# IEEE Recommended Practice for Industrial Agents: Integration of Software Agents and Low-Level Automation Functions

IEEE Industrial Electronics Society

Developed by the
Standards Committee

**IEEE Std 2660.1™-2020**

STANDARDS

# IEEE Recommended Practice for Industrial Agents: Integration of Software Agents and Low-Level Automation Functions

Developed by the

**Standards Committee**
of the
**IEEE Industrial Electronics Society**

Approved 24 September 2020

**IEEE SA Standards Board**

**Abstract:** The recommended practices to solve the interface problem when applying industrial agents, namely, integrating intelligent software agents with low-level automation devices in the context of cyber-physical systems, are described in this recommended practice. In particular, a method to select the best interfacing practice for a given application scenario, defined by the user, from a set of available interfacing templates and technologies, aiming to improve reuse, consistency, and transparency in the integration of industrial agents and low-level control functions, is defined.

**Keywords:** cyber-physical systems, IEEE 2660.1™, industrial agents, industrial automation, intelligent agents, multi-agent system

## Important Notices and Disclaimers Concerning IEEE Standards Documents

IEEE Standards documents are made available for use subject to important notices and legal disclaimers. These notices and disclaimers, or a reference to this page (https://standards.ieee.org/ipr/disclaimers.html), appear in all standards and may be found under the heading "Important Notices and Disclaimers Concerning IEEE Standards Documents."

## Notice and Disclaimer of Liability Concerning the Use of IEEE Standards Documents

IEEE Standards documents are developed within the IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Association (IEEE SA) Standards Board. IEEE develops its standards through an accredited consensus development process, which brings together volunteers representing varied viewpoints and interests to achieve the final product. IEEE Standards are documents developed by volunteers with scientific, academic, and industry-based expertise in technical working groups. Volunteers are not necessarily members of IEEE or IEEE SA, and participate without compensation from IEEE. While IEEE administers the process and establishes rules to promote fairness in the consensus development process, IEEE does not independently evaluate, test, or verify the accuracy of any of the information or the soundness of any judgments contained in its standards.

IEEE makes no warranties or representations concerning its standards, and expressly disclaims all warranties, express or implied, concerning this standard, including but not limited to the warranties of merchantability, fitness for a particular purpose and non-infringement. In addition, IEEE does not warrant or represent that the use of the material contained in its standards is free from patent infringement. IEEE standards documents are supplied "AS IS" and "WITH ALL FAULTS."

Use of an IEEE standard is wholly voluntary. The existence of an IEEE Standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard.

In publishing and making its standards available, IEEE is not suggesting or rendering professional or other services for, or on behalf of, any person or entity, nor is IEEE undertaking to perform any duty owed by any other person or entity to another. Any person utilizing any IEEE Standards document, should rely upon his or her own independent judgment in the exercise of reasonable care in any given circumstances or, as appropriate, seek the advice of a competent professional in determining the appropriateness of a given IEEE standard.

IN NO EVENT SHALL IEEE BE LIABLE FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL, EXEMPLARY, OR CONSEQUENTIAL DAMAGES (INCLUDING, BUT NOT LIMITED TO: THE NEED TO PROCURE SUBSTITUTE GOODS OR SERVICES; LOSS OF USE, DATA, OR PROFITS; OR BUSINESS INTERRUPTION) HOWEVER CAUSED AND ON ANY THEORY OF LIABILITY, WHETHER IN CONTRACT, STRICT LIABILITY, OR TORT (INCLUDING NEGLIGENCE OR OTHERWISE) ARISING IN ANY WAY OUT OF THE PUBLICATION, USE OF, OR RELIANCE UPON ANY STANDARD, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE AND REGARDLESS OF WHETHER SUCH DAMAGE WAS FORESEEABLE.

## Translations

The IEEE consensus development process involves the review of documents in English only. In the event that an IEEE standard is translated, only the English version published by IEEE is the approved IEEE standard.

## Official statements

A statement, written or oral, that is not processed in accordance with the IEEE SA Standards Board Operations Manual shall not be considered or inferred to be the official position of IEEE or any of its committees and shall not be considered to be, nor be relied upon as, a formal position of IEEE. At lectures, symposia, seminars, or educational courses, an individual presenting information on IEEE standards shall make it clear that the presenter's views should be considered the personal views of that individual rather than the formal position of IEEE, IEEE SA, the Standards Committee, or the Working Group.

## Comments on standards

Comments for revision of IEEE Standards documents are welcome from any interested party, regardless of membership affiliation with IEEE or IEEE SA. However, **IEEE does not provide interpretations, consulting information, or advice pertaining to IEEE Standards documents**.

Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments. Since IEEE standards represent a consensus of concerned interests, it is important that any responses to comments and questions also receive the concurrence of a balance of interests. For this reason, IEEE and the members of its Societies and Standards Coordinating Committees are not able to provide an instant response to comments, or questions except in those cases where the matter has previously been addressed. For the same reason, IEEE does not respond to interpretation requests. Any person who would like to participate in evaluating comments or in revisions to an IEEE standard is welcome to join the relevant IEEE working group. You can indicate interest in a working group using the Interests tab in the Manage Profile & Interests area of the IEEE SA myProject system. An IEEE Account is needed to access the application.

Comments on standards should be submitted using the Contact Us form.

## Laws and regulations

Users of IEEE Standards documents should consult all applicable laws and regulations. Compliance with the provisions of any IEEE Standards document does not constitute compliance to any applicable regulatory requirements. Implementers of the standard are responsible for observing or referring to the applicable regulatory requirements. IEEE does not, by the publication of its standards, intend to urge action that is not in compliance with applicable laws, and these documents may not be construed as doing so.

## Data privacy

Users of IEEE Standards documents should evaluate the standards for considerations of data privacy and data ownership in the context of assessing and using the standards in compliance with applicable laws and regulations.

## Copyrights

IEEE draft and approved standards are copyrighted by IEEE under US and international copyright laws. They are made available by IEEE and are adopted for a wide variety of both public and private uses. These include both use, by reference, in laws and regulations, and use in private self-regulation, standardization, and the promotion of engineering practices and methods. By making these documents available for use and adoption by public authorities and private users, IEEE does not waive any rights in copyright to the documents.

## Photocopies

Subject to payment of the appropriate licensing fees, IEEE will grant users a limited, non-exclusive license to photocopy portions of any individual standard for company or organizational internal use or individual, non-commercial use only. To arrange for payment of licensing fees, please contact Copyright Clearance Center, Customer Service, 222 Rosewood Drive, Danvers, MA 01923 USA; +1 978 750 8400; https://www.copyright .com/. Permission to photocopy portions of any individual standard for educational classroom use can also be obtained through the Copyright Clearance Center.

## Updating of IEEE Standards documents

Users of IEEE Standards documents should be aware that these documents may be superseded at any time by the issuance of new editions or may be amended from time to time through the issuance of amendments, corrigenda, or errata. An official IEEE document at any point in time consists of the current edition of the document together with any amendments, corrigenda, or errata then in effect.

Every IEEE standard is subjected to review at least every 10 years. When a document is more than 10 years old and has not undergone a revision process, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE standard.

In order to determine whether a given document is the current edition and whether it has been amended through the issuance of amendments, corrigenda, or errata, visit IEEE Xplore or contact IEEE. For more information about the IEEE SA or IEEE's standards development process, visit the IEEE SA Website.

## Errata

Errata, if any, for all IEEE standards can be accessed on the IEEE SA Website. Search for standard number and year of approval to access the web page of the published standard. Errata links are located under the Additional Resources Details section. Errata are also available in IEEE Xplore. Users are encouraged to periodically check for errata.

## Patents

IEEE Standards are developed in compliance with the IEEE SA Patent Policy.

Attention is called to the possibility that implementation of this standard may require use of subject matter covered by patent rights. By publication of this standard, no position is taken by the IEEE with respect to the existence or validity of any patent rights in connection therewith. If a patent holder or patent applicant has filed a statement of assurance via an Accepted Letter of Assurance, then the statement is listed on the IEEE SA Website at https://standards.ieee.org/about/sasb/patcom/patents.html. Letters of Assurance may indicate whether the Submitter is willing or unwilling to grant licenses under patent rights without compensation or under reasonable rates, with reasonable terms and conditions that are demonstrably free of any unfair discrimination to applicants desiring to obtain such licenses.

Essential Patent Claims may exist for which a Letter of Assurance has not been received. The IEEE is not responsible for identifying Essential Patent Claims for which a license may be required, for conducting inquiries into the legal validity or scope of Patents Claims, or determining whether any licensing terms or conditions provided in connection with submission of a Letter of Assurance, if any, or in any licensing agreements are reasonable or non-discriminatory. Users of this standard are expressly advised that determination of the validity of any patent rights, and the risk of infringement of such rights, is entirely their own responsibility. Further information may be obtained from the IEEE Standards Association.

## IMPORTANT NOTICE

IEEE Standards do not guarantee or ensure safety, security, health, or environmental protection, or ensure against interference with or from other devices or networks. IEEE Standards development activities consider research and information presented to the standards development group in developing any safety recommendations. Other information about safety practices, changes in technology or technology implementation, or impact by peripheral systems also may be pertinent to safety considerations during implementation of the standard. Implementers and users of IEEE Standards documents are responsible for determining and complying with all appropriate safety, security, environmental, health, and interference protection practices and all applicable laws and regulations.

## Participants

At the time this IEEE recommended practice was completed, the Software Agents Low Level Automation Functions (IES/IES/IA Software Agents) Working Group had the following membership:

**Paulo Leitao,** *Chair*
**Loi Lei Lai,** *Vice Chair*
**Thomas Strasser,** *Secretary*

| | | |
|---|---|---|
| Reza Abrishambaf | Birgit Vogel Heuser | Massimiliano Pirani |
| José Barbosa | Victor Huang | Luis Ribeiro |
| Wenbin Dai | Stamatis Karnouskos | Andre Dionisio Rocha |
| Cheng-Jen Chen | Amit Kumar Mondal | Roopak Sinha |
| Cheng Siong Chin | Panayiotis Moutis | Spyros Skarvelis- |
| Luis Filipe Gomes | Cheng Pang | Kazakos |

The following members of the individual balloting committee voted on this recommended practice. Balloters may have voted for approval, disapproval, or abstention.

| | | |
|---|---|---|
| Robert Aiello | Chun Sing Lai | Spyros Skarvelis- |
| Mihaela Albu | Dewitt Latimer | Kazakos |
| Dietmar Bruckner | Kang Lee | Yuyin Song |
| Lyle Bullock | Wei-Jen Lee | Robert Stemp |
| Paul Cardinal | Paulo Leitao | Thomas Strasser |
| Cheng-Jen Chen | Javier Luiso | David Tepen |
| Jin Seek Choi | Aleksander Malinowski | Mark-Rene Uchida |
| Wenbin Dai | Alan Mustafa | John Vergis |
| Werner Hoelzl | Nick S. A. Nikjoo | Keith Waters |
| Victor Huang | Joanna Olszewska | Z.J. Yang |
| Piotr Karocki | Vincenzo Paciello | Yu Yuan |
| Stuart Kerry | Stefano Scanzio | Oren Yuen |

When the IEEE SA Standards Board approved this recommended practice on 24 September 2020, it had the following membership:

**Gary Hoffman,** *Chair*
**Jon Walter Rosdahl,** *Vice Chair*
**John D. Kulick,** *Past Chair*
**Konstantinos Karachalios,** *Secretary*

| | | |
|---|---|---|
| Ted Burse | David J. Law | Mehmet Ulema |
| J.Travis Griffith | Howard Li | Lei Wang |
| Grace Gu | Dong Liu | Sha Wei |
| Guido R. Hiertz | Kevin Lu | Philip B. Winston |
| Joseph L. Koepfinger* | Paul Nikolich | Daidi Zhong |
| John D. Kulick | Damir Novosel | Jingyi Zhou |
| | Dorothy Stanley | |

*Member Emeritus

## Introduction

This document provides assistance on how to select a recommended practice with respect to the interfacing when applying industrial agents, namely, integrating intelligent software agents with low-level automation devices in the context of cyber-physical systems. The recommended practice defines a set of interfacing templates and a method to select the best interfacing practice for a given application scenario, defined by the user, considering the defined set of interfacing templates and a repository of feedback assessment of the implementation of these interface practices from experts in the field.

This recommended practice aims to help the engineers by leveraging the best practices of developing industrial agents for specific automation control problems and application fields, improving the reuse, consistency, and transparency in the integration of industrial agents and low-level control functions.

# Contents

# IEEE Recommended Practice for Industrial Agents: Integration of Software Agents and Low-Level Automation Functions

## 1. Overview

### 1.1 General

The recommended practice is organized as follows: Clause 1 provides an overview of the scope of this recommended practice. Clause 2 lists normative references to other standards and documents that are useful in applying this standard. Clause 3 provides definitions that are either unavailable in the *IEEE Standards Dictionary Online* or have been modified for use with this standard. Clause 4 presents a justification for this proposal with a brief description of it. Clause 5 introduces the methodology to select the recommended interface practice, which is detailed in the three next clauses. Namely, Clause 6 describes the established interfacing practice templates that will be considered to select the recommended one, Clause 7 defines the method to score the existing interfacing practices taking into consideration the feedback from experts, and finally Clause 8 defines the engine to sort the alternative interface practices for a specific application scenario and ultimately select the best one.

Annexes are included for completeness. Annex A provides examples of application the described methodology for selection of recommended interface practices in industrial agents, and Annex B provides the repository data. Annex C provides a bibliography.

### 1.2 Scope

This recommended practice describes integrating and deploying the multi-agent systems (MAS) (Ferber [B4] and Wooldridge [B24]) technology in industrial environments for use in building the intelligent decision-making layer on top of legacy industrial control platforms.[1]

The integration of software agents with the low-level real-time control systems, mainly based on the programmable logic controllers (PLCs) running the IEC 61131-3:2013 control programs (forming in this manner a new component known as "industrial agents") are also identified.[2] In addition, the integration of software agents with the control applications based on IEC 61499-1:2012 or executed on embedded controllers is described. This recommended practice supports and helps the engineers leverage the best practices of developing industrial agents for specific automation control problems and given application fields. Therefore, corresponding rules, guidelines and design patterns are provided.

---

[1]The numbers in brackets correspond to those of the bibliography in Annex C.
[2]Information on references can be found in Clause 2.