

# Increased Data Quality in Home Blood Pressure Monitoring through Context Awareness

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**Abstract**— A range of recommendations exists on how to obtain a valid blood pressure. With the blood pressure devices currently available it cannot be verified whether a user is actually following these recommendations or not. This paper reports on the findings from a feasibility study on ubiquitous sensing of user behavioral context during blood pressure monitoring in the home setting. A prototype system using a context-aware chair-cover is evaluated through laboratory experiments and user evaluation. Results indicate that relevant user-context can be successfully monitored. Findings may lead to better user guidance and increase the quality of data available to caretakers.

**Keywords**— component; Home blood pressure monitoring, ubiquitous computing, pervasive computing, recommendations, context-aware, adherence, compliance, telemonitoring.

## I. INTRODUCTION

Blood pressure above 140/90 mmHg, measured at heart level, is defined as hypertension. Persistent hypertension is a chronic medical condition and a risk factor for heart attacks, strokes, heart and kidney failure and other heart and circulatory diseases [1]. There are usually no symptoms and frequent blood pressure readings are thus relevant to consider for high-risk groups, as this is the main factor in the decision to start antihypertensive therapy. Patients often exhibit elevated blood pressure in a clinical setting. It is believed that this is due to the anxiety some people experience during a visit to the clinic. This is known as the white coat effect and is reported to be affecting between 20 to 40 % of all patients visiting a clinic [2]. Patients suspected of white coat effect are usually referred to measuring their blood pressure at home, either using an ambulatory or home blood pressure measurement device [1, 2].

Both ambulatory and automatic home blood pressure monitoring devices have proven successful for obtaining measurements in clinical trials, if used correctly and according to the recommendations [1-3]. However, errors in home blood pressure measurements are reported to occur often due to procedural mistakes. Some of these errors result in overestimates of the blood pressure which could cause almost twice as many patients receiving the diagnosis of hypertension [1-4].

A range of recommendations (see Table I) on how to perform a valid blood pressure measurement have been specified by the American Hypertension Association, the

British Hypertension Society, and other clinical expert organizations. With the blood pressure devices for home use currently available on the market, it cannot be verified whether a user has actually followed the recommendations as specified or not [4-8].

The use of technology for improving home blood pressure measurement has been comprehensively investigated. A recent review by Abudagga et al. report on the impact of 15 longitudinal home blood pressure telemonitoring studies, including a total of more than 3.000 patients [9]. Technology included home blood pressure measurement devices interfacing with cell phones, personal digital assistants, touch screen computers, and other gateway devices, reporting data online to caretakers. The authors concluded that the use of telemonitoring resulted in reducing the blood pressure of the patients at comparable levels to certain antihypertensive drugs. They also conclude that telemonitoring can be used to reach a higher level of patient self-empowerment and self-medication, and that it affords healthcare providers with more reliable and frequent blood pressure information than can be obtained in the clinical setting. However, none of the reported studies investigated whether the recommendations were being followed and the quality of data is thus undeterminable.

TABLE I. LIST OF RECOMMENDATIONS

No.	Recommendation
1	Do not drink coffee or smoke cigarettes 30 minutes before having your blood pressure measured
2	Go to the bathroom prior to the reading. A full bladder can change a blood pressure reading.
3	Before the test, sit and rest for five minutes with back supported and your feet flat on the ground.
4	Make sure of being in quiet surroundings and not talking while doing the reading
5	Rest your arm on a table at the level of your heart
6	Wear short sleeves so the arm is exposed
7	Get two readings, taken at least two minutes apart, and average the results
8	Record the reading.
9	Make sure to keep accurate record
10	Do not round the numbers
11	Record any medications taken and when
12	Record whether you have just exercised
13	Record whether you have just eaten

List of recommendations for obtaining valid home blood pressure measurement. Items 3 to 10 are relevant during the measurement process. This paper examines recommendation no. 3.

In an ongoing study, a context-aware conceptual model is being explored for monitoring the activities of the user before, during and after measurements, to ensure that the recommendations in Table 1 are followed. In a range of clinical proof-of-concept feasibility sub-studies, we explore different aspects of the problem domain, and how ubiquitous computing technology might support more valid data from the users' home by verifying user compliance with the recommendations [8]. This is mainly done using various context-aware sensor technologies embedded in furniture and biomedical devices. The overall objective of this study is to provide enhanced guidance to the users in order to improve the compliance with the recommendations, and to obtain higher quality of data to support more informed medical diagnostics. In this sub study, we consider the case study of a physician prescribing three days of home blood pressure self-measurement to a patient for diagnostic purposes. The specific aim is to determine whether we can successfully sense the context of the user, with regard to recommendation no. 3 and qualify the level of adherence.

We suggest handing out a context-aware chair-cover as a supplement to the home blood pressure device, mounting it on a chair in the home of the patient and logging use-context, in order to quantify the data quality. To assess the feasibility of this approach a prototype has been constructed for evaluation purposes.

### I. EVALUATION PROTOTYPE

We have equipped a chair with a tailor-made cover embedded with four sensors in the fabric for collecting user-behavior data for verification purposes. The cover is designed in such a way that it would fit most regular chairs. This would allow patients to easily transport the cover home from the clinic, and equip a chair with it.

The "Back sensor" is used to ensure that the user has his back supported during measurement and is not leaning forward. The "Seat sensor" is used to verify that the user remains seated during the entire process, while the two "foot sensors" ensures that the user will not move or cross his legs during testing. Any of the above incidents would imply that the user had diverted from the recommendations which could potentially result in a misleading blood pressure reading, and would thus render the data obtained invalid, diminishing its diagnostic value.

Many different sensor types may support us in obtaining these goals, including strain gauges, accelerometers, and pressure sensors. We have focused on employing cost-effective and simple sensors for the initial evaluation prototype that only requires a digital interface and no significant signal processing in order to give a valid response. More advanced sensor types would provide a higher data-precision, but would also require more hardware and programming effort, which is not feasible before more experiences have been collected.

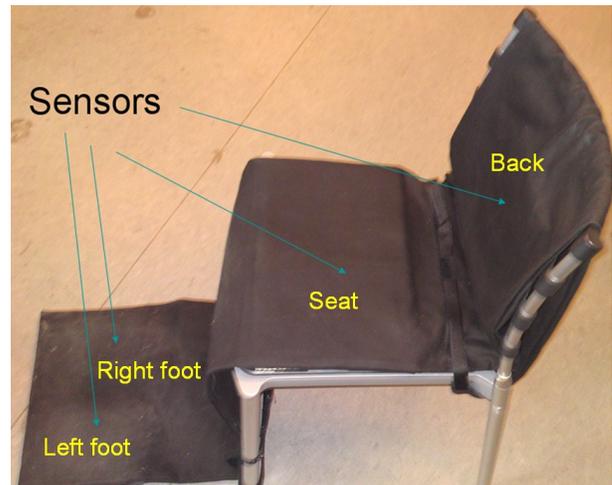


Figure 1. A domestic chair with a tailor-made cover containing four sensors; one in the seat, one in the back-support and one for each foot.

In order to better evaluate the sensor-augmented cover, we have chosen to integrate with a wireless blood pressure device. In this way, we can obtain blood pressure data in combination with the context-data from the chair sensors.

#### A. Materials

For prototype construction and evaluation, the following materials are used:

The cover is equipped with pressure sensors, one for each foot, one for the seat and one for the back (used: Defender 1146763 Standard Pressure Mat, Farnell, UK).

An embedded single board computer (SBC) equipped with external WiFi dongle and a digital input interface is used to accommodate data collection and distribution from the pressure sensors (used: PhidgetSBC, Phidgets Inc, Canada).

An automatic home blood pressure device with wireless capabilities for transferring data to the automated test facility, where we have implemented a Bluetooth service to accept the data (used: A&D Digital Blood Pressure Monitor UA-767PBT, A&D Company Limited, Japan).

A computer running Windows XP and .NET is used for test-procedure and data registration purposes, as part of the automated test facility (used: Dell Precision M4300, Dell Inc., US).

### II. EVALUATION METHODS

We divide the evaluation into three phases. First, we use an automated test facility to verify sensor functionality. Second, we test with 10 users, sequentially seated in the chair measuring their blood pressure, in order to gain a qualitative understanding of the user experience. We ask the test users to provide their immediate feedback on the chair sensor after testing. Finally, we present and discuss our experiences in a multidisciplinary and patient informed workshop.

### A. Automated Test Facility Evaluation

Four test cases have been designed to test whether the relevant user behavior is registered by the solution as expected, and thus to verify sensor functionality. The test application guides the user through the four test cases and registers all relevant context-events from the chair sensors, and logs these for each test session to a text file for later inspection. A total of 10 test scenarios and 40 test cases are used to verify the feasibility of the suggested solution. In all four test cases, the user is guided by the automated test facility application, and the user behavior is recorded for later inspection.

In test case 1, the objective is to determine whether it can be accurately measured that a user is seated in the chair or not. The user is guided through a series of actions using the test application, and the system records compliance levels and timing.

In test case 2, the objective is to determine whether it can be accurately measured that a user is sitting with his back supported or not. Again, the user is guided through a series of actions using the test application.

In test case 3, the objective is to determine whether it can be measured that the user keeps both feet flat on the ground, and that his legs are not crossed.

In test case 4 we combine the test cases and test whether the user is sitting correctly as specified by the recommendations no. 3.

### B. User Evaluation

User acceptance is vital when introducing new technology and concepts into the healthcare domain. Therefore, a qualitative user study was designed in the laboratory setting, inviting ten users with varying background, including hypertensive patients, to use the augmented chair in collaboration with the blood pressure measurement device.

Users were instructed how to use the system and behave during measurements. The user should rest for approximately 5 minutes, strap on the cuff of the blood pressure device, and activate the blood pressure measurement using the on-device button. Then wait approximately 2 minutes before starting the second measurement. The test application gathers the data from both the blood pressure device and the chair sensors.

Users were observed during the measurement process without intervening, except when asking specifically for help. Interesting findings were noted for future reference. User task time was between 15-20 minutes including instructions.

After the observation phase, the users were asked open ended questions on the user experience and feasibility.

### C. Workshop

To gain a deeper understanding, a focus group consisting of three selected hypertensive patients, three engineers, one general practitioner, and one industrial designer, was invited to a workshop. The evaluation prototype was presented, along with several state-of-the-art blood pressure devices used by

clinicians at the Aarhus University Hospitals. Also, the Intel Health Guide gateway [10], which features a touch screen interface, that can guide the user through the blood pressure measurement process were introduced and discussed with the patients.

## III. RESULTS

### A. Automated Test Facility Evaluation

Ten test sessions were executed in a lab setting. All 40 test cases completed successfully, and sensor functionality was as expected. From the sensors we could reliably deduce whether the user was in compliance with recommendation no. 3 or not.

### B. User Evaluation Results

All users were able to measure their blood pressure while staying seated for the duration of the task. Some users had trouble estimating how much time to wait. Several reported that 5 minutes of waiting felt like a very long time to wait, while trying to keep relaxed and not moving. Especially the two minutes between measurements were perceived painstakingly slow, and more feedback on progress was requested.

The idea of using a chair with a cover was considered acceptable to the test users. However, the need for removing the shoes before placing both feet on the cover was considered problematic by some, and the aesthetics of the prototype were perceived as low. One test user underlined that she did not want to display her disease to guests, stating that the cover should be easy to remove from the chair and store. The idea of having a special healthcare chair was in general turned down. Furniture are highly personal items, not to be used for healthcare.

Several users felt that the cover helped increase awareness to the fact that recommendations existed and that they were important to consider. In particular the instructions from recommendation no. 3 were easy to remember, as the cover in itself was a cue. The floor-part of the cover afforded placing both feet flat on the ground as required, and the back-cover afforded leaning back in the chair.

### C. Workshop Results

The eight workshop participants discussed the overall idea of achieving more reliable blood pressure data through increased technology use. Specifically current state-of-the-art biomedical devices for home blood pressure measurement and the Intel Health Guide gateway was debated and compared with the evaluation prototype and several other low fidelity conceptual-level prototypes, based on their own background and preferences.

Many findings correlate with those from the user evaluation study, including the need for a more aesthetic design, while also being able to hide away the devices more easily, as the users did not want to display their disease to visiting guests. Also, users stated the need for simplicity of use, including one-button activation, and better feedback than is available on the existing devices. The idea of providing data to the caretaker over the internet was in general well received. All found the

existing practice of writing down the data to be annoying and error-prone. All participants welcomed that the device itself would evaluate the quality of the measurement. Neither of the patients remembered ever having taken a valid blood pressure measurement at home. The general practitioner reiterated the high importance of always following the recommendations.

One user travelled much, and was keen on keeping devices sufficiently portable. It was suggested that part of the device could be stationary (for high precision measurement) while other could be mobile (for easy transportation).

The concept of employing different ways of operating blood pressure devices was discussed. This included: 1) using the blood pressure device as a stand-alone device, 2) in conjunction with a smart phone as interface, or 3) with a touch screen computer mounted on the wall. Users stated that the latter should be a natural part of the room, e.g. acting as a picture frame when not being used for measurement purposes, rather than equipment signaling disease. The youngest participants favored the smart phone solution, while all found the touchscreen picture frame a possible alternative to having a larger blood pressure device, capable of mounting a sufficient user interface. Other suggestions discussed included voice controlled, or even automatic blood pressure measurements, once the user had fulfilled the recommendations.

A participant warned of the risk of blood pressure measurements belonging to guests and other casual users could end up in a central data-store. She did not herself own a blood pressure device, but rather relied on using the devices of other people, and when visiting the clinic at her half-yearly follow-up.

#### IV. DISCUSSION

Results indicate that it is feasible to use the suggested solution to measure user-context while performing a seated systemic blood pressure reading in the users' home. This indicates, that using the right combination of sensors can correctly judge whether a user is following the guidelines regarding user position and activity level. This contextual knowledge may be used to design a better user interface which may give more relevant and timely guidance, rather than overloading the user with a range of things to consider.

A few potential sources of bias were discovered during the user evaluation sessions. First of all, the two foot sensors required the user to place the feet at the correct position to be working, which might not be evident to users. A more clear indication of correct feet placement might be required in the final design. Also, the low level of sensitivity of the two foot sensors meant, that a test user wearing shoes would not be correctly sensed by the system, probably due to the increased weight distribution on the sensors. As the system was designed to support bare-foot usage, this might not be a problem; however, it might be advantageous to support users wearing shoes as well. Also, it was observed, that a user could "cheat" the foot sensors, by stemming the heels into the fabric, rather than keeping the feet "flat on the ground" as required. It could be argued, that users might not have the deliberate intent of

cheating the system, but it would still be relevant to consider a redesign that could handle this type of situation, using different sensor types.

The produced cover is able to reliably collect the required data, but appears rather impractical and with low aesthetics. Especially the lower part of the cover, which is intended for the feet, appears unhandy in the context of a home. A novel design should be considered with more emphasis on aesthetics, if patients should be convinced to introduce this technology into their homes.

Also, the user evaluation and workshop indicated a need for designing better user interfaces than currently used on state-of-the-art biomedical devices. As it appears feasible to sense different levels of contexts in the future, this calls for a development of novel user interface paradigms for such devices. Devices for use in the home setting, appears to exhibit other requirements to interface and aesthetics than in the clinic.

#### V. FUTURE WORK

More conceptual design work is needed on the chair-cover prototype with regard to sensor accuracy and precision. This includes a novel approach to more reliably sense correct feet placement. Also, design aesthetics and appearance seemed essential to improve, in order to gain user acceptance. A revised prototype should also be evaluated in the home setting of the users, to provide in situ feasibility data.

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