C ID	Causes			M ID	Mitigation	H ID	(Latent-) Hazard
C1	No data from sensor (transient)	C27	Too many number of label	M1	Acoustic guidance system	H1	Loss of safe distance to asset
C2	No data from sensor (permanent)	C28	Too less number of label	M2	Transient data error has limited impact on trajectory	H2	Insufficient energy/power
C3	Incomplete sensor data	C29	Data washing incomplete	M3	Situational awareness (route mapped and planned in advance)	H3	Erratic trajectory
C4	Corrupted sensor data	C30	Washing additional data	M4	Camera health monitor (e.g. sanity check for blank images)	H4	Loss of communication
C5	Late sensor data	C31	Ignore parameters setting	M5	Separation of camera data storage	H5	Ineffectiveness of the inspection
C6	Early sensor data	C32	Using default setting	M6	Maximum safe distance maintained if uncertain	H6	Loss of Classifications/Misclassification
C7	Too much data from camera (fills buffer)	C33	Hyperparameter setting is incomplete/part of setting	M7	Reliable camera (robust to environment etc.)	H7	Loss of data value
C8	Data to incorrect location	C34	Parameter setting error/out of range	M8	Common time (NTP) to synchronise data and results	H8	Deploy delay from model
C9	Sensor data too large (oversized image)	C35	Hardware match not well with ML	M9	Classifier accuracy/reliability for critical objects > X	H9	Model robustness decreases
C10	Sensor data too little (partial image)	C36	Data flow transmation error	M10	Sanity check (e.g. ground truth and label attribute)	H10	Robot data was leaked
C11	Early sensor data	C37	Insert a calculated disturbance into the input data	M11	Consistency Check (e.g. Value range)	H11	Loss of prediction
C12	Late sensor data	C38	Input data is contaminated	M12	Model monitor		
C13	False negative (missing classification) - transient	C39	Data was stolen during model training	M13	User deeper layers		
C14	False negative (missing classification) - permanent	C40	Data is mined from sensors to ML models	M14	Defensive Distillation		
C15	False positive (additional false classification) - transient	C41	No data flow from data preprocessing (transient)	M15	Detector trained on the activations of a specific layer		
C16	False positive (additional false classification) - permanent	C42	No data flow from data preprocessing (permanent)	M16	Detection based on data provenance		
C17	Incomplete set of classifications	C43	Incomplete data flow	M17	Class Labels		
C18	Late classification	C44	Batch value too small	M18	Feature Squeezing		
C19	Early classification	C45	Wrong parameter setting	M19	Explainable AI		
C20	No data from classifier	C46	Unsuitable kernel size setting	M20	Adjust Batch Value if memory is allowed		
C21	Incorrect classification	C47	Less layers	M21	Limited impact on prediction		
C22	Too many outputs communicated (floods comms)	C48	Losing information of figures	M22	Calculate recall value		
C23	Classification sent to wrong location			M23	Kernel size need to match data set		
C24	Data in wrong format						
C25	Incorrect data						
C26	Definition ignores ground truth						

Hazop Item (Node)	Deviation	Cause ID	Cause	Mode	Hazard ID	Consequence / Implication	Mitigation ID	Mitigation
1 -Data transmission (Flow from camera to classifier)	No Action	C1	No data from sensor (transient)	Inspection	H1, H3, H5	No image can be classified. Limited impact due to additional situation awareness systems.	M2	Transient data error has limited impact on trajectory
							M1	Acoustic guidance system
							M6	Maximum safe distance maintained if uncertain
							M3	Situational awareness (route mapped and planned in advance)
		C1	No data from sensor (transient)	Docking	H1, H2, H3	No image can be classified. Could lead to collision with dock, or failure to dock	M2	Transient data error has limited impact on trajectory
							M1	Acoustic guidance system
		C2	No data from sensor (permanent)	Inspection	H1, H5	No image can be classified. Limited impact due to additional situation awareness systems, but overall performance may be impaired.	M3	Situational awareness (route mapped and planned in advance)
							M1	Acoustic guidance system
							M4	Camera health monitor (e.g. sanity check for blank images)
							M6	Maximum safe distance maintained if uncertain
		C2	No data from sensor (permanent)	Docking	H1, H2	No images can be classified at all. Could prevent a successful docking from taking place.	M1	Acoustic guidance system

Hazop Item (Node)	Deviation	Cause ID	Cause	Mode	Hazard ID	Consequence / Implication	Mitigation ID	Mitigation
							M4	Camera health monitor (e.g. sanity check for blank images)
	Faster / slower	C5	Late sensor data	Inspection	H1, H3, H5	Runs on out of date information. Potential conflict between other systems with contradictory data.	M8	Common time (NTP) to synchronise data and results
							M2	Transient data error has limited impact on trajectory
							M3	Situational awareness (route mapped and planned in advance)
							M1	Acoustic guidance system
		C5	Late sensor data	Docking	H1, H2, H3	Runs on out of date information. Potential conflict between other systems with contradictory data.	M8	Common time (NTP) to synchronise data and results
							M1	Acoustic guidance system
	Part of Action	C4	Corrupted sensor data	Inspection	H1, H3, H5	Images could be classified incorrectly with either FP or FN depending on nature of corruption. This could lead to contradictory information.	M4	Camera health monitor (e.g. sanity check for blank images)
							M1	Acoustic guidance system
							M7	Reliable camera (robust to environment etc.)

Hazop Item (Node)	Deviation	Cause ID	Cause	Mode	Hazard ID	Consequence / Implication	Mitigation ID	Mitigation
							M3	Situational awareness (route mapped and planned in advance)
		C4	Corrupted sensor data	Docking	H1, H3	Images could be classified incorrectly with either FP or FN depending on nature of corruption. This could lead to contradictory information.	M4	Camera health monitor (e.g. sanity check for blank images)
							M1	Acoustic guidance system
	As well as / other than	C7	Too much data from camera (fills buffer)		H1, H2, H3, H4, H5	Slows down ability to process images, leading to late arrivals of classification or no output.	M5	Separation of camera data storage
							M8	Common time (NTP) to synchronise data and results
	Early / Late Action	C5	Late sensor data			See above - faster/slower		
		C6	Early sensor data			See above - faster/slower		
	Wrong Value	C4	Corrupted sensor data			See above - part of action.	M4	Camera health monitor (e.g. sanity check for blank images)
							M7	Reliable camera (robust to environment etc.)
							M2	Transient data error has limited impact on trajectory
							M1	Acoustic guidance system

Hazop Item (Node)	Deviation	Cause ID	Cause	Mode	Hazard ID	Consequence / Implication	Mitigation ID	Mitigation
	Invalid Value	C4	Corrupted sensor data			See above - part of action.		
	Too much	C9	Sensor data too large (oversized image)			Oversized (large number of bytes) addressed as slow processing. Too large an image in terms of dimensions not felt to have meaning (assuming consistent size). Too many images dealt with above.		
	Too little	C10	Sensor data too little (partial image)			See above - part of action.		
2 -Data transmission (From classifier to localisation)				Planning				
	No Action	C13	False negative (missing classification) - transient	Inspection	H1, H3, H5	High value asset could be missed as not detected. Alternatively a missing classification could lead to the wrong safe distance being determined.	M2	Transient data error has limited impact on trajectory
							M6	Maximum safe distance maintained if uncertain
							M1	Acoustic guidance system
							M9	Classifier accuracy/reliability for critical objects > X

Hazop Item (Node)	Deviation	Cause ID	Cause	Mode	Hazard ID	Consequence / Implication	Mitigation ID	Mitigation
							M3	Situational awareness (route mapped and planned in advance)
		C13	False negative (missing classification) - transient	Docking	H1, H2, H3	Dock is not detected, potentially causes a collision.	M2	Transient data error has limited impact on trajectory
							M1	Acoustic guidance system
							M9	Classifier accuracy/reliability for critical objects > X
		C14	False negative (missing classification) - permanent	Inspection	H1, H5	High value asset could be missed as not detected. Alternatively a missing classification could lead to the wrong safe distance being determined.	M6	Maximum safe distance maintained if uncertain
							M1	Acoustic guidance system
							M3	Situational awareness (route mapped and planned in advance)
							M9	Classifier accuracy/reliability for critical objects > X
		C14	False negative (missing classification) - permanent	Docking	H1, H2	Dock is not detected, potentially causes a collision.	M1	Acoustic guidance system

Hazop Item (Node)	Deviation	Cause ID	Cause	Mode	Hazard ID	Consequence / Implication	Mitigation ID	Mitigation
							M9	Classifier accuracy/reliability for critical objects > X
		C18	Late classification	Inspection	H1, H3, H5	Movement is based on out of date information. Potential for conflicting information if error is persistant.	M8	Common time (NTP) to synchronise data and results
							M1	Acoustic guidance system
							M3	Situational awareness (route mapped and planned in advance)
		C18	Late classification	Docking	H1, H2, H3	Movement is based on out of date information.	M8	Common time (NTP) to synchronise data and results
								Accoustic guidance system
	Part of Action	C17	Incomplete set of classifications	Inspection	H1, H3, H5	High value asset could be missed as not detected. Alternatively a missing classification could lead to the wrong safe distance being determined.	M1	Acoustic guidance system
							M3	Situational awareness (route mapped and planned in advance)
							M9	Classifier accuracy/reliability for critical objects > X

Hazop Item (Node)	Deviation	Cause ID	Cause	Mode	Hazard ID	Consequence / Implication	Mitigation ID	Mitigation
							M6	Maximum safe distance maintained if uncertain
		C17	Incomplete set of classifications	Docking	H1, H2, H3	Dock is not detected, potentially causes a collision or system too cautious based on accoustic guidance.	M1	Acoustic guidance system
							M9	Classifier accuracy/reliability for critical objects > X
	As well as / other than	C15	False positive (additional false classification) - transient	Inspection	H1, H3, H5	Incorrect action taken by UAS depending on what the false positive is. If it is high criticality object may impact on inspection, or safe distances.	M2	Transient data error has limited impact on trajectory
							M3	Situational awareness (route mapped and planned in advance)
							M1	Acoustic guidance system
							M9	Classifier accuracy/reliability for critical objects > X

Hazop Item (Node)	Deviation	Cause ID	Cause	Mode	Hazard ID	Consequence / Implication	Mitigation ID	Mitigation
		C22	Too many outputs communicated (floods comms)		H1, H2, H3, H4, H5	Slows down ability to process images, leading to late arrivals of classification or no output.	M8	Common time (NTP) to synchronise data and results
		C15	False positive (additional false classification) - transient	Docking	H1, H2, H3	Possibly attempts to dock with wrong item or with something that isn't there. Conflicting information into the guidance system (e.g. object identified as two different things)	M1	Acoustic guidance system
							M9	Classifier accuracy/reliability for critical objects > X
							M6	Maximum safe distance maintained if uncertain
							M3	Situational awareness (route mapped and planned in advance)
							M6	Maximum safe distance maintained if uncertain
							M9	Classifier accuracy/reliability for critical objects > X
		C16	False positive (additional false classification) - permanent	Docking	H1, H2	Possibly attempts to dock with wrong item or with something that isn't there. Consistent not erratic.	M1	Acoustic guidance system

Hazop Item (Node)	Deviation	Cause ID	Cause	Mode	Hazard ID	Consequence / Implication	Mitigation ID	Mitigation
							M9	Classifier accuracy/reliability for critical objects > X
	Early / Late Action					See above - faster/slower		
	Wrong Value	C21	Incorrect classification	Inspection	H1, H3, H5	This is similar to false postive. Here we only consider where it is the only classification. This could lead to erratic navigation, collision or failed inspection if not mitigated.	M1	Acoustic guidance system
							M3	Situational awareness (route mapped and planned in advance)
							M2	Transient data error has limited impact on trajectory
							M9	Classifier accuracy/reliability for critical objects > X
							M6	Maximum safe distance maintained if uncertain

Hazop Item (Node)	Attribute	Guide word	Cause ID	Cause	Mode	Latent-Hazard ID	Consequence / Implication	Mitigation ID	Mitigation
1 - Manually defining labels	Label	Part of define	C26	Ignores ground truth	Data preparation	H1,H3,H5, H6	Partial definition of the label may result in low output accuracy	M9	Classifier accuracy/reliability for critical objects > X
								M10	Sanity check for ground truth and label attribute
		Too many	C27	Too many number of label		H3,H6	Too many labels will lead to decreased classification accuracy and increased training time	M10	Sanity check for ground truth and label attribute
		Too less	C28	Too less number of label		H1,H3,H4, H6	Too less labels will lead to obvious differences between classification and ground truth	M9	Classifier accuracy/reliability for critical objects > X
								M10	Sanity check for ground truth and label attribute
2 - Data pre-processing	Data Washing	Part of Data Washing	C29	Data washing incomplete	Data preparation	H1,H4,H5, H7	Incomplete data cleaning may result in incorrect data ranges	M9	Classifier accuracy/reliability for critical objects > X
								M11	Consistency Check (e.g. Value range)
		As well as Data Washing	C30	Washing additional data		H3,H4,H7	See above - part of data washing	M8	Common time (NTP) to synchronise data and results

Hazop Item (Node)	Attribute	Guide word	Cause ID	Cause	Mode	Latent-Hazard ID	Consequence / Implication	Mitigation ID	Mitigation
								M11	Consistency Check (e.g. Value range)
		Wrong Data Washing	C29	Data washing incomplete		H1,H4,H7	Incorrect data cleaning can cause the data flow to fail and the model cannot be deployed	M11	Consistency Check (e.g. Value range)
		Invalid Data Washing	C29	Data washing incomplete		H4,H7	Invalid data cleaning means that this process fails and may result in lower output accuracy	M11	Consistency Check (e.g. Value range)
3 - YOLO Object detection	CPU/GPU Replace	Part of replace	C8	Data with incorrect location	Training	H3,H8	Data training requires more time and cannot be real-time data transmission	M12	Model monitor
	hyperparameter setting	No Parameters Setting	C31	Ignore parameters setting		H1,H4,H7, H8	Using the default setting or no setting for a hyperparameter can result in an inappropriate fit for your model, affecting the final output	M10	Sanity check
			C32	Using default setting				M12	Model monitor
		Part of Parameters Setting	C33	Hyperparameter setting is incomplete/part of setting		H7,H8	Part of setting hyperparameters may not fit the data model perfectly	M10	Sanity check
		Wrong Parameters Setting	C34	Parameter setting error/out of range		H4,H6	Incorrect overparameter Settings may result in no output	M10	Sanity check

Hazop Item (Node)	Attribute	Guide word	Cause ID	Cause	Mode	Latent-Hazard ID	Consequence / Implication	Mitigation ID	Mitigation
		Invalid Parameters Setting	C34	Parameter setting error/out of range		H4,H6	see above - Wrong Parameters Setting	M10	Sanity check
		Incompatible Parameters Setting	C34	Parameter setting error/out of range		H4,H6	see above - Wrong Parameters Setting	M10	Sanity check
	Bounding box	Wrong bounding box	C3	Incomplete sensor data	Training	H2,H3,H5, H6,H8	Wrong bounding boxes may cause deploy's actions to go wrong, causing irreversible losses to the robots	M8	Common time (NTP) to synchronise data and results
								M9	Classifier accuracy/reliability for critical objects > X
			C21	Incorrect classification		H2,H3,H5, H6,H8	See above - Wrong bounding box	M11	Consistency Check (e.g. Value range)
								M12	Model monitor
4 - Localisation	Localizatio n	No localisation	C35	Hardware match not well with ML	Mapping	H1,H3,H4	The absence of positioning information may cause the robot to lose judgment of its own position, and collisions may happen	M3	Situational awareness (route mapped and planned in advance)
								M6	Maximum safe distance maintained if uncertain
								M13	General Adversarial Training
			C36	Data flow transmation error		H1,H3,H4	See above - No localisation	M8	Common time (NTP) to synchronise data and results

Hazop Item (Node)	Attribute	Guide word	Cause ID	Cause	Mode	Latent-Hazard ID	Consequence / Implication	Mitigation ID	Mitigation
		Wrong localisation	C35	Hardware match not well with ML		H1,H4	See above - No localisation	M13	General adversarial training
5 - Environment	Attack	Evasion Attacks	C37	Insert a calculated disturbance into the input data	Training	H5,H6,H9	An evasion attack involves adversaries constantly probing classifiers with new inputs in an attempt to evade detection	M14	Defensive Distillation
								M15	Detector trained on the activations of a specific layer
		Data Poisoning	C38	Input data is contaminated			See above - Data poisoning	M17	Class Labels
			C29	Data washing incomplete		H5,H6,H8, H9	Data poisoning attacks involve adversaries feeding polluted training data to a classifier, blurring the boundary between what is classified as good and bad in the adversaries' favor.	M16	Detection based on data provenance
		Model Stealing	C39	Data was stolen during model training		H7,H9	Model stealing techniques are used to recover models or information about data used during training.	M13	General adversarial training

Hazop Item (Node)	Attribute	Guide word	Cause ID	Cause	Mode	Latent-Hazard ID	Consequence / Implication	Mitigation ID	Mitigation
		Inference	C40	Data is mined from sensors to ML models		H9,H10	Inference Attack is a data mining technique performed by analyzing data in order to illegitimately gain knowledge about a subject or database	M13	General adversarial training
								M18	Feature Squeezing
6 - Data Transmission (Data flow and Data value)	Transfer	No data transfer	C41	No data flow from data preprocessing (transient)	YOLO training	H4,H7	A brief interruption in data transmission may cause output to be slower, but it may only have a manageable effect	M12	Model monitor
			C42	No data flow from data preprocessing (permanent)		H3,H4,H7	Permanent interruption of data transmission at this stage could lead to serious consequences and the robot could lose the correct trajectory	M12	Model monitor
								M11	Sanity check
		Part of Date Flow	C43	Incomplete data flow		H4,H7,H8	Part of the data flow will cause inaccurate samples, which may lead to slow output speed	M12	Model monitor
								M9	Classifier accuracy/reliability for critical objects > X

Hazop Item (Node)	Attribute	Guide word	Cause ID	Cause	Mode	Latent-Hazard ID	Consequence / Implication	Mitigation ID	Mitigation
Base Model N	Feature Extraction	No Feature	C43	Incomplete data flow		H1,H5,H7, H11	Failure of feature extraction may result in no output results of the whole model, which will have a huge impact on the subsequent process of the robot	M13	General adversarial training
								M19	Explainable AI
			C44	Batch value too small		H1,H5,H7, H11	See above - Feature Extraction	M20	Adjust Batch Value if memory is allowed
		Part of feature	C45	The training set is not spread across three scales		H1,H5,H7, H8,H11	Failure of partial feature extraction may not cause serious consequences, depending on whether training data is spread across three layers	M21	Limited impact on prediction
			C43	Incomplete data flow				M12	Model monitor
8 - Prediction	Detection	No/Part of detection	C44, C45	Batch value too small/The training set is not spread across three scales		H5,H7,H11	No output results of the model will directly lead to the failure of the robot to make correct responses in the follow-up actions	M22	Calculate recall value
			C43	Incomplete data flow		H5,H7,H8, H11		M12	Model monitor