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Contactless Patient Monitoring for General Wards: A Systematic Technology Review

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Abstract. Introduction: Sudden, serious life-threatening situations happen even on general wards. Current technologies are working with sensors which are attached to every patient, which is a source of failures and false alarms. The goal of this review was to assess the state of the art of potential techniques for contactless patient monitoring in general wards. Methods: The MEDLINE database was used for literature retrieval. Results: 453 unique references screened, 34 research articles met inclusion criteria. Ballistocardiography, Radar and Thermography technologies are the most widely tested techniques. The Majority of the studies are done in a laboratory setting. No study shows the feasibility of one contactless monitoring technology over the distance required for monitoring rooms. Conclusion: Today no technology is feasible. A combination of technologies may become feasible in 10 or more years, until then we have to think about ethical and privacy issues of these pervasive technologies.

Keywords. Patient Monitoring, Digital Signal Processing, General Ward, Contactless, Pervasive Technology, Review, Systematic

1. Introduction

Even in general wards often occur sudden, serious life-threatening situations, e.g. 18% of patients develop post-surgery complications [1]. State of the art to forecast critical situations is to measure the early warning score (EWS) or to monitor the vital signs of patients [2]. This requires personal resources for measuring the EWS. On the other hand a monitor connected to each patient is needed. Currently this needs sensors on every patient, which is a source of failures and false alarms. An alternative solution might be technologies for non-contact monitoring like ballistocardiography (BCG), radar or thermography based technologies [3].

The purpose of this review is to assess the state of the art of potential techniques for contactless patient monitoring in general wards and the challenge of monitoring rooms from any direction and with long distances between the sensors and the humans.

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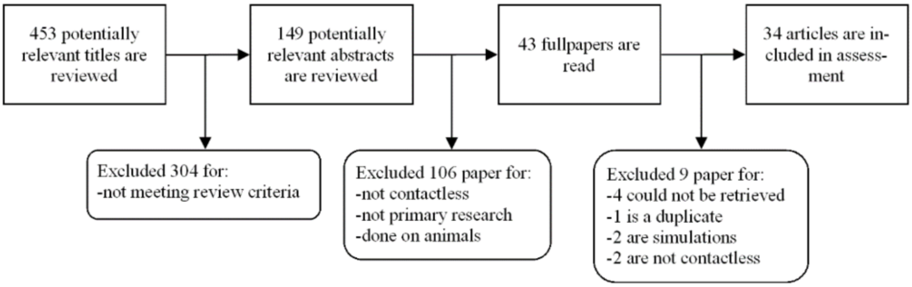

Figure 1. PRIMSA flow diagram for database search.

2. Methods

The Search was performed on MEDLINE. The Inclusion criteria were studies with technologies to receive cardio and respiratory signals from humans without contact. To maximize recall and precision, three categories of search terms was built: The first describes the technology used, second what kind of data was collected and the third included terms that described a contactless system (Full search string available at https://www.uni-oldenburg.de/medizininformatik/downloads/). A computer scientist and a public health informatician performed an independent assessment of the relevance of the papers in three stages: First stage the title, second stage the abstract and in third stage the full paper was reviewed. In every stage both experts rated the paper with accept, decline or unsure. In case of disagreement the paper was discussed, and in case of no consent a third person (physician and medical informatics) was consulted. Finally, all remaining articles were read and a customized extraction sheet was used to extract the information (figure 1).

3. Results

The initial search query resulted in 453 articles of which 149 articles remained after the first step. After reviewing the abstracts, 43 full texts remained to be read. Finally 34 articles made it into the resulting table as can be seen in figure 1. A majority of the studies are done using healthy subjects as a participant of the study. Few studies included patient with sleep disorder [4-7], Heart failure [8], and respiratory pathology [9] and lung cancer [10]. Although the majority of the studies were carried out in controlled laboratory conditions, there are studies that conducted the experiments in the hospital: BCG [8,11-13], radar [5,10,14,15] and thermography [6,9]. Thermography was widely tested only to find respiratory function [6,7,9,16-21] while radar was implemented mainly to measure both respiratory and cardiac signals [5,10,15,22-28], and BCG either of the three vital signs. Regarding distance, longer distance measurement was observed in thermography 0.7 m [9] to 3 m [7]. Radar ranges minimum of 35mm [15] to maximum 50cm [25,27]. As there is no measurable distance in BCG between the mattress and the sensor the distance stated as a few cm with indirect contact nature. Moreover, there are studies in radar technologies [5,10,15,23-31] and in thermography [6,21] with no clear information in the article about the distance between the sensor and the subject.

Table 1. Result of studies investigating contactless patient monitoring technologies until January 2016. The articles are ordered by technology and by ascending year. NA means that the information could not be found.

Technology	Distance	Vital Signs	Setting	Number of tested Subjects	Health Domain	Year	Ref.
Ballistography	few cm	Respiration	Lab	4	Healthy	2007	[32]
Ballistography	few cm	Heart rate	Lab	17	Healthy	2009	[33]
Ballistography	few cm	Respiration	Lab	1	Healthy	2012	[4]
Ballistography	few cm	Cardiopulmonary	Hospital	40	Healthy	2012	[12]
Ballistography	few cm	Heart rate	Hospital	33	Insomnia	2013	[11]
Ballistography	few cm	NA	Hospital	10	Heart Failure	2014	[8]
Ballistography	few cm	Heart rate	Hospital	22	At. Fib	2015	[13]
Radar	0.5-2.5	Cardiopulmonary	Lab	1	Healthy	2005	[22]
Radar	15cm	Heart rate	Lab	3	Healthy	2006	[34]
Radar	50cm	Cardiopulmonary	Hospital	8	Healthy	2006	[14]
Radar	40cm	Cardiopulmonary	Lab	1	NA	2007	[35]
Radar	NA	Cardiopulmonary	Lab	NA	NA	2007	[23]
Radar	10cm	Cardiopulmonary	Hospital	8	Healthy	2008	[15]
Radar	20-45cm	Heart rate	Lab	NA	NA	2010	[29]
Radar	30mm	Heart rate	NA	7	Healthy	2011	[30]
Radar	35cm	Cardiopulmonary	Lab	8	Healthy	2011	[24]
Radar	NA	Respiration	Hospital	1	Lung Cancer	2011	[10]
Radar	50cm	Cardiopulmonary	Lab	1	Healthy	2012	[25]
Radar	NA	Respiration	Lab	1	Healthy	2012	[26]
Radar	10cm	Cardiopulmonary	Hospital	8	Sleep disorder	2013	[5]
Radar	50cm	Cardiopulmonary	Lab	10	Healthy	2014	[27]
Radar	NA	Cardiopulmonary	Lab	15	Healthy	2014	[28]
Radar	NA	Respiration	Lab	2	Healthy	2015	[31]
Radar	50cm	Respiration	Lab	10	Healthy	2015	[36]
Thermography	1.8m	Heart rate	Lab	5	Healthy	2004	[37]
Thermography	1.8-2.4m	Respiration	Lab	9	Healthy	2005	[16]
Thermography	1.8-2.4m	Respiration	Lab	5	Healthy	2006	[17]
Thermography	1.8m	Heart rate	Lab	34	Healthy	2006	[18]
Thermography	1.8-2.4m	Respiration	Lab	3	Healthy	2006	[19]
Thermography	NA	Respiration	Hospital	27	Sleep Apnea	2009	[6]
Thermography	3m	Respiration	Lab	22	Sleep Apnea	2009	[7]
Thermography	1.8m	Respiration	Lab	20	Healthy	2010	[20]
Thermography	NA	Respiration	Lab	25	Healthy	2012	[21]
Thermography	0.7-1.2m	Respiration	Hospital	17	Res. Path	2012	[9]

4. Discussion

The current evidence base contains various studies describing the use of contactless monitoring techniques to measure cardiopulmonary signals. In spite of encouraging efforts to find better hardware and tracking software algorithm [20,27,31], the majority of included studies share some common technical problems. Developing better algorithms and technologies which can accurately track and classify patient movement artifacts apart from heartbeat or respiration signals are the major noted problems.

In a general ward setting the ideal contactless patient monitoring requires a considerable distance between the sensors and the patients. In the included studies, most radar based tests were performed from a very short distance, measured in centimeter. Neither the justification to choose the mentioned distance nor the effect of a variation in distance on the accuracy is explicitly explained in the articles with a few exceptions [22,27]. The use of multiple devices or a combination of technologies in different categories was shown as a means providing better accuracy in tracking signals

[4,5,10,23,26]. This could be a good solution to minimize the limitations of a single technology.

5. Conclusion

In conclusion, it's a long way to get nearly 100% sensitivity and a good positive prediction that are required to implement contactless monitoring systems in general wards. A combination of technologies may become feasible in 10 or more years. However, we have to use this time to think about ethical and privacy issues of these pervasive technologies.

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