Wellbeing in Smart Environments: Definition, Measurement, Prediction and Control

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Abstract
What does well-being mean in the context of smart environments? What restrictions are set, how can well-being be measured and predicted? Can smart environments control or influence individual well-being? We seek to answer these questions by aggregating existing research on well-being and identifying the concepts relevant for smart environments. As a result, we provide a falsifiable definition candidate for well-being in smart environments and outline the experiments necessary for verifying the validity of the definition.

Author Keywords
Well-being; Smart environment; Definition; Prediction; Control.

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H.5.m [Information interfaces and presentation (e.g., HCI)]: Miscellaneous.

Introduction
Despite millenia of thought, well-being remains an elusive concept. Sometimes referred to as quality of life, well-being is extensively studied in multiple fields including philosophy, medicine, psychology, sociology, and socio-economics [19, 2, 15, 10, 22, 8, 25]. While the definition remains unclear [7], common patterns can be

identified. First, the dimensions of well-being include mental, emotional, physical, social, material, and professional [8, 28]. Second, while essentially a subjective assessment, both subjective and objective measurement methodologies exist [10]. Third, the scope of well-being is predominantly long-term, with "a few weeks" a usual time scale in subjective self-assessments [28].

Limiting the context to smart environment sets further restrictions on each of the above three observations. First, while measuring and predicting an individual's social or material well-being may be possible, given sufficient access, there is little possibility of a smart environment influencing them. Second, a smart environment by definition must rely on objective methods only. Third, a smart environment, aiming to measure, predict and control (to a given extent) an individual's well-being, primarily operates on an immediate or short term timescale. For example, a disturbingly hot room temperature needs to be changed *now*, or at least *really soon*.

Yet, a smart environment can potentially have a great effect on an individual's well-being. Stoll et al. [27] and Huppert [12] both identify natural and living environments as one of the crucial drivers of well-being. According to Bergs [3] 20-50 percent of Western European and North American buildings are "problem buildings" that lower the well-being and productivity of the office workers.

This study aims to 1) define well-being in a useful and relevant manner in the context of smart environments; and 2) propose methods to measure, predict and control well-being by means available for smart environments.

Definition

Out of the six identified dimensions of well-being identified (mental, emotional, physical, social, material, professional), the first three are feasible for short-term measurement, prediction and control. Further, desirable states correlating (and somewhat overlapping) with those three remaining dimensions include *flow* [16, 23, 21, 30], *low stress* [6, 5, 24], and a *balance between positive and negative affect* [9, 26, 29, 28].

We thus propose the following falsifiable definition hypothesis: *"Well-being in smart environments is a latent feature of an individual, manifesting as her immediate mental, physical and emotional states. A desirable state of well-being is characterized by 1) a flow state of mind, 2) low levels of stress, and 3) a balance between negative and positive affect."*

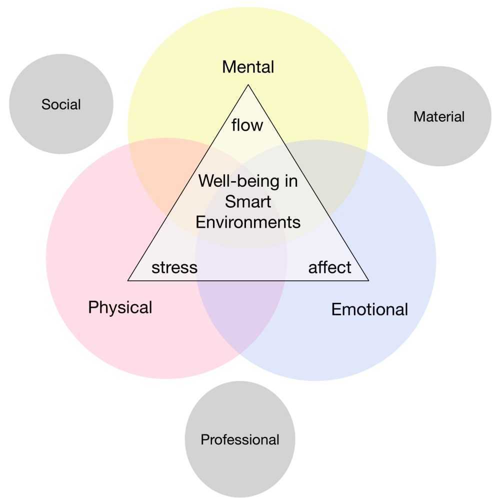

Figure 1: Well-being in smart environments.

The definition is further elaborated in Fig 1. If the definition is valid, there should be a strong correlation between the observed quantities (flow, stress, affect) and a self-assessment of well-being. Conversely, if the definition is invalid, the association between the observed quantities and a self-assesment is weak or nonexistant.

Measurement

Mental, physical, and emotional states can be measured by, for example, wearable sensors or video and audio analysis. Yoshida et al. [30] and Nakamura et al. [16] detected flow by scanning brain activity, while Peifer [17] observed heart rate variability, skin conductance level, and cortisol reactivity, among others. Ahern et al. [1] detected emotions by brain activity as early as 1985. Choi et al. [4] and Muaremi et al. [14], among others, detected stress by way of e.g. heart rate variability monitoring, while Healey, Picard et al. [11, 18] observed, in addition, skin conductivity to detect both stress and affect.

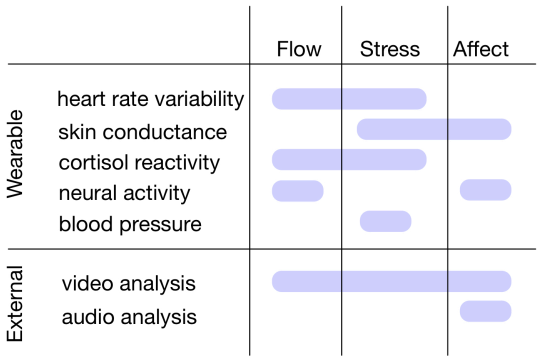

Figure 2: Existing methods to measure selected proxies of well-being.

On the other hand, Zeng et al. [31] list several attempts to detect affect by video and audio analysis. Such analysis methods have gained major attention in recent years due to recent breakthroughs in machine learning [13]. Video analysis has also been successfully employed to detect pulse [20] and thus, consequentially, also both flow and stress.

The above observation methods and their applications for measuring well-being are collected in Fig 2.

Suggestions for Future Research

To assess the validity of the given definition for well-being in smart environments, the following research questions need to be answered:

1. How strong is the association between objective measurement of flow, stress and affect, and a subjective assessment of well-being?
2. Can well-being be predicted by means of only external monitoring (e.g. video / audio sensors embedded in the smart environment)?
3. Can well-being be controlled by means of smart adjustment of environment, responding to predictions of individual current state of well-being?

To answer the first two of the above questions, respectively, we propose the following experiments:

1. Test for association between both personal and external monitoring (together and separately) and a subjective self-assessment.
2. Test for association between personal monitoring and external monitoring.

Question (3) poses a control problem, aiming to maximise predicted individual well-being by changing the smart environment's conditions (e.g room temperature, lighting). To that end, we suggest first identifying available environmental control methods and then training a reinforcement learning model with select few individuals over a sufficiently long period of time. Having succesfully built the model, the final step is to generalize it for previously unknown individuals.

Conclusion

We have proposed a definition hypothesis for well-being, suitable for smart environments. Further, we have identified the related research questions, and outlined experiments to answer those questions, testing the validity of the hypothesis.

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