Task Delegation and Architecture for Autonomous Excavators

Jake Rankin
Wolfson School
Loughborough University
LE11 3TU
j.rankin@lboro.ac.uk

Laura Justham
Wolfson School
Loughborough University
LE11 3TU
l.justham@lboro.ac.uk

Yee Mey Goh
Wolfson School
Loughborough University
LE11 3TU
y.goh@lboro.ac.uk

James Morley
JCB Research
JCB Excavators Ltd
ST14 5JP
james.morley@jcb.com

***Abstract* — The construction industry is required to deliver safe, productive machines. One method being considered by heavy equipment manufacturers is autonomy. Implementing autonomy to heavy machines is unique, due to the highly skilled nature of a machine's operation meaning that different levels of autonomy may be more suitable for different tasks. Therefore, effective collaboration strategies between human operators and machines are needed. This paper proposes a machine architecture that considers the task delegation between the operator and machine.**

Keywords — Autonomy, System design, Task delegation

I. Introduction

Many autonomous achievements can be seen within the automotive industry, with features such as cruise control and emergency braking becoming more common place, guided by SAE J3014 [1]. This has been essential for standardising a roadmap towards full autonomy for the whole sector for safety reasons. A difficulty that is faced by the automotive industry is the clarity of task delegation between SAE J3014 levels 2 and 3, with the end-user being the most notable example. There are several examples, such as Tesla's Autopilot [2], where users assume a higher capability than stated.

The shrinking skilled workforce in the construction industry and task complexity means that task delegation between machines and operators is a challenge that needs to be understood when implementing autonomy. Heavy plant manufacturers face this challenge without a standard framework to follow. Heavy plant manufacturers also face several unique aspects such as actuator task delegation, a shrinking skilled workforce and dynamic environments. Autonomy can be achieved using established strategies like A* [3] and Rapidly-Exploring Random Tree but these struggle with task complexities [3].

Having a standardised architecture will help heavy plant manufacturers implement solutions across several types of machines whilst providing clarity of the machine capability to the construction industry. This paper addresses the issue of task delegation through the development of a novel autonomous excavator architecture and identifies opportunities to use technology such as Building Information Modelling (BIM) and Reinforcement Learning (RL) for a more integrated implementation of heavy plant machinery in the construction site.

II. Existing Literature

One of the first autonomous excavator architectures was in LUCIE [4]. However, this was solely focused on trenches and doesn't seem to have a layered architecture to enable fast and slow reactions. LUCIE also required hard-coding actions, such as when to curl the bucket, which resulted in less flexibility and, potentially, more processing during run-time.

One company that provides autonomy solutions, ASI, proposes a three-stage autonomy system which can be applied to different machines [5]. This doesn't discuss how task delegation was decided for automation tasks nor does it discuss the scenario of driver assist. It also seems more focused on bulk-digging for mining.

Mastalli investigated a control system that used learning and simulation [6] but didn't investigate driver roles. Stentz proposed an autonomous loading system for truck loading [7] but this architecture is complex and task specific. An aspect that both these authors focused on was the visual aspect which has advanced significantly. Mastalli also discussed the advantages of using RL for working in highly constrained environments without the need for hard-coding.

To date, little work has been done on task delegation for excavators, despite its importance for developing autonomy. Kim investigated task-planning for excavation, which would divide the excavator's project into tasks to be completed [8]. This could have been an opportunity to mention how tasks could be delegated to operators as autonomy developed. The purpose of the current work is to extend that which has already been done through the proposed task delegation process and architecture, as detailed in Section III.

III. Proposed Design

There are two main stages before proposing an architecture design. First, a task break-down is needed to understand the machine operation. This was undertaken using the digital twin software, Mevea [9]. Once the complex and repetitive tasks were identified, delegation could be designed that not only considers the machine, but also the user. This helped to determine the requirements of the architecture. Next, viewpoints were used to further develop a suitable architecture before proposing a final design. By using a modular design, in future, technology such as BIM and machine learning can be integrated into the architecture.

A. *Task Delegation*

Task delegation is made more difficult for excavation because the skill levels of the operator affect the performance more than they would in an autonomous car. This is because, during the excavation process, the control of multiple hydraulic services in multiple ground conditions towards a set criterion is needed, which differs based on operator style. However, performance is not the only issue; autonomous features could lead to operator mind wandering, leading to accidents [10]. The transition between tasks is also important [11] as there is an adjustment period.

A turn-taking system could address operator mind wandering, with turn changeover occurring between excavations. By taking turns, the machine can help to guide a novice and can help alleviate the workload of an expert operator without the expert losing a skill set. Tasks can be divided by duration or by action. A combination is proposed here as it allows novices to delegate challenging tasks whilst sharing the workload of expert operators. Handover between tasks will help to ensure a smoother transition and less erratic behaviour. In future, these tasks can be generalised so that they can be applied to other earth-moving machines.

B. Architecture

To accompany the task delegation, a three-layered architecture that is made of planning, control and hardware layers has been used, see Figure 1. The control layer has also been designed with human and machine operation in mind with a task delegation module. The operator and controller work together on a task, based on the user needs, exchanging information as instructions or feedback.

The planning layer is where long-term plans and delegation occur. By using turn-taking, control alternates between the operator and the controller. Memory contains the excavation plans and can be the link-up to BIM, reducing site setting-out and providing managers with work information. These are divided into tasks that are then delegated to the machine and operator.

In the control layer, designers have the option of implementing their own control system and determining their own inputs. This split allows the introduction of machine-learning algorithms, such as RL, to be easily implemented. The operator can interrupt the controller and the controller informs the operator on its progress as well as identifying if it is uncertain for a decision. Training can be done with an excavator digital twin, using software like Mevea [9] before testing on a real-world machine. This improves the level of testing and simulations that can be done in advance.

The hardware layer is where control commands enter the CAN bus and control the requested actuators. Sensors receive data which then undergo any necessary preparation prior to being inputted into the controller. This modular approach can then be applied to other machines, reducing costs and providing a standard architecture. This is where safety features are included to ensure a reactive response.

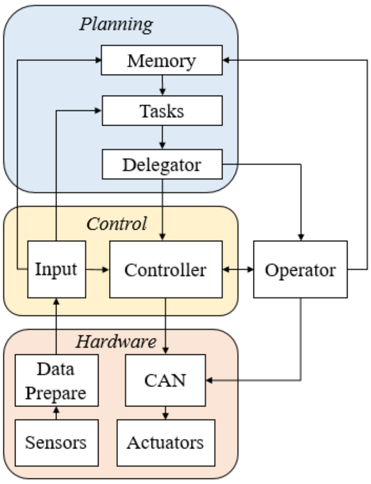

Fig. 1. Autonomous Excavator Architecture

IV. Conclusions

A standardised architecture for autonomous excavation that considers task-delegation has been proposed within this paper, which is simple to implement and flexible for different applications. One of the most promising control strategies is RL, as it has been applied to several robotics tasks [12]. Therefore, it is the focal point for future work because of its operator-like behaviour. It also has the potential of being flexible enough to be applied to new machines outside of excavators and the construction industry.

The next stage in this research is to implement the architecture into real-world machines to confirm transferability. Although future work is focused on investigating the feasibility of RL, it is also important to consider how it can be implemented. Task delegation and turn-taking will also include the further investigation of human factors such as mind wandering to ensure safety and well-being.

V. Acknowledgements

The research work presented is sponsored by the EPSRC-CDT, grant reference EP/L014998/1.

VI. References

[1] SAE International, “Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles (J3016 Ground Vehicle Standard) - SAE Mobilus,” 2018.

[2] S. Levin, “Tesla fatal crash: ‘autopilot’ mode sped up car before driver killed, report finds | Technology | The Guardian,” *The Guardian*, 2018.

[3] G. Ye and R. Alterovitz, “Demonstration-guided motion planning,” in *Springer Tracts in Advanced Robotics*, 2017, vol. 100, pp. 291–307.

[4] D. A. Bradley and D. W. Seward, “The Development, Control and Operation of an Autonomous Robotic Excavator,” *J. Intell. Robot. Syst.*, vol. 21, pp. 73–97, 1998.

[5] ASI, “Robotic Excavator | ASI,” 2019. [Online]. Available: https://www.asirobots.com/mining/excavator/. [Accessed: 28-May-2019].

[6] C. Mastalli and G. Fernández-López, “A proposed architecture for autonomous operations in backhoe machines,” in *Advances in Intelligent Systems and Computing*, 2015, vol. 302, pp. 1549–1559.

[7] A. Stentz, J. Bares, S. Singh, and P. Rowe, “Robotic excavator for autonomous truck loading,” *Auton. Robots*, vol. 7, no. 2, pp. 175–186, 1999.

[8] J. Kim, D. eun Lee, and J. Seo, “Task planning strategy and path similarity analysis for an autonomous excavator,” *Autom. Constr.*, vol. 112, p. 103108, Apr. 2020.

[9] Mevea, “Mevea Simulation Solutions,” 2019. [Online]. Available: https://mevea.com/.

[10] M. Cunningham and M. Regan, “Driver inattention, distraction and autonomous vehicles,” in *4th International Driver Distraction and Inattention Conference 2015*, 2015.

[11] H. E. B. Russell, L. K. Harbott, I. Nisky, S. Pan, A. M. Okamura, and J. C. Gerdes, “Motor learning affects Car-To-Driver handover in automated vehicles,” *Sci. Robot.*, vol. 1, no. 1, Dec. 2016.

[12] T. Haarnoja, A. Zhou, P. Abbeel, and S. Levine, “Soft Actor-Critic: Off-Policy Maximum Entropy Deep Reinforcement Learning with a Stochastic Actor,” Jan. 2018.