engineers from OGT, Dr. Jan Shi and his team from Georgia Tech as well as engineers and experts from industrial partners.

SUMMARY OF RESULTS

The R&D team has completed all objectives in Phase II, having designed, fabricated and tested new prototypes with additional functions. The prototypes were tested in laboratory and on-site for various operation conditions during the evaluation and refinement period. They had also been handed over to the participating industrial partners (steel mills and forging shops) and used in day-to-day operations trials.

The R&D team had also successfully implemented a mathematical model to compensate the perspective angle effect caused by none-parallel measurement between OC and the object. Other measurement noises occurred during onsite tests were also overcome by a series of newly developed review, reprocess, and re-calibration functions.

The R&D team also successfully developed a 3D measurement function with no additional investment of hardware or equipment to measure low or room temperature object dimensions. Several tests were conducted in the reality environment to evaluate the measurement results. This new application will require additional development in product design.

Technically, the objectives were met as shown in the table below:

Parameter	**Target**	**Phase II Results**
Measurement range	Up to 500mm	Lens selectable, over 1000mm.
Working distance	0.5~2.5m	Lens selectable, over 5m.
Accuracy	0.1% of measurement range	<0.1% of measurement range for instrument 0.18% of measurement range in daily operation
Battery life	> 30 min,	> 45 min
Weight	<2.5kg	1.6Kg
Size	< 300 x 150 x 100mm	190 x 115 x 90mm
Communication	Wireless	Wireless
Data application	Support real-time dimension control	Support real-time dimension control

As a result of this SBIR project, a patent entitled "*Method and apparatus of a portable imaging-based measurement with self calibration*" is granted by the US Patent and Trademark Office (US Pat. No. 8,233,157).

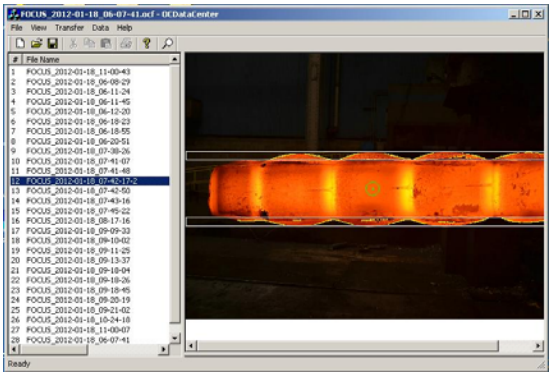
In addition to the technical efforts, a new product, the Optical Caliper, was presented to the hot manufacture facilities worldwide. Specifically, a presentation was given by Ellwood City Forge, entitled "*Update on Trials with OG Technologies Optical Caliper Instruments at Ellwood City Forge*" in the 29th Forging Industry Association Technical Conference (Cleveland, OH; September 2012). Evidence showed a great interest and practical need for this product. OGT is in the pilot commercialization mode for this new development. Pilot commercialization proposals have been submitted to a few prospects for hot object measurements. The new product represents an affordable, high accuracy measurement tool for the hot forming industry.

The Phase II project has been carried out in accordance to the proposed tasks, schedule and budget. To sum up current progress, the following are materialized:

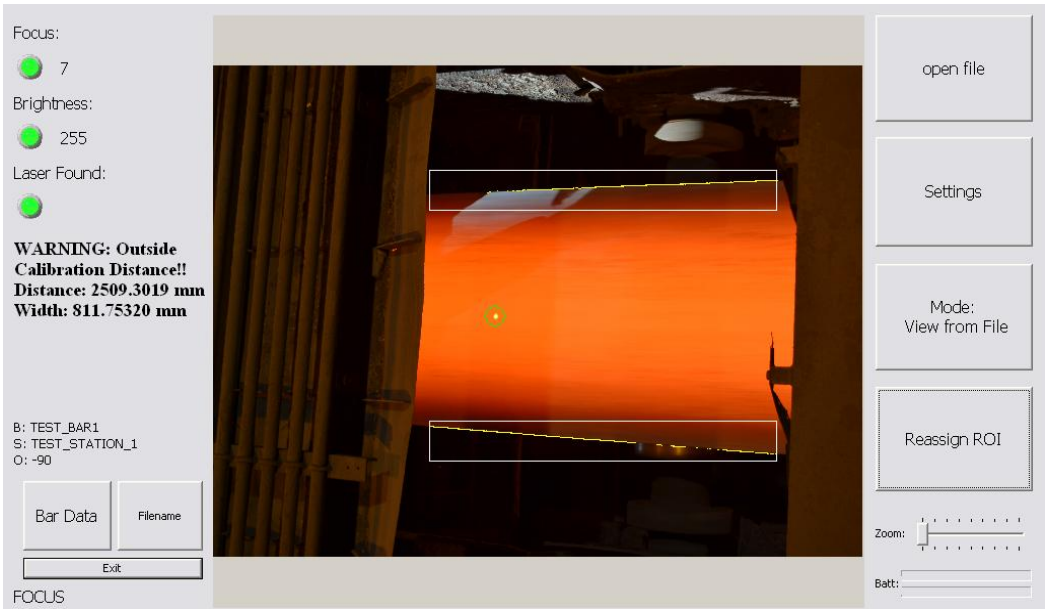
- Embodiment of a robustness of the OC device that can be used by site operators and still provide accurate measurements.
- Demonstration of the swappable lens functions in the software for Zoom and other optical component change.
- Measurements can compensate on-site environmental noises with least operation effort.
- Development of the capability for performing measurements under perspective distortions.
- Development of the capability of the 3D room temperature objects measurements.
- Development of data center that collects data from the portable unit and interact with the manufacturing facility's process control systems.

SNAPSHOTS

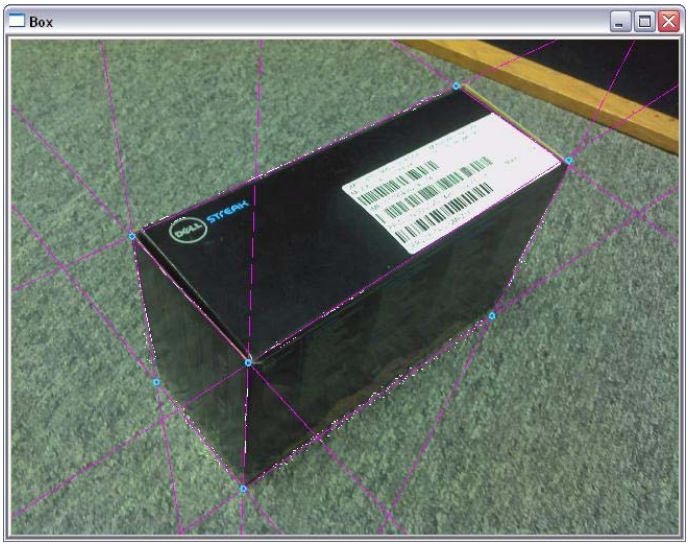
An OC prototype was evaluated by two participating bar mill operators.



Sample picture of OC operation at an open die forge plant.
[left] Operation
[Right] Sample intermediate measurement during a long forging sequence



Onsite test of a cast slab with perspective distortion.



Edge extraction for 3D measurement of a high contrast object.