Visitrack: A Pervasive Service for Monitoring the Social Activity of Older Adults Living at Home

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Abstract. Advances in medical science allow people to live longer and more independently than some decades ago. However, this does not directly help older adults improve their mental wellbeing. Several studies show that elderly people usually suffer from some level of social isolation that negatively impacts on their physical and mental conditions. As a way to address such a problem, this paper presents Visitrack, a pervasive and unobtrusive service conceived to monitor the social activity of older adults living at home. Based on sensing data retrieved and processed by the system, it can take several actions. For instance, informing family members and friends about long periods with no social activity at the older adult's home. The proposed service has been evaluated through a controlled experimental study, obtaining highly accurate results.

Keywords: Older adults · Aging in place · Ambient assisted living · Monitoring · Social interaction · Empirical study

1 Introduction

Worldwide population is progressively getting older at a dramatic speed, given the current advances in health provision, technology support, and prosperous living conditions that extend the life expectancy of people. This aging phenomenon represents a challenge to the public social and health services of many developed and developing countries, mainly because of the costs and required effort to sustain the independent living of older adults. Over the last years, several studies have identified aging in place strategies as a potential solution to deal with this situation (e.g., [17, 24–26, 34]).

Aging in place is generally understood as the ability to live in one's own home and community safely, independently, and comfortably, regardless of age, income, or ability level. Typically, Ambient Assisted Living (AAL) technology is envisioned as a facilitator for improving the wellbeing of older adults and extending the period in which these people can live autonomously at their home.

Jointly with this tendency of improving the living conditions of older adults, it has appeared an antagonist tendency that reduces the time that family members have

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available to devote to spare activities [20], such as interacting face-to-face with their older adults [16]. Several reasons justify this tendency; for instance: the need of women to work for ensuring the sustainability of their own family, an increase on the length of working shifts, and the desire to spend time in leisure activities.

Face-to-face interactions are a key factor that helps keep older adults emotionally up, physically active, and motivated [2]. In that respect, a low level of social interaction tends to produce depression and other mental health issues, particularly among older adults [10, 11], as well as a reduced life expectancy in this user group [18, 19, 27]. In other words, it does not make sense to try improving the wellbeing of older adults without considering social support as a fundamental aspect to address. Several researchers state that face-to-face social support is the cornerstone for the quality of human life [2, 6, 13, 21]. Therefore, addressing this concern results in technology with high impact in the quality of life and overall wellbeing of older adults. In particular, this turns critical for those people that have small social networks and spend long time periods at home, i.e., those at high risk of becoming socially isolated. Although the proportion of socially isolated older adults varies across different cultures and societies, it is clear that this is currently a global issue [8].

In order to address this challenge considering the needs of both older adults and other family members, this paper presents a pervasive service to monitor the face-to-face social activity conducted by older adults living independently at home. This information would allow the system to promote visits to the older adult when required, balance the load of performing these visits among family members, and keep a permanent diagnosis of the social connectedness of the older adult.

Identifying visits of family members and friends to the older adults is a highly valuable asset for addressing this challenge. However, accomplishing with this task is not trivial, since the acquired information must be accurate, reliable, objective, and recorded on time. Moreover, the monitoring process should non-intrusive, hopefully pervasive, secure, and consider privacy restrictions that limit technology adoption among older adults [15]. Although literature reports several proposals for in-home activity recognition targeted to older adults, most of them fail in simultaneously addressing all these quality requirements.

The monitoring service presented in this article, named Visitrack, addresses the stated requirements in order to extend the capabilities of the SocialConnector system [23]. Through a controlled experimental study, we evaluated the overall performance of Visitrack in a simulated setting under lab conditions. The obtained results have been highly accurate, both in terms of overall precision (90.5%) and recall (93.5%), as well as unobtrusive and useful for older adults and their family members.

The rest of the paper is structured as follows. Section 2 reviews related work. Section 3 describes Visitrack and presents its main functionality. Section 4 reports the conducted empirical evaluation and discusses the obtained results. Finally, Sect. 5 concludes and provides perspectives on future work.

2 Related Work

Monitoring incoming visits to the home of older adults is the first step of a larger endeavor aiming to provide effective social support in aging in place scenarios. While the problem of remote sensing and activity monitoring of older adults is not new in AAL, it has been strongly reliant on external hardware [9, 33].

On the one hand, previous attempts to provide in-home monitoring to older adults use ambient and wearable sensors to collect biomedical, physiological, and activity data in the form of a wireless network installed in or around the house, appliances, and furniture [3, 29]. On the other hand, devices like smartphones [7] and Microsoft Kinect [4, 28] have also proven useful for instrumenting pervasive monitoring of older adults.

McDuff et al. [22] followed a more holistic approach involving a multimodal sensor set-up for continuous logging of audio, visual, physiological and contextual data. Using a webcam, a Microsoft Kinect device, an ambient microphone, and an electro-dermal wrist sensor along a portable GPS carried by the user, the proposed system enabled user reflection on their affective state through an interactive interface.

Following a different line of reasoning, Fogarty et al. [14] through an in-home deployment trial reflected on trade-offs regarding instrumentation and quantity and quality of collected information. Similarly, Demiris et al. [12] state that older adults generally accept sensors and actuators once they are assimilated as being part of their surrounding environment. For instance, this could be the case of smart home systems or residence care facilities already equipped with sensor networks.

While valuable, prior research shows limitations with regard to the pervasiveness of these systems in line with the expectations of older adults about technology acceptance. Instrumenting a house is a challenge, since elderly people perceive this task as disruptive, difficult to achieve, and expensive. These concerns have been reported as being problematic to older adults, particularly in terms of technology adoption [15]. In that respect, Birnholtz and Jones-Rounds [5] state that aging in place schemas need to foster a sense of independence, while simultaneously enable monitoring and frequent interaction in an unobtrusive way. Vines et al. [31] emphasize that mediating the caregiving space of older adults with AAL technology does have an impact on the involved stakeholders, which goes beyond non-invasive sensing. Issues like explicit reassurance, information control, prompt feedback, and access to activity data all need to be addressed with regard to acceptance and adoption of assistive technologies.

As a first attempt to design a system for monitoring incoming visits at the home of an older adult, we initially rely on state-of-the-art algorithms for detecting and identifying people within a family network. Viola and Jones [32] conceived an object detection framework based on the sequential identification of image features through an iterative probabilistic approach. With proper training, this system works fairly well for detecting people faces under multiple lighting conditions and different levels of resolutions, even in the cases with a noisy training dataset. Although the obtained results from this approach seem promising for detecting faces in standalone images, it shows limitations in the case of properly recognizing people from a larger set, such as accurately identifying what family members visited an older adult over a long period of time.

In order to overcome this limitation, literature reports several classification models supporting people identification from a trained dataset of photos. This approach is commonly based on extracting particular features from the image—which varies between models—and comparing these features against the training dataset. For instance, Turk and Pentland [30] follow an approach based on principal component analysis to reduce the dimensionality of images and induce a classifier comparing the target image with those in the training set. Ahonen et al. [1] identify local binary pattern histograms to compare images and classify them following similitude measures, which displays fairly good results in practice according to a literature survey conducted by Zhao et al. [35].

Building upon these lines of research, our proposal explicitly address factors that contribute to improve technology acceptance by older adults, such as perceived usability, usefulness, availability, and ubiquity. Therefore, the odds for an effective in-home deployment and acceptance of Visitrack seem increased.

3 System Design

Visitrack was implemented as an extension—running in background—of the Social-Connector system [23]. The latter is a ubiquitous application that allows older adults to interact with other family members exchanging messages, family pictures, and through videoconferences (Fig. 1).

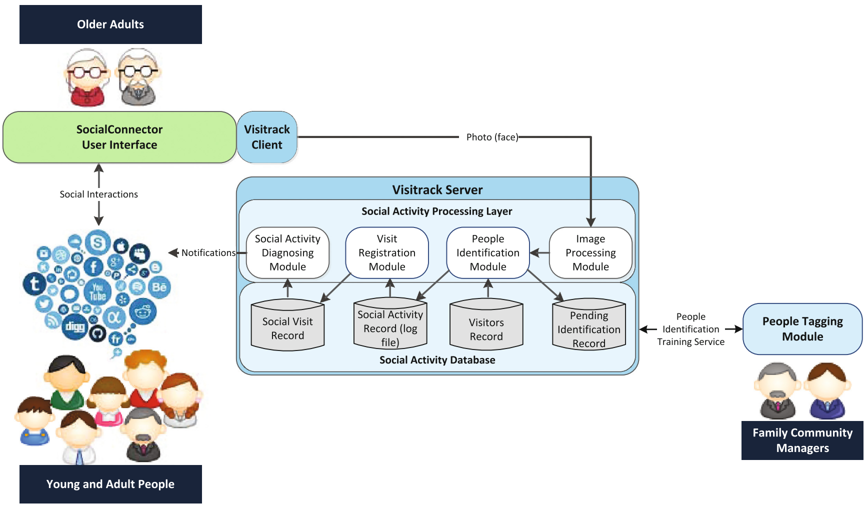

Fig. 1. Architecture of the physical environment

The service uses the frontal camera and the microphone of the tablet. When this application detects a person, it uploads a picture of his/her face to the server. Then, the server runs a process to recognize that face. Regardless of the result of such an operation, it records the visit in a log file that keeps the history of the social activity in that house.

If the face of the visitor is not recognized, family community managers can manually tag it using a particular software module. This new information is then used as input for future automatic face recognitions. The information about the social activity of the older adults can be periodically sent to particular family members, such as those acting as caregivers or monitors, as a way to making them aware about the social activity status of the older adult, deliver alerts, or try persuading other family members to visit the elderly person.

The system architecture shows data coupling among various components of the system; e.g., between the Visitrack client and the server, and also among the services provided by the server. This decoupling of the functionality (or data coupling) allows the system to evolve its components in a quite autonomous way. For instance, it is possible to reengineer the social activity diagnosis module (Fig. 1), without the need to change source code in the rest of the server components. The same happens if we decide to evolve the visit registration or people identification modules, which represents an advantage for the system.

4 Visitrack Client

This service uses the microphone of the tablet PC to capture samples of the environmental noise. If the detected sound intensity is over certain threshold, then the service assumes that a potential social activity is being conducted at home, so it runs the monitoring process. This starts by activating the frontal camera of the device and tries to detect a phace in the physical environment using video (Fig. 2). Such detection is performed using the *FaceRecognizer* algorithm available in the OpenCV library[1]. Once the algorithm detects a face, the service takes a picture of the scene, and then crops all the faces in the picture using the *haarcascade* algorithm (also available in OpenCV).

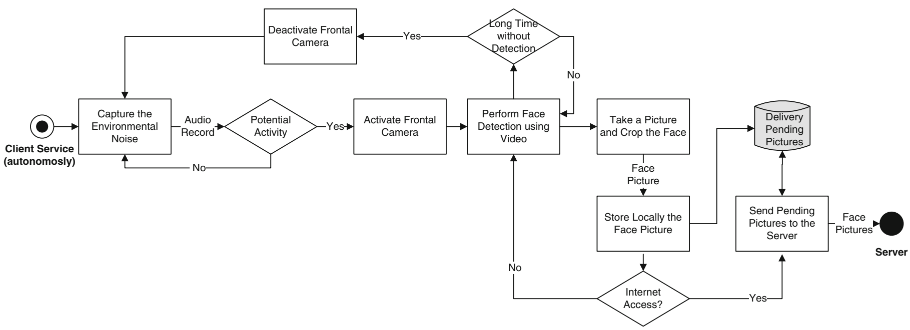

Fig. 2. Information processing flow at the client side

Finally, once cropped, the faces are stored locally in the device, and then sent to the server via Internet. If the connection between the client and the server is not available, the face pictures are kept in the local storage until the communication link is

[1] http://www.opencv.org/.

reestablished. In the server side there is a listener agent that is permanently waiting for new pictures.

4.1 Visitrack Server

When a picture with a face is received from the tablet, the system extracts its characteristics through the Image Processing Module (depicted in Fig. 1) that uses Local Binary Pattern Histograms [1]. Using the picture description, the People Identification Module intends to recognize the identity of the person by matching this description with those stored in the database of potential visitors for such a family (i.e., the Visitors Record). Figure 3 shows the information flow between each component of the Visitrack server application.

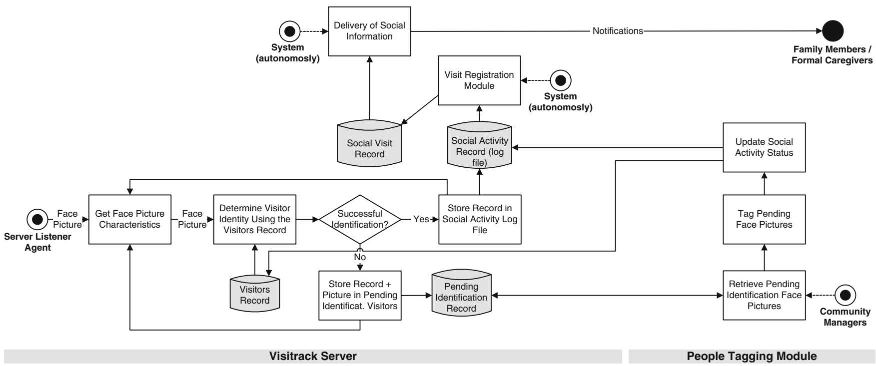

Fig. 3. Information processing flow at the server side

If the person in the new picture is identified, then such a picture is deleted and a record is added to the system log file (i.e., the Social Activity Record) alongside contextual metadata related to such a visit. In other case, the cropped photo is stored in the Pending Identification Record. At any time, as indicated with dashed lines in Fig. 3, the community managers can manually label these images, which triggers a reprocessing of the pending pictures and an updates all the records in the server in order to keep a coherent status of the Social Visits and Visitors Records. Using such a mechanism, the system is fed and retrained.

Periodically, the *Visit Registration Module* processes the system log file, determines the length and frequency of the visits, and stores such information in the *Social Visit Record*. The information of these visits can then be used by the system to keep informed, according to a set of rules, family members, community managers, and formal caregivers.

4.2 Visit Registration

Accurately determining the length of a visit is a challenge for the system, given that the video recording process only captures a part of the older adult's house. Therefore, locating strategically the camera helps increase the chance for effectively capturing a visit.

The visit registration process uses as input the stored information in the *Social Activity Record*, which corresponds to several triples ordered chronologically. Each triple has an ID that identifies the tablet PC, the ID of the person captured by the camera, and a timestamp indicating the instant in which such a picture was taken.

In order to determine the visits, the whole time period to be monitored is discretized using short time blocks (e.g., slots of 2 or 3 min), where each block has an ID. Then, the triples in the *Social Activity Record* are reviewed chronologically, where every time block that matches with a certain face capture is consequently labeled for each person. Multiples captures for the same time block are ignored.

Consecutive time blocks having the same person are defined as the *time range of the visit*, which includes a beginning time for the visit and an associated duration for the visit. If the number of time blocks between two consecutive visits is small (e.g., 1–4 blocks), the system assumes that it is the same visit and the camera was not able to capture the visitor all the time. In other case, the system assumes that they correspond to different visits.

The ID of the tablet PC, the ID of the visitor, the beginning time of the visit, and its duration conform a tuple that is maintained in the *Social Visit Record*. Although this information is coarse-grained, it is still highly valuable for the system given that it can be directly used by the system to decide when to deliver a notification, identify a target person to persuade or keep informed, or provide visual awareness information about the social status of the older adults. These latter mechanisms will be designed and evaluated as part of future work.

5 Evaluation Results

In order to assess the overall performance of Visitrack, we conducted a controlled experiment simulating three independent family meetings. Each meeting was held in a living room that was equipped with a tablet PC running a version of the SocialConnector system that embedded Visitrack. As hardware support, we used a tablet Samsung Galaxy Tab E, 9.6, running over WiFi.

In every scenario, participants were prompted to enter and leave the room simulating visits to an older adult. The authors kept independent records of who entered and left the room, and at what times. These notes then served to compute the ground truth for evaluating Visitrack. Each case scenario was individually and independently observed in time periods of 2 h, replicated over a period of two days.

As performance metrics, we computed the service *precision* (i.e., how many visits were effectively conducted with regard to the total number of those detected by the system), *recall* (i.e., how many visits were effectively detected by the system with regard to the total number of those performed by the study participants), and F_1 *score* (i.e., the harmonic mean between precision and recall, hence representing a balance measure). These metrics were selected because they are commonly used in information retrieval for evaluating the performance of classifier models. Table 1 reports the obtained results in the experiment.

Table 1. Performance of Visitrack in simulated family meetings

	Precision	Recall	F_1 score
Scenario 1	0.909	0.952	0.930
Scenario 2	0.906	0.935	0.920
Scenario 3	0.901	0.917	0.909

A 100% of the simulated visits were detected, even if they lasted less than ten seconds. If the person is in the capturing area of the camera during 2–3 s, and his/her face is in a frontal or semi-frontal position with regard the camera, the system is going to detect and record that visit. The *precision* shown in Table 1 is high, although the system identified as visit some situations that were not as such. However, these false detections can be identified and fixed by the family community managers using the *people tagging module* (Fig. 1). For instance, if the detected object (e.g., a mug) is recognized by the system as a face, then it is enough that such an object be labeled as "no person" in the pending identification record. Therefore, the system will iterate over all the pending visits and recalculate them with this new base of knowledge. Fixing these situations takes family community managers only a couple of minutes and allows the system to increase its detection precision to 100% of the visits.

Concerning the obtained *recall*, there were only some few short visits that were not recorded properly. In these cases, visits involved several people that were not recorded properly. Although most visitors were detected, some of them were missing. Finally, considering the *F_1 score*, we can see that the algorithm of visit detection not only is highly accurate but also reliable. The social information that it records is objective and is available to be used by the system once it arrives to the server. Therefore, it turns possible to make on-time decisions or deliver messages based upon this information. These are highly desirable quality attributes for this type of systems.

Given that the monitoring process ran in background, users were not really aware of the monitoring activity, which provided pervasiveness to the service. Both the information stored in the tablet and the server, as well as the data communicated to the server travelled through secure—encrypted—channels. This provides an important security level to the system.

On the other hand, only face pictures are stored and communicated from the tablet to the server, and those pictures are deleted once communicated to the server (in the case of the data stored in the tablet) or once the identity of the person has been established (in case of the server). Moreover, the information about the visits is aggregated to use only by the system, which provides some privacy protection to the visitors. Furthermore, given that all participants are relatives or friends of monitored older adults, and since the social interaction among them does not represent a taboo or something to negatively care about, this aspect was not an issue for the people participating in the evaluation process. Indeed, through informal observation on the process, study participants and older adults proved somewhat favorable to the installation of Visitrack in their own homes if they had the chance to do so. This will be formally evaluated through a controlled in-the-wild experiment as future work. Similarly, the quality attributes shown by the proposed monitoring service make us expect a contribution of it in other application domains, such as monitoring social activities of persons suffering autism, Asperger, or in the case of informal caregivers of chronically-ill patients or handicapped people.

6 Conclusions and Future Work

Aging in place is envisioned as an instrumental strategy to deal with the accelerated aging process experimented by the worldwide population over the last decades. This strategy usually requires technology—such as AAL systems—to support the daily living activities of older adults. In particular, a key need to address is the social support of elderly people within their close social networks. Particularly, literature acknowledges that face-to-face social support is the cornerstone for improving wellbeing and sustaining acceptable levels of quality of life [2, 6, 13, 21]. Therefore, it is important to consider this value when conceiving AAL systems targeted to support older adults living at home. However, this consideration is also constrained by quality requirements that are related to how older adults perceive and expect to accept domestic technology. In that respect, it turns equally important that social supporting solutions be accurate, non-intrusive, reliable, objective, and that they record and provide information on time with a particular focus on sustaining people's privacy.

Given that most of the solutions reported in the literature for monitoring social activities usually consider broader and less restrictive interaction scenarios, they are particularly not concerned by addressing the stated quality attributes. As a way to bridge this gap, the Visitrack service contributes with an alternative strategy to monitoring the social activity of older adults, with a particular emphasis on not disrupting the living and social ecosystems of elderly users.

This work also shows that an excessive instrumentation is not necessarily required to monitor complex ecosystems, without compromising pervasiveness, information accuracy, and privacy. Although the reported results are still preliminary, we expect this research helps positively impact the quality of life and wellbeing of older adults.

The next step in this research initiative includes replicating the evaluation study in real-life scenarios, by monitoring social activity directly at home. We also envisage to define decision rules to promote and balance the engagement of family members in providing face-to-face social support to their older adults.

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