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Developing flexible future-proof laboratory instrumentation

Automation-ready design principles

Automation has become a vital tool for many laboratories as they look to increase productivity as well as deliver improved data reproducibility and results. This means it is particularly important for Product Managers of laboratory instruments to consider the requirements of an automated workflow (i.e., integrated with a robotic mover) early in the product creation process. Creating automation-ready instruments provides customers the flexibility to react to an increased throughput or productivity requirement, by ensuring easy integration into an automated workflow approach.

What does it take to create an automation-ready instrument? There are three key areas to consider: The instrument's design and physical interface, the consumables, reagents or labware used by the instrument, and the instrument's software including the Application Programming Interface (API). The top ten considerations within these areas are:

Instrument design

1 **Robustness and reliability**—An instrument used in an integrated system, will usually experience higher usage rates and the consequences of an error are more severe

2 **Physical compatibility**—Nests for loading labware should be designed for easy robotic access

3 **Unattended operation**—Instruments should support the ability to run unattended for extended periods of time

4 **Device access**—Ensure the required user access is maintained if a device is integrated into a larger automated system

Consumables

5 **Consumable compatibility**—For robot loading, SLAS standard plates are recommended

6 **Microplate orientation**—Landscape vs portrait orientation impacts system performance

7 **Reagent supply**—Simple and ergonomic reagent supply to support extended runs

Application Programming Interface

8 **Robustness and reliability**—As with the instrument itself, the robustness of the API is key for reliable communication between the automation platform and the instrument

9 **Full command set**—Commands should be provided for every functionality available on the instrument

10 **Error handling and recovery**—Errors should be handled elegantly, and the device should have the ability to be reset remotely without human intervention

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Top ten considerations

Here we will dive deeper into the top ten considerations for automation-ready instruments and provide guidance for each one. We will share examples of successful implementations as well as potential pitfalls to avoid. For robot access questions we will focus on compatibility with our suite of Thermo Scientific™ movers, although the general guidelines will apply to most robotic movers.

Instrument design

1 Robustness and reliability

Robustness and reliability are critical factors to ensure customer confidence in an instrument and by extension an automated system that incorporates that instrument. As larger and more sophisticated workflows are automated, more instruments are required, increasing the likelihood of a failure impacting the overall system.

The impact of an instrument failure is also magnified when it occurs on an automated system as it will potentially result in the entire workflow coming to a halt. There are mitigation approaches that can be applied, such as adding redundant devices, but these increase the cost, complexity, and space requirements of the automation.

2 Physical compatibility

It is essential that instruments integrated into automation solutions work well with robotic movers. There are a range of movers used in the laboratory and confirming compatibility with multiple movers is recommended. (Note—Any specific measurements given below are for our robotic movers. For other movers, please confirm with the vendor using their specifications).

The most important physical interaction point between an instrument and a mover is the plate nest, or nests. Some key considerations include:

- Nests should be presented in such a way that the mover can approach and exit easily without having to make complex moves. This helps with reliability and mover teaching.
- If a nest presentation is active (i.e., presented to the mover via a drawer or slide) the instrument should be able to present a nest quickly to enable rapid loading and unloading of the device (Figure 1).

Figure 1. The Applied Biosystems™ QuantStudio™ 7 Pro Real-time PCR System shows an active nest. The drawer of the QuantStudio 7 Pro System opens when the robotic mover loads or unloads a plate from the device.

- Multiple nests can be arrayed in rows, columns, or radially. Clearance should be left to accommodate standard gripper fingers (15 mm minimum recommended). If placing nests in columns, be aware of the vertical clearance needed to access locations behind others.
- Nests embedded below the deck surface require more clearance for the robot's gripper fingers when lifting out the plate and can add access time. If the nest must be embedded, ensure adequate access for the gripper fingers to reach down into the nest for lidded/unlidded plates.

- Grippers will require clearance on each side of the plate to make it accessible for the robot. For example, the Thermo Scientific™ Spinnaker™ Microplate Robot requires clearance on each side (15 mm recommended) of the plate, so the gripper is able to access the plate (Figure 2).

Figure 2. The Thermo Scientific™ KingFisher™ Flex System shows the appropriate clearance space for the gripper fingers of the robotic mover to access the plate inside the instrument.

- The use of small monuments placed near the plate corners are the preferred locating feature. Monuments should be no taller than 3 mm and result in a gap of at least 48 mm in between and have a bevel or chamfer of at least 2 mm × 45°. If the monument is taller than 3 mm there must be a gap of at least 63 mm to enable vision teaching workflows (Figure 3).

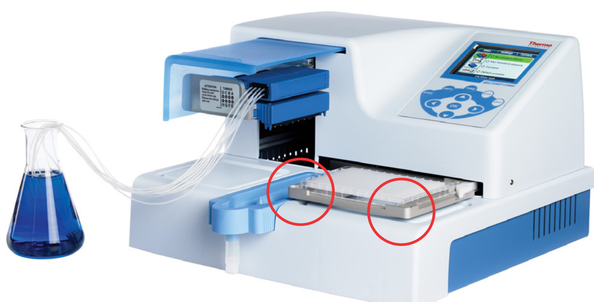

Figure 3. Monuments help secure the plate in place and reduces the risk of the plate shifting. This ensures ease of transfer when the robotic mover is loading or unloading the device.

- Avoid physical mechanisms to locate and/or secure plates in the nest unless necessary as the shift in positioning can cause pick-and-place reliability issues for the mover.

TIP—Vision teach compatibility: The Spinnaker robot is equipped with vision teaching—a convenient, easy, and quick way to teach instruments (Figure 4). For an instrument to be taught with vision, the nest must be accessible for a teach jig to sit for vision capture (see image below). Reflective materials should be avoided, and embedded nests will not be compatible with vision teaching.

Figure 4. The Spinnaker robot performing vision teaching using the smart jig.

3 Unattended operation

One of the major advantages of laboratory automation is the increase in productivity achieved by running systems for extended periods, without human intervention. It is important that any instrument on the system can support continuous operation in such a scenario. This includes being able to schedule any daily maintenance tasks so that they happen during working hours and having the capacity for any consumables used by the device be sufficient to, at a minimum, support an overnight run (14–16 hours). Allowing full automated control of the instrument via an API is also vital to support unattended operation.

TIP—Tracking consumable levels helps users know if the device has enough supply to continue throughout an overnight run.

❹ Device access

When designing an instrument that can be used manually or as part of an integrated system, it is important to consider human access in both cases. Typically, when used on a bench, the plates nest(s), control panel, reagent loading interface will be easily accessible to the scientist standing in front of the device. When used as part of an automation system, the instrument will be positioned so that the robotic mover can load and unload the device. This will have a major impact on how the user is able to interact with the device. There are options to use turntables or slides for some devices depending on size and sensitivity. Some examples are given below:

We recommend working with us directly to discuss device access considerations before a final design direction is decided. Simplified Computer Aided Design (CAD) models can be used to assess the options.

> **TIP**—Don't forget about service access. Considering how service technicians will access the instrument for maintenance and repair is also important.

Figure 5. The QuantStudio 7 Pro as a standalone device is easy for a researcher to access and utilize the special features such as face recognition, the large touch screen, and voice commands.

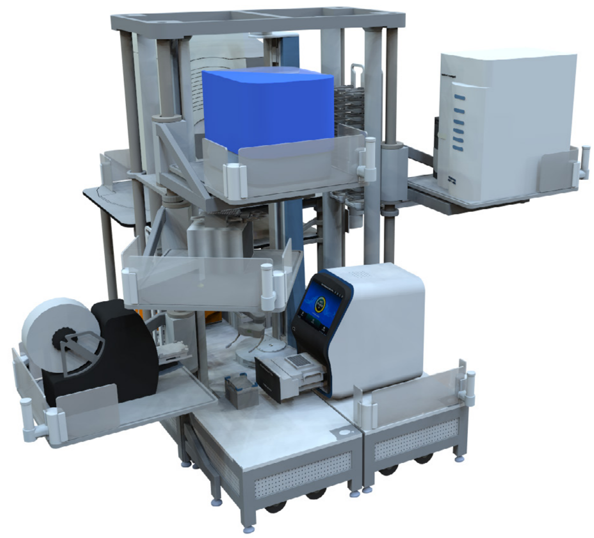

Figure 7. Setup for robotic interaction (online use) with the option for researcher interaction via SmartHandle technology (offline use).

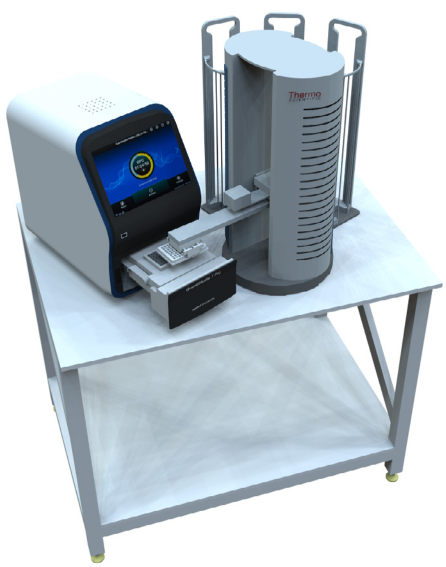

Figure 6. Easy access for researcher and robotic interaction. The researcher can still utilize most of the QuantStudio 7 Pro features.

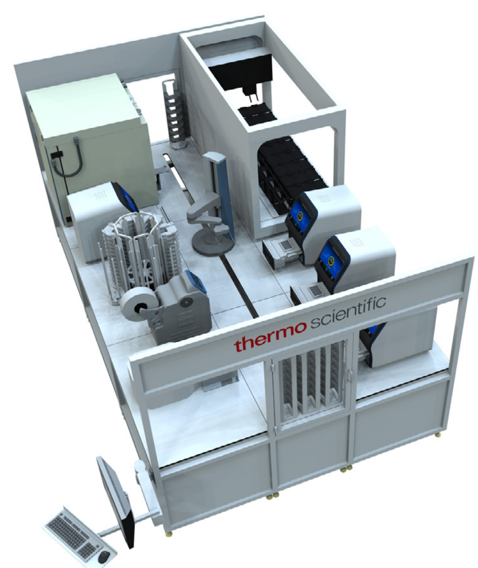

Figure 8. Setup for robotic interaction and continuous automated use.

Consumables

5 Consumable compatibility

The Society for Lab Automation and Screening (SLAS) has developed microplate standards. As directed by the American National Standards Institute (ANSI), the five standards developed should be adhered to as a standard for the industry.

It is important to test the instrument with a broad range of consumables that will be used. Multiple batches of microplates should be included in the testing to account for variation between lots. Common issues include:

- Bevels: Angled plate walls are difficult to grip. This can be overcome with special fingers, provided that the plate has locater features (aka “dimples”). The plate can be grabbed at these specific locations, but this limits the ability to pick the plate from a different position.
- Flanges: Flanges change the thickness of the plate at different points of elevation requiring multiple grip positions (or offsets). ANSI/SBS 3-2004 specifically allows for interruptions in the flange height, which can make setting the grip position for a mover more challenging.
- Flexing: Many plastics are semi-rigid, allowing the plate wall to flex and bow without reinforcement. This is allowed under the standard, which “does not imply any preferred or required construction” (ANSI/SBS 1-2004). Even a small variance, however, can cause plates to slip or pop out.
- Skirts: Some plates have indents or pushouts on the skirt that cannot be gripped. While most plates sit on the skirt rather than the well bottoms, many PCR (Polymerize Chain Reaction) plates for use in thermocyclers are semi-skirted. The skirt sits into the raised edges of the nest. If there is not enough skirt to align in this area, this can lead to unreliable handling, especially if plates are stacked.

TIP—Get the full details and access the standards here: https://www.slas.org/education/ansi-slas-microplate-standards/

6 Microplate orientation

An instrument nest can be in two orientations—portrait or landscape related to the A1 position on a plate giving rise to up to four loading orientations. Having multiple orientations on an automated system will increase the need for regripping of a plate to swap orientations; increasing the number of handling steps that occur and reducing efficiency and throughput.

Allowing mover access to load plates in either portrait or landscape gives integration flexibility. As does being able to configure the A1 orientation programmatically (especially important if device loaded from the back, such as a liquid handler).

7 Reagent supply

It can be easy to underestimate the quantity of reagents needed for an extended run, such as overnight. A mechanism should be supplied to expand the built-in capacity and/or the ability to connect to larger sources of reagents.

TIP—Reagent packaging can be a common source of frustration for automation users. Kits designed for benchtop throughputs can become a bottleneck if they are the only option available for higher throughput customers.

Application Programming Interface (API)

8 Robustness and reliability

The digital connection in an automated setup is just as important as the physical compatibility. The API is what connects the instrument to the automation scheduling software via a dedicated piece of code called a device driver. We strongly recommend connecting with us as early as possible in the development cycle to discuss requirements. Some key considerations:

- The API should be robust, well documented and interact well with the automation software.
- Changes between online and offline status need to occur rapidly without needing to re-position, re-teach or reset the instrument.
- Forward and backward compatibility is important for migration between versions. Also be prepared to provide advance notice of version changes. A function to return firmware version should also be supplied.

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- Communications
  - Instruments' control software should support remote operation thereby making sure that the instrument is on, working and in a remote-operated state.
  - During remote operation, error and event notifications should appear in the automation software as opposed to the UI (User Interface) of the remote instrument. If an instrument needs to present its own error message, the automation software should also be notified enabling the user to be alerted through either means.
  - Commands should be provided for every functionality and appropriate status of instruments should be updated when an operation is complete.
  - Commands should be written which return without lag.
  - A simulation mode enables customers to test protocols and supports in driver development.
- Event logging
  - Allows customers to log information to track and analyze system failures. They should also be able to choose from general, verbose and debug levels of logging.
  - Metadata should be generated for all output data and an open format like XML (Extensible Markup Language) should be used to simplify collection and logging.
  - Entries for basic communications, operations, and error events need to be tagged, making them easier to sort and categorize. Information exported from the instrument should contain error type and device instance name.
  - Logging barcode numbers or other ID information for test plates and other consumables can help keep track of errors with consumable media.

9 Full command set

It's important to ensure that the full command set is available through the API. This allows the automation control software to have full control of the instrument. Standard procedures can not only be executed but also low level control can be exerted to address errors preparing the instrument in the process for use or avoiding issues.

TIP—An example of this is with plate sealers where the ability to open and close the door independent of a plate seal action proved to be essential in avoiding over-heating and seal degradation issues when integrated in an automation system operating 24/7.

10 Error handling and recovery

Being able to elegantly recover from errors with minimal impact to the work in progress is essential to the success of an automated system. Using the Thermo Scientific™ Momentum™ Workflow Scheduling software, recovery actions are consistently shown in increasing order of impact (i.e., from retry to abort entire run) and we use detailed, but concise descriptions of the error and possible fixes in plain language. To support effective and elegant error recovery, instruments should:

- Pass error messages to the automation software and the instrument should be able to return status to automation client when queried.
- Error dialog generation and recovery should follow a common strategy with useful human readable descriptions and recovery suggestions. Error recovery strategies should be simple and include options that don't require human intervention.
- Option to reset instruments through the automation software should be made available to reduce inconvenience and the need to reset the automation system.
- Testing regimes should include long (24–48 hour) unattended runs to confirm robustness is at an acceptable level. Reach out if we can help with this by providing a robot and software to run such tests.

If you'd like additional information about automation-ready instruments, email us at **info.labautomation@thermofisher.com** to connect with our automation experts.

Find out more at **thermofisher.com/labautomation**

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