ASSURED AUTONOMY SUPERVISORY INTERVENTION SYSTEM TECHNOLOGY (AASIST)

Mine Automation Partnership Meeting-9/14/2022

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AASIST

Assured Autonomy (AA):

Safe autonomous function in the presence of humans. AA is the level at which autonomy is "self aware" enough to actively prevent human injury.

Safety Intervention (SI):

The solution to safety in complex systems is redundancy. AASIST would be a parallel system that's sole purpose was to evaluate its environment (digital twin) and minimize risk/cost. It would "intervene" in standard operations to avoid accidents.

System Technology (ST):

In complex systems, standard Risk Analysis (RA) is difficult due to unforeseen outliers. Using a real-time systems approach, the risk can be evaluated for any set of circumstances that arises to determine the safest approach.

PROJECT GOALS

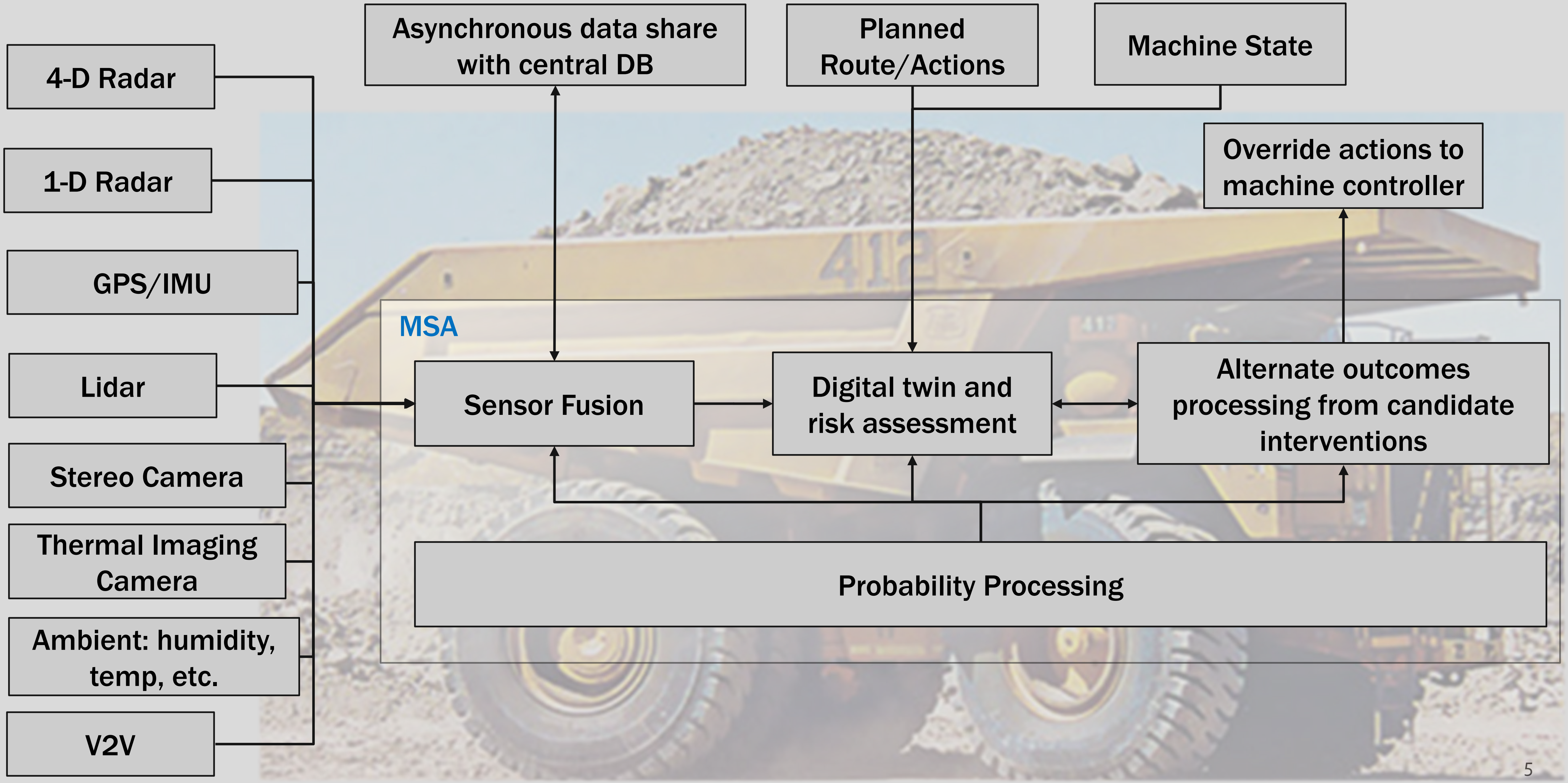
As a pilot project, we are conducting initial research on the following objectives:

- Determine if technologies and methodologies exist to construct a real-time systems risk assessment and intervention framework that would eliminate the need for human oversight.
- Provide a higher level of safety and assured autonomy, based on a systems approach.
- Provide a framework for equipment providers to use as a standard approach to real-time risk mitigation based on variable environmental inputs.
- Provide industry wide methods of evaluating safety and integrity of autonomous systems.
- Provide industry wide methods of determining sensor requirements for different autonomous applications

DESIGN GOALS

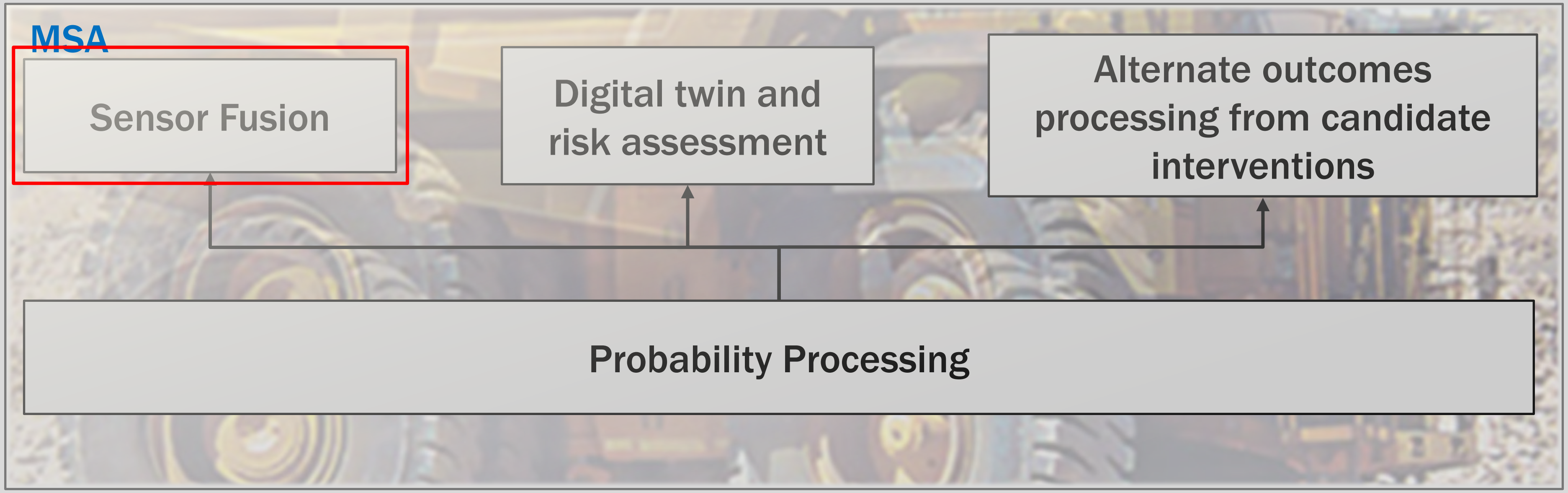
- Avoid reliance on communications-these should augment performance but not be required. Mapping, object detection, risk assessment can be managed onboard.
- Limit false alarms-erodes user trust.
- Fast-prototyping will target ~10Hz in the first pass.
- Limit usage of AI-avoid non-deterministic solutions in safety applications. This is inline with ISO work.
- Make use of rich data and in-house expertise.

OVERVIEW



4-D Radar
1-D Radar
GPS/IMU
Lidar
Stereo Camera
Thermal Imaging Camera
Ambient: humidity, temp, etc.
V2V
Asynchronous data share with central DB
Planned Route/Actions
Machine State
Override actions to machine controller
MSA
Sensor Fusion
Digital twin and risk assessment
Alternate outcomes processing from candidate interventions
Probability Processing
412

SENSOR FUSION AND OBJECT TRACKING



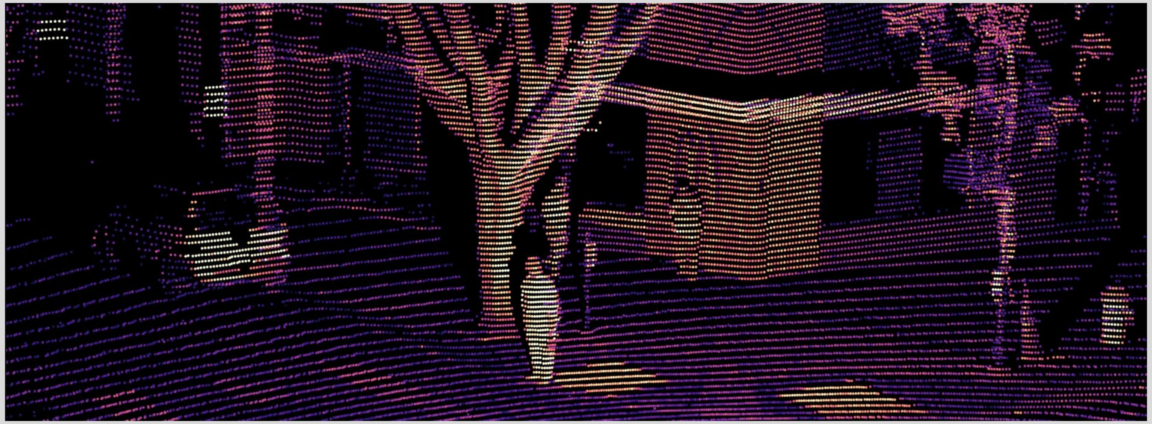
Why is this important?

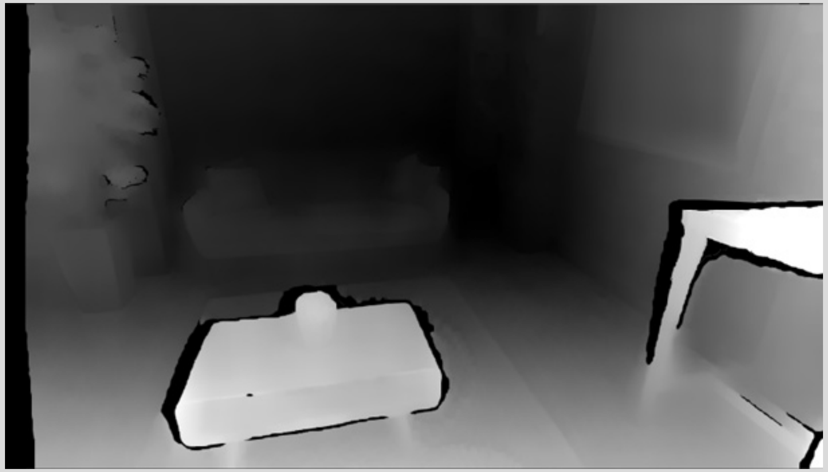
Our goal with AASIST is to leverage a high volume of data for accurate tracking while safely managing uncertainty.

SENSOR FUSION AND OBJECT TRACKING

Data can be assigned to four categories:

- 3D-lidar
- 2D-camera, thermal
- 1D-radar, ultrasonic
- Ambient-weather, for example, can be viewed globally.





SENSOR FUSION AND OBJECT TRACKING

Common Process:

1. Fuse Point cloud data using K-means, Poisson, or Least-Square methods.
2. Object tracking: assign object-based data to respective filters (Kalman typically).
3. Update state vectors for each object using assigned data.
4. Remove objects from point cloud to establish topography.

SENSOR FUSION AND OBJECT TRACKING

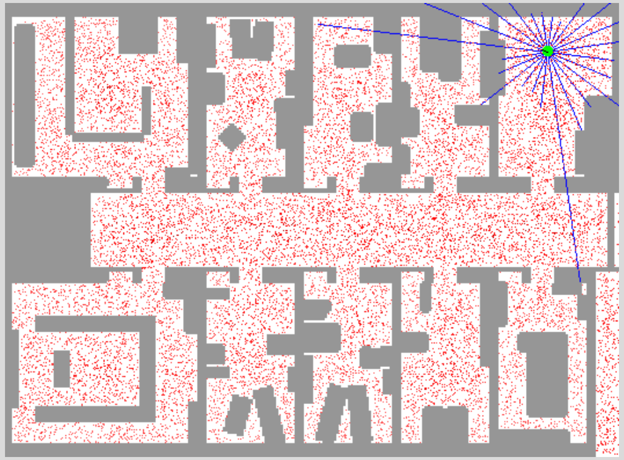
Object Tracking Algorithms:

- Joint Probabilistic Data Association (JPDA)-joint probability across tracked objects.
- Multiple Hypothesis Tracking (MTT)-decision tree representing hypotheses.
- Random Finite Sets (RFS)-combines filtering and tracking using set statistics.
- deepSORT-uses deep learning and image features to track objects.

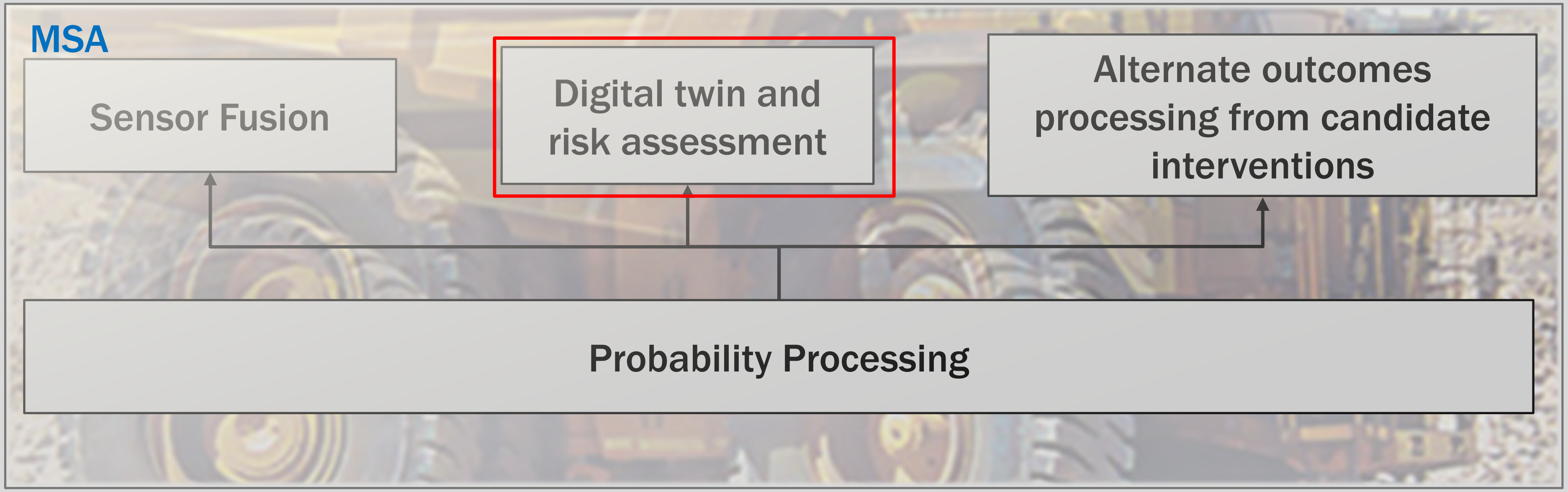
SENSOR FUSION AND OBJECT TRACKING

Filter Algorithms:

- Extended Kalman Filter-baseline for testing, highly popular. Basic idea is to use Bayesian inference and weight measurements against predicted position based on previous time step.
- Particle Filter-sequential Monte Carlo method. Also uses Bayesian inference, but weighted particles track hypotheses and generate arbitrary probability distributions.
- Weighted-Dempster Shafer-similar to Bayesian inference, but uses probability masses. Designed around managing uncertainty.



DIGITAL TWIN AND RISK ASSESSMENT

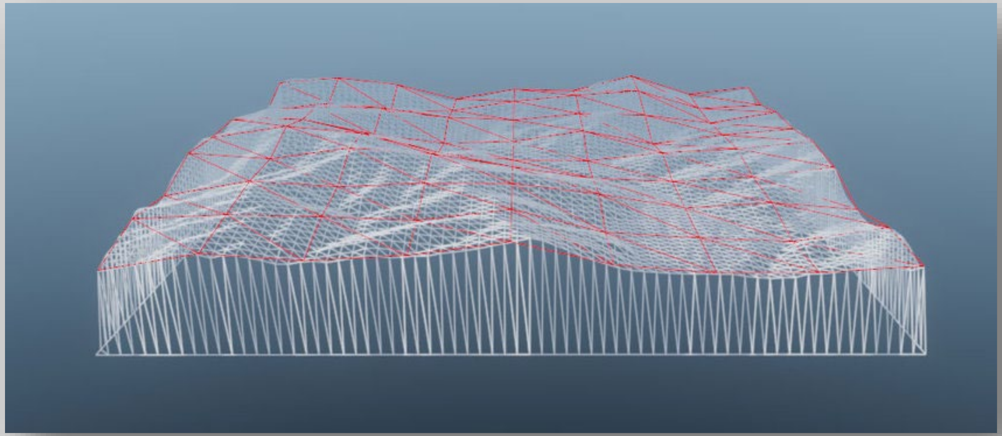


Why is this important?

Real-time risk assessment is vital to determining the safest system response. This allows intelligent system responses that can triage hazards to minimize injury.

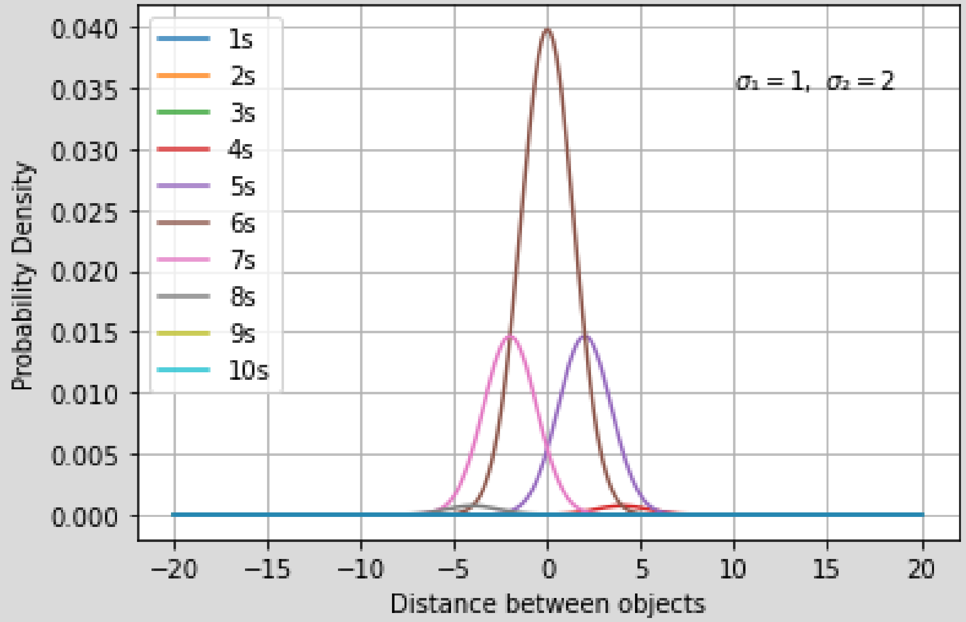
DIGITAL TWIN AND RISK ASSESSMENT

- The “digital twin” is the tracked state surrounding autonomous equipment: topography and objects.
- AASIST can use prebuilt maps, but the goal is to detect and report deviations from the original map to the central server.
- As a given piece of equipment builds a local digital twin, significant deviations from the master version are shared asynchronously.



DIGITAL TWIN AND RISK ASSESSMENT

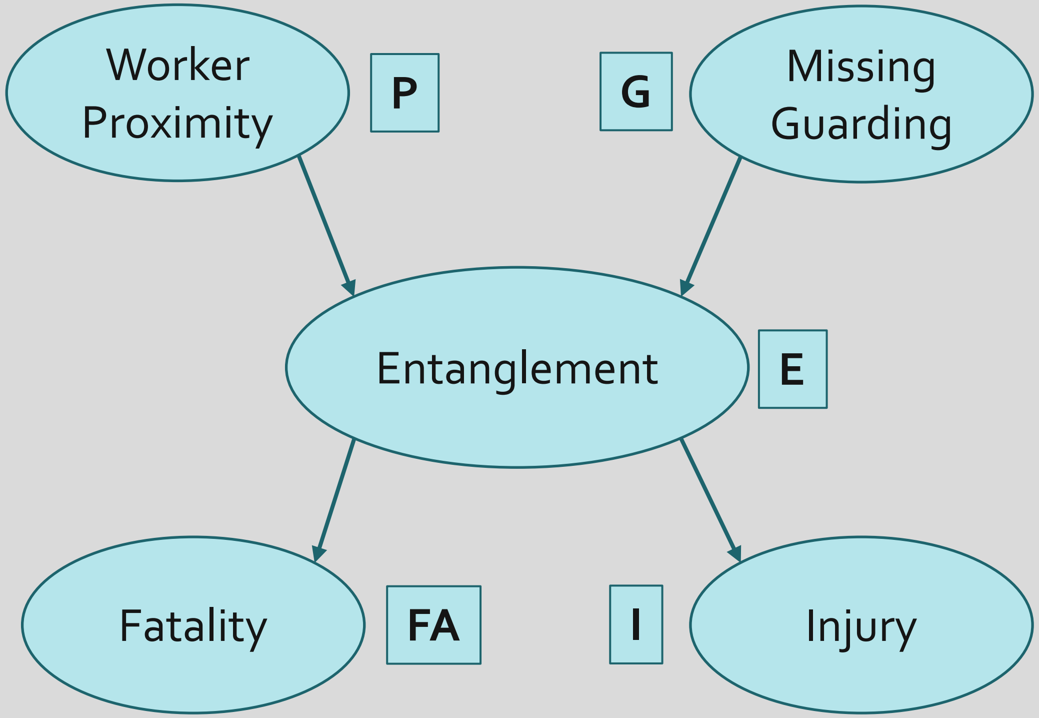
- The likelihood of collision/interactions will be estimated through probability fields. The basic idea is that trajectory profiles are projected through time using a Normal distribution or a composite created through kernel density estimation. The overlap in profile determines the likelihood of interaction between two objects.



DIGITAL TWIN AND RISK ASSESSMENT

- Risk likelihood will be tracked through a Bayesian Belief Network. This will allow the combination of objective (sensor) data and subjective (expert) evaluation. The generated posterior likelihoods are exported to the risk matrix.

T	F
0.850	0.150



T	F
0.011	0.989

P	G	P(E=T)	P(E=F)
T	T	0.703	0.297
T	F	0.592	0.408
F	T	0.615	0.385
F	F	0.001	0.999

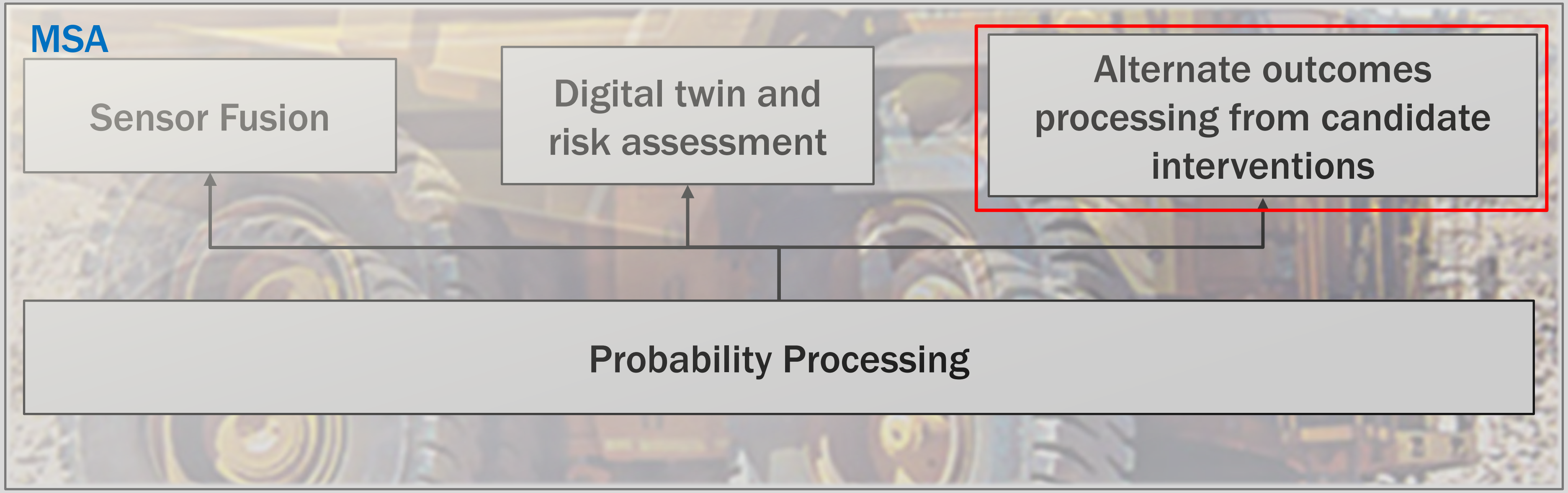
E	T	F
P(FA=T)	0.250	0.001
P(FA=F)	0.750	0.999

E	T	F
P(I=T)	0.900	0.003
P(I=F)	0.100	0.997

DIGITAL TWIN AND RISK ASSESSMENT

- Risk assessment will rank hazards based on a product of the likelihood of an event and its severity.
- Likelihoods will be generated by the Bayesian Belief Network and velocity field.
- Severity is generated by a cost function for collisions, which is based on the kinetic energy of the objects and preassigned values that preserve human life above all.
- Outside of collision, hazards such as particulate exposure, entanglement, or heat will be assigned a range of hazard scores by soliciting expert opinions.

INTERVENTION



Why is this important?

The system response can’t be reliably hard-coded in a dynamic environment. The aim of AASIST is to determine the best course of action by estimating the system state at future points in time.

INTERVENTION

- The positions of moving objects can be estimated using the current state vectors for each tracked object.
- Forward dynamics can be calculated using rigid or articulated body dynamics and applying the uncertainty at each time step.
- The Bayesian Belief Network probabilities will also be applied in estimating the system state.
- Intervention doesn’t necessarily mean changing trajectory-it will include warning lights, alarms for example.

INTERVENTION

Challenges:

- The overall time interval for forward projection will depend on the speed and braking distance of vehicles in the environment. For testing the estimate is 3-5 seconds. These values will have to corroborated in the future through field work.
- At each time step a risk assessment will be needed to evaluate whether a candidate intervention is reducing exposure to hazards.
- A challenge in our future work will be determining an algorithm to efficiently manage the forward projection, as the problem space will be quite large.
  - One potential approach is to configure a decision tree which can trim branches that markedly increase risk. This will reduce the problem space but will limit parallelism to the current time step.
  - Potential responses will be discretized. This could take the form of a rough first pass, say ±10°, which is refined around regions more likely to avoid accidents.

THANK YOU

We welcome any and all partners. Please reach out if you are interested in collaborating or have any thoughts to share:

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