United States Patent	12383183
Kind Code	B2
Date of Patent	August 12, 2025
Inventor(s)	Hoglund; Brandon K. et al.

Disturbance detection and removal in cardiac signals

Abstract

Systems and methods are described herein for detecting disturbances in cardiac signals. An electrode apparatus includes a plurality of external electrodes to be disposed proximate a patient's skin. A computing apparatus includes processing circuitry. The computing apparatus is operably coupled to the electrode apparatus. The computing apparatus is configured to monitor electrical activity from tissue of a patient using a plurality of external electrodes to generate a plurality of electrical signals. At least one of the electrical signals of the plurality of electrical signals is filtered. At least one disturbance in the at least one electrical signal is detected using the at least one filtered signal. A temporal location of the at least one disturbance in the at least one electrical signal is determined based on a time that the at least one filtered signal crosses a predetermined threshold.

Inventors: **Hoglund; Brandon K. (North Oaks, MN), Kleckner; Karen J. (Blaine, MN), Steckler; Marc C. (Lino Lakes, MN), Fischer; Trent M. (St. Paul, MN), Ghosh; Subham (Blaine, MN), Comia; Irah-Vanesa H. (Tigard, OR)**

Applicant: **Medtronic, Inc.** (Minneapolis, MN)

Family ID: **1000008750155**

Assignee: **Medtronic, Inc. (Minneapolis, MN)**

Appl. No.: **17/143474**

Filed: **January 07, 2021**

Prior Publication Data

Document Identifier	Publication Date
US 20210236038 A1	Aug. 05, 2021

Related U.S. Application Data

us-provisional-application US 62968008 20200130

Publication Classification

Int. Cl.: **A61B5/318** (20210101); **A61B5/00** (20060101); **A61B5/282** (20210101); **A61B5/308** (20210101); **A61B5/33** (20210101); **A61B5/349** (20210101); **A61B5/353** (20210101)

U.S. Cl.:

CPC **A61B5/308** (20210101); **A61B5/282** (20210101); **A61B5/33** (20210101); **A61B5/349** (20210101); **A61B5/353** (20210101); **A61B5/7214** (20130101); **A61B5/7217** (20130101); A61B2562/043 (20130101)

Field of Classification Search

CPC: A61B (5/316); A61B (5/349); A61B (5/4836); A61B (5/318); A61B (5/7203); A61B (5/7264); A61B (5/7275); A61B (5/0245); A61B (5/7282); A61B (5/7221); A61B (5/364); A61B (5/308); A61B (5/0044); A61N (1/3625); A61N (1/36014); A61N (1/00)

References Cited

U.S. PATENT DOCUMENTS

Patent No.	Issued Date	Patentee Name	U.S. Cl.	CPC
4233987	12/1979	Feingold	N/A	N/A
4402323	12/1982	White	N/A	N/A
4428378	12/1983	Anderson et al.	N/A	N/A
4497326	12/1984	Curry	N/A	N/A
4566456	12/1985	Koning et al.	N/A	N/A
4593702	12/1985	Kepski	N/A	N/A
4674511	12/1986	Cartmell	N/A	N/A
4763660	12/1987	Kroll et al.	N/A	N/A
4777955	12/1987	Brayten et al.	N/A	N/A
4787389	12/1987	Tarjan	N/A	N/A
4979507	12/1989	Heinz et al.	N/A	N/A
5052388	12/1990	Sivula et al.	N/A	N/A
5054496	12/1990	Wen et al.	N/A	N/A
5311873	12/1993	Savard et al.	N/A	N/A
5331960	12/1993	Lavine	N/A	N/A
5334220	12/1993	Sholder	N/A	N/A
5443492	12/1994	Stokes et al.	N/A	N/A
5485849	12/1995	Panescu et al.	N/A	N/A
5514163	12/1995	Markowitz et al.	N/A	N/A
5552645	12/1995	Weng	N/A	N/A
5628778	12/1996	Kruse et al.	N/A	N/A
5671752	12/1996	Sinderby et al.	N/A	N/A
5683429	12/1996	Mehra	N/A	N/A
5683432	12/1996	Goedeke et al.	N/A	N/A
5687737	12/1996	Branham et al.	N/A	N/A
5792069	12/1997	Greenwald	N/A	N/A
5810740	12/1997	Paisner	N/A	N/A
5876336	12/1998	Swanson et al.	N/A	N/A

5891045	12/1998	Albrecht et al.	N/A	N/A
5922014	12/1998	Warman et al.	N/A	N/A
6055448	12/1999	Anderson et al.	N/A	N/A
6128535	12/1999	Maarse et al.	N/A	N/A
6141588	12/1999	Cox et al.	N/A	N/A
6187032	12/2000	Ohyu et al.	N/A	N/A
6205357	12/2000	Ideker et al.	N/A	N/A
6226542	12/2000	Reisfeld	N/A	N/A
6236883	12/2000	Ciaccio et al.	N/A	N/A
6243603	12/2000	Ideker et al.	N/A	N/A
6246898	12/2000	Vesely et al.	N/A	N/A
6301496	12/2000	Reisfeld	N/A	N/A
6311089	12/2000	Mann et al.	N/A	N/A
6330476	12/2000	Ben-Haim et al.	N/A	N/A
6358214	12/2001	Tereschouk	N/A	N/A
6377856	12/2001	Carson	N/A	N/A
6381493	12/2001	Stadler et al.	N/A	N/A
6393316	12/2001	Gillberg et al.	N/A	N/A
6418346	12/2001	Nelson et al.	N/A	N/A
6442433	12/2001	Linberg	N/A	N/A
6456867	12/2001	Reisfeld	N/A	N/A
6473638	12/2001	Ferek-Petric	N/A	N/A
6480745	12/2001	Nelson et al.	N/A	N/A
6484118	12/2001	Govari	N/A	N/A
6507756	12/2002	Heynen et al.	N/A	N/A
6532379	12/2002	Stratbucker	N/A	N/A
6584343	12/2002	Ransbury et al.	N/A	N/A
6599250	12/2002	Webb et al.	N/A	N/A
6625482	12/2002	Panescu et al.	N/A	N/A
6640136	12/2002	Helland et al.	N/A	N/A
6650927	12/2002	Keidar	N/A	N/A
6766189	12/2003	Yu et al.	N/A	N/A
6772004	12/2003	Rudy	N/A	N/A
6804555	12/2003	Warkentin	N/A	N/A
6847836	12/2004	Sujdak	N/A	N/A
6856830	12/2004	He	N/A	N/A
6882882	12/2004	Struble et al.	N/A	N/A
6885889	12/2004	Chinchoy	N/A	N/A
6915149	12/2004	Ben-Haim	N/A	N/A
6968237	12/2004	Doan et al.	N/A	N/A
6975900	12/2004	Rudy et al.	N/A	N/A
6978184	12/2004	Marcus et al.	N/A	N/A
6980675	12/2004	Evron et al.	N/A	N/A
7016719	12/2005	Rudy et al.	N/A	N/A
7031777	12/2005	Hine et al.	N/A	N/A
7033350	12/2005	Bahk et al.	N/A	N/A
7058443	12/2005	Struble	N/A	N/A
7062315	12/2005	Koyrakh et al.	N/A	N/A
7092759	12/2005	Nehls et al.	N/A	N/A
7142922	12/2005	Spinelli et al.	N/A	N/A

7184835	12/2006	Kramer et al.	N/A	N/A
7215998	12/2006	Wesselink et al.	N/A	N/A
7238158	12/2006	Abend	N/A	N/A
7286866	12/2006	Okerlund et al.	N/A	N/A
7308297	12/2006	Reddy et al.	N/A	N/A
7308299	12/2006	Burrell et al.	N/A	N/A
7313444	12/2006	Pianca et al.	N/A	N/A
7321677	12/2007	Evron et al.	N/A	N/A
7346381	12/2007	Okerlund et al.	N/A	N/A
7398116	12/2007	Edwards	N/A	N/A
7426412	12/2007	Schecter	N/A	N/A
7454248	12/2007	Burrell et al.	N/A	N/A
7499743	12/2008	Vass et al.	N/A	N/A
7509170	12/2008	Zhang et al.	N/A	N/A
7565190	12/2008	Okerlund et al.	N/A	N/A
7587074	12/2008	Zarkh et al.	N/A	N/A
7599730	12/2008	Hunter et al.	N/A	N/A
7610088	12/2008	Chinchoy	N/A	N/A
7613500	12/2008	Vass et al.	N/A	N/A
7616993	12/2008	Müssig et al.	N/A	N/A
7664550	12/2009	Eick et al.	N/A	N/A
7684863	12/2009	Parikh et al.	N/A	N/A
7742629	12/2009	Zarkh et al.	N/A	N/A
7747047	12/2009	Okerlund et al.	N/A	N/A
7751882	12/2009	Helland et al.	N/A	N/A
7769451	12/2009	Yang et al.	N/A	N/A
7778685	12/2009	Evron et al.	N/A	N/A
7778686	12/2009	Vass et al.	N/A	N/A
7787951	12/2009	Min	N/A	N/A
7813785	12/2009	Okerlund et al.	N/A	N/A
7818040	12/2009	Spear et al.	N/A	N/A
7848807	12/2009	Wang	N/A	N/A
7860580	12/2009	Falk et al.	N/A	N/A
7894889	12/2010	Zhang	N/A	N/A
7912544	12/2010	Min et al.	N/A	N/A
7917214	12/2010	Gill et al.	N/A	N/A
7941213	12/2010	Markowitz et al.	N/A	N/A
7953475	12/2010	Harlev et al.	N/A	N/A
7953482	12/2010	Hess	N/A	N/A
7983743	12/2010	Rudy et al.	N/A	N/A
7996063	12/2010	Vass et al.	N/A	N/A
7996070	12/2010	van Dam et al.	N/A	N/A
8010191	12/2010	Zhu et al.	N/A	N/A
8010194	12/2010	Muller	N/A	N/A
8019402	12/2010	Kryzpow et al.	N/A	N/A
8019409	12/2010	Rosenberg et al.	N/A	N/A
8032229	12/2010	Gerber et al.	N/A	N/A
8036743	12/2010	Savage et al.	N/A	N/A
8060185	12/2010	Hunter et al.	N/A	N/A
8075486	12/2010	Tal	N/A	N/A

8150513	12/2011	Chinchoy	N/A	N/A
8160700	12/2011	Ryu et al.	N/A	N/A
8175703	12/2011	Dong et al.	N/A	N/A
8180428	12/2011	Kaiser et al.	N/A	N/A
8195292	12/2011	Rosenberg et al.	N/A	N/A
8213693	12/2011	Li	N/A	N/A
8214041	12/2011	Van Gelder et al.	N/A	N/A
8265736	12/2011	Sathaye et al.	N/A	N/A
8265738	12/2011	Min et al.	N/A	N/A
8285377	12/2011	Rosenberg et al.	N/A	N/A
8295943	12/2011	Eggen et al.	N/A	N/A
8326419	12/2011	Rosenberg et al.	N/A	N/A
8332030	12/2011	Hess et al.	N/A	N/A
8380308	12/2012	Rosenberg et al.	N/A	N/A
8401616	12/2012	Verard et al.	N/A	N/A
8478388	12/2012	Nguyen et al.	N/A	N/A
8509896	12/2012	Doerr et al.	N/A	N/A
8527051	12/2012	Hedberg et al.	N/A	N/A
8583230	12/2012	Ryu et al.	N/A	N/A
8615298	12/2012	Ghosh et al.	N/A	N/A
8617082	12/2012	Zhang et al.	N/A	N/A
8620433	12/2012	Ghosh et al.	N/A	N/A
8639333	12/2013	Stadler et al.	N/A	N/A
8694099	12/2013	Ghosh et al.	N/A	N/A
8731642	12/2013	Zarkh et al.	N/A	N/A
8738132	12/2013	Ghosh et al.	N/A	N/A
8744576	12/2013	Munsterman et al.	N/A	N/A
8768465	12/2013	Ghosh et al.	N/A	N/A
8805504	12/2013	Sweeney	N/A	N/A
8861830	12/2013	Brada et al.	N/A	N/A
8929984	12/2014	Ghosh et al.	N/A	N/A
8972228	12/2014	Ghosh et al.	N/A	N/A
9002454	12/2014	Ghosh et al.	N/A	N/A
9037238	12/2014	Stadler et al.	N/A	N/A
9060699	12/2014	Nearing et al.	N/A	N/A
9119959	12/2014	Rys et al.	N/A	N/A
9155897	12/2014	Ghosh et al.	N/A	N/A
9199087	12/2014	Stadler et al.	N/A	N/A
9265951	12/2015	Sweeney	N/A	N/A
9265954	12/2015	Ghosh	N/A	N/A
9265955	12/2015	Ghosh	N/A	N/A
9272148	12/2015	Ghosh	N/A	N/A
9278219	12/2015	Ghosh	N/A	N/A
9278220	12/2015	Ghosh	N/A	N/A
9282907	12/2015	Ghosh	N/A	N/A
9320446	12/2015	Gillberg et al.	N/A	N/A
9381362	12/2015	Ghosh et al.	N/A	N/A
9474457	12/2015	Ghosh et al.	N/A	N/A
9486151	12/2015	Ghosh et al.	N/A	N/A
9510763	12/2015	Gosh et al.	N/A	N/A

9586050	12/2016	Ghosh et al.	N/A	N/A
9586052	12/2016	Gillberg et al.	N/A	N/A
9591982	12/2016	Ghosh et al.	N/A	N/A
9700728	12/2016	Ghosh	N/A	N/A
9737223	12/2016	Du	N/A	A61B 5/349
9757567	12/2016	Ghosh et al.	N/A	N/A
9764143	12/2016	Ghosh et al.	N/A	N/A
9776009	12/2016	Ghosh et al.	N/A	N/A
9962097	12/2017	Ghosh et al.	N/A	N/A
10022060	12/2017	Nearing et al.	N/A	N/A
10154794	12/2017	Stadler et al.	N/A	N/A
10780279	12/2019	Ghosh	N/A	N/A
2002/0072682	12/2001	Hopman et al.	N/A	N/A
2002/0087089	12/2001	Ben-Haim	N/A	N/A
2002/0143264	12/2001	Ding et al.	N/A	N/A
2002/0161307	12/2001	Yu et al.	N/A	N/A
2002/0169484	12/2001	Mathis et al.	N/A	N/A
2003/0018277	12/2002	He	N/A	N/A
2003/0050670	12/2002	Spinelli et al.	N/A	N/A
2003/0105495	12/2002	Yu et al.	N/A	N/A
2003/0236466	12/2002	Tarjan et al.	N/A	N/A
2004/0015081	12/2003	Kramer et al.	N/A	N/A
2004/0059237	12/2003	Narayan et al.	N/A	N/A
2004/0097806	12/2003	Hunter et al.	N/A	N/A
2004/0102812	12/2003	Yonce et al.	N/A	N/A
2004/0122479	12/2003	Spinelli et al.	N/A	N/A
2004/0162496	12/2003	Yu et al.	N/A	N/A
2004/0172078	12/2003	Chinchoy	N/A	N/A
2004/0172079	12/2003	Chinchoy	N/A	N/A
2004/0193223	12/2003	Kramer et al.	N/A	N/A
2004/0215245	12/2003	Stahmann et al.	N/A	N/A
2004/0215252	12/2003	Verbeek et al.	N/A	N/A
2004/0220635	12/2003	Burnes	N/A	N/A
2004/0267321	12/2003	Boileau et al.	N/A	N/A
2005/0008210	12/2004	Evron et al.	N/A	N/A
2005/0027320	12/2004	Nehls et al.	N/A	N/A
2005/0090870	12/2004	Hine et al.	N/A	N/A
2005/0096522	12/2004	Reddy et al.	N/A	N/A
2005/0107839	12/2004	Sanders	N/A	N/A
2005/0149138	12/2004	Min et al.	N/A	N/A
2006/0074285	12/2005	Zarkh et al.	N/A	N/A
2006/0224198	12/2005	Dong et al.	N/A	N/A
2006/0235478	12/2005	Van Gelder et al.	N/A	N/A
2006/0253162	12/2005	Zhang et al.	N/A	N/A
2007/0142871	12/2006	Libbus et al.	N/A	N/A
2007/0167809	12/2006	Dala-Krishna	N/A	N/A
2007/0167858	12/2006	Virtanen	N/A	N/A
2007/0232943	12/2006	Harel et al.	N/A	N/A
2007/0250129	12/2006	Van Oort	N/A	N/A

2007/0265508	12/2006	Sheikhzadeh-Nadjar et al.	N/A	N/A
2008/0021336	12/2007	Dobak et al.	N/A	N/A
2008/0058656	12/2007	Costello et al.	N/A	N/A
2008/0119903	12/2007	Arcot-Krishnamurthy et al.	N/A	N/A
2008/0140143	12/2007	Ettori et al.	N/A	N/A
2008/0146954	12/2007	Bojovic et al.	N/A	N/A
2008/0242976	12/2007	Robertson et al.	N/A	N/A
2008/0269818	12/2007	Sullivan et al.	N/A	N/A
2008/0269823	12/2007	Burnes et al.	N/A	N/A
2008/0281195	12/2007	Heimdal	N/A	N/A
2008/0306567	12/2007	Park et al.	N/A	N/A
2008/0306568	12/2007	Ding et al.	N/A	N/A
2009/0005832	12/2008	Zhu et al.	N/A	N/A
2009/0036947	12/2008	Westlund et al.	N/A	N/A
2009/0043352	12/2008	Brooke et al.	N/A	N/A
2009/0048528	12/2008	Hopenfeld et al.	N/A	N/A
2009/0053102	12/2008	Rudy et al.	N/A	N/A
2009/0054941	12/2008	Eggen et al.	N/A	N/A
2009/0054946	12/2008	Sommer et al.	N/A	N/A
2009/0084382	12/2008	Jalde et al.	N/A	N/A
2009/0093857	12/2008	Markowitz et al.	N/A	N/A
2009/0099468	12/2008	Thiagalingam et al.	N/A	N/A
2009/0099469	12/2008	Flores	N/A	N/A
2009/0099619	12/2008	Lessmeier et al.	N/A	N/A
2009/0112109	12/2008	Kuklik et al.	N/A	N/A
2009/0143838	12/2008	Libbus et al.	N/A	N/A
2009/0157134	12/2008	Ziglio et al.	N/A	N/A
2009/0157136	12/2008	Yang et al.	N/A	N/A
2009/0198298	12/2008	Kaiser et al.	N/A	N/A
2009/0216112	12/2008	Assis et al.	N/A	N/A
2009/0232448	12/2008	Barmash et al.	N/A	N/A
2009/0234414	12/2008	Sambelashvili et al.	N/A	N/A
2009/0254140	12/2008	Rosenberg et al.	N/A	N/A
2009/0270729	12/2008	Corbucci et al.	N/A	N/A
2009/0270937	12/2008	Yonce et al.	N/A	N/A
2009/0299201	12/2008	Gunderson	N/A	N/A
2009/0299423	12/2008	Min	N/A	N/A
2009/0306732	12/2008	Rosenberg et al.	N/A	N/A
2009/0318995	12/2008	Keel et al.	N/A	N/A
2010/0022873	12/2009	Hunter et al.	N/A	N/A
2010/0049063	12/2009	Dobak, III	N/A	N/A
2010/0069987	12/2009	Min et al.	N/A	N/A
2010/0087888	12/2009	Maskara	N/A	N/A
2010/0094149	12/2009	Kohut et al.	N/A	N/A
2010/0113954	12/2009	Zhou	N/A	N/A
2010/0114229	12/2009	Chinchoy	N/A	N/A
2010/0121403	12/2009	Schecter et al.	N/A	N/A

2010/0145405	12/2009	Min et al.	N/A	N/A
2010/0174137	12/2009	Shim	N/A	N/A
2010/0198292	12/2009	Honeck et al.	N/A	N/A
2010/0228138	12/2009	Chen	N/A	N/A
2010/0234916	12/2009	Turcott et al.	N/A	N/A
2010/0249622	12/2009	Olson	N/A	N/A
2010/0254583	12/2009	Chan et al.	N/A	N/A
2010/0268059	12/2009	Ryu et al.	N/A	N/A
2011/0004111	12/2010	Gill et al.	N/A	N/A
2011/0004264	12/2010	Siejko et al.	N/A	N/A
2011/0014510	12/2010	Miyashisa et al.	N/A	N/A
2011/0022112	12/2010	Min	N/A	N/A
2011/0054286	12/2010	Crosby	N/A	N/A
2011/0054559	12/2010	Rosenberg et al.	N/A	N/A
2011/0054560	12/2010	Rosenberg et al.	N/A	N/A
2011/0075896	12/2010	Matsumoto	N/A	N/A
2011/0092809	12/2010	Nguyen et al.	N/A	N/A
2011/0112398	12/2010	Zarkh et al.	N/A	N/A
2011/0118803	12/2010	Hou et al.	N/A	N/A
2011/0137369	12/2010	Ryu et al.	N/A	N/A
2011/0144510	12/2010	Ryu et al.	N/A	N/A
2011/0172728	12/2010	Wang	N/A	N/A
2011/0190615	12/2010	Phillips et al.	N/A	N/A
2011/0201915	12/2010	Gogin et al.	N/A	N/A
2011/0213260	12/2010	Keel et al.	N/A	N/A
2011/0319954	12/2010	Niazi et al.	N/A	N/A
2012/0004567	12/2011	Eberle et al.	N/A	N/A
2012/0101543	12/2011	Demmer et al.	N/A	N/A
2012/0101546	12/2011	Stadler et al.	N/A	N/A
2012/0109244	12/2011	Anderson et al.	N/A	N/A
2012/0203090	12/2011	Min	N/A	N/A
2012/0253419	12/2011	Rosenberg et al.	N/A	N/A
2012/0283587	12/2011	Ghosh et al.	N/A	N/A
2012/0284003	12/2011	Ghosh et al.	N/A	N/A
2012/0296387	12/2011	Zhang et al.	N/A	N/A
2012/0296388	12/2011	Zhang et al.	N/A	N/A
2012/0302904	12/2011	Lian et al.	N/A	N/A
2012/0303084	12/2011	Kleckner et al.	N/A	N/A
2012/0310297	12/2011	Sweeney	N/A	N/A
2012/0330179	12/2011	Yuk et al.	N/A	N/A
2013/0006332	12/2012	Sommer et al.	N/A	N/A
2013/0018250	12/2012	Caprio et al.	N/A	N/A
2013/0018251	12/2012	Caprio et al.	N/A	N/A
2013/0030491	12/2012	Stadler et al.	N/A	N/A
2013/0060298	12/2012	Splett et al.	N/A	N/A
2013/0072790	12/2012	Ludwig et al.	N/A	N/A
2013/0096446	12/2012	Michael et al.	N/A	N/A
2013/0116739	12/2012	Brada et al.	N/A	N/A
2013/0131529	12/2012	Jia et al.	N/A	N/A
2013/0131749	12/2012	Sheldon et al.	N/A	N/A

2013/0131751	12/2012	Stadler et al.	N/A	N/A
2013/0136035	12/2012	Bange et al.	N/A	N/A
2013/0150913	12/2012	Bornzin et al.	N/A	N/A
2013/0165983	12/2012	Ghosh et al.	N/A	N/A
2013/0165988	12/2012	Ghosh	N/A	N/A
2013/0261471	12/2012	Saha et al.	N/A	N/A
2013/0261688	12/2012	Dong et al.	N/A	N/A
2013/0289640	12/2012	Zhang et al.	N/A	N/A
2013/0296726	12/2012	Niebauer et al.	N/A	N/A
2013/0304407	12/2012	George et al.	N/A	N/A
2013/0324828	12/2012	Nishiwaki et al.	N/A	N/A
2014/0005563	12/2013	Ramanathan et al.	N/A	N/A
2014/0018872	12/2013	Siejko et al.	N/A	N/A
2014/0135866	12/2013	Ramanathan et al.	N/A	N/A
2014/0135867	12/2013	Demmer et al.	N/A	N/A
2014/0163633	12/2013	Ghosh et al.	N/A	N/A
2014/0222099	12/2013	Sweeney	N/A	N/A
2014/0236252	12/2013	Ghosh et al.	N/A	N/A
2014/0276125	12/2013	Hou et al.	N/A	N/A
2014/0277233	12/2013	Ghosh	N/A	N/A
2014/0323882	12/2013	Ghosh et al.	N/A	N/A
2014/0323892	12/2013	Ghosh et al.	N/A	N/A
2014/0323893	12/2013	Ghosh et al.	N/A	N/A
2014/0371807	12/2013	Ghosh et al.	N/A	N/A
2014/0371808	12/2013	Ghosh et al.	N/A	N/A
2014/0371832	12/2013	Ghosh et al.	N/A	N/A
2014/0371833	12/2013	Ghosh et al.	N/A	N/A
2015/0032016	12/2014	Ghosh	N/A	N/A
2015/0032171	12/2014	Ghosh	N/A	N/A
2015/0032172	12/2014	Ghosh	N/A	N/A
2015/0032173	12/2014	Ghosh	N/A	N/A
2015/0045849	12/2014	Ghosh et al.	N/A	N/A
2015/0142069	12/2014	Sambelashvili	N/A	N/A
2015/0157225	12/2014	Gillberg et al.	N/A	N/A
2015/0157231	12/2014	Gillberg et al.	N/A	N/A
2015/0157232	12/2014	Gillberg et al.	N/A	N/A
2015/0157865	12/2014	Gillberg et al.	N/A	N/A
2015/0216434	12/2014	Ghosh et al.	N/A	N/A
2015/0265840	12/2014	Ghosh et al.	N/A	N/A
2016/0030747	12/2015	Thakur et al.	N/A	N/A
2016/0030751	12/2015	Ghosh et al.	N/A	N/A
2016/0045737	12/2015	Ghosh et al.	N/A	N/A
2016/0045738	12/2015	Ghosh et al.	N/A	N/A
2016/0045744	12/2015	Gillberg et al.	N/A	N/A
2016/0059002	12/2015	Grubac et al.	N/A	N/A
2016/0184590	12/2015	Ghosh	N/A	N/A
2017/0049347	12/2016	Ghosh et al.	N/A	N/A
2017/0071675	12/2016	Dawoud et al.	N/A	N/A
2017/0303840	12/2016	Steckler et al.	N/A	N/A
2018/0140847	12/2017	Taff et al.	N/A	N/A

2018/0264258	12/2017	Cheng et al.	N/A	N/A
2019/0290909	12/2018	Ghosh et al.	N/A	N/A

FOREIGN PATENT DOCUMENTS

Patent No.	Application Date	Country	CPC
1043621	12/1989	CN	N/A
1253761	12/1999	CN	N/A
1878595	12/2005	CN	N/A
101073502	12/2006	CN	N/A
1 072 284	12/2000	EP	N/A
1 504 713	12/2004	EP	N/A
2 016 976	12/2008	EP	N/A
2 391 270	12/2010	EP	N/A
1 925 337	12/2011	EP	N/A
2 436 309	12/2011	EP	N/A
2 435 132	12/2012	EP	N/A
WO 1998/026712	12/1997	WO	N/A
WO 1999/006112	12/1998	WO	N/A
WO 2000/045700	12/1999	WO	N/A
WO 2001/067950	12/2000	WO	N/A
WO 2003/070323	12/2002	WO	N/A
WO 2005/056108	12/2004	WO	N/A
WO 2006/069215	12/2005	WO	N/A
WO 2006/105474	12/2005	WO	N/A
WO 2006/115777	12/2005	WO	N/A
WO 2006/117773	12/2005	WO	N/A
WO 2007/013994	12/2006	WO	N/A
WO 2007/027940	12/2006	WO	N/A
WO 2007/013994	12/2006	WO	N/A
WO 2007/027940	12/2006	WO	N/A
WO 2007/139456	12/2006	WO	N/A
WO 2008/151077	12/2007	WO	N/A
WO 2006/069215	12/2008	WO	N/A
WO 2009/079344	12/2008	WO	N/A
WO 2009/139911	12/2008	WO	N/A
WO 2009/148429	12/2008	WO	N/A
WO 2010/019494	12/2009	WO	N/A
WO 2010/071520	12/2009	WO	N/A
WO 2010/088040	12/2009	WO	N/A
WO 2010/088485	12/2009	WO	N/A
WO 2011/070166	12/2010	WO	N/A
WO 2011/090622	12/2010	WO	N/A
WO 2011/099992	12/2010	WO	N/A
WO 2012/037471	12/2011	WO	N/A
WO 2012/037471	12/2011	WO	N/A
WO 2012/106297	12/2011	WO	N/A
WO 2012/109618	12/2011	WO	N/A
WO 2012/110940	12/2011	WO	N/A
WO 2012/109618	12/2011	WO	N/A

WO 2012/151364	12/2011	WO	N/A
WO 2012/151389	12/2011	WO	N/A
WO 2013/006724	12/2012	WO	N/A
WO 2013/010165	12/2012	WO	N/A
WO 2013/010184	12/2012	WO	N/A
WO 2013/006724	12/2012	WO	N/A
WO 2014/179454	12/2013	WO	N/A
WO 2014/179459	12/2013	WO	N/A
WO 2014/179459	12/2014	WO	N/A
WO 2015/013271	12/2014	WO	N/A
WO 2015/013493	12/2014	WO	N/A
WO 2015/013574	12/2014	WO	N/A

OTHER PUBLICATIONS

International Search Report and Written Opinion issued May 3, 2012 for International Application No. PCT/US2012/036262; 9 pages. cited by applicant

International Search Report and Written Opinion issued May 3, 2012 for International Application No. PCT/US2012/036302; 9 pages. cited by applicant

International Search Report and Written Opinion issued Sep. 3, 2012 for International Application No. PCT/US2012/036262 9 pages. cited by applicant

International Search Report and Written Opinion issued Aug. 6, 2014 for International Application No. PCT/US2014/036153; 14 pages. cited by applicant

International Search Report and Written Opinion issued Nov. 7, 2014 for International Application No. PCT/US2014/036163; 12 pages. cited by applicant

International Search Report and Written Opinion issued Oct. 24, 2014 for International Application No. PCT/US2014/041929; 14 pages. cited by applicant

International Search Report and Written Opinion issued Oct. 28, 2014 for International Application No. PCT/US2014/041928; 15 pages. cited by applicant

International Search Report and Written Opinion issued on Nov. 4, 2014 for International Application No. PCT/US2014/0247583; 7 pages. cited by applicant

International Search Report and Written Opinion issued on Nov. 12, 2014 for International Application No. PCT/US2014/047971; 7 pages. cited by applicant

International Search Report and Written Opinion issued on Nov. 12, 2014 for International Application No. PCT/US2014/048120; 7 pages. cited by applicant

International Search Report and Written Opinion issued on Mar. 9, 2015 for International Application No. PCT/US2014/069214; 11 pages. cited by applicant

International Search Report and Written Opinion issued on Mar. 16, 2015 for International Application No. PCT/US2014/069182; 11 pages. cited by applicant

International Search Report and Written Opinion issued Mar. 16, 2015 for International Application No. PCT/US2014/069182; 11 pages. cited by applicant

International Search Report and Written Opinion issued on Mar. 17, 2015, for International Application No. PCT/US2014/069192; 11 pages. cited by applicant

International Search Report and Written Opinion issued Mar. 17, 2015 for International Application No. PCT/US2014/069192; 11 pages. cited by applicant

International Search Report and Written Opinion issued on Apr. 8, 2015 for International Application No. PCT/US2014/069070; 11 pages. cited by applicant

International Search Report and Written Opinion issued on Jun. 11, 2015 for International Application No. PCT/US2015/021442; 13 pages. cited by applicant

International Search Report and Written Opinion issued May 27, 2019 for International Application No. PCT/US2019/023549; 15 pages. cited by applicant

International Search Report and Written Opinion issued Jun. 4, 2020 for International Application No. PCT/US2020/019589; 11 pages. cited by applicant
International Search Report and Written Opinion from PCT Application No. PCT/US2020/053474 dated Jan. 13, 2021, 8 pages. cited by applicant
Biffi et al., "Occurrence of Phrenic Nerve Stimulation in Cardiac Resynchronization Therapy Patients: the Role of Left Ventricular Lead Type and Placement Site," *Europace*, 2013; 15:77-82. cited by applicant
Bortolotto et al., "Pre-implantation interlead EKG heterogeneity is superior to QRS complex duration in predicting mechanical super-response and survival in patients receiving cardiac resynchronization therapy", Heart Rhythm, Mar. 10, 2020, 35 pages. cited by applicant
Botker MD, PhD., et al., "Electromechanical Mapping for Detection of Myocardial Viability in Patients with ischemia Cardiomyopathy," Circulation, Mar. 2001; vol. 103, No. 12, pp. cited by applicant
"CardioGuide System Enables Real-Time Navigation of Left Ventricular Leads During Medtronic CRT Implants," Press Release, Apr. 9, 2013, Medtronic, Inc., 2 pgs. cited by applicant
Cuculich, P.S., et al., "The Electrophysiological Cardiac Ventricular Substrate in Patients After Myocardial Infection" J. Am. Coll. Cardiol. 2011; 58:1893-1902. cited by applicant
Czerwińska et al., "Method of Segmentation of Thorax Organs Images Applied to Modeling the Cardiac Electrical Field," *Engineering in Medicine and Biology Society*, Proceedings of the 22.SUP.nd .Annual International Conference of the IEEE, vol. 1, 23, Jul. 23, 2000.; pp. 402-405. cited by applicant
Dawoud, F. et al., "Inverse Electrocardiogramaging to Assess Electrical Dyssynchrony in Cardiac Resynchronization Therapy Patients," Computing in Cardiology, 2012; 39:993-996. cited by applicant
Freund et al., "A Decision-Theoretic Generalization of Online Learning and an Application to Boosting." *Journal of Computer and System Sciences*, 1997; 55(1):119-139. cited by applicant
Friedman, "Greedy Function Approximation: A Gradient Boosting Machine," *Annals of Statistics*, 2001; 29(5):1189-1232. cited by applicant
Friedman, "Stochastic Gradient Boosting," *Computational Statistics and Data Analysis*, 2002; 38(4):367-378. cited by applicant
Friedman et al., "Additive Logistic Regression: a Statistical View of Boosting," *Annals of Statistics*, 2000; 28(2):337-374. cited by applicant
Fung et al., Chapter 20, Optimization of Cardiac Resynchronization Therapy, Cardiac Resynchronization Therapy, Second Edition, Copyright 2008, Blackwell Publishing Ltd., pp. 356-373. cited by applicant
Ghosh et al. "Accuracy of Quadratic Versus Linear Interpolation in Noninvasive Electrocardiogramaging (ECGI)," *Annuals of Biomedical Engineering*, vol. 33, No. 9. Sep. 2005; pp. 1187-1201. cited by applicant
Ghosh et al., "Cardiac Memory in Patents with Wolff-Parkinson-White Syndrome; Noninvasive Imaging of Activation and Repolarization Before and After Catheter Ablation" *Circulation*, 2008; 118:907-915. Published online Aug. 12, 2008. cited by applicant
Ghosh et al. "Application of L1-Norm Regularization to Epicardial Potential Solution of the Inverse Electrocardiogramablem," *Annuals of Biomedical Engineering*, vol. 37, No. 5, May 2009; pp. 902-912. cited by applicant
Ghosh et al., "Electrophysiological Substrate and Intraventricular LV Dyssynchrony in Non-ischemic Heart Failure Patients Undergoing Cardiac Resynchronization Therapy," *Heart rhythm : the official journal of the Heart Rhythm Society*, 2011; 8(5):692-699. cited by applicant
Gold et al., "Comparison of Stimulation Sites within Left Ventricular Veins on the Acute Hemodynamic Effects of Cardiac Resynchronization Therapy" *Heart Rhythm*, Apr. 2005; 2(4):376-381. cited by applicant

Gulrajani, “The Forward and Inverse Problems of Electrocardiography,” *IEEE Engineering in Medicine and Biology*, IEEE Service Center, vol. 17, No. 5, Sep. 1, 1988; pp. 84-101, 122. cited by applicant
Hansen, “Regularization Tools: A Matlab Package for Analysis and Solution of Discrete Ill-Posed Problems,” Version 4.1 for Matlab 7.3; Mar. 2008; 128 pages. Retrieved from the Internet: Jun. 19, 2014 http://www.mathworks.com/matlabcentral/fileexchange/52-regtools. cited by applicant
Hayes et al., “Cardiac Resynchronization Therapy and the Relationship of Percent Biventricular Pacing to Symptoms and Survival,” *Heart Rhythm*, Sep. 2011; 8(9):1469-1475. cited by applicant
“Heart Failure Management” datasheet [online]. Medtronic, Minneapolis, Minnesota, [Last updated on Jun. 3, 2013].Retrieved from the Internet: www.medtronic.com; 9 pages. cited by applicant
Hopenfeld et al., “The Effect of Conductivity on ST—Segment Epicardial Potentials Arising from Subendocardial Ischemia,” Annals of Biomedical Eng., Jun. 2005; vol. 33, No. 6, pp. 751-763. cited by applicant
Hurtado, “Electrical and Anatomical Modeling of the Specialized Cardiac Conduction System, A Simulation Study”, Universitat Politecnica de Valenica, March 211, 96 pp. cited by applicant
Jia et al., “Electrocardiogramaging of Cardiac Resynchronization Therapy in Heart Failure: Observation of Variable Electrophysiologic Responses,” *Heart Rhythm*, vol. 3, No. 3; Mar. 1, 2006, pp. 296-310. cited by applicant
Kentta et al., “Prediction of sudden cardiac death with automated high-throughput analysis of heterogeneity in standard resting 12-lead electrocardiograms”, Heart Rhythm Societ, 2016, 8 pages. cited by applicant
Komreich, “Body Surface Potential Mapping of ST Segment Changes in Acute Myocardial Infarction,” *Circulation*, 1993; 87: 773-782. cited by applicant
Liu et al., “Three-Dimensional Imaging of Ventricular Activation and Electrograms from Intercavitary Recordings”, IEEE 2011, vol. 58, No. Apr. 2011, pp. 868-875. cited by applicant
Lumason™, Brochure, Bracco Diagnostocs. Oct. 2014. cited by applicant
Medtronic Vitatron CARELINK ENCORE® Programmer Model 29901 Reference Manual, 2013, Medtronic, Inc., Minneapolis, MN. cited by applicant
Miri et al., “Applicability of body surface potential map in computerized optimization of biventricular pacing,” Annals of Biomedical Engineering, vol. 38, No. 3, Mar. 2010, pp. 865-875. cited by applicant
Miri et al., “Comparison of the electrophysiologically based optimization methods with different pacing parameters in patient undergoing resynchronization treatment,” 30th Annual International IEEE EMBS Conference, Aug. 2008, pp. 1741-1744. cited by applicant
Miri et al., “Computerized Optimization of Biventricular Pacing Using Body Surface Potential Map,” 31st Annual International Conference of the IEEE EMBS, Sep. 2009, pp. 2815-2818. cited by applicant
Miri et al., “Efficiency of Timing Delays and Electrode Positions in Optimization of Biventricular Pacing: A Simulation Study,” IEEE Transactions on Biomedical Engineering, Nov. 2009, pp. 2573-2582. cited by applicant
Modre et al., “Noninvasive Myocardial Activation Time Imaging: A Novel Inverse Algorithm Applied to Clinical ECG Mapping Data” *IEEE Transactions on Biomedical Engineering*, vol. 49; No. 10, Oct. 2002; pp. 1153-1161. cited by applicant
Nash et al., “An Experimental-Computational Framework for Validating in-vivo ECG Inverse Algorithms,” International Journal of Bioelectromagnetism, vol. 2, No. 2, Dec. 31, 2000, 9 pp. cited by applicant
Potse et al., “Mathematical Modeling and Simulation of Ventricular Activation Sequences: Implications for Cardiac Resynchronization Therapy,” *J. of Cardiovasc. Trans. Res*., 2012; 5:146-158. cited by applicant
Prinzen et al., “Cardiac Resynchronization Therapy State-of-the-Art of Current Applications,

Guidelines, Ongoing Trials, and Areas of Controversy" *Circulation*, 2013; 128: 2407-2418. cited by applicant
Ridgeway, "The State of Boosting," *Computing Science and Statistics*, 1999; 31:172-181. cited by applicant
Ryu et al., "Simultaneous Electrical and Mechanical Mapping Using 3D Cardiac Mapping System: Novel Approach for Optimal Cardiac Resynchronization Therapy," *Journal of Cardiovascular Electrophysiology*, Feb. 2010; 21(2):219-22. cited by applicant
Silva et al., "Cardiac Resynchronization Therapy in Pediatric Congenital Heart Disease: Insights from Noninvasive Electrocardiogramaging" *Heart Rhythm*, vol. 6, No. 8. Aug. 1, 2009; pp. 1178-1185. cited by applicant
Singh et al., "Left Ventricular Lead Position and Clinical Outcome in the Multicenter Automatic Defibrillator Implantation Trial-Cardiac Resynchronization Therapy (MADIT-CRT) Trial," *Circulation*, 2011; 123:1159-1166. cited by applicant
Sperzel et al., "Intraoperative Characterization of Interventricular Mechanical Dyssynchrony Using Electroanatomic Mapping System—A Feasibility Study," *Journal of Interventional Cardiac Electrophysiology*, Nov. 2012; 35(2):189-96. cited by applicant
Steinhaus BM., "Estimating cardiac transmembrane activation and recovery times from unipolar and bipolar extracellular electrograms: a simulation study," Circulation Research, 1989, 64:449-462. cited by applicant
Strik et al., "Electrical and Mechanical Ventricular Activation During Left Bundle Branch Block and Resynchronization," *J. of Cardiovasc. Trans. Res.*, 2012; 5:117-126. cited by applicant
Svendsen et al., "Computational Models of Cardiac Electrical Activation," Chapter 5, Computational Nov. 2010, pp. 73-88. cited by applicant
Sweeney et al., "Analysis of Ventricular Activation Using Surface Electrocardiogra Predict Left Ventricular Reverse Volumetric Remodeling During Cardiac Resynchronization Therapy," *Circulation*, Feb. 9, 2010; 121(5):626-34. Available online Jan. 25, 2010. cited by applicant
Sweeney et al., QRS Fusion Complex Analysis Using Wave Interference to Predict Reverse Remodeling During Cardiac Resynchronization Therapy, heart Rhythm, 2014, 11:806-813. cited by applicant
Tan et al., "Interlead heterogeneit of R- and T-wave morphology in standard 12-lead ECGs predicts sustained ventricular tachycardia/fibrillation and arrhythmic death in patients with cardiomyopathy", J. Cardiovasc Electrophysiol. 2017, 28, pp. 1324-1333. cited by applicant
Turner et al., "Electrical and Mechanical Components of Dyssynchrony in Heart Failure Patients with Normal QRS Duration and Left Bundle-Branch Block," *Circulation* 2004; 109:2544-2549. cited by applicant
Van Deursen et al., "Vectorcardiography as a Tool for Easy Optimization of Cardiac Resynchronization Therapy in Canine LBBB Hearts," *Circulation Arrhythmia and Electrophysiology*, Jun. 1, 2012; 5(3):544-52. Available online Apr. 24, 2012. cited by applicant
Van Deursen et al., "Vectorcardiography for Optimization of Stimulation Intervals in Cardiac Resynchronization Therapy", J. of Cardiovasc. Trans. Res., vol. 8, No. 2, Mar. 6, 2015, pp. 128-137. cited by applicant
Vardas et al., The Task Force for Cardiac Pacing and Cardiac Resynchronization Therapy of the European Society of Cardiology. Developed in Collaboration with the European Heart Rhythm Association, *European Heart Journal*, 2007; 28:2256-2295. cited by applicant
Varma et al., "Placebo CRT," *Journal of Cardiovascular Electrophysiology*, vol. 19, Aug. 2008; p. 878. cited by applicant
Wang et al., "Application of the Method of Fundamental Solutions to Potential-based Inverse Electrocardiography," Annals of Biomedical Engineering, Aug. 2006, pp. 1272-1288. cited by applicant
Wellens, MD et al., "The Electrocardiogram 102 Years After Einthoven," Circulation, Feb. 2004;

vol. 109, No. 5, pp. 562-564. cited by applicant
Williams et al., “Short-Term Hemodynamic Effects of Cardiac Resynchronization Therapy in Patients With Heart Failure, a Narrow QRS Duration, and No Dyssynchrony,” *Circulation*, Oct. 27, 2009; 120: 1687-1694. cited by applicant
Office Action issued in Europe for Application No. 21 704 059.1 dated Aug. 28, 2024 (5 pages). cited by applicant

---

Primary Examiner: Malamud; Deborah L

Attorney, Agent or Firm: Mueting Raasch Group

Background/Summary

(1) The present application claims the benefit of U.S. Provisional Application No. 62/968,008, filed Jan. 30, 2020, which is incorporated herein by reference in its entirety.

(1) The disclosure herein relates to systems and methods for use in the detection and removal of disturbances in cardiac signal using a plurality of external electrodes.
(2) Implantable medical devices (IMDs), such as implantable pacemakers, cardioverters, defibrillators, or pacemaker-cardioverter-defibrillators, provide therapeutic electrical stimulation to the heart. IMDs may provide pacing to address bradycardia, or pacing or shocks in order to terminate tachyarrhythmia, such as tachycardia or fibrillation. In some cases, the medical device may sense intrinsic depolarizations of the heart, detect arrhythmia based on the intrinsic depolarizations (or absence thereof), and control delivery of electrical stimulation to the heart if arrhythmia is detected based on the intrinsic depolarizations.
(3) IMDs may also provide cardiac resynchronization therapy (CRT), which is a form of pacing. CRT involves the delivery of pacing to the left ventricle, or both the left and right ventricles. The timing and location of the delivery of pacing pulses to the ventricle(s) may be selected to improve the coordination and efficiency of ventricular contraction.
(4) Systems for implanting medical devices may include workstations or other equipment in addition to the implantable medical device itself. In some cases, these other pieces of equipment assist the physician or other technician with placing the intracardiac leads at particular locations on the heart. In some cases, the equipment provides information to the physician about the electrical activity of the heart and the location of the intracardiac lead. The equipment may perform similar functions as the medical device, including delivering electrical stimulation to the heart and sensing the depolarizations of the heart. In some cases, the equipment may include equipment for obtaining an electrocardiogram (ECG) via electrodes on the surface, or skin, of the patient. More specifically, the patient may have a plurality of electrodes on an ECG belt or vest that surrounds the torso of the patient. After the belt or vest has been secured to the torso, a physician can perform a series of tests to evaluate a patient's cardiac response. The evaluation process can include detection of a baseline rhythm in which no electrical stimuli is delivered to cardiac tissue and another rhythm after electrical stimuli is delivered to the cardiac tissue.
(5) The ECG electrodes placed on the body surface of the patient may be used for various therapeutic purposes (e.g., cardiac resynchronization therapy) including optimizing lead location, pacing parameters, etc. based on one or more metrics derived from the signals captured by the ECG electrodes. For example, electrical heterogeneity information may be derived from electrical activation times computed from multiple electrodes on the body surface.
(6) Further, the signals from multiple electrodes on the body surface can be used to determine one or more specific ECG features such as, e.g., QRS onset, peak, QRS offset, etc. for a series of

multiple heartbeats. Such ECG features may be used by themselves to evaluate cardiac health and/or therapy, or may be used to calculate, or compute, activation times. However, in one or more instances, signals upon which activation times are based, or computed from, may contain various disturbances that may, for example, result false detection of activation times. Detection and/or removal of these disturbances may lead to more accurate determination of activation times.

SUMMARY

(7) The exemplary systems and methods described herein may be configured to assist users (e.g., physicians) in configuring cardiac therapy (e.g., cardiac therapy being performed on a patient during and/or after implantation of cardiac therapy apparatus). The systems and methods may be described as being noninvasive. For example, the systems and methods may not need implantable devices such as leads, probes, sensors, catheters, etc. to evaluate and configure the cardiac therapy. Instead, the systems and methods may use electrical measurements taken noninvasively using, e.g., a plurality of external electrodes attached to the skin of a patient about the patient's torso.

(8) One exemplary system for use in cardiac evaluation may include an electrode apparatus comprises a plurality of external electrodes to be disposed proximate a patient's skin. A computing apparatus comprises processing circuitry. The computing apparatus is operably coupled to the electrode apparatus. The computing apparatus is configured to monitor electrical activity from tissue of a patient using a plurality of external electrodes to generate a plurality of electrical signals. At least one of the electrical signals of the plurality of electrical signals is filtered. At least one disturbance in the at least one electrical signal is detected using the at least one filtered signal. A temporal location of the at least one disturbance in the at least one electrical signal is determined based on a time that the at least one filtered signal crosses a predetermined threshold.

(9) One exemplary system for use in cardiac evaluation may include an electrode apparatus comprising a plurality of external electrodes to be disposed proximate a patient's skin. A computing apparatus comprises processing circuitry. The computing apparatus is operably coupled to the electrode apparatus. The computing apparatus is configured to monitor electrical activity from tissue of a patient using a plurality of external electrodes to generate a plurality of electrical signals. At least one disturbance is detected in at least one of the plurality of electrical signals. Temporal locations of the at least one disturbance in the at least one electrical signal are determined. The at least one disturbance is removed based on the temporal locations of the at least one disturbance in the at least one electrical signal.

(10) An exemplary method for use in cardiac evaluation includes monitoring electrical activity from tissue of a patient using a plurality of external electrodes to generate a plurality of electrical signals. At least one electrical signal of the plurality of electrical signals is filtered. At least one disturbance is detected in the at least one electrical signal using the at least one filtered signal. A temporal location of the at least one disturbance in the at least one electrical signal is determined based on a time that the at least one filtered signal crosses a predetermined threshold.

(11) In one or more embodiments, the illustrative systems and methods may be described as utilizing a filtering algorithm that starts with a sampled signal. Next, the sampling frequency may be used to determine an appropriate threshold for a second derivative (or higher order) of a pacing spike for a known pulse width or range of pulse widths. The signal may be processed, or “run through,” the second derivative filter and the resulting signal may be examined for threshold crossings. If threshold crossings are identified, the temporal location of the crossing is recorded. The original signal (or a commonly filtered ECG signal) may then be examined at the recorded temporal location. The pacing spike may be removed from the original signal via a smoothing across a window (e.g., fixed and adjusted for pulse width, or auto calculated based on a baseline departure and return) that starts slightly before the temporal location and extends beyond the temporal location sufficiently to remove the pacing spike.

(12) The above summary is not intended to describe each embodiment or every implementation of the present disclosure. A more complete understanding will become apparent and appreciated by

referring to the following detailed description and claims taken in conjunction with the accompanying drawings.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) FIG. **1** is a diagram of an exemplary system including electrode apparatus, display apparatus, and computing apparatus.

(2) FIGS. **2**-**3** are diagrams of exemplary external electrode apparatus for measuring torso-surface potentials.

(3) FIG. **4** is a block diagrams of an exemplary method for detecting and removing disturbances.

(4) FIG. **5** is a detailed block diagram of a process of the exemplary method of FIG. **4**.

(5) FIGS. **6**A and **6**B show examples of a plurality of sampled electrical signals.

(6) FIG. **7** illustrates an example of filtered electrical signals.

(7) FIG. **8**A illustrates example signals after removal of the disturbances in some of the signals within a window.

(8) FIG. **8**B shows the signals of FIG. **8**A with additional filtering.

(9) FIG. **9**A illustrates an example where false activation times are detected due to a disturbance.

(10) FIG. **9**B shows the same signals shown in FIG. **9**A with the disturbance removed.

(11) FIG. **10** is a diagram of an illustrative system including an illustrative implantable medical device (IMD).

(12) FIG. **11**A is a diagram of the illustrative IMD of FIG. **10**.

(13) FIG. **11**B is a diagram of an enlarged view of a distal end of the electrical lead disposed in the left ventricle of FIG. **11**A.

(14) FIG. **12**A is a block diagram of an illustrative IMD, e.g., of the systems of FIGS. **10**-**11**.

(15) FIG. **12**B is another block diagram of an illustrative IMD (e.g., an implantable pulse generator) circuitry and associated leads employed in the systems of FIGS. **10**-**11**).

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

(16) In the following detailed description of illustrative embodiments, reference is made to the accompanying figures of the drawing which form a part hereof, and in which are shown, by way of illustration, specific embodiments which may be practiced. It is to be understood that other embodiments may be utilized and structural changes may be made without departing from (e.g., still falling within) the scope of the disclosure presented hereby.

(17) Illustrative systems and methods shall be described with reference to FIGS. **1**-**12**. It will be apparent to one skilled in the art that elements or processes from one embodiment may be used in combination with elements or processes of the other embodiments, and that the possible embodiments of such systems, methods, and devices using combinations of features set forth herein is not limited to the specific embodiments shown in the Figures and/or described herein. Further, it will be recognized that the embodiments described herein may include many elements that are not necessarily shown to scale. Still further, it will be recognized that timing of the processes and the size and shape of various elements herein may be modified but still fall within the scope of the present disclosure, although certain timings, one or more shapes and/or sizes, or types of elements, may be advantageous over others.

(18) A plurality of electrocardiogram (ECG) signals (e.g., torso-surface potentials) may be measured, or monitored, using a plurality of external electrodes positioned about the surface, or skin, of a patient. The ECG signals may be used to evaluate and configure cardiac therapy such as, e.g., cardiac therapy provide by an implantable medical device performing cardiac resynchronization therapy (CRT). As described herein, the ECG signals may be gathered or obtained noninvasively since, e.g., implantable electrodes may not be used to measure the ECG

signals. Further, the ECG signals may be used to determine cardiac electrical activation times, which may be used to generate various metrics (e.g., electrical heterogeneity information) that may be used by a user (e.g., physician) to optimize one or more settings, or parameters, of cardiac therapy (e.g., pacing therapy) such as CRT.

(19) Various illustrative systems, methods, and graphical user interfaces may be configured to use electrode apparatus including external electrodes, display apparatus, and computing apparatus to noninvasively assist a user (e.g., a physician) in the evaluation of cardiac health and/or the configuration (e.g., optimization) of cardiac therapy. An illustrative system **100** including electrode apparatus **110**, computing apparatus **140**, and a remote computing device **160** is depicted in FIG. **1**.

(20) The electrode apparatus **110** as shown includes a plurality of electrodes incorporated, or included, within a band wrapped around the chest, or torso, of a patient **14**. The electrode apparatus **110** is operatively coupled to the computing apparatus **140** (e.g., through one or wired electrical connections, wirelessly, etc.) to provide electrical signals from each of the electrodes to the computing apparatus **140** for analysis, evaluation, etc. Illustrative electrode apparatus may be described in U.S. Pat. No. 9,320,446 entitled “Bioelectric Sensor Device and Methods” filed Mar. 27, 2014 and issued on Mar. 26, 2016, which is incorporated herein by reference in its entirety. Further, illustrative electrode apparatus **110** will be described in more detail in reference to FIGS. **2-3**.

(21) Although not described herein, the illustrative system **100** may further include imaging apparatus. The imaging apparatus may be any type of imaging apparatus configured to image, or provide images of, at least a portion of the patient in a noninvasive manner. For example, the imaging apparatus may not use any components or parts that may be located within the patient to provide images of the patient except noninvasive tools such as contrast solution. It is to be understood that the illustrative systems, methods, and interfaces described herein may further use imaging apparatus to provide noninvasive assistance to a user (e.g., a physician) to locate, or place, one or more pacing electrodes proximate the patient's heart in conjunction with the configuration of cardiac therapy.

(22) For example, the illustrative systems and methods may provide image guided navigation that may be used to navigate leads including electrodes, leadless electrodes, wireless electrodes, catheters, etc., within the patient's body while also providing noninvasive cardiac therapy configuration including determining an effective, or optimal, pre-excitation intervals such as A-V and V-V intervals, etc. Illustrative systems and methods that use imaging apparatus and/or electrode apparatus may be described in U.S. Pat. App. Pub. No. 2014/0371832 to Ghosh published on Dec. 18, 2014, U.S. Pat. App. Pub. No. 2014/0371833 to Ghosh et al. published on Dec. 18, 2014, U.S. Pat. App. Pub. No. 2014/0323892 to Ghosh et al. published on Oct. 30, 2014, U.S. Pat. App. Pub. No. 2014/0323882 to Ghosh et al. published on Oct. 20, 2014, each of which is incorporated herein by reference in its entirety.

(23) Illustrative imaging apparatus may be configured to capture x-ray images and/or any other alternative imaging modality. For example, the imaging apparatus may be configured to capture images, or image data, using isocentric fluoroscopy, bi-plane fluoroscopy, ultrasound, computed tomography (CT), multi-slice computed tomography (MSCT), magnetic resonance imaging (MRI), high frequency ultrasound (HIFU), optical coherence tomography (OCT), intra-vascular ultrasound (IVUS), two dimensional (2D) ultrasound, three dimensional (3D) ultrasound, four dimensional (4D) ultrasound, intraoperative CT, intraoperative MRI, etc. Further, it is to be understood that the imaging apparatus may be configured to capture a plurality of consecutive images (e.g., continuously) to provide video frame data. In other words, a plurality of images taken over time using the imaging apparatus may provide video frame, or motion picture, data. An exemplary system that employs ultrasound can be found in U.S. Pat. App. Pub. No. 2017/0303840 entitled NONINVASIVE ASSESSMENT OF CARDIAC RESYNCHRONIZATION THERAPY to Stadler et al., incorporated by reference in its entirety. Additionally, the images may also be obtained and

displayed in two, three, or four dimensions. In more advanced forms, four-dimensional surface rendering of the heart or other regions of the body may also be achieved by incorporating heart data or other soft tissue data from a map or from pre-operative image data captured by MRI, CT, or echocardiography modalities. Image datasets from hybrid modalities, such as positron emission tomography (PET) combined with CT, or single photon emission computer tomography (SPECT) combined with CT, could also provide functional image data superimposed onto anatomical data, e.g., to be used to navigate implantable apparatus to target locations within the heart or other areas of interest.

(24) Systems and/or imaging apparatus that may be used in conjunction with the illustrative systems and method described herein are described in U.S. Pat. App. Pub. No. 2005/0008210 to Evron et al. published on Jan. 13, 2005, U.S. Pat. App. Pub. No. 2006/0074285 to Zarkh et al. published on Apr. 6, 2006, U.S. Pat. No. 8,731,642 to Zarkh et al. issued on May 20, 2014, U.S. Pat. No. 8,861,830 to Brada et al. issued on Oct. 14, 2014, U.S. Pat. No. 6,980,675 to Evron et al. issued on Dec. 27, 2005, U.S. Pat. No. 7,286,866 to Okerlund et al. issued on Oct. 23, 2007, U.S. Pat. No. 7,308,297 to Reddy et al. issued on Dec. 11, 2011, U.S. Pat. No. 7,308,299 to Burrell et al. issued on Dec. 11, 2011, U.S. Pat. No. 7,321,677 to Evron et al. issued on Jan. 22, 2008, U.S. Pat. No. 7,346,381 to Okerlund et al. issued on Mar. 18, 2008, U.S. Pat. No. 7,454,248 to Burrell et al. issued on Nov. 18, 2008, U.S. Pat. No. 7,499,743 to Vass et al. issued on Mar. 3, 2009, U.S. Pat. No. 7,565,190 to Okerlund et al. issued on Jul. 21, 2009, U.S. Pat. No. 7,587,074 to Zarkh et al. issued on Sep. 8, 2009, U.S. Pat. No. 7,599,730 to Hunter et al. issued on Oct. 6, 2009, U.S. Pat. No. 7,613,500 to Vass et al. issued on Nov. 3, 2009, U.S. Pat. No. 7,742,629 to Zarkh et al. issued on Jun. 22, 2010, U.S. Pat. No. 7,747,047 to Okerlund et al. issued on Jun. 29, 2010, U.S. Pat. No. 7,778,685 to Evron et al. issued on Aug. 17, 2010, U.S. Pat. No. 7,778,686 to Vass et al. issued on Aug. 17, 2010, U.S. Pat. No. 7,813,785 to Okerlund et al. issued on Oct. 12, 2010, U.S. Pat. No. 7,996,063 to Vass et al. issued on Aug. 9, 2011, U.S. Pat. No. 8,060,185 to Hunter et al. issued on Nov. 15, 2011, and U.S. Pat. No. 8,401,616 to Verard et al. issued on Mar. 19, 2013, each of which is incorporated herein by reference in its entirety.

(25) The computing apparatus **140** and the remote computing device **160** may each include display apparatus **130**, **170**, respectively, that may be configured to display and analyze data such as, e.g., electrical signals (e.g., electrocardiogram data), electrical activation times, electrical heterogeneity information, etc. For example, one cardiac cycle, or one heartbeat, of a plurality of cardiac cycles, or heartbeats, represented by the electrical signals collected or monitored by the electrode apparatus **110** may be analyzed and evaluated for one or more metrics including activation times and electrical heterogeneity information that may be pertinent to the therapeutic nature of one or more parameters related to cardiac therapy such as, e.g., pacing parameters, lead location, etc. More specifically, for example, the QRS complex of a single cardiac cycle may be evaluated for one or more metrics such as, e.g., QRS onset, QRS offset, QRS peak, electrical heterogeneity information (EHI), electrical activation times referenced to earliest activation time, left ventricular or thoracic standard deviation of electrical activation times (LVED), standard deviation of activation times (SDAT), average left ventricular or thoracic surrogate electrical activation times (LVAT), QRS duration (e.g., interval between QRS onset to QRS offset), difference between average left surrogate and average right surrogate activation times, relative or absolute QRS morphology, difference between a higher percentile and a lower percentile of activation times (higher percentile may be 90%, 80%, 75%, 70%, etc. and lower percentile may be 10%, 15%, 20%, 25% and 30%, etc.), other statistical measures of central tendency (e.g., median or mode), dispersion (e.g., mean deviation, standard deviation, variance, interquartile deviations, range), etc. Further, each of the one or more metrics may be location specific. For example, some metrics may be computed from signals recorded, or monitored, from electrodes positioned about a selected area of the patient such as, e.g., the left side of the patient, the right side of the patient, etc.

(26) In at least one embodiment, one or both of the computing apparatus **140** and the remote

computing device **160** may be a server, a personal computer, a tablet computer, a mobile device, and a cellular telephone. The computing apparatus **140** may be configured to receive input from input apparatus **142** (e.g., a keyboard) and transmit output to the display apparatus **130**, and the remote computing device **160** may be configured to receive input from input apparatus **162** (e.g., a touchscreen) and transmit output to the display apparatus **170**. One or both of the computing apparatus **140** and the remote computing device **160** may include data storage that may allow for access to processing programs or routines and/or one or more other types of data, e.g., for analyzing a plurality of electrical signals captured by the electrode apparatus **110**, for determining QRS onsets, QRS offsets, medians, modes, averages, peaks or maximum values, valleys or minimum values, for determining electrical activation times, for driving a graphical user interface configured to noninvasively assist a user in configuring one or more pacing parameters, or settings, such as, e.g., pacing rate, ventricular pacing rate, A-V interval, V-V interval, pacing pulse width, pacing vector, multipoint pacing vector (e.g., left ventricular vector quad lead), pacing voltage, pacing configuration (e.g., biventricular pacing, right ventricle only pacing, left ventricle only pacing, etc.), and arrhythmia detection and treatment, rate adaptive settings and performance, etc.
(27) The computing apparatus **140** may be operatively coupled to the input apparatus **142** and the display apparatus **130** to, e.g., transmit data to and from each of the input apparatus **142** and the display apparatus **130**, and the remote computing device **160** may be operatively coupled to the input apparatus **162** and the display apparatus **170** to, e.g., transmit data to and from each of the input apparatus **162** and the display apparatus **170**. For example, the computing apparatus **140** and the remote computing device **160** may be electrically coupled to the input apparatus **142**, **162** and the display apparatus **130**, **170** using, e.g., analog electrical connections, digital electrical connections, wireless connections, bus-based connections, network-based connections, internet-based connections, etc. As described further herein, a user may provide input to the input apparatus **142**, **162** to view and/or select one or more pieces of configuration information related to the cardiac therapy delivered by cardiac therapy apparatus such as, e.g., an implantable medical device.
(28) Although as depicted the input apparatus **142** is a keyboard and the input apparatus **162** is a touchscreen, it is to be understood that the input apparatus **142**, **162** may include any apparatus capable of providing input to the computing apparatus **140** and the computing device **160** to perform the functionality, methods, and/or logic described herein. For example, the input apparatus **142**, **162** may include a keyboard, a mouse, a trackball, a touchscreen (e.g., capacitive touchscreen, a resistive touchscreen, a multi-touch touchscreen, etc.), etc. Likewise, the display apparatus **130**, **170** may include any apparatus capable of displaying information to a user, such as a graphical user interface **132**, **172** including electrode status information, graphical maps of electrical activation, a plurality of signals for the external electrodes over one or more heartbeats, QRS complexes, various cardiac therapy scenario selection regions, various rankings of cardiac therapy scenarios, various pacing parameters, electrical heterogeneity information (EHI), textual instructions, graphical depictions of anatomy of a human heart, images or graphical depictions of the patient's heart, graphical depictions of locations of one or more electrodes, graphical depictions of a human torso, images or graphical depictions of the patient's torso, graphical depictions or actual images of implanted electrodes and/or leads, etc. Further, the display apparatus **130**, **170** may include a liquid crystal display, an organic light-emitting diode screen, a touchscreen, a cathode ray tube display, etc.
(29) The processing programs or routines stored and/or executed by the computing apparatus **140** and the remote computing device **160** may include programs or routines for computational mathematics, matrix mathematics, decomposition algorithms, compression algorithms (e.g., data compression algorithms), calibration algorithms, image construction algorithms, signal processing algorithms (e.g., various filtering algorithms, Fourier transforms, fast Fourier transforms, etc.), standardization algorithms, comparison algorithms, vector mathematics, or any other processing used to implement one or more illustrative methods and/or processes described herein. Data stored

and/or used by the computing apparatus **140** and the remote computing device **160** may include, for example, electrical signal/waveform data from the electrode apparatus **110** (e.g., a plurality of QRS complexes), electrical activation times from the electrode apparatus **110**, cardiac sound/signal/waveform data from acoustic sensors, graphics (e.g., graphical elements, icons, buttons, windows, dialogs, pull-down menus, graphic areas, graphic regions, 3D graphics, etc.), graphical user interfaces, results from one or more processing programs or routines employed according to the disclosure herein (e.g., electrical signals, electrical heterogeneity information, etc.), or any other data that may be used for carrying out the one and/or more processes or methods described herein.

(30) In one or more embodiments, the illustrative systems, methods, and interfaces may be implemented using one or more computer programs executed on programmable computers, such as computers that include, for example, processing capabilities, data storage (e.g., volatile or non-volatile memory and/or storage elements), input devices, and output devices. Program code and/or logic described herein may be applied to input data to perform functionality described herein and generate desired output information. The output information may be applied as input to one or more other devices and/or methods as described herein or as would be applied in a known fashion.

(31) The one or more programs used to implement the systems, methods, and/or interfaces described herein may be provided using any programmable language, e.g., a high-level procedural and/or object orientated programming language that is suitable for communicating with a computer system. Any such programs may, for example, be stored on any suitable device, e.g., a storage media, that is readable by a general or special purpose program running on a computer system (e.g., including processing apparatus) for configuring and operating the computer system when the suitable device is read for performing the procedures described herein. In other words, at least in one embodiment, the illustrative systems, methods, and interfaces may be implemented using a computer readable storage medium, configured with a computer program, where the storage medium so configured causes the computer to operate in a specific and predefined manner to perform functions described herein. Further, in at least one embodiment, the illustrative systems, methods, and interfaces may be described as being implemented by logic (e.g., object code) encoded in one or more non-transitory media that includes code for execution and, when executed by a processor or processing circuitry, is operable to perform operations such as the methods, processes, and/or functionality described herein.

(32) The computing apparatus **140** and the remote computing device **160** may be, for example, any fixed or mobile computer system (e.g., a controller, a microcontroller, a personal computer, minicomputer, tablet computer, etc.). The exact configurations of the computing apparatus **140** and the remote computing device **160** are not limiting, and essentially any device capable of providing suitable computing capabilities and control capabilities (e.g., signal analysis, mathematical functions such as medians, modes, averages, maximum value determination, minimum value determination, slope determination, minimum slope determination, maximum slope determination, graphics processing, etc.) may be used. As described herein, a digital file may be any medium (e.g., volatile or non-volatile memory, a CD-ROM, a punch card, magnetic recordable tape, etc.) containing digital bits (e.g., encoded in binary, trinary, etc.) that may be readable and/or writeable by the computing apparatus **140** and the remote computing device **160** described herein. Also, as described herein, a file in user-readable format may be any representation of data (e.g., ASCII text, binary numbers, hexadecimal numbers, decimal numbers, graphically, etc.) presentable on any medium (e.g., paper, a display, etc.) readable and/or understandable by a user.

(33) In view of the above, it will be readily apparent that the functionality as described in one or more embodiments according to the present disclosure may be implemented in any manner as would be known to one skilled in the art. As such, the computer language, the computer system, or any other software/hardware which is to be used to implement the processes described herein shall not be limiting on the scope of the systems, processes, or programs (e.g., the functionality provided

by such systems, processes, or programs) described herein.
(34) The illustrative electrode apparatus **110** may be configured to measure body-surface potentials of a patient **14** and, more particularly, torso-surface potentials of a patient **14**. As shown in FIG. **2**, the illustrative electrode apparatus **110** may include a set, or array, of external electrodes **112**, a strap **113**, and interface/amplifier circuitry **116**. The electrodes **112** may be attached, or coupled, to the strap **113** and the strap **113** may be configured to be wrapped around the torso of a patient **14** such that the electrodes **112** surround the patient's heart. As further illustrated, the electrodes **112** may be positioned around the circumference of a patient **14**, including the posterior, lateral, posterolateral, anterolateral, and anterior locations of the torso of a patient **14**.
(35) The illustrative electrode apparatus **110** may be further configured to measure, or monitor, sounds from at least one or both the patient **14**. As shown in FIG. **2**, the illustrative electrode apparatus **110** may include a set, or array, of acoustic sensors **120** attached, or coupled, to the strap **113**. The strap **113** may be configured to be wrapped around the torso of a patient **14** such that the acoustic sensors **120** surround the patient's heart. As further illustrated, the acoustic sensors **120** may be positioned around the circumference of a patient **14**, including the posterior, lateral, posterolateral, anterolateral, and anterior locations of the torso of a patient **14**.
(36) Further, the electrodes **112** and the acoustic sensors **120** may be electrically connected to interface/amplifier circuitry **116** via wired connection **118**. The interface/amplifier circuitry **116** may be configured to amplify the signals from the electrodes **112** and the acoustic sensors **120** and provide the signals to one or both of the computing apparatus **140** and the remote computing device **160**. Other illustrative systems may use a wireless connection to transmit the signals sensed by electrodes **112** and the acoustic sensors **120** to the interface/amplifier circuitry **116** and, in turn, to one or both of the computing apparatus **140** and the remote computing device **160**, e.g., as channels of data. In one or more embodiments, the interface/amplifier circuitry **116** may be electrically coupled to the computing apparatus **140** using, e.g., analog electrical connections, digital electrical connections, wireless connections, bus-based connections, network-based connections, internet-based connections, etc.
(37) Although in the example of FIG. **2** the electrode apparatus **110** includes a strap **113**, in other examples any of a variety of mechanisms, e.g., tape or adhesives, may be employed to aid in the spacing and placement of electrodes **112** and the acoustic sensors **120**. In some examples, the strap **113** may include an elastic band, strip of tape, or cloth. Further, in some examples, the strap **113** may be part of, or integrated with, a piece of clothing such as, e.g., a t-shirt. In other examples, the electrodes **112** and the acoustic sensors **120** may be placed individually on the torso of a patient **14**. Further, in other examples, one or both of the electrodes **112** (e.g., arranged in an array) and the acoustic sensors **120** (e.g., also arranged in an array) may be part of, or located within, patches, vests, and/or other manners of securing the electrodes **112** and the acoustic sensors **120** to the torso of the patient **14**. Still further, in other examples, one or both of the electrodes **112** and the acoustic sensors **120** may be part of, or located within, two sections of material or two patches. One of the two patches may be located on the anterior side of the torso of the patient **14** (to, e.g., monitor electrical signals representative of the anterior side of the patient's heart, measure surrogate cardiac electrical activation times representative of the anterior side of the patient's heart, monitor or measure sounds of the anterior side of the patient, etc.) and the other patch may be located on the posterior side of the torso of the patient **14** (to, e.g., monitor electrical signals representative of the posterior side of the patient's heart, measure surrogate cardiac electrical activation times representative of the posterior side of the patient's heart, monitor or measure sounds of the posterior side of the patient, etc.). And still further, in other examples, one or both of the electrodes **112** and the acoustic sensors **120** may be arranged in a top row and bottom row that extend from the anterior side of the patient **14** across the left side of the patient **14** to the posterior side of the patient **14**. Yet still further, in other examples, one or both of the electrodes **112** and the acoustic sensors **120** may be arranged in a curve around the armpit area and may have an electrode/sensor-density that less

dense on the right thorax that the other remaining areas.
(38) The electrodes **112** may be configured to surround the heart of the patient **14** and record, or monitor, the electrical signals associated with the depolarization and repolarization of the heart after the signals have propagated through the torso of a patient **14**. Each of the electrodes **112** may be used in a unipolar configuration to sense the torso-surface potentials that reflect the cardiac signals. The interface/amplifier circuitry **116** may also be coupled to a return or indifferent electrode (not shown) that may be used in combination with each electrode **112** for unipolar sensing.
(39) In some examples, there may be about 12 to about 50 electrodes **112** and about 12 to about 50 acoustic sensors **120** spatially distributed around the torso of a patient. Other configurations may have more or fewer electrodes **112** and more or fewer acoustic sensors **120**. It is to be understood that the electrodes **112** and acoustic sensors **120** may not be arranged or distributed in an array extending all the way around or completely around the patient **14**. Instead, the electrodes **112** and acoustic sensors **120** may be arranged in an array that extends only part of the way or partially around the patient **14**. For example, the electrodes **112** and acoustic sensors **120** may be distributed on the anterior, posterior, and left sides of the patient with less or no electrodes and acoustic sensors proximate the right side (including posterior and anterior regions of the right side of the patient).
(40) The computing apparatus **140** may record and analyze the torso-surface potential signals sensed by electrodes **112** and the sound signals sensed by the acoustic sensors **120**, which are amplified/conditioned by the interface/amplifier circuitry **116**. The computing apparatus **140** may be configured to analyze the electrical signals from the electrodes **112** to provide electrocardiogram (ECG) signals, information, or data from the patient's heart as will be further described herein. The computing apparatus **140** may be configured to analyze the electrical signals from the acoustic sensors **120** to provide sound signals, information, or data from the patient's body and/or devices implanted therein (such as a left ventricular assist device).
(41) Additionally, the computing apparatus **140** and the remote computing device **160** may be configured to provide graphical user interfaces **132**, **172** depicting various information related to the electrode apparatus **110** and the data gathered, or sensed, using the electrode apparatus **110**. For example, the graphical user interfaces **132**, **172** may depict ECGs including QRS complexes obtained using the electrode apparatus **110** and sound data including sound waves obtained using the acoustic sensors **120** as well as other information related thereto. Illustrative systems and methods may noninvasively use the electrical information collected using the electrode apparatus **110** and the sound information collected using the acoustic sensors **120** to evaluate a patient's cardiac health and to evaluate and configure cardiac therapy being delivered to the patient.
(42) Further, the electrode apparatus **110** may further include reference electrodes and/or drive electrodes to be, e.g. positioned about the lower torso of the patient **14**, that may be further used by the system **100**. For example, the electrode apparatus **110** may include three reference electrodes, and the signals from the three reference electrodes may be combined to provide a reference signal. Further, the electrode apparatus **110** may use of three caudal reference electrodes (e.g., instead of standard references used in a Wilson Central Terminal) to get a “true” unipolar signal with less noise from averaging three caudally located reference signals.
(43) FIG. **3** illustrates another illustrative electrode apparatus **110** that includes a plurality of electrodes **112** configured to surround the heart of the patient **14** and record, or monitor, the electrical signals associated with the depolarization and repolarization of the heart after the signals have propagated through the torso of the patient **14** and a plurality of acoustic sensors **120** configured to surround the heart of the patient **14** and record, or monitor, the sound signals associated with the heart after the signals have propagated through the torso of the patient **14**. The electrode apparatus **110** may include a vest **114** upon which the plurality of electrodes **112** and the plurality of acoustic sensors **120** may be attached, or to which the electrodes **112** and the acoustic

sensors **120** may be coupled. In at least one embodiment, the plurality, or array, of electrodes **112** may be used to collect electrical information such as, e.g., surrogate electrical activation times. Similar to the electrode apparatus **110** of FIG. **2**, the electrode apparatus **110** of FIG. **3** may include interface/amplifier circuitry **116** electrically coupled to each of the electrodes **112** and the acoustic sensors **120** through a wired connection **118** and be configured to transmit signals from the electrodes **112** and the acoustic sensors **120** to computing apparatus **140**. As illustrated, the electrodes **112** and the acoustic sensors **120** may be distributed over the torso of a patient **14**, including, for example, the posterior, lateral, posterolateral, anterolateral, and anterior locations of the torso of a patient **14**.

(44) The vest **114** may be formed of fabric with the electrodes **112** and the acoustic sensors **120** attached to the fabric. The vest **114** may be configured to maintain the position and spacing of electrodes **112** and the acoustic sensors **120** on the torso of the patient **14**. Further, the vest **114** may be marked to assist in determining the location of the electrodes **112** and the acoustic sensors **120** on the surface of the torso of the patient **14**. In some examples, there may be about 25 to about 256 electrodes **112** and about 25 to about 256 acoustic sensors **120** distributed around the torso of the patient **14**, though other configurations may have more or fewer electrodes **112** and more or fewer acoustic sensors **120**.

(45) The illustrative systems and methods may be used to provide noninvasive assistance to a user in the evaluation of a patient's cardiac health and/or evaluation and configuration of cardiac therapy being presently delivered to the patient (e.g., by an implantable medical device delivering pacing therapy, by a LVAD, etc.). Further, it is to be understood that the computing apparatus **140** and the remote computing device **160** may be operatively coupled to each other in a plurality of different ways so as to perform, or execute, the functionality described herein. For example, in the embodiment depicted, the computing device **140** may be wireless operably coupled to the remote computing device **160** as depicted by the wireless signal lines emanating therebetween. Additionally, as opposed to wireless connections, one or more of the computing apparatus **140** and the remoting computing device **160** may be operably coupled through one or wired electrical connections.

(46) According to embodiments described herein, the ECG belt is used with CRT systems to calculate the SDAT of cardiac cycles (or heart beats). According to various embodiments, the ECG belt is used to calculate the SDAT of cardiac cycles after CRT paces. For example, the ECG belt may be used to calculate the SDAT of cardiac cycles for biventricular and/or left ventricular paces. Embodiments described herein may be used in non-CRT pacing. If the SDAT is inaccurate, the output of the ECG belt could be misleading and could potentially impact lead placement (e.g. lead not being placed at the optimal spot) and/or optimal device programming. For example, if the SDAT is inaccurate, the SDAT may be artificially low, causing the lead to be left in its current position, rather than repositioned to get a better response. Disturbances in the signals detected by the ECG belt could cause false activation times to be detected leading to an inaccurate SDAT. Detecting and/or removing the disturbance could reduce the risk of an inaccurate SDAT.

(47) An exemplary method **400** for detecting disturbances in electrical signals is depicted in FIG. **4**. As shown, the method **400** includes monitoring **410** electrical activity to generate a plurality of electrical signals. According to various embodiments, the electrical activity is monitored using a plurality of electrodes. The plurality of electrodes may be external surface electrodes configured in a band or a vest similar to as described herein with respect to FIGS. **1-3**. Each of the electrodes may be positioned or located about the torso of the patient so as to monitor electrical activity (e.g., acquire torso-potentials) from a plurality of different locations about the torso of the patient. Each of the different locations where the electrodes are located may correspond to the electrical activation of different portions or regions of cardiac tissue of the patient's heart.

(48) The plurality of electrical signals are filtered **420**. According to embodiments described herein, the electrical signals are filtered using a higher order filter such as a second order filter, for

example. In some embodiments, the filter may be a second order difference filter. According to various implementations, the filter may be a second order derivative filter. More specifically, each of the plurality of electrical signals may be filtered individually resulting in a plurality of filtered signals. Further, in some embodiments, each of the plurality of electrical signals may be filtered by the same filter. Therefore, the plurality of electrical signals may be processed to put them in a form so as to be able to detect disturbances.

(49) At least one disturbance is detected **430** in the filtered electrical signals. The disturbance may be detected by determining that the filtered signal crosses a predetermined threshold, for example. The disturbance may include one or more of pacing spikes and/muscle generated noise. Other types of disturbance may include artifacts due to movement, breathing, etc. The detection methods described herein may be used to detect a His potential for use in His bundle pacing or left bundle potential for targeted lead placement aiming to capture the left bundle in a patient with conduction system disease like left bundle branch block.

(50) In one or more embodiments, a temporal location of the at least one disturbance in the at least one electrical signal is determined **440** based on a time that an absolute value the amplitude of the at least one filtered signal crosses a predetermined amplitude threshold. The predetermined threshold may be based on a sampling rate of the at least one electrical signal. In some cases, the threshold may be determined based on a predetermined number of samples of the electrical signals. According to various embodiments, the temporal location of the disturbance is determined by a predetermined threshold. The predetermined threshold may be based on amplitude measurements of the electrical signals. More specifically, the predetermined threshold may be determined by determining a time when the filtered signal reaches a predetermined amplitude.

(51) According to one or more embodiments, the detected disturbance may be removed **450** from at least one of the plurality of electrical signals. The disturbance may be removed **450** using various methods. For example, the disturbance may be removed **450** by smoothing the electrical signals within a window using the determined temporal location of the disturbance. Smoothing the electrical signals within a window may be performed, or executed, using any known smoothing algorithm or technique. For instance, the electrical signals may be smoothed within a window by replacing one or more signals within the window with a line to connect the signals at their start and end points within the window. In some cases, a best fit line may replace the electrical signal in the window and/or the window during the disturbance is blanked such that it is not used for activation time determinations.

(52) The window, within which the disturbance may be removed, may begin, or have a start time, a predetermined period of time prior to the temporal location of the disturbance. Likewise, the window may end, or have an end time, a predetermined period of time following the temporal location of the disturbance. In other words, the window may start a predetermined period of time before the temporal location of the at least one disturbance and extend a predetermined amount of time after the temporal location. For example, a predetermined period of time prior to the temporal location of the disturbance (for determination of the window) may be between about 0.5 ms milliseconds (ms) to about 2 ms. In at least one embodiment, the predetermined period of time prior to the temporal location of the disturbance is about 1 ms. Further, for example, a predetermined period of time following the temporal location of the disturbance (for determination of the window) may be between about 5 ms to about 15 ms. In at least one embodiment, the predetermined period of time following the temporal location of the disturbance is about 10 ms.

(53) Further, in at least one embodiment, the window may be a fixed length from a predetermined start point. For example, the window length may be in a range of about 5 ms to about 15 ms. In some cases, the window length is about 10 ms. The window start time and end time may be determined based on a baseline departure from the threshold amplitude and a return to the threshold amplitude. In other words, the window start time may be based on a first threshold crossing and the end time may be based on a second threshold crossing occurring after the first threshold crossing.

(54) After the at least one disturbance has been removed, the electrical signals may be used to determine a plurality of activation times. Further, electrical heterogeneity information may be determined based on the plurality of cardiac activation times.
(55) In some embodiments, more than one disturbance is detected and/or removed. For example, a first disturbance may be detected and a second disturbance occurring after the first disturbance may also be detected. The first disturbance and/or the second disturbance may be removed by smoothing the electrical signal within a window starting a predetermined amount of time before the temporal location of the first disturbance and extending a predetermined amount of time after the second disturbance. While two disturbances are described here, it is to be understood that more disturbances may be detected and/or removed from the electrical signals. Additionally, in some embodiments, each of the first and second disturbances and any other additional disturbance may be removed individually, each within its own window.
(56) According to one or more embodiments, the disturbances are detected in at least one of the electrical signals. In some cases, a detected disturbance is only removed if it is sensed in a predetermined number of electrical signals of the plurality of electrical signals. FIG. **5** shows a process **500** for removing disturbances in electrical signals based on a disturbance detected in a predetermined number of electrical signals in accordance with embodiments described herein. A plurality of electrical signals are sensed using a plurality of electrodes. At least one disturbance is detected **510**. It is determined whether there is a disturbance in at least a predetermined number of the sensed electrical signals. The predetermined number of signals within which the disturbance needs to be detected may be in a range of about three to about ten. In some cases, the predetermined number of signals within which the disturbance needs to be detected is four. If it is determined **510** that a disturbance is not detected in at least the predetermined number of electrical signals, then the disturbance is not removed **520**. If it is determined **510** that a disturbance is detected in at least the predetermined number of electrical signals, the disturbance is removed **530** from at least the predetermined number of electrical signals. In some cases, if it is determined **510** that a disturbance is detected in at least the predetermined number of electrical signals, the disturbance is removed **530** from all of the plurality of electrical signals. In some implementations, if a disturbance is detected in the predetermined number of electrical signals, the disturbance is removed from more than the predetermined number of signals, but less than all of the electrical signals.
(57) According to various implementations, the disturbance may only be removed if it is sensed in predetermined number of electrical signals that are derived from a group predetermined electrodes. For example, the disturbance may only be removed if it is sensed in at least four electrical signals that are derived from four electrodes in a subset of the electrodes. For example, the subset of electrodes may be about 12 electrodes located in a top row and left of the sternum on the anterior and left of the spine on the posterior.
(58) FIGS. **6**A and **6**B show examples of a plurality of sampled electrical signals in accordance with embodiments described herein. As shown, a portion of an electrical signal, or electrical activity, is plotted on along a time axis **605**. As described herein, the sampled electrical signals may be filtered and activation times may be determined based on the filtered signals. According to various implementations, the activation times may be determined based on a slope of the filtered signal. FIG. **6**B illustrates a close-up view in the vertical direction of the signals shown in FIG. **6**A.
(59) In this example, the sensed signals include cardiac activity **610** in response to a pace. A first disturbance **612** and smaller second disturbance **620** appear before the sensed cardiac response activity **610**. The first disturbance **612** and/or the second disturbance **620** have a slope that may be indicative of an activation time of the signal. This can lead to a false detections of activation times which may result in inaccurate data. More specifically, the fiducial point used to determine the activation time for each signal may be the temporal location of the greatest slope within each signal, and the disturbances may cause, or create, the greatest slope within each signal resulting in

inaccurate activation time data.
(60) To detect the disturbances, a sampling frequency is used to determine a threshold for a second (or higher order) difference of the disturbance for a known pulse width or range of pulse widths. The signals are run through the second order filter and the resulting filtered signal is examined for threshold crossings. FIG. **7** illustrates an example of sampled signals after being filtered using a second order filter. Signals **710** whose amplitude exceed the threshold **720** are detected as disturbances. Once the disturbances **710** are identified, the temporal locations of the disturbances are determined. This may be done by determining a time that the disturbances cross the threshold **720**, for example.
(61) As described herein, the disturbances are removed from at least one signal within a window. FIG. **8**A illustrates example signals after removal of the disturbances in some of the signals within window **825**. Here it can be observed that the disturbances have been removed on the signals having straight sections within the window **825**. FIG. **8**B shows the signals of FIG. **8**A with additional filtering as described herein. Here, it can be observed that the disturbances have been removed. The activation times can now be determined based on these filtered signals without interference from the disturbances.
(62) As described herein, without removing the disturbances from the electrical signals, inaccurate activation times may be detected. FIG. **9**A illustrates an example in which false activation times **930** are detected based on a location of the disturbance **925**. Detection and/or removal of the one or more disturbances may be used to reduce the occurrence of false activation time detection. Detection of the disturbances may be accomplished using a controller, for example. In some cases, detection of the disturbances is carried out using a commercial chip. FIG. **9**B shows the same signals shown in FIG. **9**A, but with the disturbance **925** removed. As can be observed, the false activation time **930** is no longer detected. The SDAT generated based on the electrical activation times of the electrical signals of the FIG. **9**A is 46.0 ms, and the SDAT generated based on the electrical activation times of the electrical signals of the FIG. **9**B is 28.5 ms. Thus, disturbance removal according to the present disclosure may result in a measurable improvement in the accuracy of a measurement of electrical cardiac heterogeneity such as, e.g., SDAT.
(63) Illustrative cardiac therapy systems and devices may be further described herein with reference to FIGS. **10-12** that may utilizes the illustrative systems, interfaces, methods, and processes described herein with respect to FIGS. **1-9**.
(64) FIG. **10** is a conceptual diagram illustrating an illustrative therapy system **10** that may be used to deliver pacing therapy to a patient **14**. Patient **14** may, but not necessarily, be a human. The therapy system **10** may include an implantable medical device **16** (IMD), which may be coupled to leads **18**, **20**, **22**. The IMD **16** may be, e.g., an implantable pacemaker, cardioverter, and/or defibrillator, that delivers, or provides, electrical signals (e.g., paces, etc.) to and/or senses electrical signals from the heart **12** of the patient **14** via electrodes coupled to one or more of the leads **18**, **20**, **22**.
(65) The leads **18**, **20**, **22** extend into the heart **12** of the patient **14** to sense electrical activity of the heart **12** and/or to deliver electrical stimulation to the heart **12**. In the example shown in FIG. **10**, the right ventricular (RV) lead **18** extends through one or more veins (not shown), the superior vena cava (not shown), and the right atrium **26**, and into the right ventricle **28**. The left ventricular (LV) coronary sinus lead **20** extends through one or more veins, the vena cava, the right atrium **26**, and into the coronary sinus **30** to a region adjacent to the free wall of the left ventricle **32** of the heart **12**. The right atrial (RA) lead **22** extends through one or more veins and the vena cava, and into the right atrium **26** of the heart **12**.
(66) The IMD **16** may sense, among other things, electrical signals attendant to the depolarization and repolarization of the heart **12** via electrodes coupled to at least one of the leads **18**, **20**, **22**. In some examples, the IMD **16** provides pacing therapy (e.g., pacing pulses) to the heart **12** based on the electrical signals sensed within the heart **12**. The IMD **16** may be operable to adjust one or

more parameters associated with the pacing therapy such as, e.g., A-V delay and other various timings, pulse wide, amplitude, voltage, burst length, etc. Further, the IMD **16** may be operable to use various electrode configurations to deliver pacing therapy, which may be unipolar, bipolar, quadripoloar, or further multipolar. For example, a multipolar lead may include several electrodes that can be used for delivering pacing therapy. Hence, a multipolar lead system may provide, or offer, multiple electrical vectors to pace from. A pacing vector may include at least one cathode, which may be at least one electrode located on at least one lead, and at least one anode, which may be at least one electrode located on at least one lead (e.g., the same lead, or a different lead) and/or on the casing, or can, of the IMD. While improvement in cardiac function as a result of the pacing therapy may primarily depend on the cathode, the electrical parameters like impedance, pacing threshold voltage, current drain, longevity, etc. may be more dependent on the pacing vector, which includes both the cathode and the anode. The IMD **16** may also provide defibrillation therapy and/or cardioversion therapy via electrodes located on at least one of the leads **18**, **20**, **22**. Further, the IMD **16** may detect arrhythmia of the heart **12**, such as fibrillation of the ventricles **28**, **32**, and deliver defibrillation therapy to the heart **12** in the form of electrical pulses. In some examples, IMD **16** may be programmed to deliver a progression of therapies, e.g., pulses with increasing energy levels, until a fibrillation of heart **12** is stopped.

(67) FIGS. **11**A-**11**B are conceptual diagrams illustrating the IMD **16** and the leads **18**, **20**, **22** of therapy system **10** of FIG. **13** in more detail. The leads **18**, **20**, **22** may be electrically coupled to a therapy delivery module (e.g., for delivery of pacing therapy), a sensing module (e.g., for sensing one or more signals from one or more electrodes), and/or any other modules of the IMD **16** via a connector block **34**. In some examples, the proximal ends of the leads **18**, **20**, **22** may include electrical contacts that electrically couple to respective electrical contacts within the connector block **34** of the IMD **16**. In addition, in some examples, the leads **18**, **20**, **22** may be mechanically coupled to the connector block **34** with the aid of set screws, connection pins, or another suitable mechanical coupling mechanism.

(68) Each of the leads **18**, **20**, **22** includes an elongated insulative lead body, which may carry a number of conductors (e.g., concentric coiled conductors, straight conductors, etc.) separated from one another by insulation (e.g., tubular insulative sheaths). In the illustrated example, bipolar electrodes **40**, **42** are located proximate to a distal end of the lead **18**. In addition, bipolar electrodes **44**, **45**, **46**, **47** are located proximate to a distal end of the lead **20** and bipolar electrodes **48**, **50** are located proximate to a distal end of the lead **22**.

(69) The electrodes **40**, **44**, **45**, **46**, **47**, **48** may take the form of ring electrodes, and the electrodes **42**, **50** may take the form of extendable helix tip electrodes mounted retractably within the insulative electrode heads **52**, **54**, **56**, respectively. Each of the electrodes **40**, **42**, **44**, **45**, **46**, **47**, **48**, **50** may be electrically coupled to a respective one of the conductors (e.g., coiled and/or straight) within the lead body of its associated lead **18**, **20**, **22**, and thereby coupled to a respective one of the electrical contacts on the proximal end of the leads **18**, **20**, **22**.

(70) Additionally, electrodes **44**, **45**, **46** and **47** may have an electrode surface area of about 5.3 mm.sup.2 to about 5.8 mm.sup.2. Electrodes **44**, **45**, **46**, and **47** may also be referred to as LV**1**, LV**2**, LV**3**, and LV**4**, respectively. The LV electrodes (i.e., left ventricle electrode **1** (LV**1**) **44**, left ventricle electrode **2** (LV**2**) **45**, left ventricle electrode **3** (LV**3**) **46**, and left ventricle **4** (LV**4**) **47** etc.) on the lead **20** can be spaced apart at variable distances. For example, electrode **44** may be a distance of, e.g., about 21 millimeters (mm), away from electrode **45**, electrodes **45** and **46** may be spaced a distance of, e.g. about 1.3 mm to about 1.5 mm, away from each other, and electrodes **46** and **47** may be spaced a distance of, e.g. 20 mm to about 21 mm, away from each other.

(71) The electrodes **40**, **42**, **44**, **45**, **46**, **47**, **48**, **50** may further be used to sense electrical signals (e.g., morphological waveforms within electrograms (EGM)) attendant to the depolarization and repolarization of the heart **12**. The electrical signals are conducted to the IMD **16** via the respective leads **18**, **20**, **22**. In some examples, the IMD **16** may also deliver pacing pulses via the electrodes

40, **42**, **44**, **45**, **46**, **47**, **48**, **50** to cause depolarization of cardiac tissue of the patient's heart **12**. In some examples, as illustrated in FIG. **11**A, the IMD **16** includes one or more housing electrodes, such as housing electrode **58**, which may be formed integrally with an outer surface of a housing **60** (e.g., hermetically-sealed housing) of the IMD **16** or otherwise coupled to the housing **60**. Any of the electrodes **40**, **42**, **44**, **45**, **46**, **47**, **48**, **50** may be used for unipolar sensing or pacing in combination with the housing electrode **58**. It is generally understood by those skilled in the art that other electrodes can also be selected to define, or be used for, pacing and sensing vectors. Further, any of electrodes **40**, **42**, **44**, **45**, **46**, **47**, **48**, **50**, **58**, when not being used to deliver pacing therapy, may be used to sense electrical activity during pacing therapy.

(72) As described in further detail with reference to FIG. **11**A, the housing **60** may enclose a therapy delivery module that may include a stimulation generator for generating cardiac pacing pulses and defibrillation or cardioversion shocks, as well as a sensing module for monitoring the electrical signals of the patient's heart (e.g., the patient's heart rhythm). The leads **18**, **20**, **22** may also include elongated electrodes **62**, **64**, **66**, respectively, which may take the form of a coil. The IMD **16** may deliver defibrillation shocks to the heart **12** via any combination of the elongated electrodes **62**, **64**, **66** and the housing electrode **58**. The electrodes **58**, **62**, **64**, **66** may also be used to deliver cardioversion pulses to the heart **12**. Further, the electrodes **62**, **64**, **66** may be fabricated from any suitable electrically conductive material, such as, but not limited to, platinum, platinum alloy, and/or other materials known to be usable in implantable defibrillation electrodes. Since electrodes **62**, **64**, **66** are not generally configured to deliver pacing therapy, any of electrodes **62**, **64**, **66** may be used to sense electrical activity and may be used in combination with any of electrodes **40**, **42**, **44**, **45**, **46**, **47**, **48**, **50**, **58**. In at least one embodiment, the RV elongated electrode **62** may be used to sense electrical activity of a patient's heart during the delivery of pacing therapy (e.g., in combination with the housing electrode **58**, or defibrillation electrode-to-housing electrode vector).

(73) The configuration of the illustrative therapy system **10** illustrated in FIGS. **10-12** is merely one example. In other examples, the therapy system may include epicardial leads and/or patch electrodes instead of or in addition to the transvenous leads **18**, **20**, **22** illustrated in FIG. **10**. Additionally, in other examples, the therapy system **10** may be implanted in/around the cardiac space without transvenous leads (e.g., leadless/wireless pacing systems) or with leads implanted (e.g., implanted transvenously or using approaches) into the left chambers of the heart (in addition to or replacing the transvenous leads placed into the right chambers of the heart as illustrated in FIG. **10**). Further, in one or more embodiments, the IMD **16** need not be implanted within the patient **14**. For example, the IMD **16** may deliver various cardiac therapies to the heart **12** via percutaneous leads that extend through the skin of the patient **14** to a variety of positions within or outside of the heart **12**. In one or more embodiments, the system **10** may utilize wireless pacing (e.g., using energy transmission to the intracardiac pacing component(s) via ultrasound, inductive coupling, RF, etc.) and sensing cardiac activation using electrodes on the can/housing and/or on subcutaneous leads.

(74) In other examples of therapy systems that provide electrical stimulation therapy to the heart **12**, such therapy systems may include any suitable number of leads coupled to the IMD **16**, and each of the leads may extend to any location within or proximate to the heart **12**. For example, other examples of therapy systems may include three transvenous leads located as illustrated in FIGS. **10-12**. Still further, other therapy systems may include a single lead that extends from the IMD **16** into the right atrium **26** or the right ventricle **28**, or two leads that extend into a respective one of the right atrium **26** and the right ventricle **28**.

(75) FIG. **12**A is a functional block diagram of one illustrative configuration of the IMD **16**. As shown, the IMD **16** may include a control module **81**, a therapy delivery module **84** (e.g., which may include a stimulation generator), a sensing module **86**, and a power source **90**.

(76) The control module, or apparatus, **81** may include a processor **80**, memory **82**, and a telemetry

module, or apparatus, **88**. The memory **82** may include computer-readable instructions that, when executed, e.g., by the processor **80**, cause the IMD **16** and/or the control module **81** to perform various functions attributed to the IMD **16** and/or the control module **81** described herein. Further, the memory **82** may include any volatile, non-volatile, magnetic, optical, and/or electrical media, such as a random-access memory (RAM), read-only memory (ROM), non-volatile RAM (NVRAM), electrically-erasable programmable ROM (EEPROM), flash memory, and/or any other digital media. An illustrative capture management module may be the left ventricular capture management (LVCM) module described in U.S. Pat. No. 7,684,863 entitled "LV THRESHOLD MEASUREMENT AND CAPTURE MANAGEMENT" and issued Mar. 23, 2010, which is incorporated herein by reference in its entirety.

(77) The processor **80** of the control module **81** may include any one or more of a microprocessor, a controller, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field-programmable gate array (FPGA), and/or equivalent discrete or integrated logic circuitry. In some examples, the processor **80** may include multiple components, such as any combination of one or more microprocessors, one or more controllers, one or more DSPs, one or more ASICs, and/or one or more FPGAs, as well as other discrete or integrated logic circuitry. The functions attributed to the processor **80** herein may be embodied as software, firmware, hardware, or any combination thereof.

(78) The control module **81** may control the therapy delivery module **84** to deliver therapy (e.g., electrical stimulation therapy such as pacing) to the heart **12** according to a selected one or more therapy programs, which may be stored in the memory **82**. More, specifically, the control module **81** (e.g., the processor **80**) may control various parameters of the electrical stimulus delivered by the therapy delivery module **84** such as, e.g., A-V delays, V-V delays, pacing pulses with the amplitudes, pulse widths, frequency, or electrode polarities, etc., which may be specified by one or more selected therapy programs (e.g., A-V and/or V-V delay adjustment programs, pacing therapy programs, pacing recovery programs, capture management programs, etc.). As shown, the therapy delivery module **84** is electrically coupled to electrodes **40**, **42**, **44**, **45**, **46**, **47**, **48**, **50**, **58**, **62**, **64**, **66**, e.g., via conductors of the respective lead **18**, **20**, **22**, or, in the case of housing electrode **58**, via an electrical conductor disposed within housing **60** of IMD **16**. Therapy delivery module **84** may be configured to generate and deliver electrical stimulation therapy such as pacing therapy to the heart **12** using one or more of the electrodes **40**, **42**, **44**, **45**, **46**, **47**, **48**, **50**, **58**, **62**, **64**, **66**.

(79) For example, therapy delivery module **84** may deliver pacing stimulus (e.g., pacing pulses) via ring electrodes **40**, **44**, **45**, **46**, **47**, **48** coupled to leads **18**, **20**, **22** and/or helical tip electrodes **42**, **50** of leads **18**, **22**. Further, for example, therapy delivery module **84** may deliver defibrillation shocks to heart **12** via at least two of electrodes **58**, **62**, **64**, **66**. In some examples, therapy delivery module **84** may be configured to deliver pacing, cardioversion, or defibrillation stimulation in the form of electrical pulses. In other examples, therapy delivery module **84** may be configured deliver one or more of these types of stimulation in the form of other signals, such as sine waves, square waves, and/or other substantially continuous time signals.

(80) The IMD **16** may further include a switch module **85** and the control module **81** (e.g., the processor **80**) may use the switch module **85** to select, e.g., via a data/address bus, which of the available electrodes are used to deliver therapy such as pacing pulses for pacing therapy, or which of the available electrodes are used for sensing. The switch module **85** may include a switch array, switch matrix, multiplexer, or any other type of switching device suitable to selectively couple the sensing module **86** and/or the therapy delivery module **84** to one or more selected electrodes. More specifically, the therapy delivery module **84** may include a plurality of pacing output circuits. Each pacing output circuit of the plurality of pacing output circuits may be selectively coupled, e.g., using the switch module **85**, to one or more of the electrodes **40**, **42**, **44**, **45**, **46**, **47**, **48**, **50**, **58**, **62**, **64**, **66** (e.g., a pair of electrodes for delivery of therapy to a bipolar or multipolar pacing vector). In other words, each electrode can be selectively coupled to one of the pacing output circuits of the

therapy delivery module using the switching module **85**.
(81) The sensing module **86** is coupled (e.g., electrically coupled) to sensing apparatus, which may include, among additional sensing apparatus, the electrodes **40**, **42**, **44**, **45**, **46**, **47**, **48**, **50**, **58**, **62**, **64**, **66** to monitor electrical activity of the heart **12**, e.g., electrocardiogram (ECG)/electrogram (EGM) signals, etc. The ECG/EGM signals may be used to measure or monitor activation times (e.g., ventricular activations times, etc.), heart rate (HR), heart rate variability (HRV), heart rate turbulence (HRT), deceleration/acceleration capacity, deceleration sequence incidence, T-wave *alternans* (TWA), P-wave to P-wave intervals (also referred to as the P-P intervals or A-A intervals), R-wave to R-wave intervals (also referred to as the R-R intervals or V-V intervals), P-wave to QRS complex intervals (also referred to as the P-R intervals, A-V intervals, or P-Q intervals), QRS-complex morphology, ST segment (i.e., the segment that connects the QRS complex and the T-wave), T-wave changes, QT intervals, electrical vectors, etc.
(82) The switch module **85** may also be used with the sensing module **86** to select which of the available electrodes are used, or enabled, to, e.g., sense electrical activity of the patient's heart (e.g., one or more electrical vectors of the patient's heart using any combination of the electrodes **40**, **42**, **44**, **45**, **46**, **47**, **48**, **50**, **58**, **62**, **64**, **66**). Likewise, the switch module **85** may also be used with the sensing module **86** to select which of the available electrodes are not to be used (e.g., disabled) to, e.g., sense electrical activity of the patient's heart (e.g., one or more electrical vectors of the patient's heart using any combination of the electrodes **40**, **42**, **44**, **45**, **46**, **47**, **48**, **50**, **58**, **62**, **64**, **66**), etc. In some examples, the control module **81** may select the electrodes that function as sensing electrodes via the switch module within the sensing module **86**, e.g., by providing signals via a data/address bus.
(83) In some examples, sensing module **86** includes a channel that includes an amplifier with a relatively wider pass band than the R-wave or P-wave amplifiers. Signals from the selected sensing electrodes may be provided to a multiplexer, and thereafter converted to multi-bit digital signals by an analog-to-digital converter for storage in memory **82**, e.g., as an electrogram (EGM). In some examples, the storage of such EGMs in memory **82** may be under the control of a direct memory access circuit.
(84) In some examples, the control module **81** may operate as an interrupt-driven device and may be responsive to interrupts from pacer timing and control module, where the interrupts may correspond to the occurrences of sensed P-waves and R-waves and the generation of cardiac pacing pulses. Any necessary mathematical calculations may be performed by the processor **80** and any updating of the values or intervals controlled by the pacer timing and control module may take place following such interrupts. A portion of memory **82** may be configured as a plurality of recirculating buffers, capable of holding one or more series of measured intervals, which may be analyzed by, e.g., the processor **80** in response to the occurrence of a pace or sense interrupt to determine whether the patient's heart **12** is presently exhibiting atrial or ventricular tachyarrhythmia.
(85) The telemetry module **88** of the control module **81** may include any suitable hardware, firmware, software, or any combination thereof for communicating with another device, such as a programmer. For example, under the control of the processor **80**, the telemetry module **88** may receive downlink telemetry from and send uplink telemetry to a programmer with the aid of an antenna, which may be internal and/or external. The processor **80** may provide the data to be uplinked to a programmer and the control signals for the telemetry circuit within the telemetry module **88**, e.g., via an address/data bus. In some examples, the telemetry module **88** may provide received data to the processor **80** via a multiplexer.
(86) The various components of the IMD **16** are further coupled to a power source **90**, which may include a rechargeable or non-rechargeable battery. A non-rechargeable battery may be selected to last for several years, while a rechargeable battery may be inductively charged from an external device, e.g., on a daily or weekly basis.

(87) FIG. **15**B is another embodiment of a functional block diagram for IMD **16** that depicts bipolar RA lead **22**, bipolar RV lead **18**, and bipolar LV CS lead **20** without the LA CS pace/sense electrodes and coupled with an implantable pulse generator (IPG) circuit **31** having programmable modes and parameters of a biventricular DDD/R type known in the pacing art. In turn, the sensor signal processing circuit **91** indirectly couples to the timing circuit **43** and via data and control bus to microcomputer circuitry **33**. The IPG circuit **31** is illustrated in a functional block diagram divided generally into a microcomputer circuit **33** and a pacing circuit **21**. The pacing circuit **21** includes the digital controller/timer circuit **43**, the output amplifiers circuit **51**, the sense amplifiers circuit **55**, the RF telemetry transceiver **41**, the activity sensor circuit **35** as well as a number of other circuits and components described below.
(88) Crystal oscillator circuit **89** provides the basic timing clock for the pacing circuit **21** while battery **29** provides power. Power-on-reset circuit **87** responds to initial connection of the circuit to the battery for defining an initial operating condition and similarly, resets the operative state of the device in response to detection of a low battery condition. Reference mode circuit **37** generates stable voltage reference and currents for the analog circuits within the pacing circuit **21**. Analog-to-digital converter (ADC) and multiplexer circuit **39** digitize analog signals and voltage to provide, e.g., real time telemetry of cardiac signals from sense amplifiers **55** for uplink transmission via RF transmitter and receiver circuit **41**. Voltage reference and bias circuit **37**, ADC and multiplexer **39**, power-on-reset circuit **87**, and crystal oscillator circuit **89** may correspond to any of those used in illustrative implantable cardiac pacemakers.
(89) If the IPG is programmed to a rate responsive mode, the signals output by one or more physiologic sensors are employed as a rate control parameter (RCP) to derive a physiologic escape interval. For example, the escape interval is adjusted proportionally to the patient's activity level developed in the patient activity sensor (PAS) circuit **35** in the depicted, illustrative IPG circuit **31**. The patient activity sensor **27** is coupled to the IPG housing and may take the form of a piezoelectric crystal transducer. The output signal of the patient activity sensor **27** may be processed and used as an RCP. Sensor **27** generates electrical signals in response to sensed physical activity that are processed by activity circuit **35** and provided to digital controller/timer circuit **43**. Activity circuit **35** and associated sensor **27** may correspond to the circuitry disclosed in U.S. Pat. No. 5,052,388 entitled “METHOD AND APPARATUS FOR IMPLEMENTING ACTIVITY SENSING IN A PULSE GENERATOR” and issued on Oct. 1, 1991 and U.S. Pat. No. 4,428,378 entitled “RATE ADAPTIVE PACER” and issued on Jan. 31, 1984, each of which is incorporated herein by reference in its entirety. Similarly, the illustrative systems, apparatus, and methods described herein may be practiced in conjunction with alternate types of sensors such as oxygenation sensors, pressure sensors, pH sensors, and respiration sensors, for use in providing rate responsive pacing capabilities. Alternately, QT time may be used as a rate indicating parameter, in which case no extra sensor is required. Similarly, the illustrative embodiments described herein may also be practiced in non-rate responsive pacemakers.
(90) Data transmission to and from the external programmer is accomplished by way of the telemetry antenna **57** and an associated RF transceiver **41**, which serves both to demodulate received downlink telemetry and to transmit uplink telemetry. Uplink telemetry capabilities may include the ability to transmit stored digital information, e.g., operating modes and parameters, EGM histograms, and other events, as well as real time EGMs of atrial and/or ventricular electrical activity and marker channel pulses indicating the occurrence of sensed and paced depolarizations in the atrium and ventricle.
(91) Microcomputer **33** contains a microprocessor **80** and associated system clock and on-processor RAM and ROM chips **82**A and **82**B, respectively. In addition, microcomputer circuit **33** includes a separate RAM/ROM chip **82**C to provide additional memory capacity. Microprocessor **80** normally operates in a reduced power consumption mode and is interrupt driven. Microprocessor **80** is awakened in response to defined interrupt events, which may include A-TRIG, RV-TRIG, LV-

TRIG signals generated by timers in digital timer/controller circuit **43** and A-EVENT, RV-EVENT, and LV-EVENT signals generated by sense amplifiers circuit **55**, among others. The specific values of the intervals and delays timed out by digital controller/timer circuit **43** are controlled by the microcomputer circuit **33** by way of data and control bus from programmed-in parameter values and operating modes. In addition, if programmed to operate as a rate responsive pacemaker, a timed interrupt, e.g., every cycle or every two seconds, may be provided in order to allow the microprocessor to analyze the activity sensor data and update the basic A-A, V-A, or V-V escape interval, as applicable. In addition, the microprocessor **80** may also serve to define variable, operative A-V delay intervals, V-V delay intervals, and the energy delivered to each ventricle and/or atrium.

(92) In one embodiment, microprocessor **80** is a custom microprocessor adapted to fetch and execute instructions stored in RAM/ROM unit **82** in a conventional manner. It is contemplated, however, that other implementations may be suitable to practice the present disclosure. For example, an off-the-shelf, commercially available microprocessor or microcontroller, or custom application-specific, hardwired logic, or state-machine type circuit may perform the functions of microprocessor **80**.

(93) Digital controller/timer circuit **43** operates under the general control of the microcomputer **33** to control timing and other functions within the pacing circuit **21** and includes a set of timing and associated logic circuits of which certain ones pertinent to the present disclosure are depicted. The depicted timing circuits include URI/LRI timers **83**A, V-V delay timer **83**B, intrinsic interval timers **83**C for timing elapsed V-EVENT to V-EVENT intervals or V-EVENT to A-EVENT intervals or the V-V conduction interval, escape interval timers **83**D for timing A-A, V-A, and/or V-V pacing escape intervals, an A-V delay interval timer **83**E for timing the A-LVp delay (or A-RVp delay) from a preceding A-EVENT or A-TRIG, a post-ventricular timer **83**F for timing post-ventricular time periods, and a date/time clock **83**G.

(94) The A-V delay interval timer **83**E is loaded with an appropriate delay interval for one ventricular chamber (e.g., either an A-RVp delay or an A-LVp) to time-out starting from a preceding A-PACE or A-EVENT. The interval timer **83**E triggers pacing stimulus delivery and can be based on one or more prior cardiac cycles (or from a data set empirically derived for a given patient).

(95) The post-event timer **83**F times out the post-ventricular time period following an RV-EVENT or LV-EVENT or a RV-TRIG or LV-TRIG and post-atrial time periods following an A-EVENT or A-TRIG. The durations of the post-event time periods may also be selected as programmable parameters stored in the microcomputer **33**. The post-ventricular time periods include the PVARP, a post-atrial ventricular blanking period (PAVBP), a ventricular blanking period (VBP), a post-ventricular atrial blanking period (PVARP) and a ventricular refractory period (VRP) although other periods can be suitably defined depending, at least in part, on the operative circuitry employed in the pacing engine. The post-atrial time periods include an atrial refractory period (ARP) during which an A-EVENT is ignored for the purpose of resetting any A-V delay, and an atrial blanking period (ABP) during which atrial sensing is disabled. It should be noted that the starting of the post-atrial time periods and the A-V delays can be commenced substantially simultaneously with the start or end of each A-EVENT or A-TRIG or, in the latter case, upon the end of the A-PACE which may follow the A-TRIG. Similarly, the starting of the post-ventricular time periods and the V-A escape interval can be commenced substantially simultaneously with the start or end of the V-EVENT or V-TRIG or, in the latter case, upon the end of the V-PACE which may follow the V-TRIG. The microprocessor **80** also optionally calculates A-V delays, V-V delays, post-ventricular time periods, and post-atrial time periods that vary with the sensor-based escape interval established in response to the RCP(s) and/or with the intrinsic atrial and/or ventricular rate.

(96) The output amplifiers circuit **51** contains a RA pace pulse generator (and a LA pace pulse generator if LA pacing is provided), a RV pace pulse generator, a LV pace pulse generator, and/or

any other pulse generator configured to provide atrial and ventricular pacing. In order to trigger generation of an RV-PACE or LV-PACE pulse, digital controller/timer circuit **43** generates the RV-TRIG signal at the time-out of the A-RVp delay (in the case of RV pre-excitation) or the LV-TRIG at the time-out of the A-LVp delay (in the case of LV pre-excitation) provided by A-V delay interval timer **83**E (or the V-V delay timer **83**B). Similarly, digital controller/timer circuit **43** generates an RA-TRIG signal that triggers output of an RA-PACE pulse (or an LA-TRIG signal that triggers output of an LA-PACE pulse, if provided) at the end of the V-A escape interval timed by escape interval timers **83**D.

(97) The output amplifiers circuit **51** includes switching circuits for coupling selected pace electrode pairs from among the lead conductors and the IND-CAN electrode **20** to the RA pace pulse generator (and LA pace pulse generator if provided), RV pace pulse generator and LV pace pulse generator. Pace/sense electrode pair selection and control circuit **53** selects lead conductors and associated pace electrode pairs to be coupled with the atrial and ventricular output amplifiers within output amplifiers circuit **51** for accomplishing RA, LA, RV and LV pacing.

(98) The sense amplifiers circuit **55** contains sense amplifiers for atrial and ventricular pacing and sensing. High impedance P-wave and R-wave sense amplifiers may be used to amplify a voltage difference signal that is generated across the sense electrode pairs by the passage of cardiac depolarization wavefronts. The high impedance sense amplifiers use high gain to amplify the low amplitude signals and rely on pass band filters, time domain filtering and amplitude threshold comparison to discriminate a P-wave or R-wave from background electrical noise. Digital controller/timer circuit **43** controls sensitivity settings of the atrial and ventricular sense amplifiers **55**.

(99) The sense amplifiers may be uncoupled from the sense electrodes during the blanking periods before, during, and after delivery of a pace pulse to any of the pace electrodes of the pacing system to avoid saturation of the sense amplifiers. The sense amplifiers circuit **55** includes blanking circuits for uncoupling the selected pairs of the lead conductors and the IND-CAN electrode **20** from the inputs of the RA sense amplifier (and LA sense amplifier if provided), RV sense amplifier and LV sense amplifier during the ABP, PVABP and VBP. The sense amplifiers circuit **55** also includes switching circuits for coupling selected sense electrode lead conductors and the IND-CAN electrode **20** to the RA sense amplifier (and LA sense amplifier if provided), RV sense amplifier and LV sense amplifier. Again, sense electrode selection and control circuit **53** selects conductors and associated sense electrode pairs to be coupled with the atrial and ventricular sense amplifiers within the output amplifiers circuit **51** and sense amplifiers circuit **55** for accomplishing RA, LA, RV, and LV sensing along desired unipolar and bipolar sensing vectors.

(100) Right atrial depolarizations or P-waves in the RA-SENSE signal that are sensed by the RA sense amplifier result in a RA-EVENT signal that is communicated to the digital controller/timer circuit **43**. Similarly, left atrial depolarizations or P-waves in the LA-SENSE signal that are sensed by the LA sense amplifier, if provided, result in a LA-EVENT signal that is communicated to the digital controller/timer circuit **43**. Ventricular depolarizations or R-waves in the RV-SENSE signal are sensed by a ventricular sense amplifier result in an RV-EVENT signal that is communicated to the digital controller/timer circuit **43**. Similarly, ventricular depolarizations or R-waves in the LV-SENSE signal are sensed by a ventricular sense amplifier result in an LV-EVENT signal that is communicated to the digital controller/timer circuit **43**. The RV-EVENT, LV-EVENT, and RA-EVENT, LA-SENSE signals may be refractory or non-refractory and can inadvertently be triggered by electrical noise signals or aberrantly conducted depolarization waves rather than true R-waves or P-waves.

(101) The techniques described in this disclosure, including those attributed to the IMD **16**, the computing apparatus **140**, and/or various constituent components, may be implemented, at least in part, in hardware, software, firmware, or any combination thereof. For example, various aspects of the techniques may be implemented within one or more processors, including one or more

microprocessors, DSPs, ASICS, FPGAs, or any other equivalent integrated or discrete logic circuitry, as well as any combinations of such components, embodied in programmers, such as physician or patient programmers, stimulators, image processing devices, or other devices. The term “module,” “processor,” or “processing circuitry” may generally refer to any of the foregoing logic circuitry, alone or in combination with other logic circuitry, or any other equivalent circuitry.
(102) Such hardware, software, and/or firmware may be implemented within the same device or within separate devices to support the various operations and functions described in this disclosure. In addition, any of the described units, modules, or components may be implemented together or separately as discrete but interoperable logic devices. Depiction of different features as modules or units is intended to highlight different functional aspects and does not necessarily imply that such modules or units must be realized by separate hardware or software components. Rather, functionality associated with one or more modules or units may be performed by separate hardware or software components or integrated within common or separate hardware or software components.
(103) When implemented in software, the functionality ascribed to the systems, devices and techniques described in this disclosure may be embodied as instructions on a computer-readable medium such as RAM, ROM, NVRAM, EEPROM, FLASH memory, magnetic data storage media, optical data storage media, or the like. The instructions may be executed by processing circuitry and/or one or more processors to support one or more aspects of the functionality described in this disclosure.
ILLUSTRATIVE EMBODIMENTS
(104) Embodiment 1. A system for use in cardiac evaluation comprising: an electrode apparatus comprising a plurality of external electrodes to be disposed proximate a patient's skin; and a computing apparatus comprising processing circuitry, the computing apparatus operably coupled to the electrode apparatus and configured to: monitor electrical activity from tissue of a patient using a plurality of external electrodes to generate a plurality of electrical signals; filter at least one of the electrical signals of the plurality of electrical signals; detect at least one disturbance in the at least one electrical signal using the at least one filtered signal; and determine a temporal location of the at least one disturbance in the at least one electrical signal based on a time that the at least one filtered signal crosses a predetermined threshold.
(105) Embodiment 2. The system of embodiment 1, wherein the electrical activity comprises electrical activation times representative of depolarization of cardiac tissue that propagates through the torso of the patient.
(106) Embodiment 3. The system as in any one of embodiments 1-2, wherein the plurality of external electrodes comprises a plurality of surface electrodes to be located proximate skin of the patient's torso.
(107) Embodiment 4. The system as in any one of embodiments 1-3, wherein the predetermined threshold is based on a sampling rate of the at least one electrical signal.
(108) Embodiment 5. The system as in any one of embodiments 1-4, further wherein the computing apparatus is configured to remove the at least one disturbance.
(109) Embodiment 6. The system of embodiment 5, wherein after removing the at least one disturbance, the computing apparatus is configured to use the electrical signals to determine a plurality of cardiac activation times.
(110) Embodiment 7. The system as in any one of embodiments 1-6, wherein the computing apparatus is configured to smooth the at least one electrical signal within a window starting at a predetermined time period before the temporal location of the at least one disturbance and extending a predetermined amount of time after the temporal location of the at least one disturbance.
(111) Embodiment 8. The system as in any one of embodiments 1-7, wherein the computing apparatus is configured to: determine temporal locations of the at least one disturbance in at least

two electrical signals; and smooth the plurality of electrical signals at the temporal locations of the at least one disturbance in the at least two signals.
(112) Embodiment 9. The system as in any one of embodiments 1-8, wherein the computing apparatus is configured to filter the at least one electrical signal using a second difference filter.
(113) Embodiment 10. The system as in any one of embodiments 1-9, wherein the computing apparatus is configured to determine the predetermined threshold based on a predetermined pulse width range.
(114) Embodiment 11. The system as in any one of embodiments 1-10, wherein the computing apparatus is configured to determine the temporal location of the at least one disturbance within a predetermined window, the predetermined window based on an amplitude of the at least one electrical signal.
(115) Embodiment 12. The system as in any one of embodiments 1-11, wherein the at least one disturbance comprises one or more of a pacing spike and muscle generated noise.
(116) Embodiment 13. A system for use in cardiac evaluation comprising: an electrode apparatus comprising a plurality of external electrodes to be disposed proximate a patient's skin; and a computing apparatus comprising processing circuitry, the computing apparatus operably coupled to the electrode apparatus and configured to: monitor electrical activity from tissue of a patient using a plurality of external electrodes to generate a plurality of electrical signals; detect at least one disturbance in at least one of the plurality of electrical signals; determine temporal locations of the at least one disturbance in the at least one electrical signal; and remove the at least one disturbance based on the temporal locations of the at least one disturbance in the at least one electrical signal.
(117) Embodiment 14. The system of embodiment 13, wherein the computing apparatus is configured to remove the at least one disturbance based on the temporal location of the at least one disturbance in the at least one electrical signal if the at least one disturbance is detected in at least a selected number of the plurality of signals.
(118) Embodiment 15. The system of embodiment 14, wherein the selected number comprises at least four of the electrical signals.
(119) Embodiment 16. The system as in any one of embodiments 13-15, wherein the computing apparatus is configured to smooth the plurality of signals within a window starting at a predetermined time period before the temporal location of the at least one disturbance and extending a predetermined amount of time after the temporal location of the at least one disturbance.
(120) Embodiment 17. The system as in any one of embodiments 13-16 wherein after removing the at least one disturbance, the computing apparatus is configured to use the electrical signals to determine a plurality of cardiac activation times.
(121) Embodiment 18. A method for use in cardiac evaluation comprising: monitoring electrical activity from tissue of a patient using a plurality of external electrodes to generate a plurality of electrical signals; filtering at least one electrical signal of the electrical signals of the plurality of electrical signals; detecting at least one disturbance in the at least one electrical signal using the at least one filtered signal; and determining a temporal location of the at least one disturbance in the at least one electrical signal based on a time that the at least one filtered signal crosses a predetermined threshold.
(122) Embodiment 19. The method of embodiment 18, wherein the electrical activity comprises electrical activation times representative of depolarization of cardiac tissue that propagates through the torso of the patient.
(123) Embodiment 20. The method as in any one of embodiments 18-19, wherein the plurality of external electrodes comprises a plurality of surface electrodes to be located proximate skin of the patient's torso.
(124) Embodiment 21. The method as in any one of embodiments 18-20, wherein the predetermined threshold is based on a sampling rate of the at least one electrical signal.

(125) Embodiment 22. The method as in any one of embodiments 18-21, further comprising removing the at least one disturbance from the at least one electrical signal.
(126) Embodiment 23. The method of embodiment 22, wherein removing the at least one disturbance comprises smoothing the at least one electrical signal within a window starting at a predetermined time period before the temporal location of the at least one disturbance and extending a predetermined amount of time after the temporal location of the at least one disturbance.
(127) Embodiment 24. The method as in any one of embodiments 22-23, wherein detecting at least one disturbance in the at least one electrical signal using the at least one filtered signal comprises detecting at least a first disturbance and a second disturbance in the at least one electrical signal, the second disturbance occurring after the first disturbance, wherein determining a temporal location of the at least one disturbance in the at least one electrical signal comprises determining a temporal location of the first disturbance and the second disturbance, wherein the method further comprises removing the first disturbance and the second disturbance by smoothing the at least one electrical signal within a window starting at a predetermined amount of time before the temporal location of the first disturbance and extending a predetermined amount of time after the second disturbance.
(128) Embodiment 25. The method as in any one of embodiments 22-24, further comprising, after removing the at least one disturbance, using the electrical signals to determine a plurality of cardiac activation times.
(129) Embodiment 26. The method as in any one of embodiments 18-25, wherein determining the temporal location of the at least one disturbance comprises: determining temporal locations of the at least one disturbance in at least two electrical signals; and smoothing the plurality of electrical signals at the temporal locations of the at least one disturbance in the at least two signals.
(130) Embodiment 27. The method as in any one of embodiments 18-26, wherein filtering the at least one electrical signal comprises filtering the at least one signal using a second difference filter.
(131) This disclosure has been provided with reference to illustrative embodiments and is not meant to be construed in a limiting sense. As described previously, one skilled in the art will recognize that other various illustrative applications may use the techniques as described herein to take advantage of the beneficial characteristics of the apparatus and methods described herein. Various modifications of the illustrative embodiments, as well as additional embodiments of the disclosure, will be apparent upon reference to this description.

Claims

1. A system for use in cardiac evaluation comprising: a display apparatus configured to display a graphical user interface; an electrode apparatus comprising a plurality of external electrodes configured to be disposed proximate a patient's skin; and a computing apparatus comprising processing circuitry, the computing apparatus operably coupled to the display apparatus and the electrode apparatus and configured to: monitor electrical activity from tissue of the patient using a plurality of external electrodes to generate a plurality of electrical signals; filter at least one of the electrical signals of the plurality of electrical signals; detect at least one disturbance in the at least one electrical signal using the at least one filtered signal; determine a temporal location of the at least one disturbance in the at least one electrical signal based on a time that the at least one filtered signal crosses a predetermined threshold; remove the at least one disturbance from the at least one electrical signal by smoothing the at least one disturbance using the temporal location of the at least one disturbance; determine a plurality of cardiac activation times based on the plurality of electrical signals following the removal of the at least one disturbance from the at least one electrical signal; and display one or more of a graphical map of electrical activation and at least one metric based on the determined plurality of cardiac activation times on the graphical user interface of the display apparatus.

2. The system of claim 1, wherein the plurality of cardiac activation times are representative of depolarization of cardiac tissue that propagates through the torso of the patient.
3. The system of claim 1, wherein the plurality of external electrodes comprises a plurality of surface electrodes to be located proximate skin of the patient's torso.
4. The system of claim 1, wherein the predetermined threshold is based on a sampling rate of the at least one electrical signal.
5. The system of claim 1, wherein removing the at least one disturbance from the at least one electrical signal by smoothing the at least one disturbance using the temporal location of the at least one disturbance comprises smoothing the at least one electrical signal within a window starting at a predetermined time period before the temporal location of the at least one disturbance and extending a predetermined amount of time after the temporal location of the at least one disturbance.
6. The system of claim 1, wherein removing the at least one disturbance from the at least one electrical signal by smoothing the at least one disturbance using the temporal location of the at least one disturbance comprises: determining temporal locations of the at least one disturbance in at least two electrical signals; and smoothing the plurality of electrical signals at the temporal locations of the at least one disturbance in the at least two signals.
7. The system of claim 1, wherein the computing apparatus is configured to filter the at least one electrical signal using a second difference filter.
8. The system of claim 1, wherein the computing apparatus is configured to determine the predetermined threshold based on a predetermined pulse width range.
9. The system of claim 1, wherein the computing apparatus is configured to determine the temporal location of the at least one disturbance within a predetermined window, the predetermined window based on an amplitude of the at least one electrical signal.
10. The system of claim 1, wherein the at least one disturbance comprises one or more of a pacing spike and muscle generated noise.
11. The system of claim 1, wherein the at least one metric comprises electrical heterogeneity information.
12. The system of claim 11, wherein the electrical heterogeneity information comprises a standard deviation of activation times.
13. A method for use in cardiac evaluation comprising: monitoring electrical activity from tissue of a patient using a plurality of external electrodes to generate a plurality of electrical signals; filtering at least one electrical signal of the plurality of electrical signals; detecting at least one disturbance in the at least one electrical signal using the at least one filtered signal; determining a temporal location of the at least one disturbance in the at least one electrical signal based on a time that the at least one filtered signal crosses a predetermined threshold; removing the at least one disturbance from the at least one electrical signal by smoothing the at least one disturbance using the temporal location of the at least one disturbance; determining a plurality of cardiac activation times based on the plurality of electrical signals following the removal of the at least one disturbance from the at least one electrical signal; and displaying one or more of a graphical map of electrical activation and at least one metric based on the determined plurality of cardiac activation times on a graphical user interface.
14. The method of claim 13, wherein the plurality of cardiac activation times are representative of depolarization of cardiac tissue that propagates through the torso of the patient.
15. The method of claim 13, wherein the plurality of external electrodes comprises a plurality of surface electrodes to be located proximate skin of the patient's torso.
16. The method of claim 13, wherein the predetermined threshold is based on a sampling rate of the at least one electrical signal.
17. The method of claim 13, wherein removing the at least one disturbance from the at least one electrical signal by smoothing the at least one disturbance using the temporal location of the at least

one disturbance comprises smoothing the at least one electrical signal within a window starting at a predetermined time period before the temporal location of the at least one disturbance and extending a predetermined amount of time after the temporal location of the at least one disturbance.

18. The method of claim 13, wherein detecting the at least one disturbance in the at least one electrical signal using the at least one filtered signal comprises: detecting at least a first disturbance and a second disturbance in the at least one electrical signal, the second disturbance occurring after the first disturbance, wherein determining a temporal location of the at least one disturbance in the at least one electrical signal comprises: determining a temporal location of the first disturbance and the second disturbance, and wherein the removing the at least one disturbance from the at least one electrical signal by smoothing the at least one disturbance using the temporal location of the at least one disturbance comprises removing the first disturbance and the second disturbance by smoothing the at least one electrical signal within a window starting at a predetermined amount of time before the temporal location of the first disturbance and extending a predetermined amount of time after the second disturbance.

19. The method of claim 13, wherein determining the temporal location of the at least one disturbance comprises determining temporal locations of the at least one disturbance in at least two electrical signals, and wherein the removing the at least one disturbance from the at least one electrical signal by smoothing the at least one disturbance using the temporal location of the at least one disturbance comprises smoothing the plurality of electrical signals at the temporal locations of the at least one disturbance in the at least two electrical signals.

20. The method of claim 13, wherein filtering the at least one electrical signal comprises filtering the at least one signal using a second difference filter.

21. The method of claim 13, wherein the at least one metric comprises electrical heterogeneity information.

22. The method of claim 21, wherein the electrical heterogeneity information comprises a standard deviation of activation times.