EMBEDTEK

There is a Time and Place for Machine Learning.

How to Know it is Right for You.

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Artificial intelligence is the theory and development of computer systems able to perform tasks that normally require human intelligence, such as visual perception, speech recognition, decision-making, and translation between languages. Machine learning is a subset of AI. It is the use and development of computer systems that are able to learn and adapt without following explicit instructions. This is accomplished through algorithms and statistical models to analyze and draw inferences from patterns in data.

Where artificial intelligence emulates human thought through if-then rules – such as a smart home thermostat – machine learning creates an environment where machines improve at tasks with experience, usually by collecting vast amounts of data – such as a self-driving vehicle.
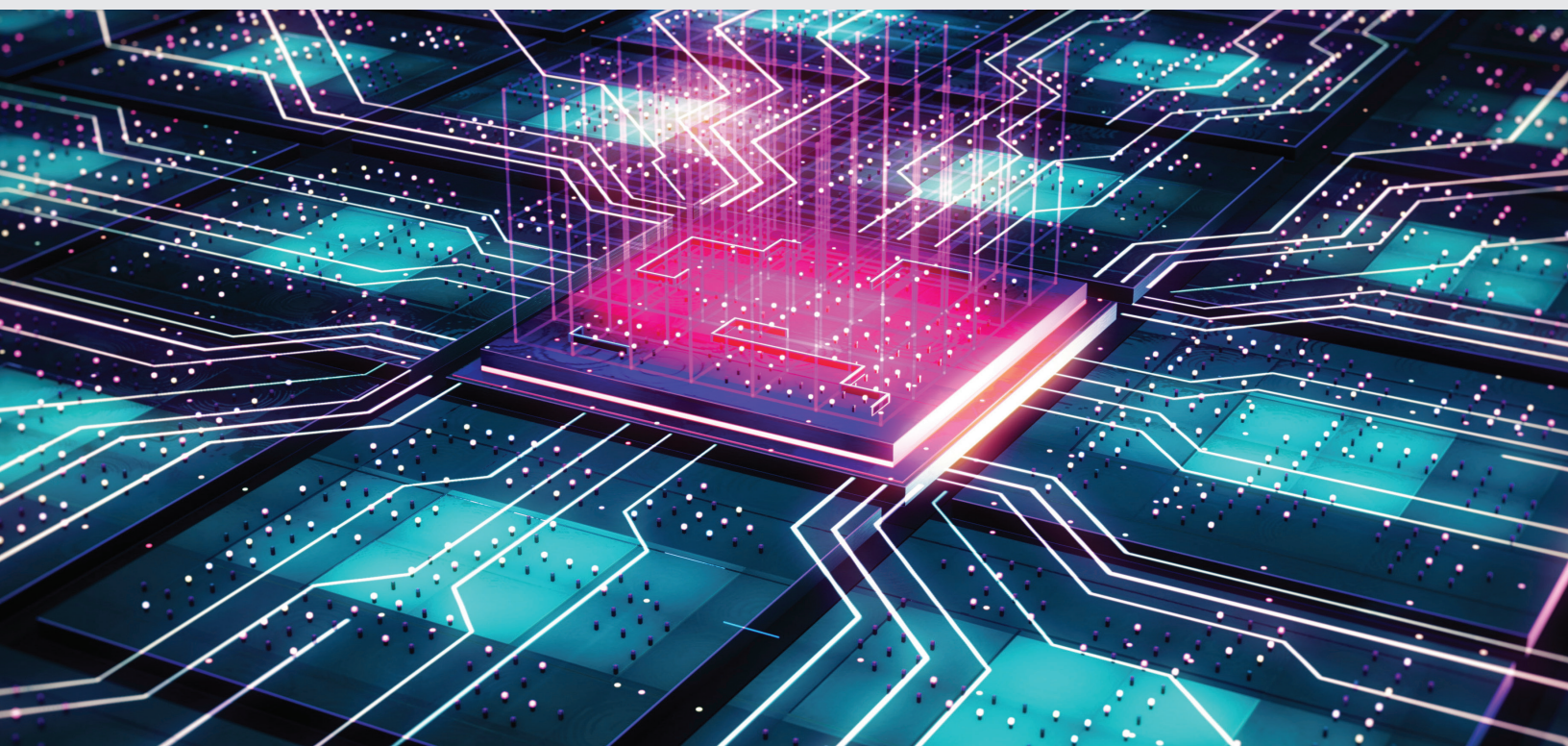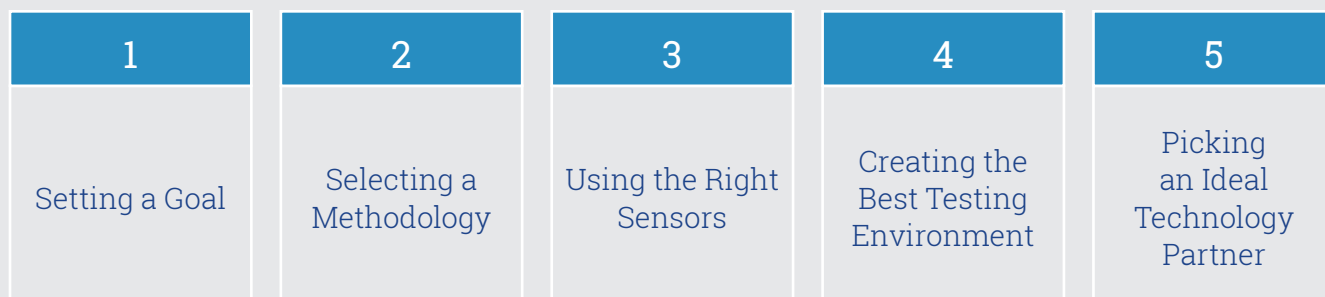
The world is experiencing the perfect AI/ML storm of continuous research and innovation, accessibility to current and historical data, and the ever-decreasing price of camera and sensor components. Leading companies have harnessed this to create new platform businesses or invent life-saving medical devices and security systems. According to **Grand View Research**, the global artificial intelligence market size was valued at $136.55 billion in 2022, **and is projected to expand at a compound annual growth rate** (CAGR) of 37.3% from 2023 to 2030.

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The **U.S. Food and Drug Administration (FDA)** recognized in 2019 that medical device manufacturers were using AI/ML to provide innovations that better assist health care providers and improve patient care. The FDA launched a Digital Health Center of Excellence and an Action Plan dedicated to continue promotion of new AI/ML medical devices. Their website says, "Artificial intelligence (AI) and machine learning (ML) technologies have the potential to transform health care by deriving new and important insights from the vast amount of data generated during the delivery of health care every day." As of October 2022, more than 500 new AI/ML-enabled medical devices were added to their **publicly available database**.

Intelligent analytics, artificial intelligence, and machine learning have become buzzwords that are used interchangeably by media, consumers, and brands alike. But to an engineer, they are very different. If an original equipment manufacturer (OEM) goes down the machine learning path when their product doesn't warrant it, development will be much more expensive, and the final product will also cost more due to the increase in computer power required. Our advice? There is a time and place for machine learning. Don't develop around it if you don't need it.

In this paper, we put machine learning into context using real-life applications to help OEMs determine if their product could benefit from it. Then, we walk through the critical steps that will set a machine learning development project up for success:

1	2	3	4	5
Setting a Goal	Selecting a Methodology	Using the Right Sensors	Creating the Best Testing Environment	Picking an Ideal Technology Partner

Putting Machine Learning into Context

Machine learning is a significant jump into the intelligent systems world. Take a motion-activated camera for example. When the camera's integrated motion sensing logic detects an image change, the camera starts recording. This is considered intelligent analytics because data is collected, analyzed and triggers an action. Artificial intelligence comes in when the motion-activated camera is able to make more complicated decisions such as the ability to recognize humans and/or animals – something that would normally require human intelligence. Machine learning takes it a step further when a motion-activated camera not only recognizes a "blob" is a human but also opens a door only when specific people are recognized. This requires the computer system to learn and adapt from events collected by authorized personnel and non-authorized personnel.

Consider the following scenarios where machine learning can increase the accuracy, safety, or efficiency of a machine function.

Medical Devices	A high-speed pill counter and identifier can inspect pill shapes, sizes markings and color(s) while counting them as they are dispensed through the machine – no matter what position they are in as they fall or if they are momentarily behind other pills. Anomalies are spotted in real-time, alerting the technician to a defect such as a broken pill or the presence of an incorrect pill altogether. The accuracy of the counter helps prevent errors in prescriptions and reduces labor by preventing manual counting of prescriptions.
Industrial Doors	Automated garage doors and pedestrian doors in an industrial setting can serve different purposes having to do with security and HVAC efficiency. Since these doors are powerful, heavy and cycle quickly, safety is always a concern. A door control system with machine learning can provide a lot of value by learning and then adapting to different scenarios. A common example is to only open a door when a pedestrian approaches in a manner that indicates their wish to pass through, not just walking in front of the door or stopping. By learning behaviors of how a person approaches the door and then pauses or slows down, ML technology can make reliable decisions to only open doors when it should. The system anticipates the intent of the pedestrian by analyzing subtle differences in the pattern of their motion as they come near or approach the door.
Material Handling	A warehouse filled with walls and inventory shelving racks upwards of 30 feet high does not provide much visibility between aisles or around corners. Large convex mirrors can help some but are limited. ML technology connected to camera sensors and vehicles can alert fork trucks and pedestrians to potential collisions by analyzing areas of possible collisions. It can also be used to actually prevent the collision of a connected vehicle by sounding an audible alarm and even actively slowing the vehicle down before impact occurs.

OEMs delving into the world of machine learning can be typically broken into two **types:** OEMs with existing products they want to make more intelligent and OEMs inventing new products with machine learning at their core. Either way, a successful project that utilizes machine learning requires a well thought out process that starts with the end goal of the OEM. Follow the steps below to ensure a streamlined project management process.

Start with a Goal

The number of data sets a software application can potentially track is infinite. Set an overall goal for the purpose of developing machine learning for your product so you can define the meaningful variables the software will measure and the boundaries of these variables that the system will need to work within.

In the industrial door scenario above, safety is always the most important goal but next, the system must add value to ensure it beats the competition. Most people have experienced standing near an automatic door while waiting for someone and having the door open and close repeatedly without anyone going through. To prevent these false open/close cycles, the system has to be adaptive to the environment it is intended for.

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Select a Methodology

Machine learning can follow one of two methods – algorithm or open data set. An algorithm sets boundaries for the data you want to monitor. It is a good way to identify trends, spot anomalies, and for the software to know what is normal and what is not normal. When something abnormal happens, or a boundary is reached, the software can send an alert to the operator to look into it. Even if the operator overrides the alert, the software continues to track within the set boundaries. Consider the high-speed pill counter and identifier application. If the system alerts a technician to a potential broken pill or presence of an incorrect pill, and the technician feels it is in error, the technician can only override the alert, not the parameters set to identify anomalies, nor the data collected by the machine. This is important to ensure the system will not learn and accept "bad behavior" that was not part of its learning and accepted data set.

An open data set is exactly what it sounds like – no rules. An open data set is beneficial when the variables needed to meet your goal are not tracked in a definitive way. For instance, if a company wanted to use a camera and machine learning to tell if someone is going to come around a corner before they actually do. Open data sets look at millions of pixels, thousands of hours of video, using terabytes of data. The benefit is that when a person does come around the corner, the software can analyze the environment several seconds before and compare every pixel to a time when someone was not coming around a corner. Then, the machine can spot the anomalies in the data – which could be as simple as a very slight color change in an array of pixels on a wall within the camera view. This change could be as simple as the camera's viewable wall seeing a momentary change due to the reflected or absorbed light of a person's clothes. This subtle change in the ambient light is enough for the camera system to detect a difference which is similar to events observed in its training and determine that a person is about to come around the corner.

The benefit of the algorithm method is that safety measures can stay in place. The benefit of the open data method is that it can be good for a training environment where the software needs a period of time to learn through crunching vast amounts of data and adapting its program.

Use the Right Sensors

Machine learning is useless if your software doesn't have access to external sensors or information. The system needs the ability to hear, see or measure something in order to analyze its environment. In machine learning, sensors are the way for a computer to be able to measure these variables to gain needed information about its surroundings. Humans have five senses – touch, taste, sight, smell, and hearing. Depending on the application, one, two, or even all five senses could come into play. In addition to this, many sensors allow the detection of other things such as non-visible light or radiation. That's part of what AI is all about – by mimicking human intelligence, computers can perform tasks that humans either can't or don't want to. Choosing the appropriate sensor is very important in order to acquire meaningful and useful data. This doesn't mean buying the highest resolution sensors is best. Beyond higher cost, the higher performance sensor will require a lot more memory, storage and processing power that can slow the system **down**.

There are many different sensors available to perform specific tasks, but each have strengths and weaknesses. At EmbedTek, we commonly use sensor fusion, where multiple types of sensors can be used in combination to leverage their strengths without experiencing their weaknesses. We use sensor fusion to measure an environment with enough accuracy but also with multiple perspectives, so the machine has access to the information it needs in order to learn, adapt, and act. Following is a list of common sensors used in machine learning applications and how they work.

SENSOR	TYPE	PURPOSE
Accelerometer	Electromechanical	Detect motion X,Y & Z plus acceleration, pitch **and** yaw to know how something is moving.
Inertial Measurement Unit (IMU)	Electromechanical	Multi-type position sensor. Gyroscopes measure angular velocity, accelerometers measure change in movement, including specific force or acceleration, and sometimes a 3-axis magnetometer.
GPS	Radio Frequency	Receivers process time of flight (ToF) data from **a** satellite-based navigation system to provide and absolute location. Accurate location tracking within several meters.
Camera	Solid-state electronic device	Very common optical sensor. There are many different types and performance levels. Choosing the correct one is critical for a specific application.
LiDAR (Light Detection and Ranging)	Light in the form of a pulsed laser or LED paired with a light receiver.	Measures the round-trip time (ToF) a laser pulse takes to hit an object and reflect back.
Thermal Infrared (IR) Imaging Camera	IR Thermal Light (8 – 25um)	Converts IR radiation pixels to create visible images that show temperature. An application of this sensor is to identify humans with analytics looking for a pixel density and temperature range.
Ultra-wideband (UWB)	Radio Frequency	Uses RF to measure (ToF) distance precisely between two devices. Typically used for short to medium distance applications. Often fused with Bluetooth.
Time of Flight (ToF) Camera	Infrared and/or visible Light	Measures distance of each pixel using ToF of a camera strobe reflection.
Micro-electro-mechanical Systems (MEMS)	Electromechanical	Highly accurate microphone, detect wide range of frequency
Hyperspectral camera	Wavelength	Ability to see the full spectrum of visible and non-visible light using wavelength sensors to image narrow spectral bands.
Short Wave IR (SWIR)	Electromagnetic (0.9-1.7um)	Can see wavelengths not visible to the human eye, offering advantages in many applications over visible light.

With sensor fusion, the machine can make more adaptive decisions. For instance, a developer can write rules to ensure the information is collected from multiple sensors to ensure the data is meaningful. If a piece of equipment is relying on vision sensors, but its ultrasonic sensor detects an object closer than the optics are estimating, machine learning can rule that an object is closer than it appears visually. This would be common for autonomous vehicles. Vision systems may be the most useful in most cases but if there is fog, then radar or ultrasonic are needed to avoid collisions.

When accelerometers are used for a moving object, such as a robotic cart on a manufacturing floor, or a high-end drone used outdoors, they usually also require an optical sensor to give them vision. The accelerometer senses movement, but the optical sensor can determine if the object itself is moving and get an estimate of its size.

In the high-end drone scenario, the machine learning platform could include an IMU for the vessel's relative movement, GPS for an absolute position, a camera for vision, LiDAR for precise object or environment distance measurement, and AI software to interpret data. The IMU sensor will provide real-time changes such as acceleration and changes in the vessel's heading. GPS combined with optics and the IMU allow the craft to land precisely on the target.

This level of machine learning can create a sixth sense once all of the factors are in play, which makes the machine superhuman.

The sensors listed in the table above can also be combined to prevent unmanned material handling equipment from hitting an object in its path, and even be able to tell the difference between a person that may need to interact with it and a pallet that fell off a forklift.

In the future, a warehouse or material handling facility will have adaptive capability. A combination of multiple cameras creating 3D vision and/or LiDAR will be used to map the characteristics of a room and its contents. Because the contents will change over time, the material handling equipment can adapt when objects from its memory have changed. The combined use of vision and LiDAR as a primary guidance sensor but using non-optical sensors such as radar and ultrasonic for confirmation, will be commonplace. An example of this would be when an autonomous vehicle's primary optic sensor becomes dirty and the system then needs to rely on its other sensors until the problem is corrected. This is similar to a human using their hearing more if they no longer have good eyesight. The use of machine learning can allow the craft to adapt quickly to changing conditions and then go back to its best sensors when they are functioning properly.

Create the Best Testing Environment

The last step is to test a device, solution, or equipment in all possible scenarios it will encounter. Testing environments are often highly controlled. How will a self-driving car, which is completely dependent on sensor technology, battle fog, hail, or flooding when this weather will no doubt block some of the critical sensors to prevent a collision? How will your device handle extreme heat, weight from dirt or rain, or just a general, unpredictable occurrences?

Testing environments are also important to give the machine time to learn and adapt before it is placed in the field. More data is beneficial because ML relies on data. Put the equipment through as many experiences as possible and teach it what is good and what is bad so it can record those rules in its data. What the system needs to do when an unknown condition happens, must be considered carefully. An example of this would be when an autonomous material handler loses its vision, what should it do? Completely stop, just slow down, rely solely on the radar and/or ultrasound? It's important to create potential failures of the system sensors as part of the training.

Pick an Ideal Technology Partner

Vision systems, interconnected sensors, machine learning, and artificial intelligence are the drivers that differentiate products and develop markets. Technology and integration partners that can balance niche ML expertise with broad capabilities in design, manufacturing, supply chain, and life cycle management will be critical for OEMs working in this space. They partner to work alongside OEMs every step of the way and design for manufacturability from the start – an unfortunately overlooked step in some prototype design processes.

Machine learning is complex, and it is not for every OEM or every application. With the right approach you can determine if machine learning is right for you. And with a trusted partner, a successful launch can be a gamechanger for your company, your end users, and their industries.

About EmbedTek, LLC

EmbedTek creates, designs, and builds embedded computers, software, sensors, cameras and displays for original equipment manufacturers. We have spent decades developing application specific computers, integrated displays, and custom I/O solutions. Our expertise has expanded to include IoT solutions, combining imaging and sensor technology with intelligent analytics, machine learning, and artificial intelligence. We're a team of talented mechanical, electrical, and software engineers who are energized by solving complex problems and developing unique solutions.