UNIVERSITY OF CAMBRIDGE

Transforming construction: impact case study

Benefits to industry: proactive productivity monitoring of multiple construction workers; project time savings; project cost savings; improved work flow on site; better construction project management.

Vision-based construction worker task productivity monitoring

The challenge of improving productivity

Improving productivity in the construction sector is critical to meeting the targets set out in the Government's Industrial Strategy Sector Deal (November 2017) for Construction. Initiatives include targets to be reached by 2025 including a 33 per cent reduction in the cost of construction and the whole life cost of assets, and 50 per cent reduction in the time taken from beginning-to-end of new build and refurbished assets.

The construction sector has not managed to improve labour productivity for the past five decades. It is estimated that only 50 per cent of the total construction time is productive. Current methods of monitoring productivity on site are mainly based on manual observation and work sampling techniques and are time consuming, labour intensive and error prone. These processes are mainly reactive and only initiated after a problem has been detected.

Construction project managers currently evaluate worker performance based on questionnaires, manual observations, and work sampling practices. Construction requires proactive monitoring of labour productivity in order to detect issues sufficiently early to maintain workflow and avoid costly overruns. This is not feasible as current practices are labour intensive and time consuming due to the large number of employees and the long lasting tasks involved on a construction site.

Research has brought focus to improving these processes but there is a gap in monitoring the labour productivity of multiple workers at the same time in a way that is accurate, unobtrusive and cost and time efficient.

A new approach to measuring labour productivity

Monitoring of labour productivity relies on the calculation of the labour input and output. All construction entities should be monitored proactively to enable labour productivity to be improved. Proactively means that multiple workers should be monitored at the same time on a daily basis. This offers project managers better information for decision making.

Labour productivity is the fraction of the labour output over the labour input. In construction, the labour input is equal to the time workers spend on construction tasks, whilst the output quantifies what workers achieved during this time such as the number of

LAING O'ROURKE CENTRE *for* CONSTRUCTION ENGINEERING *and* TECHNOLOGY concrete buckets poured, the number of steel cages prepared or the metres of brick walls constructed.

This case study proposes a framework to measure the labour productivity of construction workers through their trajectory data. Video data streamed from cameras with overlapping fields of view provide the input. The first method tracks the location of workers across the range of a jobsite over time and returns their 4D trajectories – this requires that workers are matched under a unique ID not only across successive frames of a single camera (intra tracking) but also across multiple cameras (inter tracking). Two novel computer vision-based algorithms are developed to perform both the intra and the inter camera tracking.

The second method converts the 4D trajectories of workers into productivity information. These trajectories are clustered into work cycles with an accuracy of 95 per cent, recall of 76 per cent and precision of 76 per cent. Such work cycles depict the actual execution of tasks. The overall proposed framework features an average accuracy of 95 per cent in terms of determining the total time workers spend on construction-related tasks.

Computer vision-based 2D tracking

This type of tracking matches the same worker across subsequent frames of a single camera (intra camera tracking) and returns his/hers 2D trajectories. This tracking method is designed for complex working environments. None of the existing computer vision-based tracking methods has succeeded to track multiple targets like workers that share similar appearance under illumination/scale/posture variations, and abrupt movements in the long term. This is mainly because construction jobsites are complex environments due to congestion, background clutter and occlusions. The proposed 2D tracking method outperforms the latest state of the art method that also focuses on tracking of construction workers. It returns an F-measure metric equal to 72.17 of 9.81 pixels compared to the 42.38 per cent and 22.97 pixels respectively of the existing state of the art method that is used for comparison.

Automated 4D tracking of construction workers

This type of tracking requires matching the same entities across different camera views. Such matching is challenging due to the greatly similar high visibility apparel of workers, occlusions, and congestion. The proposed matching method addresses these issues by using as input the output of the computer vision-based 2D tracking method. It searches for potential matches in three sequential steps. This searching stops only when a positive match is returned for all workers. The first step searches for the strongest match by correlating 1500ms of workers' past 2D trajectories. If this step fails to return a positive match, then the second step applies geometric restrictions in order to define the area within an image that most likely contains a positive match for a worker. If more than one potential matches are detected within this geometrically defined area, then the proposed matching method activates the third step that correlates workers' colour intensity values. The proposed matching method features a very promising performance of 97 per cent precision, 98 per cent recall, and 95 per cent accuracy. After all workers are matched across multiple cameras, their 3D locations over time are calculated through the mid-point triangulation method.

Converting the trajectory data of construction workers into labour input

The trajectory analysis-based method for monitoring the labour productivity of construction workers uses as inputs the outputs of 4D tracking. It detects repetitive patterns in trajectories of workers. These patterns depict work cycles. The total duration of these work cycles is equal to the labour input of every worker on a task level. Labour productivity is calculated by dividing the total labour output over the total input. The trajectory data is clustered into work cycles regardless of the type or the number of tasks the workers perform. These trajectories are four-dimensional (4D) and describe the motion of workers across the jobsite over time. The total duration of these work cycles is equal to the labour input of workers.

Applying the framework

The performance of the proposed framework in terms of translating the trajectory data into labour input is evaluated with two data sets. The first, (data set steel fixing) captures one worker while performing a steel fixing task. The second, (data set electrical) consists of two workers who perform an electrical task. Data set steel fixing was recorded at a pre-manufacturing facility (Bison), whilst data set electrical was collected at a jobsite in Cambridge (James Dyson building). The total durations of data sets steel fixing and electrical are 35 minutes and 51.5 minutes respectively.

Productive work cycles are defined as those when workers actually perform sub-tasks while at 'stop', whilst unproductive cycles depict workers who are not involved in any construction-related task. Therefore, the time the workers spend outside the working areas is returned as unproductive. This section classifies as abnormal the productive work cycles that have durations by at least 50 per cent equal to the duration of the maximum work cycle of a worker. This threshold is not experimentally defined given that the scope of the overall proposed framework is to approach the monitoring of labour productivity in a generalised way for all types of tasks.

The benefits

An advantage of the proposed productivity monitoring framework is that it does not require prior knowledge about the type or the number of tasks being completed and can be applied to multiple workers at the same time. Workflow inefficiencies and potential management issues can be identified through the abnormal productive cycles or through the trajectories of workers. This framework monitors the productivity of multiple construction workers unobtrusively, accurately and proactively and delivers potential cost and time savings as workflow can be maintained to avoid costly schedule overruns.

The Laing O'Rourke Centre for Construction Engineering and Technology, in the University of Cambridge Department of Engineering, was launched in 2011 with industry partner Laing O'Rourke to fulfil a shared vision of transforming the construction industry through innovation, education and technology.

Case study

This case study is based upon a Laing O'Rourke Centre for Construction Engineering and Technology PhD dissertation titled *Vision-based construction worker task productivity monitoring* by Eirini Konstantinou (October 2017)

Further details

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