

An evaluation of a collaborative robot
capability for implementation into
explosive processing environments

Research Proposal

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1. Introduction

Defence Science and Technology Laboratory (Dstl) has invested in a collaborative robot (Cobot) to:

- Demonstrate the benefits of implementing cobots in an energetic environment.
- Identify the challenges to licence and authorise cobots in an energetic environment.

To successfully achieve these objectives the following research needs to be undertaken:

- Understand the forces a cobot can generate during operation (intended and un-intended).
- Develop a safe working method for implementation in an energetic environment.
- Develop a process for future equipment to be streamlined into energetic environments.

Overall, the objective is to understand the forces a cobot gripper can generate, to inform the development of safe working practices for cobots in an energetic environment. Without this data, safety assurances cannot be provided to the Explosive Safety Representative (ESR) to licence the use of cobots, and associated tooling, within an energetic environment.

The success of the project will be determined by inert testing, and report, conducted on the cobot.

2. Background

2.1 What is a collaborative robot (cobot)?

The term cobot is derived from the phrase collaborative robot, and was coined by Michael A Peshkin, and J. Edwards Colgate. [1] It refers to a robotic architecture intended for direct physical interaction with human operators [1]. Cobots are designed to be lightweight, smooth surfaced, and have reduced operating speeds/forces to reduce the severity of impact to human operators [2]. This contrasts with industrial robots, which are designed to undertake heavy duty tasks in industrial environments, often at higher speeds (Table No.1).



Figure 1 - Industrial robots enclosed from human interaction [3]



Figure 2 - Cobot assisting a worker with injection moulding [4]

Feature	Robot	Cobot
Deployment	Fixed, complex programming requirements	reconfigurable, drag-and-drop programming
Space	Larger footprint, requiring guards and cages	Smaller footprint, no guards or cages required
Safety	Operating speed not affected by personnel in vicinity	Personnel within vicinity will reduce operating speeds

Table 1 - Difference between industrial robots and cobots [5]

2.2 Why are cobots important to Dstl?

Dstl has aspirations to implement Robotic and Autonomous Systems (RAS) into hazardous environments to achieve the following objectives [6]:

- Reduce personnel exposure to hazardous materials and environments by implementing remote and (semi)-autonomous systems.
- Increase frequency and flexibility of energetic processing by implementing (semi)-automated systems

Cobots have been identified as a suitable technology to achieve these goals for the following reasons:

- Drag-and-drop programming allowing flexible (re)-deployment of cobot systems for various repetitive and/or hazardous activities. Allowing operators to attend priority tasks, while also reducing risk to personnel.
- Various tooling, and bespoke tooling, allowing capability for a variety of tasks. Increasing the capability of engineering activities which can be conducted remotely.
- Force sensing capabilities which can be used to set safe working loads and thresholds.

2.3 Explosive legislation and cobots

Cobots have proven their versatility, safety, and efficiency in mechanical environments. Being implemented for applications such as: machine tending, palletizing, screwing, packaging, and welding [5]. However, a problem Dstl faces, similar to the article *“Industry 4.0 and explosion prevention”* by Marek Wolinski, is the lack of robotic regulations in energetic environments [3].

Defence Safety Assurance 03 Part 2 Joint Service Publication 482 (DSA 03 Part 2 JSP482) chapter 8 describes the requirements for electrical equipment operating in Category B¹ and Category C² environments [7]. Unfortunately, there is little guidance for licensing RAS equipment in an energetic environment.

Chapter 8 details physical properties electrical equipment must adhere to for adoption in Category A and B environments; but it does not detail any operational requirements a cobot must adhere to when working with explosives.

Therefore, the objective of this report is to identify and report a process in which future RAS equipment can be streamlined into an energetic environment. Additionally, to establish testing requirements to authorise and licence RAS equipment.

2.4 Explosives sensitivity and robotic handling

For the Explosive Safety Representative (ESR) to authorise the use of RAS in an energetic environment a safety case is required. To build an effective safety case, an understanding of how a cobot could handle energetic materials, or components, needs to be developed.

This is because primary and secondary explosives are sensitive to stimuli such as impact, friction, heat, and static [8]. Using activation stimuli³, and operational test data from the cobot arm, safe working thresholds and procedures can be used to inform the safety case. Enabling the identification of energetic materials the cobot can safely handle.

¹ Category B is an area which contain dust atmospheres

² Category C is an area which contains an explosive/flammable atmosphere.

³ Activation stimuli refers to the energy required to cause an energetic material to undergo an energetic event.

3. Aims and objectives

ID Number	Objective Description
1	Understand the forces a cobot gripper can generate during operation, intended and un-intended, by conducting inert testing in a laboratory environment.
2	Develop safe working practices for cobot implementation in an energetic environment by identifying types of energetic materials the cobot can safely handle.
3	Develop processes to streamline future equipment into energetic environments by hosting discussions with the on-site ESR and DOSG.

Table 2 - Objective ID's and descriptions

Overall the scope of the project is to explore the forces associated and produced by the gripper. With the purpose to create safe operating procedures, and limits, for the arm when working with energetic materials.

4. Experimental Design

4.1 Outline of Experimental Procedure

Inert testing will be conducted on the cobot arm, within a lab environment, to determine if the arm can work with sensitive materials. This will be achieved by measuring the force-torque outputs of the cobot arm during operation of different tasks.

An instrumented test piece⁴ will be utilised to compare the programmed force of the cobot arm against the actual force applied. This will enable a direct comparison between the cobots force-torque sensors and the test piece force sensors to confirm that the programmed forces match the applied forces.

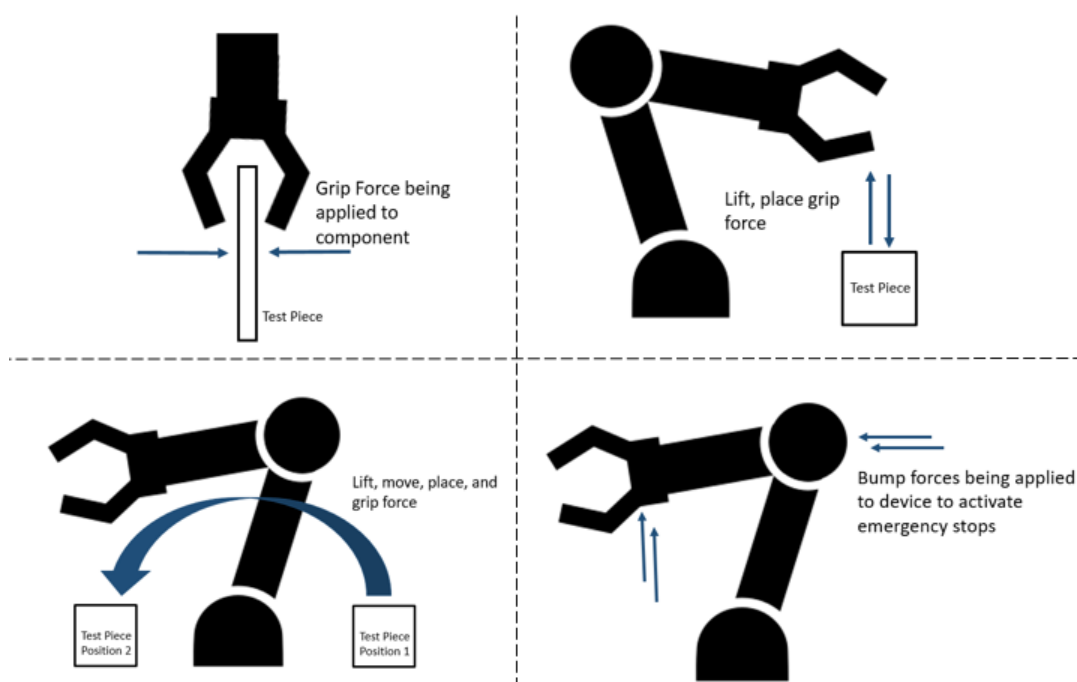


Figure 3 - Draft test configurations

Test Number	Test Description	Data Evaluation
1	To determine the grip force on a component, and to determine if this can be controlled. Showing the gripper can safely grip onto the instrument without crushing it.	Comparing the on board force torque sensors against the instrumented force sensor. Then, comparing both sensors' data against the energy required to initiate an energetic event.
2	To determine the forces the test piece instrument sustains when being picked up and placed. To determine if the device can safely pick up and place energetic components.	To investigate if the instrumented force sensor sustains a greater/smaller force when being picked up and place due to friction and gravity.

⁴ The instrument test piece will have integrated electro-mechanical force sensors via transducers and load cells.

3	Test is to pick up, move. and place the instrumented force sensor. Simulating a working environment.	Determining whether a consistent force is applied and maintained on the test piece during operation.
4	To determine the sensitivity of the bump stops and to determine how a self-sustained bump will affect the gripper forces. Replicating the arm handling an object and being exposed to an incident.	Comparing the force-torque sensors of the arm axis against the gripper sensor and instrumented sensor (held in the gripper). This will then show the forces along the arm and can be compared to determine if any forces cross the threshold to stimulate an energetic event.

Table 2 - Test configurations and data evaluation methods

4.2 Data Collection

- Data will be collected from the cobot on-board force sensors read out from a PC.
- Data will be collected from an instrumented electro-mechanical test piece which contains force sensors (transducers/load cells).

4.4 Risks, Limitations & Mitigations

Risk	Limitation	Mitigation
Device not installed or purchased due to lack of funding.	No testing can be conducted, therefore, no results collected.	University of Wales Trinity St David owns a cobot device. Testing could be conducted using the universities resources.
Force sensor instruments may not have the resolution to record the forces applied.	Testing will be restricted. Therefore, reducing the accuracy of the safety case.	Discuss with the instrumentation team to determine alternative testing equipment and processes.

Table 3 - Risks, limitations, and mitigations

4.5 Ethical Issues

The purpose of the cobot is to achieve remote operation of hazardous activities in energetic environments. However, an ethical consideration is:

- People's perceptions of their job being threatened with the replacement of cobots.

However, a counterargument to this claim is:

- Cobots are to be used as tools to assist workers. Therefore, implementing the technology would result in workers gaining knowledge and experience working with robotic systems and therefore upskilling the workforce.

6. Resources & Planning

6.1 Gantt Chart

No.	Activity	Week Commencing																																																
		Month 1							Month 2							Month 3							Month 4							Month 5							Month 6							Month 7						
		03-Apr-23	10-Apr-23	17-Apr-23	24-Apr-23	01-May-23	08-May-23	15-May-23	22-May-23	29-May-23	05-Jun-23	12-Jun-23	19-Jun-23	26-Jun-23	03-Jul-23	10-Jul-23	17-Jul-23	24-Jul-23	31-Jul-23	07-Aug-23	14-Aug-23	21-Aug-23	28-Aug-23	04-Sep-23	11-Sep-23	18-Sep-23	25-Sep-23	02-Oct-23	09-Oct-23	16-Oct-23	23-Oct-23	30-Oct-23																		
1	Project Management																																																	
1.1	Reporting To Work Package Lead					X				X				X					X			X			X			X				X																		
1.2	Weekly Journal Entry	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X																		
2	Install Equipment																																																	
2.1	Training			X	X	X	X	X	X	X	X	X	X																																					
2.2	Equipment Risk Assessment	X	X	X	X	X	X	X	X	X	X	X	X	X																																				
2.3	Safe working Methodology	X	X	X	X	X	X	X	X	X	X	X	X	X																																				
2.4	PAT Testing, and Installation	X	X	X	X	X	X	X	X	X	X	X	X	X																																				
3	Develop Testing Environment																																																	
3.1	Research, and planning					X	X	X	X	X	X	X	X	X																																				
3.1.1	Energetic Requirements														X	X																																		
3.1.2	Regulatory Requirements																																																	
3.1.3	Operational Requirements																																																	
3.2	Develop Testing Environment																X	X	X																															
3.3	Review Testing Environment																			X	X	X																												
4	Conduct Cobot Testing																																																	
4.1	Force Sensing Testing																						X	X	X																									
4.3	Result Analysis																									X	X																							
5	Documentation																																																	
5.1	Project Report																											X	X	X	X	X																		
5.2	Robotics Awareness Presentation																			X	X																													
5.3	Robotic Testing Results Presentation																									X	X																							

Figure 4 - Project Gantt chart

6.2 Project Resources

1	Project Management	Activity Description	Hours	Resources
1.1	Reporting To Work Package Lead	Reporting to Work Package Lead and Project Supervisor	3.5	Laptops, Wi-Fi
1.2	Weekly Journal Entry	Time for personal self-assessment and review	8	Journal, Pen

2	Install Equipment	Activity Description	Hours	Resources
2.1	Training	Training to use equipment at Cardiff	8	Travel and Sustenance, accommodation
2.2	Equipment Risk Assessment	Time to develop risk assessment to operate cobot device	21	Laptop, H&S Reviewer
2.3	Safe working Methodology	Time to develop safe operating procedure to be used alongside device (Listed users, safe set-up, set-down, emergency responses)	21	H&S Reviewer, Project Technical Lead
2.4	PAT Testing, and Installation	Time to organise PAT testing and installation into Lab area (Business case)	10	Electrician, Lab Space, Cobot Device

3	Develop Testing Environment	Activity Description	Hours	Resources
3.1	Research, and planning	Time to research the following points to create and develop an accurate inert testing environment. Additionally, to understand what data is required and its format. Finally, time to discuss with regulators for future processes	53	Time to network and discuss with ESR, DOSG, Work Project Lead, Instrumentation team, laptop, library resources
3.1.1	Energetic Requirements			
3.1.2	Regulatory Requirements			
3.1.3	Operational Requirements			
3.2	Develop Testing Environment	Time to develop testing regime, identifying equipment, printing resources, organising lab time with device etc.	14	Electronics, 3D Filament, Cameras, Force Sensors
3.3	Review Testing Environment	Time to share testing regime, identify errors and amend	21	Electronics, 3D Filament, Cameras, Force Sensors, Rule

4	Conduct Cobot Testing	Activity Description	Hours	Resources
4.1	Force Sensing Testing	Time to execute testing regimes	15	Lab Time, Cobot Arm, Journal, Pen, 3D prints, Electronics
4.2	Result Analysis	Time to analyse data and format	7	Laptop

5	Documentation	Activity Description	Hours	Resources
5.1	Project Report	Time to write up report, and progress.	15	Laptop, meeting room
5.2	Robotics Awareness Presentation	Time to present new capability for further collaboration	3	Laptop, meeting room, UR arm
5.3	Robotic Testing Results Presentation	Time to present to team / audience safe system discoveries	3	Laptop, meeting room

Hours Total	202.5
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Table 4 - Project milestones, objectives, objective descriptions and resources required.

7. References

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