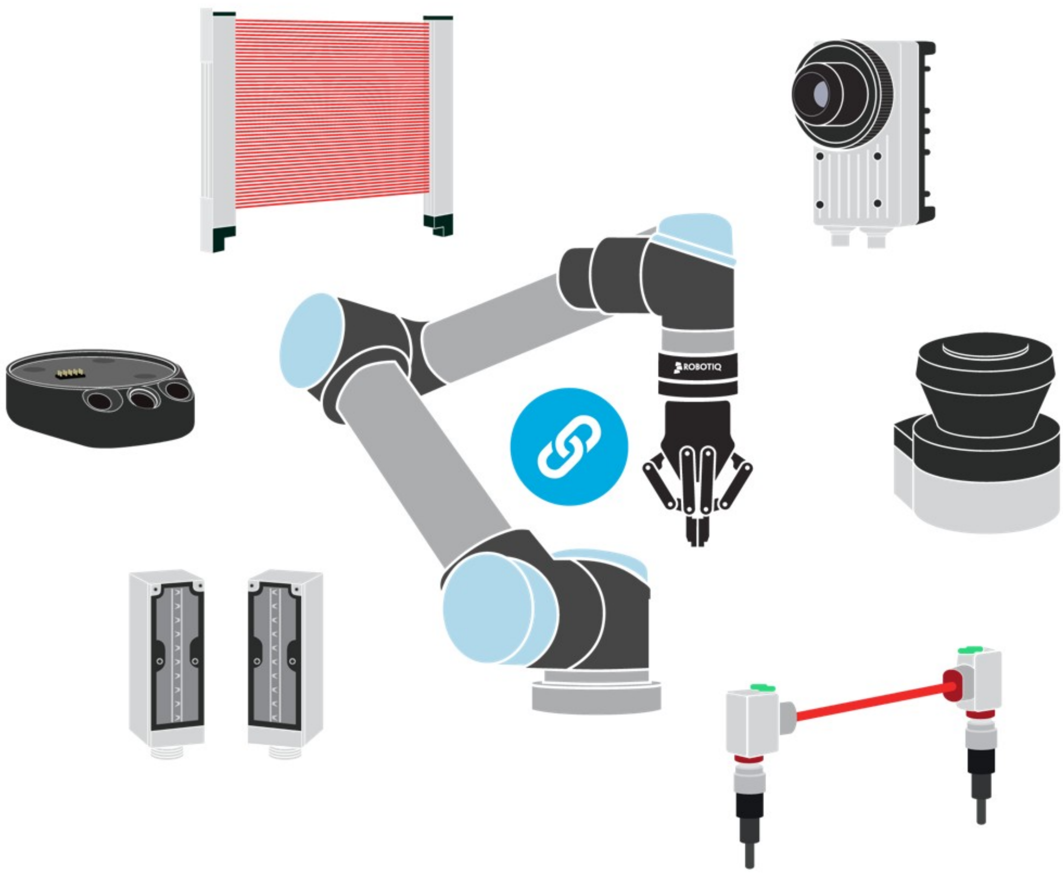
ADDING EXTRA SENSORS

HOW TO DO EVEN MORE WITH COLLABORATIVE ROBOTS



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INTRODUCTION

IS THIS EBOOK FOR ME?

If you're reading this eBook, I'm going to guess that you have already considered how a collaborative robot could be a good addition to your (or your client's) workflow. In fact, I'm going to go one step further and guess that you have already been using a collaborative robot for some time. You've seen the benefits and are wondering how you could apply the robot to even more tasks in your process.

If instead you are still considering your first collaborative robot, then by all means read on. However, if you haven't already, you might like to check out our other eBook "5 Steps for Getting Started with Collaborative Robots." We've also got great advice on our blog about how to choose the best task for your first collaborative robot application, calculating the ROI of a collaborative robot and much more.

WHAT THIS EBOOK PROVIDES

This eBook is for anyone who wants to know what benefits extra sensors could add to their process. It gives you practical information so that you can decide whether or not an extra sensor is right for you and your business, or your client's business if you are a consultant. We'll look at the various different types of available sensors, along with the benefits and potential challenges of integration for each.

This eBook comes with an accompanying series of emails. These provide clear, practical steps for assessing your application, choosing the right sensor and getting your team on board. Jump to the final section of this eBook to find out more.

HOW WILL A SENSOR IMPROVE MY EXISTING ROBOT?

Here at Robotiq, we consider that an extra sensor will give you more flexibility with your robot. However, as with most engineering additions, this added flexibility usually adds more complexity to the system. Is that added complexity offset by the benefits of the extra flexibility? That's what we're trying to find out.

Everyone's situation is unique, but generally we recommend that you develop some good experience using your collaborative robot alone before you try adding extra sensors to it. Once you're familiar with the robot's capabilities and limitations, you will be in a better position to appreciate the benefits provided by the extra sensor.

CAN MY APPLICATION BENEFIT FROM EXTRA SENSORS?

If you have been using collaborative robots for some time now, you know just how useful they can be. Even so, you might be wondering: Will adding an extra sensor be right for my specific application? This is the question that we'll try to help you to answer in the following sections.

Throughout this eBook, we will introduce some example tasks. However, even if your specific application isn't mentioned, it may still benefit from the solutions being discussed. Try to imagine how each example could be adapted to your unique situation.

We hope you find the information useful!

HOW TO DECIDE IF YOU NEED EXTRA SENSORS

The first step to integrating a new sensor should happen before you've even purchased it. You should carefully think through your process to decide if you really need an extra sensor. Collaborative robots are already very flexible, so there may be alternative ways to achieve the results you want without the addition of an extra component.

WHAT ISSUE ARE YOU TRYING TO IMPROVE?

Most likely you have a particular issue which you think could be improved by the addition of a sensor. If not, your first step should be to find one task that is causing problems or needs improvement. It's easier to justify an investment if you can show how it will improve at least one concrete application. Later, you will almost certainly be able to apply it to other tasks.

Look at the process or situation you want to improve and take a few minutes to answer these questions:

- Which specific areas of the operation are causing me trouble?
- Are they related to a particular process (e.g. assembly) or a general situation (e.g. safety around the robot)?
- Which parts of the process are the collaborative robot already able to carry out successfully?
- Which specific aspects of the process are causing the difficulty?
- What solutions have I already considered? (e.g. fixturing, part preparation, guarding, etc)

In this eBook, we're going to look at how extra sensors could work as a solution. However, there might be other ways of solving your problem without having to add the complexity of a new sensor. For example, if you've ever been in an automated factory, or watched videos of them, you will know that there are many ingenious ways to align objects without extra electronics. If your problem is one of alignment, could a simple feeder piece be made on-site to align the parts without having to resort to an expensive vision system? Simpler solutions are usually easier to integrate and maintain. However, they are not always feasible and are less flexible than sensor-based solutions.

WHICH SENSORS DO YOU HAVE ALREADY?

Before investing in a new sensor, it's important to take stock of what technology you already have. All collaborative robots include some sensors. Even the most basic robot will have sensors to detect the position of its joints, and many collaborative robots have extra sensors built-in or available for easy integration. It makes sense to maximize your use of any pre-integrated sensors because they will reduce a lot of the extra work required for integrating with an external sensor. Only invest in an extra sensor if you're sure that the built-in sensors can't be used to address the issue.

Some popular collaborative robots come with extra sensors fitted as standard, including the Green CR-35iA from Fanuc (which includes safety contact sensors), Sawyer from Rethink Robotics (which includes 2D cameras and force sensing), IIWA from KUKA (which has built-in force sensing) and Nextage from Kawada Industries (which has 3D stereo vision and hand-mounted 2D cameras).

Other collaborative robots have the option of add-on sensors, either directly from the manufacturer or from partner companies. This is a useful option if you prefer to add new sensors gradually. Examples include the YuMi from ABB (which has optional end-effector cameras) or the Universal Robots range, which have out-of-the-box integration with Robotiq force sensors and the Robotiq Wrist Camera.

We have created a useful comparison chart which shows the specifications of many of the most popular collaborative robots, including information about which sensors come fitted as standard.

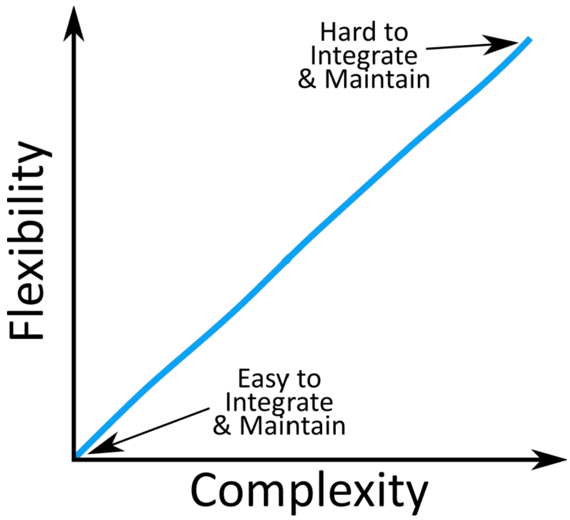
Finally, consider if any of the existing additions you have made to your robot, such as an added gripper, might have sensing capability you could utilize better. End effectors may include sensors which can be used to enhance the robot programming. For example, the Robotiq Grippers include object detection, and so could eliminate the need to add extra sensors to perform this function. You can find out about our object detection in this video.

WHAT ADVANTAGES WILL AN EXTRA SENSOR GIVE?

Different sensors will offer different advantages to your process. As all robotic applications are unique, there's no "one size fits all." In the following sections, we will look at the specific advantages of some popular sensors. However, any new sensor can provide advantages for your application.

The main advantage of adding a sensor is increased flexibility. This could be as simple as the flexibility provided by knowing when an object is in place, so the robot can perform other tasks when no new object is available. You could achieve this functionality with something as basic as a limit switch. On the other end of the scale, the added flexibility could be as complex as detecting the position and orientation of hundreds of objects in a box, allowing the robot to operate on objects which are completely unsorted. For this you might need a whole 3D vision setup with laser imaging.

As with any new technology, this flexibility comes with a cost, both in terms of budget and time. The more sensors you add, the more complex your system becomes. The more complex the system, the more work is required to integrate the sensor. It also becomes more complex to program and maintain the system.



WHAT'S THE PERFECT AMOUNT OF FLEXIBILITY?

So, increased complexity means more flexibility, right? Does that mean you can just keep adding sensors and your robotic process will become ever more flexible? Sort of, but it's not quite as simple as that.

It all depends on how you want to use your robotic system. If you want a "robust" system then, yes, adding more and more sensors could keep improving flexibility. However, if you want an "agile" system, it could actually reduce the performance of your robotic system. In both situations, however, adding more sensors will make the system harder to integrate and maintain.

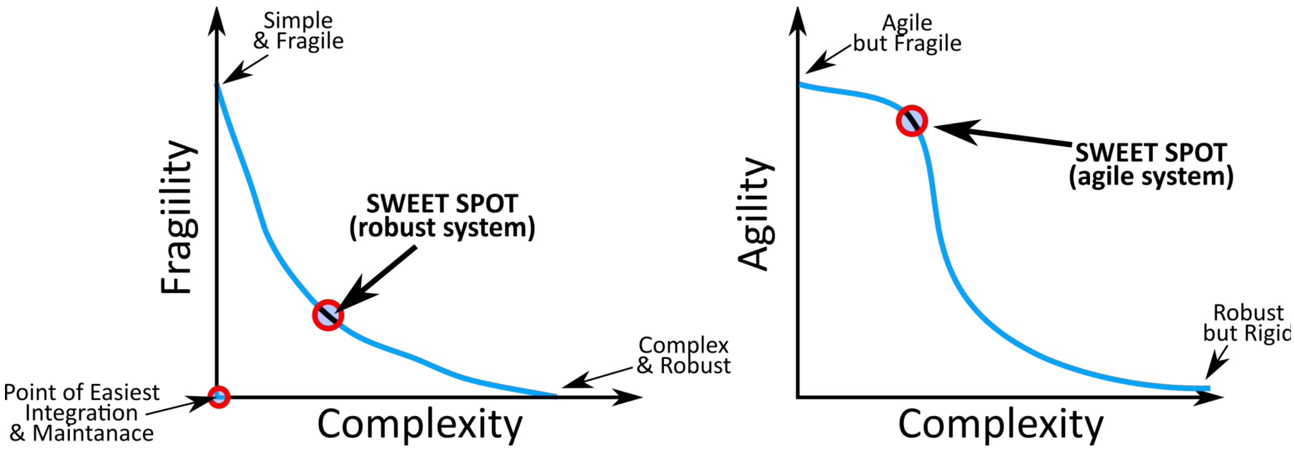
But, what do we mean by "robust" and "agile"? Let's define our terms.

If we say that your robotic system is "flexible," we mean that it is adaptable to change. For example, imagine that you are using a collaborative robot for a pick-and-place task, to move circuit boards from a tray to a testing machine. Then imagine that you want to introduce a new circuit board design, so that the robot now has to handle two different shapes of circuit board. A flexible robotic system (e.g. with a vision sensor) will be able to easily adapt its pick-and-place action to the new design. An inflexible system (e.g. a robot with no additional sensors) will be unable to adapt as it cannot detect which circuit board design is present.

There are two different approaches to flexibility which are important for adding new sensors:

- **Fragility/Robustness:** A robust system is adaptable to planned changes, whilst a fragile system is insensitive to change. As you add more components (and complexity) you can make the system more robust. In our example, you could add a whole load of different sensors to the pick-and-place robot, which would allow it to pick up on any object made of any material in any orientation or position. This is the traditional approach to flexibility used in industrial automation.
- **Agility (also called anti-fragility):** An agile system is adaptable to unplanned changes. This is especially important to consider when using collaborative robots. For example, imagine that your pick-and-place task becomes unnecessary and you want to move the robot to a machine tending task instead. With no added sensors, the collaborative robot would be very agile and easy to move to the new task. On the other hand, if you had added many sensors to improve the pick-and-place task, moving the robot to a completely different task might be more difficult. The robotic system would be robust, as it could pick up many different objects, but it would have lost agility.

Most collaborative robots are designed to be used in an agile way. One of the most useful things about them is that you can easily transfer them to another task. They are simple to move and reprogram. When adding new components to your system, you may be adding flexibility for a specific task, but reducing the overall agility of the robot.



Therefore, before you add extra sensors to your collaborative robot, consider the following two questions:

Do I want to make my robot as robust as possible, at all costs?

Do I want to preserve some of the collaborative robot's agility?

Your answers will influence which type of sensor you choose. For example, a fixed vision setup will improve the flexibility of the system by allowing the robot to pick up objects in unknown orientations and differentiate between object types. However, this could reduce the robot's mobility, and therefore, its agility. You would either have to move the entire vision setup along with the robot, which would take time, or decide not to use vision system for the new task. If you wanted a very robust system, this might be okay.

An alternative approach could be a vision sensor attached to the robot's wrist. This would give you the benefits of robot vision, whilst preserving the robot's agility. However, it might be less flexible in other ways.

For your unique situation, you can imagine there being an “optimal point of flexibility,” or "sweet spot." Beyond this point, adding more components to your robotic system will continue to increase the complexity and flexibility of the system, but agile systems will lose agility and the robustness benefits will be less clear. Also, remember that more complexity always makes a system harder to maintain and integrate.

This optimal point will be different for every robot, application, situation, and sensor technology. There may also be several different combinations of technologies which can produce the results you're looking for.

Try using the following questions to help you consider how adding a sensor (or any other new component) could affect your system's overall flexibility:

- Which functions of the robot are the most important to you and the business? List them in order of importance.
- In what ways could the new sensor improve the flexibility of each of these functions?
- In what ways could the new sensor reduce the overall agility of the robot?
- Could this be solved by using a different version of the sensor (e.g. a different camera system)?
- Which other tasks would also benefit from the sensor to improve the flexibility of another part of your operation?
- What are the top benefits that the flexibility could give to the business?
- How might the effect on the robot's agility affect the business?

It's important to remain open minded when answering such questions. They won't give you definitive answers. They are merely tools to help you think more widely about the situation. Try discussing them with other members of your team. Some people are better at noticing benefits and opportunities, whilst other people are better at noticing challenges and restrictions. Both are equally important skills so you should try to gather a balanced number of both benefits and challenges.

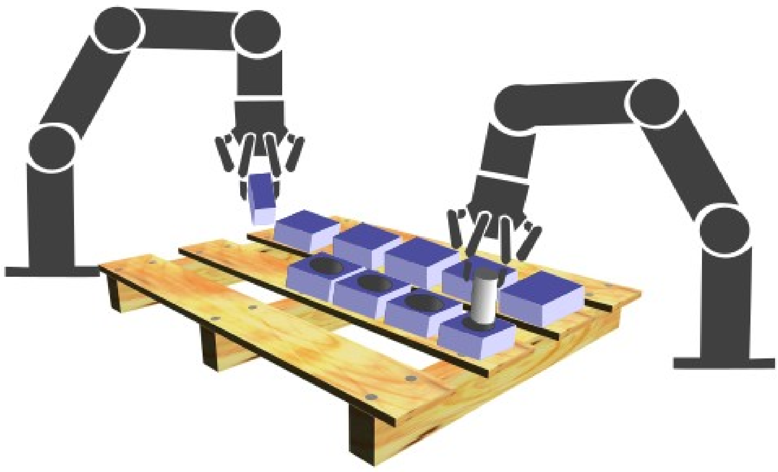
HOW TO PICK THE RIGHT APPLICATION

In this section, we will introduce a few specific applications which could benefit from additional sensors. These are just meant to be examples to introduce you to some possibilities. It is by no means an exhaustive list, so your specific application could still benefit from extra sensors even if it's not included here.

APPLICATIONS WHICH BENEFIT FROM EXTRA SENSORS

These applications can benefit from extra sensors, in some situations:

- Palletizing
- Machine Tending
- Pick-and-place
- Packing
- Dispensing
- Polishing
- Assembling
- Quality Inspection
- Welding
- Product Testing
- ...and many more...



Palletizing and assembly tasks can both be improved with extra sensors

WHICH TASKS CAN BENEFIT MOST FROM SENSORS?

If you have already read our eBook "5 Steps for Getting Started With Collaborative Robots," you will know that some tasks are harder to automate than others using a collaborative robot. For instance, it's easy to automate a task where all objects are exactly the same but its harder to automate tasks which handle objects with very divergent properties (e.g. size, shape, orientation, etc).

Sensors allow you to use a collaborative robot for quite a lot of the tasks which we listed under "harder to automate" in the previous eBook. Therefore, if you have found that a particular task in your process is not possible with your collaborative robot, it may become possible by adding extra sensors. Then again, it might not – some tasks are just more suited to humans, such as those requiring high levels of decision making or manual dexterity.

TWO APPLICATIONS WHERE EXTRA SENSORS CHANGE EVERYTHING

Here we'll look at two example applications and some of the ways that particular sensors could improve their performance.

EXAMPLE 1: PICK AND PLACE

Pick and place is a great task to give a collaborative robot. It requires a reasonably low level of dexterity, is repetitive and adds no value to a product. It simply involves picking objects up from one part of the workspace (e.g. an ordered tray) and depositing them in another (e.g. a testing machine). Programming of this type of operation usually involves moving the robot to the "pick-up" location, storing the position the robot controller, and then doing the same for the "drop-off" location.

A collaborative robotic arm with no additional sensors can be used to perform pick and place. However, there are some limitations:

- The objects must be presented in exactly the same way every time, in both position and orientation. Earlier operations in the process must make sure that objects are presented correctly.
- Objects must have similar properties, including size, shape, weight and grasp features. This limits the operation as it means that robots must be reprogrammed (or at least a different program must be selected) to handle a batch of different objects, even if the operation itself is the same.
- Objects must be provided in a fixed location (e.g. a tray or pile) or provided at a known, regular frequency (e.g. placed at equal spacing on a conveyor).
- Objects also need to be dropped off in the same location, even if they are different.

There are a variety of ways that additional sensors could help to improve the flexibility of a pick and place operation. Two good examples are vision sensors and part placement sensors.

Vision Sensors

Vision sensing systems can be simple and relatively cheap, or they can be highly complex and expensive. The basic advantage that they provide for pick and place operations is the ability to handle objects presented in less structured ways and differentiate between objects. There are many types of vision system, but two examples are:

- **2D Wrist-Mounted Vision –** This involves installing a camera to the end of the robot's arm, such as the Robotiq Wrist Camera. This approach gives the robot the ability to detect what it is grasping and orient the gripper towards it. The software can be trained to recognize objects, usually by means of a template of the object's shape. This would allow the objects to be presented in different orientations. It also allows the system to differentiate between two or more object types, assuming that their template shapes are sufficiently different. The robot could then place different objects in different drop-off locations.
- **3D Top-Down Vision –** This involves mounting 3D vision sensors above the pick-up location. When an object is detected under the sensor, the robot moves to that position and picks it up. A popular type is to use laser scanners to extract a 3D depth image. The data can be matched to a simplified version of the object's CAD model, which can allow the robot to pick up the object from any orientation. Some systems of this type allow you to present objects in an unsorted bin, which means you don't have to arrange the objects before presenting them to the robot. Download our previous eBook for an introduction to the task of bin-picking.

Part Placement Sensors

There are many types of part placement sensor, ranging from simple press-button switches to laser light curtains. They allow your robot to detect when a part has arrived into its workspace. This can be a very simple and effective way of improving your robot's flexibility, without having to use vision systems. Two advantages of using part placement sensors are:

- **Detect when an object has arrived.** Part placement sensors give the robot the ability to detect when a new object has arrived. If there are no new objects, the robot can be programmed to carry out other tasks or, at the very least, stop moving and so avoid putting itself into a fault state. When a new object arrives, it can stop what it's doing and pick it up.

- **Solving the conveyor belt problem.** Conveyor belts often present challenges because they require the robot to pick up moving objects. Without an additional sensor, the parts must be placed at very regular intervals or the system can go out of sync. Part placement sensors allow the robot to detect when an object is passing, so improve the system's flexibility for irregular placement.

Example 2: Polishing and Dispensing

These tasks involve tracing a path whilst maintaining a force on the material. Polishing often requires the robot to hold a rotary polishing tool and move it back and forward across the material to shine the surface. Dispensing (of glue or other adhesives) is a similar task but often with more complex paths.

The basic way to use a robot for such tasks is to program it point-by-point using a teach pendant, which is generally reliable and effective. However, this approach has a few disadvantages, including that:

- It makes programming quite a long process, as the robot must be driven from point to point using the arrow buttons on the teach pendant.
- It means that the robot is only able to operate on a part which is placed in exactly the same position as when it was programmed. If the part moves, areas of the material surface may remain unpolished or there may be inaccuracies in the glue line.
- If the parts have been assembled incorrectly, the will operate on them anyway and may produce non-conformities.
- Simply following a planned path, with no force sensing capability, may result in a variable quality of the polishing across the material surface or inconsistent gluing.

There are several ways that sensing could include improve the performance of these applications. Here we will look at the impact of two different sensor types: force sensors and safety sensors.

Force Sensors

Adding a force sensor, such as the FT300, to the end of the robot arm will open up the possibility to perform tasks which require information about interaction forces. Two possibilities are:

- **Hand Guiding** – Hand guiding is applicable to both polishing and dispensing tasks. It allows you to program the robot by holding the end effector and physically moving it around by hand. The force sensor detects the forces which you apply and the robot moves as a response to this force. As you can see in this video of the Robotiq ActiveDrive toolbar, hand guiding allows you to program the robot much more quickly and intuitively than with a teach pendant alone. Imagine how arduous it would be to program the complex dispensing path shown in this video with a traditional teach pendant and compare it with the simplicity of hand guiding.
- **Force Control** – Force control allows you specify the interaction forces that the robot applies onto the parts. The robot will apply a constant force rather than simply following a pre-programmed path. This allows the robot to correct for inaccuracies in both part placement and tolerances, resulting in better quality buffing or a consistent glue line. In this video from Universal Robots, you can see how manufacturers Paradigm Electronics used the in-built force sensing provided by the UR10 robot for a consistent quality polishing task. An additional force sensor would be required for robots with no in-built force sensing or for more precise force control.

Safety Sensors

There are a variety of different safety sensors, which we will cover in more detail in the next section. Light curtains are a popular example. They allow you to section off the robot's workspace, either all of it or part of it, without putting up fencing as you would have done in the past. Consider how much safety fencing is required for the traditional industrial in the Universal Robots video introduced above compared with the collaborative robot. Light curtains are much less intrusive than fencing and allow a very flexible way to ensure safe zones. When a human worker passes through the light curtain, the robot can be programmed to respond in an appropriate way. Two possibilities are:

1. **The robot halts** – Halting the robot as soon as somebody enters the workspace helps to avoid injury. This is a requirement for some robots, especially those which are not designed to be inherently collaborative. Although additional safety sensors may not be required for collaborative robots, they can still be beneficial. Some parts of the task may be more dangerous than others, e.g. when the robot is using power tools. By implementing a halt mode for dangerous parts of the task, you can use the same robot for task sequences containing both collaborative and non-collaborative parts.

2. **The robot slows down –** Light curtains and other safety sensing also allow more sophisticated controlling of safe zones. With safety fencing, there were only two operation modes: when the door was open the robot stopped; when it was closed, the robot could operate. Safety sensors allow you to define safe zones which triggers different behaviors when someone enters them, e.g. an outer zone, where the robot merely slows down, and an inner zone, where the robot stops completely.

Using safety sensors for this type of advanced safe zone manipulation is called speed and separation monitoring. You need to specifically address this in your collaborative robot risk assessment. We won't be covering the risk assessment process in this eBook but you can find all about it in our dedicated eBook "Collaborative Robots: Risk Assessment, An Introduction."

Hopefully these examples have helped you to start thinking about what possibilities there might be for adding sensors to your own application. In the next section, we'll look more deeply at some popular sensors for collaborative robots.

THE TOP 4 SENSORS FOR COLLABORATIVE ROBOTS

There are a lot of potential sensors which you could add to your robot. However, some sensors are more common than others. Many interesting robot sensors are still at the research stage, which means that they don't yet have reliable industrial versions. In this section, we'll introduce four common sensors which can add some great functionality to your collaborative robot right now.

These are:

- Vision Sensors
- Force Sensors
- Safety Sensors
- Part Detection Sensors

VISION

If we had to pick one sense which has the potential to most drastically improve the flexibility of your process, it would probably be vision. Properly implemented, robotic vision can remove some very important limitations of a robot. However, with this flexibility also comes complexity. Vision systems are getting easier and easier to use, but even so they tend to require more programming than just using the robot alone.

Robotic vision is available using several different technologies. Each technology works in quite a different way to human vision. Although this might seem a bit of an obvious thing to say, it can be easy to forget when you are in the middle of designing a vision process. It's important to remember that your own sense of vision is altogether more superior than any sensor, in terms of the flexibility at least.

Your eyes, head muscles and the visual cortex in your brain give you a very adaptable vision processing system. In contrast, robotic vision sensors are generally only good at one specific thing. Therefore, you should consider which vision sensor (if any) to integrate into your robot before making a purchase. Choosing the wrong type might end up causing more problems than it solves. On the other hand, choosing the correct type has the potential to revolutionize your process.

Benefits of adding Vision Sensors

Some of the many benefits of adding vision systems to a collaborative robot are:

- Allowing a robot to manipulate different parts without reprogramming in between
- Allowing the robot to pick up objects of unknown position and orientation
- The potential for the vision system to perform quality control checking
- Tracking of barcodes and QR codes
- Correcting for inaccuracies in the placement of the robot itself
- Simplifying costly fixturing, or removing it completely

Challenges of adding Vision Sensors

Of course, even if the sensors have been designed to be easy to use, there are some challenges of adding vision systems.

For example:

- More programming and expertise required to integrate the sensor.
- Complex calibration as the coordinate systems must be aligned between the robot, vision sensor and real-world.
- Lighting conditions of the environment can heavy affect the visual recognition.
- New challenges arise regarding physical restraints of the system, e.g. the vision sensor may be able detect parts in orientations which the robot can't manipulate or which cause physical collisions between the robot and edge of the bin.

Have you already got a vision sensor?

Some collaborative robots already have integrated vision sensors. Examples include Baxter from Rethink Robotics (or its smaller cousin Sawyer) and ABB's YuMi robot. These both include cameras in the robot's hand, which is one good option for placing your vision sensor.

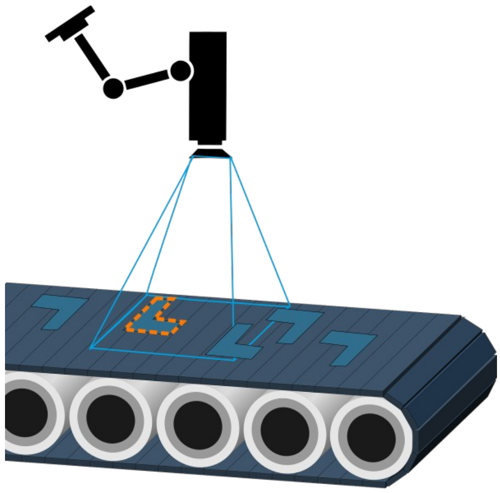
If your robot already has a vision sensor then it makes sense to use it, rather than buy an extra sensor. It will almost certainly be better integrated into the control of the robot, and therefore easier to set up. However, there are still situations where an additional vision sensor might be worthwhile. For example, adding a fixed, overhead 2D vision system would allow the system to detect objects while the robot is working in another part of the workspace, reducing the cycle time.

Types of Vision Sensor and What They're Good For

One way of considering machine vision (although not the only way) is to split it into two separate types: 2D Vision and 3D Vision. Each of these has its own application areas. Some examples are listed below:

Fixed 2D Vision

Fixed 2D Vision is very common in manufacturing industries. You can almost certainly think of some potential applications for your process. It involves a simple, fixed digital camera which is aligned so that objects pass through its field of vision. For example, the sensor may be placed rts, which the robot then picks up (as in this video).



A typical 2D Vision setup

3D Vision

3D vision systems are becoming increasingly more available, because technology keeps improving and prices keep falling. Several manufacturers now provide 3D vision systems especially for robotics, which often involve a combination of lasers and 2D cameras. The "classic application" is bin-picking, which allows you to place a pile of objects in front of the system, which will be able to detect the parts in any orientation for the robot to manipulate (as seen in this video). However, 3D vision can also be used for object tracking, product profiling and other applications.

There are three main technologies for 3D vision:

- Laser scanners
- Stereo cameras
- A combination of the two

In general, the advantage of 3D vision is that it provides even more flexibility, partly because it allows you to view multiple faces of the object. Also, laser 3D vision usually allows more accurate defect checking than camera based options. However, the biggest challenge s are its complexity and high cost. It requires more programming knowledge to integate

Wrist Mounted 2D Vision

A third vision option is to install a 2D camera to the robot's wrist. For some applications, this can be thought of as a "best of both worlds" between 2D and 3D vision, as you can simply move the robot to get a different view of the object. Some considerations of wrist mounted 2D vision are:

Robotiq Wrist Camera with integrated lighting

- This adds more flexibility than a fixed 2D camera by giving multiple views with only one camera, so is far more economical than a 3D vision setup.
- Programming can be more complex than for a fixed camera, as the position of the robot must be considered to integrate multiple views. However, programming can be made simpler by always moving the robot to the same position for detection.
- Combining multiple 2D views into one 3D model is possible, but very complex so it is advisable to use 2D vision techniques with a wrist mounted camera.
- Can be used as a part detection sensor, though only if the robot is not required to simultaneously be working in another part of the workplace.
- Removes issues of occlusion caused by the robot arm itself.
- If the sensor includes a light source, it can drastically reduce the issues caused by environmental lighting.

The challenges for integration of a wrist mounted camera are reduced by using a pre-integrated solution. For example, the Robotiq UR+Camera is a package which extends Universal Robots with a Robotiq Wrist Camera. This allows you to easily include a 2D camera with integrated light source into your UR robot.

2D Vision vs 3D Vision

On the next page, we provide a breakdown of some of some differences between the two basic approaches to robotic vision systems. These are just meant to be a rough guide and are not applicable to all commercial options. Some of the software provided by integrated vision systems are quite advanced and can overcome the basic limitations of the technologies.

	2D Vision	3D Vision
Flexibility	Makes part presentation much more flexible. Removes the need for complex and expensive fixtures or positioning devices.	Potential for even more flexibility as objects can be presented in a more or less unsorted way. The complexity of programming increases also.
Object Detection	Can be programmed to differentiate between parts by 2D template.	Can match objects to their 3D CAD shapes to detect orientation.
Non-conformity Detection	Basic non-conformities can be detected in one plane – the focal plane of the camera. By using a wrist mounted camera, you can extend this to multiple faces of the object.	Conformities in more planes can be detected, as 3D points are matched to the CAD model. Not usually a substitute for a dedicated system if accurate detection is required.
Object Presentation	Object must be already orientated and laid out flat for the robot to detect them.	Bin picking has the potential to allow presenting objects unsorted in a container, but may not yet be as robust as 2D.
Cost	A single 2D camera can be quite reasonably priced, with more advanced or accurate systems increasing in price.	More expensive than 2D Vision, particularly when multiple vision sensors are needed by the setup.
Programming	Some systems can be very straightforward, with graphical interfaces and using a simple click-and-drag to define object templates.	Getting easier, but generally involves more programming. At least a good grasp of CAD programs is required.

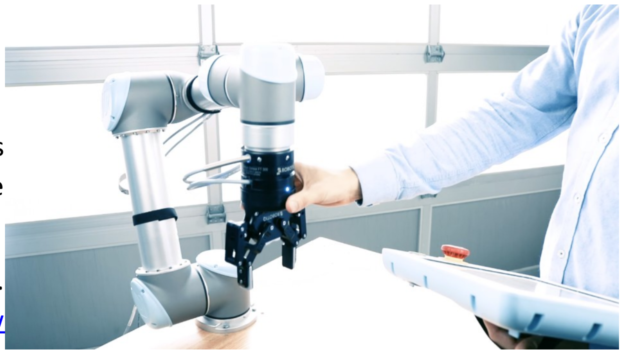
A useful webpage to check out is the Fanuc IR Vision page, which has a selection of downloadable videos demonstrating some of the different applications of various vision technologies.

FORCE SENSING

Force sensing allows you to improve the robot's performance on tasks which involve physical contact. Several important manufacturing applications can benefit from it, including deburring, finishing, assembly and product testing. The sensors are usually attached on the end of the robot's arm, before the gripper or other end effector.

Force sensors are also a key component in one of the most useful applications for collaborative robots – hand guiding. This is where the operator teaches the robot a movement by holding its end effector and physically moving it around the workspace.

Benefits of adding force sensors



Hand guiding is a very intuitive way to program collaborative robots.

- Improved control in contact tasks.
- Better quality in contact tasks, as the robot does not apply excessive force to objects or the environment.
- Possibility to hand-guide the robot to teach it. See the video of our ActiveDrive system for how to hand-guide collaborative robots.
- Introduces capability to correct for some part placement and fabrication inaccuracies.
- Can be straightforward to install and use, if the sensor has been pre-integrated with the robot.

Challenges of adding force senors

- Requires more programming and advanced control techniques.
- May not be necessary for some applications, so could add cost and complexity without extra value.
- Could reduce the payload capacity of some robots as all force sensors have a maximum force rating.

We won't cover Force Sensors further in this eBook because we already have a whole series of eBooks and other resources devoted to them. If you're interested in finding out more, you can download the eBooks for free by clicking on the following links:

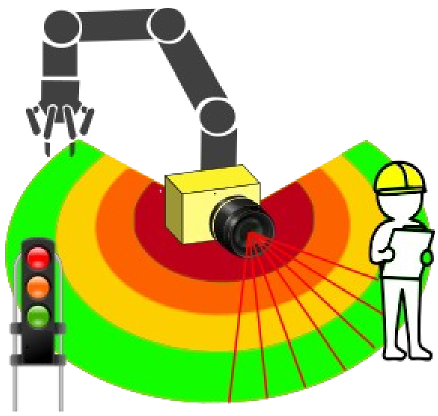
Force Sensors: An Introduction – This provides the basics of force sensors for robotics.

Force Sensor Programming and Support – This is our online guide and instruction manual for the Roboiq force sensors. It includes plug-and-play programming interfaces for Universal Robots and our ROS package.

Force Sensors in Robotics Research: The Essential Guide – This is our advanced force sensor guide for robotics researchers. It might be too much information, but could be useful if you use robots for R&D work.

We also have some great supplementary information about force sensors on our blog, including: 5 Reasons You Should Use Force Feedback in Robotics, Tactile Sensors and Force-Torque Sensors: What's the Difference?, How Do Force Sensors Work? and Electronic Assembly Using Force Sensing.

SAFETY SENSORS



Unlike the previous two senses, safety sensors don't add extra capability to a robot. Instead, they help to ensure that a robot is not a danger to human workers. Collaborative robots are designed to work alongside humans, so you might think that safety sensors are not necessary. It is certainly true that safety sensors are not as vital as with traditional industrial robots. However, they can still be beneficial to your collaborative robot application.

One of the most relevant categories of robotic safety sensors is presence or proximity sensing. These allow the system to detect when someone, or something, has entered into a particular part of the workspace. Some sensors, such as safety mats, require that the person makes contact with the sensor whilst others are non-contact. There are a wide array of presence sensing technologies, including infrared light curtains, ultrasonic and photoelectric sensors, and even laser vision technologies, like those we introduced above.

Benefits of Adding Safety Sensors to Collaborative Robots

The benefits of safety sensors are not simply that they improve the safety of the system. These sensors can also help to improve the performance of the robot. Some of the benefits are:

- Allow the robot to be run at higher speeds when there are no humans in the workspace (see the speed monitoring video in this blog post).
- Allow the system to react to obstructions in the workspace, avoiding damage to the equipment.
- Can contribute to a lower risk of the system, allowing it to stay within acceptable overall limits.
- Has the potential to reduce the floorspace required for the robot compared to traditional fencing.
- Allows you to use the same robot for both collaborative and non-collaborative tasks.

You can only use safety sensors for speed and separation monitoring, if you have carried out a risk assessment to demonstrate that it is safe to do so. Our eBook "Collaborative Robots: Risk Assessment, An Introduction" takes you through the correct process to do this.

Challenges of Adding Safety Sensors to Collaborative Robots

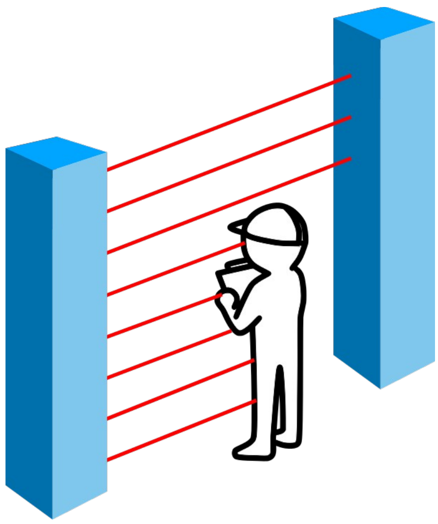
Compared to more complex sensors like vision, safety sensors are generally simpler to integrate into a system. However, there are still a few challenges when using them with collaborative robots, including:

- Detection is dependent on the size of the object being detected, so smaller objects could be missed.
- Some materials, such as thin metal, can't be detected by some sensing technologies.
- Material in the surrounding environment and airborne pollutants can affect some sensors.
- Proximity sensors placed too close together can interfere with each other.
- Some sensors could potentially restrict the collaborative robot to one area.

Types of Safety Sensor

There are several types of safety sensor, but here are some of the most common:

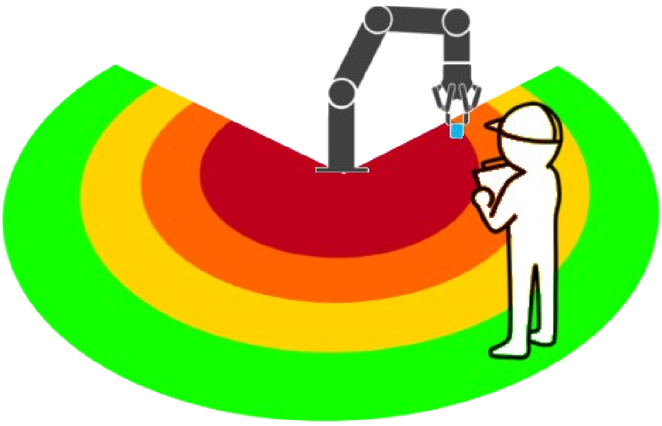
- **Light Curtains** – These are the sensor equivalent of traditional safety cages. They include multiple transmitter modules which transmit beams of light to receiver modules. The sensor detects entry into a restricted when one or more beams are broken.



Light curtains detect when a person or object has entered an area.

- **Safety Mats** – These pressure sensitive mats are laid on the floor of a restricted zone and detect when someone stands on them.
- **Perimeter/Edge Guards** – These are strips of pressure sensors which are often attached to moving parts, such as mobile robots. They detect when a collision occurs.
- **Single Beam Lasers** – These contain a single pair of transmitter and receiver modules, with a laser beam between them. They detect when the beam is broken.
- **Laser Scanners** – These use a scanning laser which builds up a 3D image of the workplace. They are basically the same technology as is used in 3D vision, but instead of detecting objects they only detect when things have moved into the workplace.
- **Protective Robot Skin –** Some collaborative robots, such as the FANUC CR-35iA Green robot have a sensorized outer skin which acts as a safety sensor. The robot stops when the skin collides with something. Such sensors come as an optional extra for some robots, e.g. the KR5-SI from MRK SYSTEME has an optional padded cover with tactile sensors.
- **Camera-based Safety Sensors –** Just as 3D vision systems can be achieved with both camera and laser technology, so too can safety sensors. These allow 3D zone monitoring using two or more calibrated cameras.

As with the other sensors in this book, various different technologies are used as safety sensors. There are also quite a lot of manufacturers, so do shop around before deciding to make a purchase. A few useful resources from manufacturers are: the Safety Sensor Selection Flowchart from Rockwell Automation, the Omron Safety Sensor Catalog (which includes some good illustrations), the Banner Engineering Photoelectric Sensor Selection Tool, and the various technical guides from Keyence.



Using sensors allows you to set distinct regions of the workspace, e.g. to slow the speed of the robot as the human worker gets closer.

How to See Safety: Robot visualization technologies

One of the most challenging things about working alongside robots is that you don't necessarily know what a robot is going to do next. Humans are social animals, so we are quite good at predicting a fellow human worker's intentions. With robots we don't have such information.

Therefore, it is worth briefly mentioning visualization technologies. These allow you to display the state of the robot in an intuitive way. A classic example would be a lightbulb which turns on when the robot is operational. However, this is a hugely simple example and there are now more advanced options. Programmable LED tower lights are one good option. They are multi-colored and can be used to display the status of safety sensors or to indicate the operating mode of the robot. Some also have audio alarms.

The potential of visualization technology can be quite powerful, even though the technology itself is very simple. [This video]() gives a good demonstration of coupling advanced presence sensing with visualization for a large industrial robot. It's from a research application, so unfortunately doesn't show a current industrial product; however, you'll admit that the potential is quite intriguing. You could achieve a simpler version of this with a set of well-placed tower lights.

Risk Assessment: Reducing Risk and Improving Performance

Risk assessment is a fact of life when working with robots. Even though collaborative robots are designed to safely operate alongside alongside humans, you still have to complete a risk assessment when using them. Safety sensors can be a good way to reduce the risk of working with a robot without decreasing performance. By using safety sensors for speed and separation monitoring, you can also sometimes use an industrial robot for collaborative tasks.

We have published a whole eBook which goes into detail about how to perform a risk assessment for collaborative robots, which we've updated recently to include the ISO/TS 15066 standard. You can download a free copy of the eBook by clicking on this link.

However, reducing risk is not the only benefit of including a safety sensor. It may also allow you to improve the performance of the robot. This is particularly true when concerning the robot's top speed. For example, FANUC's CR-35iA robot is rated with a maximum speed of 250 mm/s . However, when you add safety sensors this increases to 750 mm/s. When no human is near, the robot can move at higher speeds.

How valuable would it be for your business if your robot could be safely run 3x faster?

PART DETECTION SENSORS

The fourth and final sensors which we will cover here are part detection sensors. These are some of the simplest sensors available for industrial robots and are used extensively in automated factories. As the name suggests, they detect whether or not a part has arrived at a particular location. Some of them also allow basic part identification, e.g. by color or reading labels.

Thanks to their simplicity and relatively low cost, part detection sensors can be a good choice as a first sensor to add to your collaborative robot. However, their simplicity also means that they are not as flexible as other sensors, particularly vision which shares some technological similarities with part detection.

Benefits of adding Part Detection Sensors

There are several types of part detection sensor and each will have different benefits, e.g:

- Gives the robot capability to detect when a part is ready to be picked up.
- Allow better monitoring of objects going through the process.
- Can improve the efficiency of the robot and its operations by ensuring it does not execute a cycle of the program when no object is present.
- Some sensors can be integrated with safety sensors, to allow objects to enter a safe zone without reducing safety.
- Can be used to identify and track objects going through the process.

Challenges of Adding Part Detection Sensors

The challenges associated with part detection sensors also vary depending on the sensor technology. Some examples are:

- Integration of most part detection sensors is unlikely to be plug-and-play for collaborative robots, as they have traditionally been used in full automation.
- Each sensors can be affected by different environmental conditions, including lighting, temperature, humidity and noise levels.
- Sensors which rely on reflected signals (e.g. light, ultrasound, laser, etc) are unsuitable for some material properties. For example, infra-red sensors don't deal well with dark surfaces and lasers can be sensitive to highly-reflective surfaces.
- As with safety sensors, these are usually installed in fixed locations, which means that their use may limit the robot to one area.
- Most sensors can only reliably detect one property. If you need to detect multiple properties, several sensors would be required. In this case, more flexible options (e.g. vision) could turn out to be a better investment.

What Can Part Detection Sensors Detect?

There are a vast number of different part detection sensors available. Thanks to their wide use in industrial automation, you can probably find the perfect sensor to suit any object, and property, that you might want to detect. A few of the possibilities are:

- **Presence** – A popular application is to use sensors to detect if an object is present or not. Using the same sensor, you can then use the information to count objects passing through the process.
- **Distance and position** – One step up from presence is to detect the distance of a part from the sensor in one or more dimensions. A useful application is to install the sensor above a pile of objects, allowing the system to detect how many objects have been removed or added.
- **Color** – Some sensors can differentiate basic colors. This can be useful for part identification purposes.
- **Shape** – As with color, shape identification is useful for detecting different parts.
- **Orientation** – Several of the technologies can be used to detect that objects are oriented correctly. This can be useful to ensure that objects are flat so that they can be picked up by the robot.

Part Detection Technologies

The technologies you can choose range from the very basic (e.g. a mechanical switch) to quite complex (e.g. using 3D scanners to differentiate parts). In fact, any of the technologies already mentioned in this section could be used as a part detection sensor. We're going to focus on the some of the basic options, as we have already introduced the advanced options above. In the vision section Some popular technologies include:

- **Photoelectric sensors** – These use LEDs of either infra-red or visible light. A transmitter unit emits the light and a receiver unit detects it. Some systems include both parts as a single unit, with the object used as a reflecting surface for the light beam.
- **Ultrasonic sensors** – These use high frequency sound waves to detect objects in a similar manner to some photoelectric sensors, i.e. by bouncing off the object and detecting the reflection.

- **Laser sensors** – These use laser light instead of visible light. They are correspondingly both more accurate and expensive.
- **Inductive sensors** – These emit electro-magnetic fields and detect the changes in the field caused by metallic objects. They can be used to detect presence and measure the distance or position of objects.
- **Capacitive sensors** – Similar to inductive sensors, these allow non-contact detection of objects. They have the benefit that the objects don't have to be metallic, as they do with inductive sensors.
- **Magnetic sensors** – These are used to detect magnetic fields and have a longer range than inductive sensors. As they only detect magnetic fields, they are often used in conjunction with magnets, which are attached to objects.
- **Mechanical sensors** – Switches are possibly the simplest part detection technology. They require an object to make direct contact with the switch but are reliable and precise.

WHAT AFFECTS A SENSOR INTEGRATION

We have now seen how different sensors can impact your process. Hopefully you will now have a better idea whether adding an extra sensor is right for you, or your client. In this section, we're going to briefly introduce some of the considerations for integrating any new sensor into your application. Of course, every sensor is different and to list all the best practices for integrating all the sensors we've mentioned would make this into quite a long eBook. Instead, we'll introduce the two main concerns for integrating any sensor.

WHAT AFFECTS A SENSOR INTEGRATION?

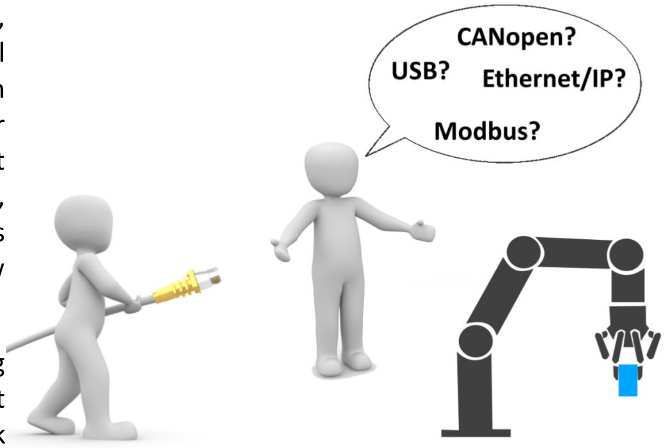
The main two factors which affect integration of a sensor into your robot are:

- The communication options of the sensor and your existing robotic system
- The programming capability of you and your business.

The former of these is fairly straightforward and should be part of your decision process when choosing a sensor. The latter is more complex and really depends on the expertise available to you and your business.

COMMUNICATING WITH A ROBOT SENSOR

Just as there are many different types of sensor, there are also many options for the physical interface. Some sensors have multiple connection options whilst others are more limited. Whichever sensor you choose, you will have to integrate it with the rest of your robotic system. Therefore, you should consider the communication options right from the beginning of your search for a new sensor.



You can think of sensor connections as having three different levels. In reality, this is a bit simplistic as the OSI model of network communication, which you can read about in our article on Industrial Robot Communication Protocols and Communications Protocol Structures & Models. However, three levels is a clearer way of thinking about it for our purposes in this eBook:

- **The physical layer** – This usually means wiring, although wireless options are on the horizon for some sensing technologies.
- **The communication layer** – This relates to how the sensor "talks" to the controller. There are a lot of different options but usually the sensor itself will limit you to a few.
- **The software layer** – This determines how the rest of your software talks to the sensor. Some sensors (e.g. safety sensors) don't traditionally need a high-level software layer. However, because we are interfacing with robotics, it will be necessary to integrate the sensors at the software level.

The physical connection and communication protocol are highly related. In some cases, one will determine the other. However, this is not always true and the protocol is often independent from the physical cabling.

The Physical Layer

The number of different physical connectors in the world is staggering. Thankfully, the automation industry has gradually converged on some standard connections. These define the physical connection itself and the low level electronic properties of the connection. Three common options are:

- **M8/M12** – These have come to be the standard connector for industrial automation and have the advantage that they keep foreign particulates (such as dust and water) out of the electrical connections. They were traditionally screw fixings, but some manufacturers moved to quick release bayonet locks. A lot of the sensors which originate in industrial automation (such as part detection and safety sensors) will have this type of connector.
- **CAT 5 / Ethernet –** The internet is built on Ethernet cables and some sensors will have an Ethernet option. This can be useful to integrate the sensor directly into an existing Local Area Network.
- **USB** – Although M12 might be the standard connector for industrial automation, USB has become the standard connector for the wider world. Therefore, it is quite common to find sensors which come with a USB option

There are also many other connector types, including RS485, Fiber optic, TTL, 2-wire, etc. There are far too many to go into detail here, but for further information you can check out our blog posts on RS485 vs Ethernet, there are often ways to convert between connector types if you are using a different one from the options provided by the sensor.

The Communication Layer

Above the physical layer is the communication or protocol layer. Here are some of the possibilities for the connector types listed above:

- **TTL** – This refers to the low level transistor signal (i.e. the 1s and 0s). It is more common for use with M8/M12 connectors or even simply screw terminals. Security sensors will often provide output at this level, as the lack of higher level protocol allows less room for error.
- **Modbus** – Modbus is the de facto standard for PLC communication. It is easy to implement and widely used.
- **CANopen** – The CANopen protocol is very common in the automation industry and determines the network protocol between devices.
- **DeviceNet** – This is a network system which is used to connect control devices in automation. It is a proprietary protocol which is managed by the Open DeviceNet Vendors Association.
- **EtherCAT** – This protocol was invented in order to use the Ethernet protocol for real-time applications.
- **Ethernet/IP** – Like EtherCAT, the Ethernet/IP was invented to allow the use of the Ethernet protocol in industrial applications. Read our blog post on Ethernet/IP for a more in-depth explanation of it.

You can see that there are many options, and there are even more than the ones listed. We have several dedicated articles about the different communication protocols used in industrial robotics, including What are the Communications Protocols Used in Industrial Robotics, Robot Gripper Communication Protocols, It might seem like there are too many options. However, it doesn't need to be overwhelming. As you probably have a robotic system already, the most important thing is to make sure the sensor is compatible with your existing robotic system. You can use the following process to reduce your options:

1. List all of the connectors and protocols which are compatible with your existing robotic system. Use our Robot Communication Cheat Sheet to see which protocols are supported by each robot brand.
2. List the communication options which are available for any sensors you are considering.
3. If a sensor does not have a suitable connection option, there may be ways of converting to another connector type or protocol. However, this could potentially decrease the performance of the connection, so make sure to consider this also.

DON'T FORGET THE POWER!

Communication is not the only connection you need to consider. Sensors often require external power, which can produce lots of cabling if you're using many sensors together. Some communication options (e.g. Power over Ethernet) allow you to power the sensor using the same cable, but often this isn't an option.

PROGRAMMING WITH A SENSOR

The final consideration when incorporating a sensor is to integrate it into the programming of your robot. Adding any extra sensor will add complexity to the control logic of your programming.

A lot of the collaborative robots are self-contained and allow for simple programming without much extra hardware. Some sensors might require that you add hardware in order to be able to program them, such as computers. You may already have these available, but you might also need to purchase them which would increase the price of the system.

The following table gives considerations for some lower and higher levels programming options.

Factor	**Low-level programming (complex)**	**Higher-level programming (simpler)**
Provided Software	No software provided, only data about the signals the sensor produces.	Integrated software solution, possibly with graphical interface.
Training required	If no expertise is available in-house this is likely to require an external integrator or more involved training.	The training for integrated software packages may only take a few hours.
Integration with existing programming methods (e.g. teach pendant)	Integration will probably have to be performed by an experienced programmer, and may not be flexible to much reprogramming by others.	Some sensors have been pre-integrated with teach pendants and other programming methods, so programming can be carried out easily.
Change of setup	Likely to involve an integrator and reprogramming of the system.	Depending on the sensor and software, this could be quite a simple task.

USING THE MANUFACTURER'S CONTROLLER

Often, industrial sensor manufacturers also provide controllers for their sensors. These make programming of the sensor much easier than if you were to just try to integrate the sensor alone.

Although most sensors will be usable without using the manufacturer's controller, choosing to use it may make the programming less complex and therefore reduce the integration and training time. If you do choose the manufacturer's controller, make sure that it can communicate with your robot controller.

Like everything, this is a balancing act: Does it make more sense to integrate the sensor directly into the robot's controller (if that's possible) or to use the controller from the sensor manufacturer?

SHOULD I HIRE AN INTEGRATOR?

If you have read through this eBook and decided that you want to integrate a new sensor into your robotic system, you have two options.

- If you have enough technical expertise available in-house to integrate your chosen sensor technology, you will be able to go ahead and begin the integration.
- If your business does not have the required expertise, you will either have to hire an integrator or look into extra training. In this case, remember that the more low-level of electronics required for the integration, the higher level of training will be required.

If you are an integrator yourself, then you will know your own technical expertise. If you have read this eBook and decided that you want to offer more sensing solutions to your clients, you will know if you need to seek further training to provide that service.

WHAT'S NEXT?

Once you have added a new sensor to your robot, and seen the many benefits it provides, you might be tempted to add even more sensing capability. If so, remember that imaginary point of "maximum flexibility" which we talked about at the beginning. Will adding yet another sensor impose restrictions on your robotic system? If not, go for it!

If you found this eBook useful, remember to read through it again in future if you're considering a new sensor for your robot, and please pass it on to any of your contacts who you think could also benefit from this information.

HOW TO GET YOUR FREE RESOURCE EMAILS

This eBook is accompanied by a free “mini-series” of emails packed full of great resources to help you choose and implement new sensors for your collaborative robot

If you downloaded this eBook from the Robotiq website then the emails should be coming to your inbox any time soon.

However, if you found this eBook elsewhere online, or were passed it by a friend, don't worry. You haven't missed out!

Just follow the link below and enter your details to receive your emails.

Download Adding Extra Sensors: How to Do Even More With Collaborative Robots

WHAT'S IN THE FREE, 3-PART EMAIL SERIES

Here's what you'll get in these emails. They are packed full of practical steps which you take, to make it easier to decide if a new sensor is right for you and your business (or your client’s business).

Does Your Robot Need an Extra Sensor?

In this email, we provide some practical steps you can take to decide if a new sensor is right for your collaborative robot application.

Which Robot Sensor Is the Best for You?

So, now you’ve decided that you want to integrate a new sensor, which one should you choose? In this email, you get a practical guide you can use to decide which sensor is the best to solve your issue.

How To Get the Team On Board With a New Sensor

You’ve decided the best sensor for your application, but you’re not the only stakeholder, right? In this email, we go one step further and help you to get the team on board with your proposal.

LET'S KEEP IN TOUCH

For any questions concerning sensing or if you want to find out how you could integrate extra sensors into your application, contact us.

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WHO ARE WE?

Robotiq exists to free human hands from tedious jobs. The fast-growing company designs and manufactures advanced robot grippers and force torque sensors. Robotiq is based in Quebec City, Canada. It works with a global network of highly capable local partners to solve flexible automation challenges in more than 30 countries.