US006941543B1

(12) **United States Patent**
Brown et al.

(10) **Patent No.: US 6,941,543 B1**
(45) **Date of Patent: Sep. 6, 2005**

(54) **MOTION CONTROL SYSTEM AND METHOD**

(75) Inventors: **David W. Brown**, White Salmon, WA (US); **Jay S. Clark**, Seattle, WA (US)

(73) Assignee: **Roy-G-Biv Corporation**, Bingen, WA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 586 days.

(21) Appl. No.: **09/633,633**

(22) Filed: **Aug. 7, 2000**

Related U.S. Application Data

(63) Continuation of application No. 09/191,181, filed on Nov. 13, 1998, now Pat. No. 6,577,291, which is a continuation of application No. 08/656,421, filed on May 30, 1996, now Pat. No. 5,867,385, which is a continuation-in-part of application No. 08/454,736, filed on May 30, 1995, now Pat. No. 5,691,897.

(51) **Int. Cl.**[7] **G06F 9/45**
(52) **U.S. Cl.** **717/107**
(58) **Field of Search** 717/107; 700/56, 700/28

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,713,808	A	12/1987	Gaskill et al.	
4,767,334	A	8/1988	Throne et al.	
4,769,771	A	9/1988	Lippmann et al.	709/213
4,809,335	A	2/1989	Rumsey	
4,840,602	A	6/1989	Rose	
4,846,693	A	7/1989	Baer	
4,855,725	A	8/1989	Fernandez	
4,857,030	A	8/1989	Rose	
4,887,966	A	12/1989	Gellerman	
4,897,835	A	1/1990	Gaskill et al.	
5,120,065	A	6/1992	Driscoll et al.	
5,168,441	A	12/1992	Onarheim et al.	
5,377,258	A	12/1994	Bro	
5,392,207	A	2/1995	Wilson et al.	
5,402,518	A	3/1995	Lowery	
5,412,757	A	5/1995	Endo	
5,438,529	A	8/1995	Rosenberg et al.	709/222
5,450,079	A	9/1995	Dunaway	
5,465,215	A	11/1995	Strickland et al.	
5,493,281	A	2/1996	Owens	
5,576,727	A	11/1996	Rosenberg et al.	345/701

(Continued)

FOREIGN PATENT DOCUMENTS

EP	0 275 826	A1	7/1988
EP	0 442 676	A2	8/1991
EP	0 281 427	B1	8/1992
EP	508 912	A1	10/1992
EP	0 583 908	A2	2/1994
GB	2 244 896	A	12/1991
JP	59-228473		6/1983
WO	WO 92/11731		7/1992
WO	WO 93/08654		4/1993
WO	WO 95/07504		3/1995

OTHER PUBLICATIONS

Payton et al., Intelligent Real–Time Control of Robotic Vehicles, Aug. 1991, ACM, pp. 49–63.*

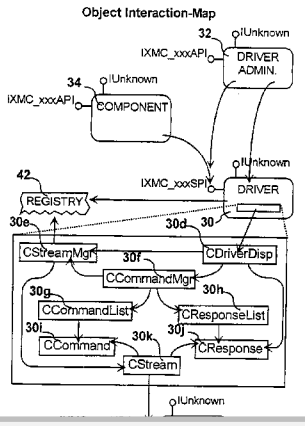
(Continued)

Primary Examiner—John Chavis
(74) *Attorney, Agent, or Firm*—Black Lowe & Graham PLLC

(57) **ABSTRACT**

A system for motion control in which an application is developed that is independent from the actual motion control hardware used to implement the system. A software system employs an application programming interface comprising component functions and a service provider interface comprising driver functions. Code associated with the component functions relates these functions to the driver functions. Driver functions are separated into core and extended driver functions. All software drivers implement the core driver functions, and optionally implement the extended driver functions. Extended driver functionality may be obtained through a combination of core driver functions.

16 Claims, 64 Drawing Sheets



U.S. PATENT DOCUMENTS

5,596,994	A		1/1997	Bro
5,600,373	A		2/1997	Chui et al.
5,607,336	A		3/1997	Lebensfeld et al.
5,617,528	A		4/1997	Stechmann et al.
5,623,582	A		4/1997	Rosenberg 345/739
5,636,994	A		6/1997	Tong
5,652,866	A		7/1997	Aldred et al.
5,655,945	A		8/1997	Jani
5,666,161	A		9/1997	Kohiyama et al.
5,670,992	A		9/1997	Yasuhara et al.
5,691,897	A	*	11/1997	Brown et al. 700/56
5,691,898	A		11/1997	Rosenberg et al. 345/701
5,701,140	A		12/1997	Rosenberg et al. 345/156
5,707,289	A		1/1998	Watanabe et al.
5,733,131	A		3/1998	Park
5,734,373	A		3/1998	Rosenberg et al. 345/161
5,737,523	A		4/1998	Callaghan et al.
5,739,811	A		4/1998	Rosenberg et al. 345/161
5,746,602	A		5/1998	Kikinis
5,764,155	A		6/1998	Kertesz et al.
5,790,178	A		8/1998	Shibata et al.
5,800,268	A		9/1998	Molnick
5,801,946	A		9/1998	Nissen et al.
5,818,537	A		10/1998	Enokida et al.
5,821,920	A		10/1998	Rosenberg et al. 345/156
5,821,987	A		10/1998	Larson
5,822,207	A		10/1998	Hazama et al.
5,825,308	A		10/1998	Rosenberg 341/20
5,828,575	A		10/1998	Sakai
5,846,132	A		12/1998	Junkin
5,848,415	A		12/1998	Guck 707/10
5,852,441	A	*	12/1998	Nakajima et al. 345/866
5,855,483	A		1/1999	Collins et al.
5,867,385	A		2/1999	Brown et al.
5,873,765	A		2/1999	Rifkin et al.
5,889,670	A		3/1999	Schuler et al. 700/83
5,889,672	A		3/1999	Schuler et al. 345/702
5,890,963	A		4/1999	Yen
5,907,704	A		5/1999	Gudmundson et al.
5,907,831	A		5/1999	Lotvin et al.
5,914,876	A		6/1999	Hirai
5,920,476	A		7/1999	Hennessey et al.
5,924,013	A		7/1999	Guido et al.
5,956,484	A		9/1999	Rosenberg et al. 709/203
5,959,613	A		9/1999	Rosenberg et al. 345/161
5,960,085	A		9/1999	de la Huerga
5,977,951	A		11/1999	Danieli et al.
6,020,876	A		2/2000	Rosenberg et al. 345/157
6,028,593	A		2/2000	Rosenberg et al. 345/156
6,038,603	A		3/2000	Joseph 709/228
6,046,727	A		4/2000	Rosenberg et al. 345/156
6,057,828	A		5/2000	Rosenberg et al. 345/701
6,061,004	A		5/2000	Rosenberg 341/20
6,078,308	A		6/2000	Rosenberg et al. 345/145
6,078,968	A		6/2000	Lo et al.
6,100,874	A		8/2000	Schena et al. 345/157
6,101,425	A		8/2000	Govindaraj et al.
6,101,530	A		8/2000	Rosenberg et al. 709/203
6,104,158	A		8/2000	Jacobus et al. 318/568.11
6,125,385	A		9/2000	Wies et al. 709/203
6,128,006	A		10/2000	Rosenberg et al. 345/163
6,131,097	A		10/2000	Peurach et al. 707/102
6,139,177	A	*	10/2000	Venkatraman et al. 700/83
6,144,895	A		11/2000	Govindaraj et al.
6,147,647	A		11/2000	Tassoudji et al. 343/785
6,161,126	A		12/2000	Wies et al. 709/203
6,166,723	A		12/2000	Schena et al. 345/161
6,169,540	B1		1/2001	Rosenberg et al. 345/701
6,195,592	B1		2/2001	Schuler et al. 700/83
6,209,037	B1		3/2001	Brown et al.
6,216,173	B1		4/2001	Jones et al.
6,219,032	B1		4/2001	Rosenberg et al. 345/157
6,219,033	B1		4/2001	Rosenberg et al. 345/157
6,232,891	B1		5/2001	Rosenberg 341/20
6,243,078	B1		6/2001	Rosenberg 345/161
6,246,390	B1		6/2001	Rosenberg 345/156
6,252,579	B1		6/2001	Rosenberg et al. 345/157
6,252,853	B1		6/2001	Ohno 370/242
6,259,382	B1		6/2001	Rosenberg 341/20
6,271,833	B1		8/2001	Rosenberg et al. 345/701
6,278,439	B1		8/2001	Rosenberg et al. 345/157
6,285,351	B1		9/2001	Chang et al. 345/156
6,288,705	B1		9/2001	Rosenberg et al. 345/701
6,292,170	B1		9/2001	Chang et al. 345/156
6,292,174	B1		9/2001	Mallett et al. 345/157
6,292,712	B1		9/2001	Bullen 700/245
6,292,714	B1		9/2001	Okabavashi 700/245
6,300,936	B1		10/2001	Braun et al. 345/156
6,300,937	B1		10/2001	Rosenberg 345/156
6,304,091	B1		10/2001	Shahoian et al. 324/662
6,310,605	B1		10/2001	Rosenberg 345/157
6,317,116	B1		11/2001	Rosenberg et al. 345/145
6,343,349	B1		1/2002	Braun et al. 711/154
6,353,850	B1		3/2002	Wies et al. 709/203
6,366,272	B1		4/2002	Rosenberg et al. 345/156
6,366,273	B1		4/2002	Rosenberg et al. 345/156
6,374,255	B1		4/2002	Peurach et al. 707/102
6,401,005	B1		6/2002	Schwarz et al. 709/400
6,470,377	B1		10/2002	Sevcik et al. 709/201
6,480,896	B1		11/2002	Brown et al. 709/231
6,519,646	B1		2/2003	Gupta et al. 709/229
6,542,925	B2		4/2003	Brown et al. 709/208
2001/0020944	A1		9/2001	Brown et al. 345/474
2001/0032268	A1		10/2001	Brown et al. 709/230
2002/0052939	A1		5/2002	Lee 709/223
2002/0165627	A1		11/2002	Brown et al. 700/56
2002/0177453	A1		11/2002	Chen et al. 455/466
2003/0069998	A1		4/2003	Brown et al. 719/310

OTHER PUBLICATIONS

Y. Katayama, Y. Nanjo and K. Shimokura; A Motion Control System With Event–Driven Motion–Module Switching Mechanism for Robotic Manipulators; 1993; IEEE; U.S.

Toshihiro Matsui et al; An Event–Driven Architecture for Controlling Behaviors of the Office Conversant Mobile Robot, Jijo–2; 1997; IEEE; U.S.

How to Write and Use Activex Controls for Microsoft Windows CE 3.0; Microsoft Windows Website; Aug. 16, 2002; U.S. ms–help://MS.MSDNQTR.2002JAN.1033/dnce30/html/activex30.htm.

Notes on Implementing an Ole Control Container; Aug. 16, 2002; U.S.; ms–help://MS.MSDNQTR.2002JAN.1033/dnaxctrl/html/msdn_contcntr.htm.

What OLE is Really About; Microfost OLE (General) Technical Articles; microsoft website; Aug. 16, 2002; U.S.; ms–help://MS.MSDNQTR.2002JAN.1033/dnolegen/html/msdn_aboutole.htm.

Platform SDK: COM; Categorizing by Component Capabilities; Microsoft Website; Aug. 16, 2002; U.S.; ms–help://MS.MSDNQTR.2002JAN.1033/com/comp_cat_3jqr.htm.

Bradley Bargen and Peter Donnely; Inside Direct X—in Depth Techniques for Developing High–Performance Mul-

Peter Kovach; Inside Direct3D—The Definitive Guide for Real–Time 3D Power and Performance for Microsoft Windows; 2000; Chapters 1, 7, and 15; Microsoft Press; U.S.

M. Farsi and M. Barbosa; CANopen Implementation—Applications to Industrial Networks; 2000; Chapters 1, 2 and 3; Research Studies Press Ltd.; England and U.S.

Wolfhard Lawrenz; CAN System Engineering—From Theory to Practical Applications; 1997; Chapters 1, 2.1, 2.2, 3.2 and 4.1; Springer–Verlag New York, Inc.; U.S.

Allen–Bradley; CNCnet Software Library; Oct., 1992; Publication 8000–6.1.1; U.S.

Robert Bosch GmbH; CAN Specification; Sep., 1991; Version 2.0.

SISCO, Inc.; Overview and Introduction to the Manufacturing Message Specification (MMS); 1994–1995; Revision 2; Systems Integration Specialists Company, Inc.; Sterling Heights, Michigan, U.S.

ISO–9506–1 Industrial Automation Systems—Manufacturing Message Specification—Part 1: Service definition; Aug. 2000; pp. i–22; ISO/IEC; Switzerland.

ISO–9506–2 Industrial Automation Systems—Manufacturing Message Specification—Part 2: Protocol specification; Aug. 2000; pp. i.–6; ISO/IEC; Switzerland.

SISCO, Inc.; MMS–EASE; Jan., 1996; Systes Integration Specialists Company, Inc.; Sterling Hieghts, Michigan, U.S.

ANSI/EIA–484–A Electrical and Mechanical Interface Characteristics and Line Control Protocol Using Communication Control Characters for Serial Data Link Between a Direct Numerical Control System and Numerical Control Equipment Employing Asynchronous Full Duplex Transmission; Jun., 1995; Electronic Industries Association; U.S.

ISO/IEC 7498–1 Information Technology—Open Systems Interconnection–Basic Reference Model: The Basic Model; Nov., 1994; U.S.

ISO/IEC 7498–3 Information Technology—Open Systems Interconnection–Basic Reference Model: Naming and Addressing; Apr., 1997; U.S.

Todd J. Schuett; The Benefits and Data Bottlenecks of High Speed Milling; Aug., 1995; Conference Paper Presented at Southeastern Michigan Chapter American Mold Builders Association; Creative Technology Corporation; U.S.

Todd J. Schuett; "The Ultimate DNC; Direct CNC Networking (DCN)"; Modern Machine Shop; Jan., 1996; Creative Technology Corporation; U.S.

Todd J. Schuett; Advanced Controls for High Speed Milling; Conference Paper Presented at the SME "High Speed Machining"; May 7–8, 1996; Creative Technology Corporation; U.S.

Leitao, Machado & Lopes; "A Manufacturing Cell Integration Solution"; Paper Developed at CCP as a Part of the ESORIT 5629 Project; Oct., 1995.

Mitsubishi Electric; Mitsubishi Electric Advance; Programmable Logic Controllers Edition; Sep., 1996; vol. 76; Mitsubishi Electric Corporation; Tokyo.

Farsi, M.; "Flexible and Reliable Robotics Cells in Factory Automation"; Proceedings of the IEEE International Conference on Systems, Man and Cybernetics, France; 1993; pp. 520–525.

Chu & Wang; "Development of a Practical SFC System for CNC Machine Shop"; International Conference on Data and Knowledge Systems for Manufacturing and Engineering; Farsi, M.; "Device Communication for Flexible Manufacturing:–A New Concept"; Ninth International Conference on System Engineering, U.K.; 1994; pp. 328–334.

Farsi, M.; "A Production Cell Communication Model in Factory Automation Using the Controller Area Network"; Proceedings of XII International Conference on Systems Science, Poland; 1995; pp. 90–95.

Marcos & Orive; "A New Solution for Integrating Control Devices Involved in Computer Integrated Manufacturing"; UKACC International Conference on Control '96 (Conference Publication No. 427); Sep., 1996; pp. 485–490, vol. 1; UK.

Farsi, M. "CANopen: The Open Communications Solution"; Proceedings of Fieldbusses and Communications for Drives and Motion Control, Drives and Control 1996 Exhibition & Conference, U.K.; 1996; pp. 112–116.

Wright et al.; "Open Architecture Manufacturing: The Impact of Open–System Computers on Self–Sustaining Machinery and Machine Tool Industry"; 7 pages; pp.

Altintas et al.; "Design and Analysis of a Modular CNC System"; pub. Mar. 4, 1990; 12 pages; Elsevier Science Publishers; pp. 305–316.

Robert Anderson; "Smart: A Modular Architectur for Robotics and Teleoperation"; pub. 1993; IEEE; 6 pages; pp. 416–421.

Microsoft; "Object Linking and Embedding 2.0 Backgrounder"; pub. Sep. 1993; 15 pages; pp. 1–15.

Microsoft; "Microsoft OLE Today and Tomorrow: Technology Overview"; pub. Dec. 1993; 9 pages; pp. 1–9.

Pritschow et al.; "Open System Controllers—A Challenge for the Future of the Machine Tool Industry"; pub Jan. 14, 1993; CIRP; 4 pages; pp. 449–452.

WEB 3.0 Product Brochure; Trihedral Engineering Ltd.; pub. 1994; 6 pages.

Chen et al.; "Computer Numerical Control: Essentials in Programming and Networking"; pub. 1994; Delmar Publishers, Inc.; 28 pages; Part 5, Chapter 27; pp. 824–848.

Chu et al.; "Development of a Practicle SFC System for CNC Machine Shop"; pub. 1994; 5 pages; 362–367.

Microsoft; "The Microsoft Object Technology Strategy"; pub. Mar. 1994; 33 pages; pp. 1–33.

Microsoft; "Open Systems: Technology Leadership and Collaboration"; pub. Mar. 1994; 15 pages; pp. 1–15.

William F. Ford; "What is an Open Architecture Robot Controller?"; pub. Aug. 16, 1994; IEEE Control Systems Society; 6 pages; pp. 27–32.

"Requirements of Open, Modular Architecture Controllers for Applications in the Automotive Industry"; pub. Dec. 13, 1994; Version 1.1; 13 pages; pp. 1–13.

Fedrowitz; "IRL–Based Expansion of the Commonly Used High–Level Language C for Robot Programming"; pub. Oct. 1995; 5 pages.

John Jackman; "Robotic Control Using Sequential Function Charts"; pub. 1996; SPIE; 9 pages; pp. 120–128.

McGraw et al.; "A Friendly Command, Control, and Information System for Astronomy"; pub. 1996; ASP Conference Series; 12 pages; pp. 356–367.

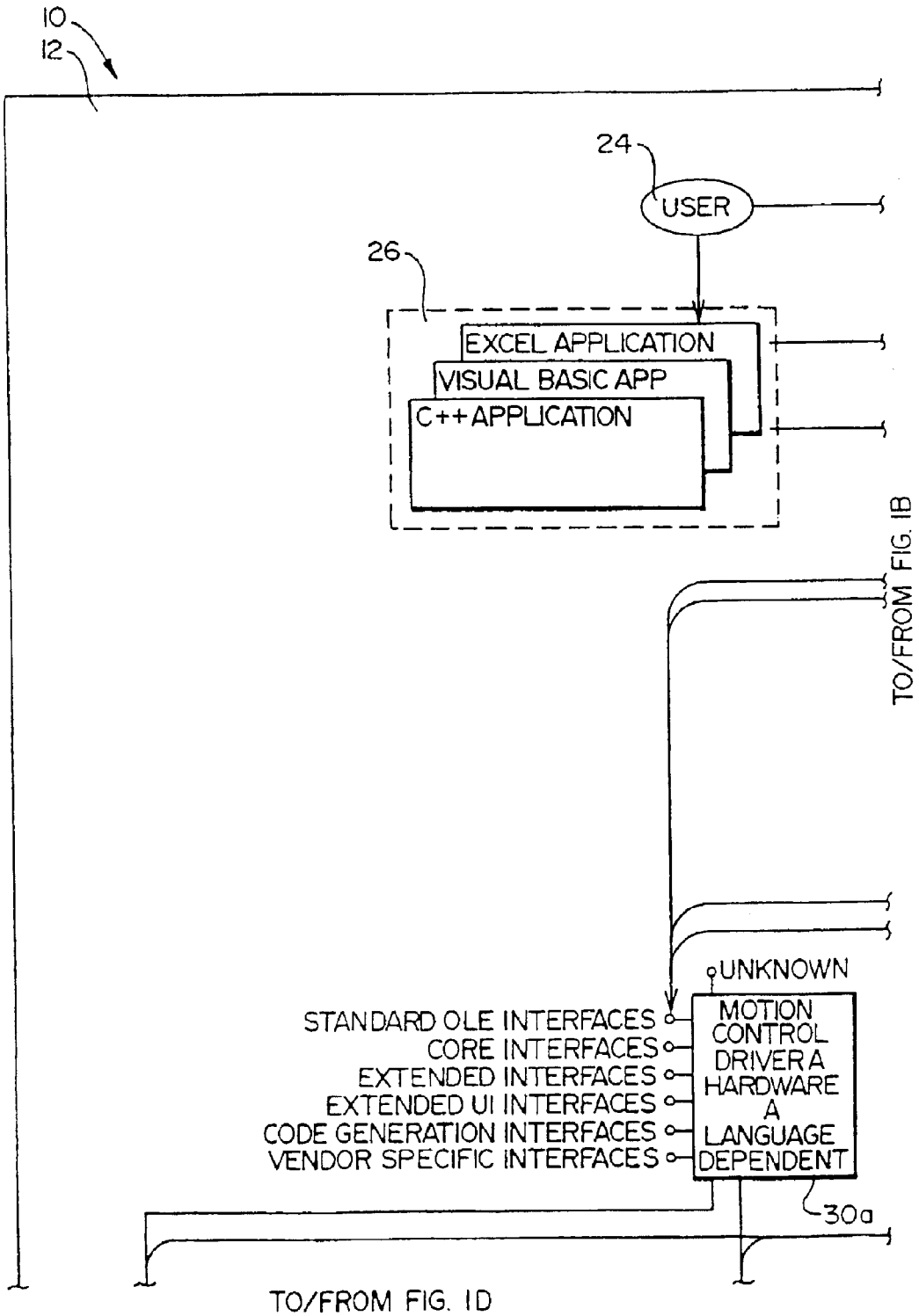
Proctor et al.; "Validation of Standard Interfaces for Machine Control"; pub. 1996; 6 pages; pp. 659–664.

Sperling et al.; "Enabling Open Control Systems—An Introduction to the OSACA System Platform"; pub. May 1996; 8 pages; pp. 1–8.

"Technologies Enabling Agile Manufacturing (TEAM) Intelligent Closed Loop Processing"; pub. Jan. 11, 1996; 30 pages; pp. 1–30.
"Open, Modular Architecture Controls at GM Powertrain—Technology and Implementation"; pub. May 14, 1996; Version 1.0; GM Powertrain Group Manufacturing Engineering Controls Council; 39 pages; pp. 1–39.
Marcos et al.; "A New Solution for Integrating Control Devices Involved in Computer Integrated Manufacturing"; pub. Sep. 2, 1996; IEE; 6 pages; pp. 485–490.
Proctor et al.; "Open–Architecture Controllers"; pub. Jun. 1996; IEEE; 5 pages; pp. 60–64.
Szabo et al.; "Validation Results of Specifications for Motion Control Interoperability"; pub. Sep. 1997; 11 pages; pp. 166–176.
Feng et al.; "Distributed Control of a Multiple Tethered Mobile Robot System for Highway Maintenance and Construction"; pub. Nov. 1997, 10 pages; pp. 383–392.
Lutz et al.; "OSACA—The Vendor Neutral Control Architecture"; pub. Dec. 1997; 10 pages.
Sperling et al.; "Designing Applications for an OSACA Control"; pub. Nov. 16, 1997; 5 pages.
Chang et al.; "Development and Implementation of An Application of an Application Programming Interface for PC/DSP Based Motion Control System"; Pub. 1998; 12 pages; p. 94–105.
Morales et al.; "A Generalised Software Control System for Industrial Robots"; pub. 1998; AMC; 6 pages; pp. 411–416.
Muir et al.; "A Three–Layer Workcell Control Architecture Design"; pub. May 1998; IEEE; 7 pages; pp. 1185–1191.
Muir et al.; "Mechatronic Objects for Real–Time Control Software Development"; pub. Nov. 1998; SPIE; 15 pages; pp. 251–265.
Leu et al.; "A Telemanufacturing Workcell Over the Internet"; pub. Nov. 1998; SPIE; 8 pages; pp. 230–237.
Michaloski et al.; "A Framework for Component–Based CNC Machines"; pub. Nov. 1998; SPIE; 12 pages; pp. 132–143.
Emilio Morales; "GENERIS: The EC–JRC Generalised Software Control System for Industrial Robots"; pub. 1998; University Press; vol. 26; 7 pages; pp. 26–33.
Mizukawa et al.; "De–Facto Standard API for Open and Networked Industrial Robots"; pub. Oct. 1999; 8 pages; pp. 455–462.
Cho et al.; "A Compact/Open Network–Based Controller Incorporating Modular Software Architecture for a Humaniod Robot"; pub. Apr. 19, 1999; Kluwer; 15 pages; pp. 341–355.
Nilsson et al.; "Integrated Architecture for Industrial Robot Programming and Control"; pub. May 20, 1999; Elsevier Science B.V.; 22 pages; pp. 205–226.
Valera et al.; "Interactive On–line Evaluation of Robot Motion Control"; Aug. 2, 1999; IEEE; 5 pages; pp. 1039–1043.
Natale et al.; "Robust Hybrid Force / Position Control with Experiments on an Industrial Robot"; pub. Sep. 19, 1999; 5 pages; pp. 956–961.
Mizukawa et al.; "ORiN: Open Robot Interface for the Network, A Proposed Standard"; pub. May 2000; MCB University Press; 7 pages' pp. 344–350.
Erol et al.; "Open System Architecture Modular Tool Kit for Motion and Machine Processing Control"; pub. Sep. 2000; IEEE/ASME; 11 pages; pp. 281–291.
Ge et al.; "A One–Stop Solution in Robotic Control System Design"; pub. Sep. 2000; IEEE; 14 pages; pp. 42–55.

* cited by examiner

FIG. 1A



DOCKET ALARM

Explore Litigation Insights

Docket Alarm provides insights to develop a more informed litigation strategy and the peace of mind of knowing you're on top of things.

Real-Time Litigation Alerts

Keep your litigation team up-to-date with **real-time alerts** and advanced team management tools built for the enterprise, all while greatly reducing PACER spend.

Our comprehensive service means we can handle Federal, State, and Administrative courts across the country.

Advanced Docket Research

With over 230 million records, Docket Alarm's cloud-native docket research platform finds what other services can't. Coverage includes Federal, State, plus PTAB, TTAB, ITC and NLRB decisions, all in one place.

Identify arguments that have been successful in the past with full text, pinpoint searching. Link to case law cited within any court document via Fastcase.

Analytics At Your Fingertips

Learn what happened the last time a particular judge, opposing counsel or company faced cases similar to yours.

Advanced out-of-the-box PTAB and TTAB analytics are always at your fingertips.

API

Docket Alarm offers a powerful API (application programming interface) to developers that want to integrate case filings into their apps.

LAW FIRMS
Build custom dashboards for your attorneys and clients with live data direct from the court.

Automate many repetitive legal tasks like conflict checks, document management, and marketing.

FINANCIAL INSTITUTIONS
Litigation and bankruptcy checks for companies and debtors.

E-DISCOVERY AND LEGAL VENDORS
Sync your system to PACER to automate legal marketing.