Digitally assisted planning and monitoring of supportive recommendations in cancer patients

Alexander Scherrer[1], Tobias Zimmermann[1], Sinan Riedel[1], Fihmi Mousa[2], Isa Wasswa-Musisi[2], Robert Zifrid[2], Hartmut Tillil[2], Philipp Ulrich[2], Thanos Kosmidis[3], Joaqium Reis[4], Gabrielle Oestreicher[5], Markus Möhler[5], Ilias Kalamaras[6], Konstantinos Votis[6], Stefanos Venios[7], Maria Plakia[8], and Sotiris Diamantopoulos[8]

[1] Fraunhofer Institute for Industrial Mathematics (ITWM), Fraunhofer-Platz 1, 67663 Kaiserslautern, Germany {alexander.scherrer, tobias.zimmermann, sinan.riedel}@itwm.fraunhofer.de

[2] MCS Data Labs GmbH, Bismarck-Straße 10-12, 10625 Berlin, Germany {fihmi.mousa, isa.wasswa-musisi, robert.zifrid, hartmut.tillil, philipp.ulrich}@mcs-datalabs.com

[3] Care Across Ltd, 1 Kings Avenue, N21 3NA London, United Kingdom thanos.kosmidis@careacross.com

[4] FCiências.ID - Associação para a Investigação e Desenvolvimento de Ciências, Campo Grande, edifício C1, piso 3, 1749-016 Lisboa, Portugal jdcreis@fc.ul.pt

[5] University Medical Center of the Johannes Gutenberg-University Mainz, Langenbeckstraße 1, 55131 Mainz, Germany {gabrielle.oestreicher, markus.moehler}@unimedizin-mainz.de

[6] Centre for Research and Technology Hellas, Charilaou Thermi Road 6km, 57001 Thermi Thessaloniki, Greece {kalamar, kvotis}@iti.gr

[7] Suite5 Data Intelligence Solutions Ltd, 1 Archiepiskopou Makariou III Mitsi Bu, 1065 Nicosia, Cyprus stefanos@suite5.eu

[8] EXUS Software Ltd, Old Broad Street 25 Tower 42, EC2N 1PB London, United Kingdom {m.plakia, s.diamantopoulos}@exus.co.uk

Abstract. This paper presents a solution approach for digitally assisted planning and monitoring of supportive recommendations in cancer patients. This solution approach shall support patients in overcoming the after-effects of therapy effectively without extensive involvement of health professionals. Health professionals and patients are provided with a web application and a mobile application respectively, which use methods from mathematical decision support and artificial intelligence. This technological basis facilitates a closed-loop workflow for the cooperation of health professional and patient in oncological aftercare. The solution approach is illustrated for an exemplary case scenario of colorectal cancer.

Keywords: Oncological Aftercare · Supportive Recommendation Planning · Patient Monitoring · Decision Support · Artificial Intelligence

1 Introduction

1.1 Oncological follow-up care

With about 492000 newly diagnosed cases and about 230000 deaths per year, cancer is one of the most common diseases and the second most common cause of death in Germany [11]. Clinical cancer treatment is widely based on surgery, system therapy, radiotherapy and their combinations [10]. Cancer therapy in addition to the immediate effects may also entail significant aftereffects for patients. They often suffer from a reduced well-being and quality of life for a long time after leaving the clinic [8]. However, patients can receive only limited medical support outside of the highly specialized clinical environment. To a major extent, they are left to their own devices to overcome the aftereffects of treatment. Even regular consultation hours allow only limited exchange of information between health professional and patient at certain intervals. The individualized planning of tailored recommendations based on little information is in turn a major challenge for health professionals. And the correct independent implementation of recommendations is also a challenging and possibly error-prone task for patients.

1.2 Planning and monitoring of supportive recommendations

The main health goal of the EU project *ONCORELIEF* is to support cancer patients in aftercare in regaining their well-being and quality of life [5]. This goal is achieved by establishing a closed-loop workflow that connects health professionals and patients by means of assisting digital solutions. This workflow allows intensive cooperation beyond consultation hours and software-supported individualized planning and close monitoring of supportive recommendations. The health professional uses a web application for the planning of recommendations and the patient uses a mobile application for their documentation and monitoring. The collected information goes through a data analysis, the results of which provide the basis for recommendation planning. *ONCORELIEF* follows a division-of-labor approach to recommendation planning and monitoring. The potentially time-consuming and error-prone process steps of analyzing health data and searching for suitable recommendations are performed using artificial intelligence (AI) methods. In contrast, the result-critical step of recommendation planning is performed by the health professional with the help of mathematical decision support methods. With this solution approach, *ONCORELIEF* follows the recommendations for an ethically correct use of AI on health topics [6].

1.3 Contents

This paper presents in Section 2 the methods used for recommendation planning and monitoring. Section 3 describes the practical application for an illustrative case scenario of colorectal cancer and Section 4 assesses the achieved research and development results.

2 Material and Methods

Figure 1 schematically depicts the digitally assisted closed-loop workflow. The results obtained with AI-based data analysis of the considered patient case form the starting point. With this information, the health professional performs recommendation planning in the web application. The planned recommendations with all their contents are transferred to the patient's mobile application. There, the patient obtains information about the supportive recommendations and documents them during implementation. Based on the documented information, the mobile application does the monitoring, provides feedback to the patient and transfers the collected information to the data analysis. From a planning perspective, this closed-loop workflow follows the principles of sequential decision making [9].

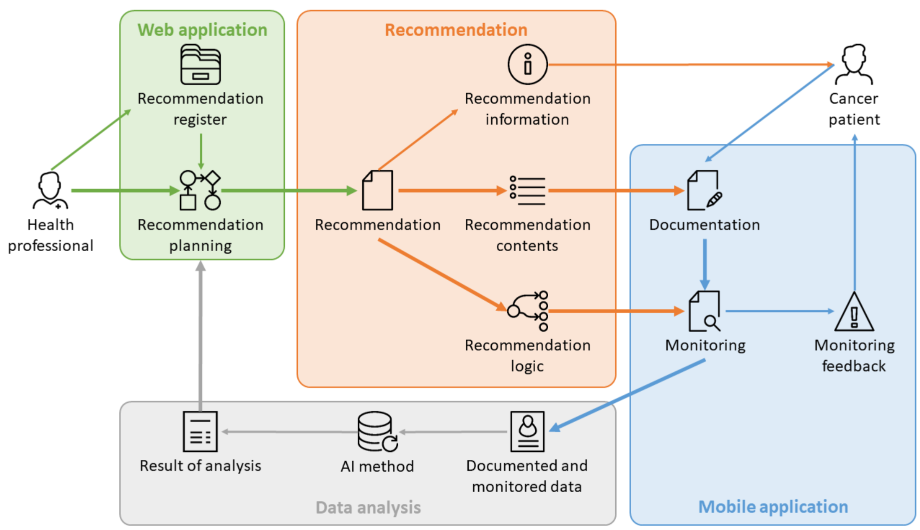

Fig. 1. Solution approach with the core components and main information flows: Recommendation planning with the web application (green) by the health professional, supportive recommendations with their contents (red), documentation and monitoring with the mobile application (blue) used by the patient and AI-based data analysis of the progress achieved with the recommendation (grey). The thick arrows indicate the main process steps of the approach. (Icons: Line Icons (iconsmind.com), Windows 8 Icons (icons8.com))

2.1 Digitally supported workflow

Results of AI-based data analysis The planning of individually suitable supportive recommendations for a patient case is based on analysis results generated with AI methods on the case data. The choice of the appropriate method in each case depends on the nature of the considered case data and the reference data available for method training. However, the solution approach followed here is in principle independent of the choice of method and uses only the obtained results. This flexibility is achieved by using a data interface based on a generic structured file format. The imported data contains a listing of the performance indicators used by the AI method and a listing of the supportive recommendations with their scores in these performance indicators. This concept also follows the general objective of Explainable Artificial Intelligence (XAI) methods of providing more insight into the origin and quality of results of analysis [7].

Register of supportive recommendations The imported results of analysis are matched with the contents of an recommendation register based on the recommendation names. This register contains templates for the recommendations available for recommendation planning, which are provided as structured files with the following information contents:

- a description of the recommendation in terms of its parameter with their individual identifier, value type, value range, position and multiplicity in the recommendation;
- a description of the parameter visualization with label, surrounding text, type of initialization including optional initial values and access rights;
- a description of logical conditions in terms of second-level predicate logic on the recommendation parameters, text descriptions and optional quality scores [1].

Supportive recommendations are made available for planning by importing such files with a registration feature of the web application. After a successful import and validation against a schema file, the recommendation can be used for recommendation planning.

2.2 AI-based decision support for health professionals

Selection of recommendations The search for suitable recommendations and their selection is treated as a multi-criteria decision problem in the web application [4]. Here, the supportive recommendation name and the performance indicators from the AI method form the planning criteria and the AI results provide the evaluations in the criterion space. The health professional can use search, sort and filter functionality on these criteria to determine the suitable recommendations. The web application thus implements a division-of-labor approach. The potentially time-consuming and error-prone search for relevant recommendations is handled by AI methods. But the outcome-critical decision about which recommendations to implement up to the health professional. With this approach, recommendation planning follows the recommended approach for the ethically correct use of AI by keeping the human in the loop [6].

Adaptation of recommendations The health professional can then adapt recommendations to the patient's needs by means of the parameters that are released for this purpose. These parameters shall inform the patient how to perform the recommendations, but they are also used in the logical conditions for monitoring. Modification of these parameters thus allows for an easy individualization of recommendations, which again follows the recommendations for the use of AI methods [6]. An explicit editing of conditions would have required an advanced understanding of certain concepts from formal mathematics and computer science. Once these adaptations are complete, the recommendations are exported back into proprietary data structures and transferred to the patient's mobile application.

2.3 Knowledge-based decision support for patients

Configuration of the mobile application The mobile application has methods for the interpretation of these files and the processing of their contents. This processing includes the visualization of recommendations, their documentation and the evaluation of the entered information in monitoring. The mobile application is thus generic over the application-specific content. This separation allows for a configuration of the mobile application also with newly registered recommendations without any software update.

Documentation of recommendations The display and processing of supportive recommendations in the mobile application for the patient takes place analogously to the web application. The patient documents the implementation of the recommendation via the parameters released for this purpose. Most of these parameters have predefined value ranges and only a few support entries of free text. This allows for a easy usability based on value selection, guarantees a high quality of the crucial data and their comparability in data analysis. The information entered is stored in the mobile application and transferred to the data analysis upon the patient's request. This ensures the patient's sovereignty over his or her own data.

Monitoring of recommendations Monitoring features a rule-based system based on an application of the logical conditions contained in the supportive recommendations to the information entered by the patient [12]. This ensures a clearly predictable behavior of the mobile application according to the instructions of the health professional and enables patient care without permanent involvement of the health professional. After each editing in a recommendation, the corresponding logical conditions are evaluated on the entered information, which again corresponds to the principle of sequential decision making. A fulfilled condition triggers a text message to the patient, following the XAI objective to communicate results in a transparent way [7]. This information is optionally combined with ratings on multiple quality scales for multi-criteria decision making by the patient during implementation of the recommendations [4]. Negative evaluations for an ongoing recommendation or also completion of a recommendation are at the patient's behest followed by a transfer of information to the health professional. This would then trigger an adaptation of the ongoing supportive recommendations by the health professional and thereby close the loop shown in Figure 1.

3 Results and discussion

3.1 Planning of supportive recommendations

Exemplary patient case and results of analysis The methods described above are illustrated for an artificial case scenario in which a patient treated for colorectal cancer suffers from the aftereffects of anxiety, depression and fatigue. This information enters a data analysis, which here uses Random Forest classification [3]. This method uses singular decision trees for the classification of data samples, in this context the applicability of a recommendation for a case scenario. They then aggregate the classification results obtained from a forest of decision trees to a majority vote with some percentage indicating its validity. The obtained results are transferred to the web application and displayed there as can be seen in Figure 2.

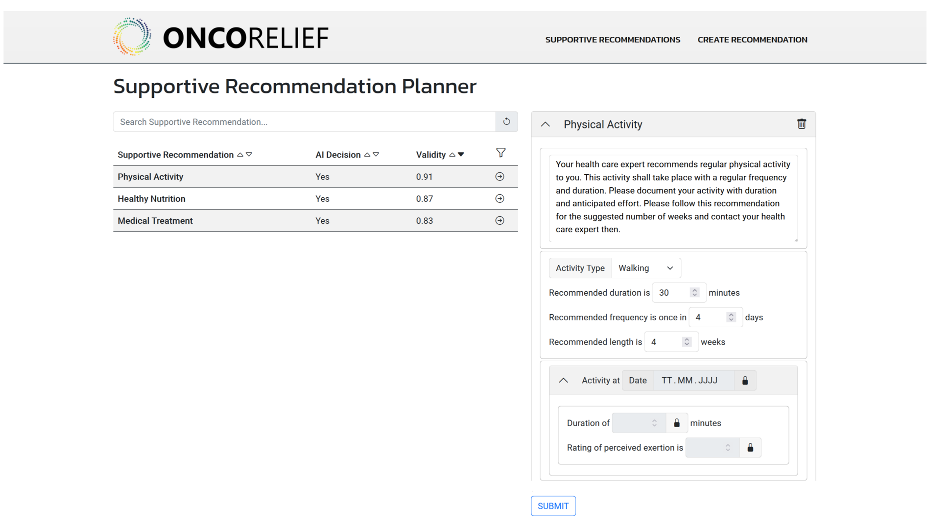

Fig. 2. Recommendation planning with the web application: Survey of the available recommendations, corresponding results of data analysis and planning features (left) and display of the selected recommendation with adaptation features (right).

Registered supportive recommendations A review of medical guidelines for the considered disease patterns of colorectal cancer and acute myeloid leukemia has so far led to the specification of altogether 24 supportive recommendations [8]:

Acupuncture, Anti-depressant therapy, Group therapy, Healthy nutrition, Intervention for sleep disturbances, Medical treatment, Mindfulness-based stress reduction, Nutrition consultation, Physical activity, Positive social relationships, Psychatric consultation, Psycho-educational therapy, Recommendations against appetite loss, Recommendations against hair loss, Recommendations against the hand foot syndrome, Recommendations against lack of sexual interest, Recommendations against sleep problems, Recommendations against sore mouth, Recommendations against weight changes, Recommendations against weight loss, Scrambler therapy, Supportive care, Treatment of medical causes.

These recommendations have parameter structures like the following one of the exemplary supportive recommendation *Physical Activity*:

- $>$ *Physical Activity (Node)*
  - $>$ *Activity type (exactly once, ordinal)*
  - $>$ *Duration recommendation (exactly once, integer)*
  - $>$ *Frequency recommendation (exactly once, integer)*
  - $>$ *Length (exactly once, integer)*
  - $>$ *Activity entry (arbitrary, node)*
    - $>$ *Activity date (exactly once, Date)*
    - $>$ *Duration (exactly once, Integer)*
    - $>$ *Rating of perceived exertion (exactly once, integer)*
  - $>$ *Recommendation result (exactly once, ordinal)*
  - $>$ ...

The indentation represents the hierarchical tree structure with nodes and leafs, The items represent the parameters with their identifier, multiplicity and value type.

Selection and adaptation of recommendations The web application first displays all the supportive recommendations analyzed by the AI method with their respective ratings. With the help of the available search, sort and filter functionality, the health professional can narrow down the recommendation options to the relevant ones. In the considered case scenario, these are the recommendations that were identified by the AI presumably suitable. These recommendations therefore carry a *Yes* in the criterion *AI Decision* and a high value close to one in the *Validity* criterion. In Figure 2, the health professional has therefore performed filtering operations on these two criteria and sorted the remaining recommendations by *Validity*. The health professional then selects one or more desired recommendations, in this case the previously mentioned recommendation *Physical Activity*. Selected recommendations are displayed in the web application according to their specifications from the recommendation register. In these views, the health professional can adapt recommendations to the individual needs of the patient via the parameters released for editing. For the displayed *Physical Activity*, these are most prominently the *Activity type*, *Recommended duration*, *Recommended frequency* and *Recommended length*. At the end of planning, the adapted recommendations are transferred to the patient's mobile application.

3.2 Processing of supportive recommendations

Documentation of recommendations The mobile application shows the patient an overview of the progress of previous and current supportive recommendations as shown in Figure 3 (left). After selecting a recommendation, it switches to a full-screen view for this recommendation, see Figure 3 (right). In this full-screen view, the patient receives the general information entered by the health professional about the recommendation is provided with input options for its documentation. The patient documents the considered recommendation *Physical Activity* by adding instances of the node parameter *Activity Entry*, which in turn contain the parameters *Activity date*, *Duration* and *Rating of Perceived exertion* (RPE) [2]. These parameters have predefined value ranges, making the information entered clearly interpretable and comparable among multiple instances of themselves. The same applies to the parameter *Recommendation result*, which is filled in after completion of a recommendation to document the perceived success.

Recommendation monitoring Every edit of a recommendation automatically triggers an evaluation of the associated logical conditions. For the considered recommendation *Physical Activity* there are 15 such conditions, which have the following exemplary form

(NOT (EXISTS (Activity entry) FULFILLS ((Activity entry).(Activity date) GREATEROREQUAL ((CURRENT DATE) MINUS (Frequency recommendation)))))

This condition checks whether there is no node entry *Activity entry*, whose date *Activity date* lies within the period determined by *Frequency recommendation* and the *CURRENT DATE*. In the considered case scenario, this condition is met and yields the quality score

(Evaluation ASSIGN Bad)

The supportive recommendations specified for the considered disease patterns use the two quality scales *Evaluation* and *Urgency* with optional value assignments depending on the specific condition. Quality scores are displayed in the recommendation overview with colored symbols, see Figure 3 (left). The

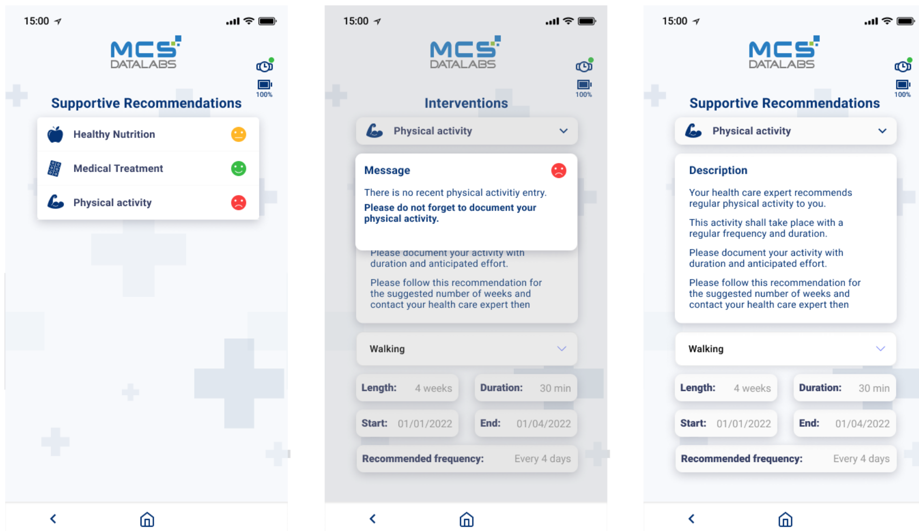

Fig. 3. Processing of recommendations with the mobile application: survey of supportive recommendations (left), monitoring feedback on a single recommendation (middle) and full-screen view of a recommendation for information and documentation (right).

colors allow the patient to quickly identify the most important or urgent information and react on it. The fulfilled condition also triggers a text message to the patient, which is displayed on top of the recommendation view after clicking the colored symbol as shown in Figure 3 (middle).

4 Conclusions

This work presents a solution approach for providing a digitally assisted aftercare service to cancer patients. The approach is developed for the exemplary disease patterns of colorectal cancer and acute myeloid leukemia. The obtained results shall enter a comprehensive medical evaluation for these fields of application in the near future. The generic concept of the approach, however, allows for a transfer into other medical and non-medical fields of application. This concept features digital assistance for the involved stakeholders with separate technological components, which nevertheless combine to an integrated closed-loop workflow. A web application featuring AI-based data analysis and multi-criteria decision making allows for an efficient planning of individualized supportive recommendations by health professionals. A mobile application featuring a rule-based system and sequential decision making assists cancer patients in the documentation and monitoring of ongoing supportive recommendations. The regular information transfer between these two components supports patients in effective aftercare guided by health professionals without their permanent involvement and beyond regular attendance of medical consultation hours.

Acknowledgments

The research work presented herein is part of the EU Horizon 2020 project *ONCORELIEF* (Grant Agreement ID 875392) [5].

References

1. George S. Boolos, John P. Burgess, Richard C. Jeffrey: Computability and Logic. 4 edn. Cambridge University Press (2002)
2. Gunnar V.A. Borg: Psychophysical bases of perceived exertion. Medicine & Science in Sports & Exercise **14**(5), 377–381 (1982)
3. Leo Breiman, Jerome Friedman, Charles J. Stone, R.A. Olshen: Classification and Regression Trees. Chapman and Hall/CRC Press (1984)
4. Matthias Ehrgott: Multicriteria Optimization. Springer-Verlag Berlin Heidelberg (2005)
5. EU Horizon 2020 Project *ONCORELIEF*: *ONCORELIEF* website. www.oncorelief.eu (2020)
6. European Parliament: EU Guidelines on ethics in artificial intelligence: Context and implementation. www.europarl.europa.eu/thinktank/en/document/EPRS_BRI(2019)640163 (2019)
7. David Gunning, Mark Stefik, Jaesik Choi, Timothy Miller, Simone Stumpf, Guang-Zhong Yang: XAI - Explainable Artificial Intelligence. Science Robotics **4**(37), eaay7120 (2019)
8. Karin Jordan, Petra Feyer, Ulrike Höller, Hartmut Link, Bernhard Wörmann, Franziska Jahn: Supportive treatments for patients with cancer - clinical practise guideline. Deutsches Ärzteblatt International **114**, 481–487 (2017)
9. Stephen M. LaValle: Planning Algorithms. Cambridge University Press (2006)
10. National Cancer Institute: Types of cancer treatment. www.cancer.gov/about-cancer/treatment/types (2020)
11. Robert-Koch-Institut: Cancer in Germany 2015/16. 12 edn. edoc.rki.de/handle/176904/8320 (2020)
12. Cord Spreckelsen, Karl Spitzer: Wissensbasen und Expertensysteme in der Medizin (Knowledge-bases and Expert Systems in Medicine). Verlag Vieweg + Teubner (2008)